~~Patterson~~ Neves

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EROSION SILT AS A FACTOR IN AQUATIC ENVIRONMENTS[1]

M. M. Ellis

Interior Fisheries Investigations, U. S. Bureau of Fisheries

The increasing loss of surface soil by erosion during the past few decades has been pointed out by various writers on soil and forestry problems (Bennett and Chapline, '28; Bates and Zeasman, '30; Bailey, Forshing and Becraft, '34), and because of this rapid, uncontrolled erosion progressively larger amounts of erosion silt are being contributed to the fresh water streams by floods, dust storms and surface run-off. These enormous loads of erosion silt (429 million tons for Mississippi River, Bennett and Chapline, '28), have already produced at numerous points marked changes in both the aquatic habitats and biota of many streams, and have changed their waters from clear to muddy for all or a greater part of the year. In order to ascertain quantitatively some of the specific effects of erosion silt on aquatic complexes, biophysical and biochemical studies have been made at over 700 stations on streams of the Mississippi-Ohio-Missouri System, and other interior waters. These field observations have been supplemented with experimental work at the Bureau of Fisheries Laboratories at Columbia, Missouri and Ft. Worth, Texas.

Erosion material added to the waters of any stream has two major contacts with the living organisms in that stream, first through the aqueous medium because of the physical and chemical changes which the erosion silt produces in the waters themselves, and second, through alterations in bottom conditions resulting from the subsequent settling out of all or part of the silt load. The data presented have been grouped accordingly.

LIGHT PENETRATION INTO WATER CARRYING EROSION SILT

As a routine procedure all water samples were first filtered through bolting cloth to remove plankton organisms and bits of debris. Direct measurements of the turbidity of the water carrying erosion silt were then made with a photoelectric apparatus (Ellis, '34), which gave values similar to those obtained by comparison with standard suspensions (U. S. G. S. turbidity units), and by the Secchi method (Standard Water Analysis, '33). However, as these turbidity values are merely statements of relative opacity, and as the readings from the photoelectric apparatus are readily convertible into light penetration values (see Ellis, '34), the depth in millimeters of water of the given turbidity required to screen out 99.9999 percent of the light entering

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at the surface, *i.e.*, the depth at which light would be reduced to one-millionth of its surface intensity, was chosen as a measure of the light screening power of the various waters studied. This depth is subsequently referred to as the "millionth intensity depth," or "m.i.d."

Limits of Penetration of Visible Light into Waters Carrying Erosion Silt

Excepting surface run-off immediately after heavy rains, the maximum opacity determined for muddy water from natural streams was that of a sample from the Missouri River collected near the surface at Boonville, Missouri, November 23, 1931. The millionth intensity depth of that water was only 84 mm. The clearest natural stream water (not springs) was taken from the Rio Saltillo, near Saltillo, Estado Coahuila, Mexico, a little mountain stream flowing over a rocky bottom and at the time carrying practically no erosion material. The millionth intensity depth for this stream was 53,887 mm. or roughly 53.9 meters. These two values, 84 and 53,887 mms., the extremes found in over 5,000 determinations of the m.i.d. of inland waters of the United States and northern Mexico, will serve to establish the general range of m.i.d. in interior waters varying from a very muddy river to a clear mountain stream.

However, as mountain streams are characteristically very clear the millionth intensity depths of waters from clear streams in central United States flowing through relatively undisturbed wooded or swampy areas which might be considered as fairly representative of conditions before uncontrolled erosion began, were determined for comparison with mountain streams like the Rio Saltillo, and with muddy rivers like the Missouri. A few examples will suffice. Portions of the Niangua River drain a sparsely settled area in the hilly Ozark country of Missouri, where limestone outcrops are numerous and where the land is covered by a good growth of scrub oak. The millionth intensity depth for clear water from this stream ranged from 11,000 mm. to 20,000 mm. The St. Francis River drains the cypress swamp district of southeastern Missouri and northeastern Arkansas and for small tributaries of this stream, flowing out of uncultivated swampy areas the m.i.d. was between 11,000 mm. and 12,000 mm. Similar degrees of clearness were found even in the Ohio and Tennessee Rivers during very low water when these rivers were receiving the minimum amount of erosion material. During the month of July, 1931, intensity depths from 4,000 mm. to 17,000 mm. were typical for the Ohio River between Cairo, Illinois and Paducah, Kentucky and from 4,700 mm. to 20.000 mm., for the Tennessee River at Paducah, Kentucky. However, when rain came the turbidity of the Tennessee River rose due to the erosion silt load, and the m.i.d. fell to less than 200 mm. in 48 hours. In contrast to this change in the Tennessee River following rain, the Sturgeon River in Baraga County, Michigan, draining a swampy woodland area had a m.i.d. of 6,000 mm. after a three day rain (August, 1934).

Collectively the data from unpolluted portions of inland streams in areas naturally protected against undue erosion showed that a clearness of water permitting light penetration 10,000 mm. to 20,000 mm. before the millionth intensity depth was reached, was maintained most of the time, and that even following unusual rains the erosion material rarely reduced the m.i.d. of streams in these protected areas below 6,000 mm. These values are in sharp contrast with those found for waters from streams receiving quantities of erosion silt.

Above Grand Rapids, Minnesota, in the unpolluted headwaters of the Mississippi which drain a swampy lake region, in protected portions of the St. Croix River, north of Hudson, Wisconsin, and in some of the small tributaries of the upper Mississippi, as the Zumbro which flows out of grassland dairy country, millionth intensity depths ranging from 6,000 mm. to 34,400 mm. were found consistently under existing conditions (1934), *i.e.* in general the headwaters of the Mississippi River, where protected from erosion silt and pollution, were of a clearness comparable to streams like the Niangua and the tributaries of the St. Francis, as previously discussed. Pollution from the Twin Cities reduces the m.i.d. of the Mississippi to around 2,000 mm. in the lower part of the Hastings Pool near Hastings, Minnesota, but the m.i.d. rises to between 4,000 mm. and 6,000 mm. at the foot of Lake Pepin. These reductions in m.i.d. as compared with the m.i.d. of the headwaters are due largely to organic matter in solution rather than to erosion silt.

Below the mouth of the Chippewa River, near Reeds Landing, Minnesota the additions of erosion material become progressively more evident, and at Alma, Wisconsin readings as small as 1,500 mm. were not unusual even during "clear water" periods. South of Alma, Wisconsin the average m.i.d. fell rapidly to 1,000 mm. or less due to the erosion load and sudden fluctuations became common. At Clayton, Iowa, on July 27 the m.i.d. was 1,209 mm. and 24 hours later at DeSoto, Wisconsin, it was 115 mm. following a heavy storm on Root River. During the summer of 1934, the m.i.d. for Mississippi above Lock 15 at Davenport, Iowa, varied from 1,854 mm. to 123 mm. with an average of 466 mm. Similarly of 392 samples from the Mississippi between Davenport, Iowa and Grafton, Illinois (May 22 to September 9, 1932), 87 per cent had a m.i.d. of less than 330 mm. with a maximum of 2,000 mm. Near St. Louis, Missouri, the Mississippi after receiving the Missouri River but before receiving the sewage and wastes of the City of St. Louis, had (September, 1934) a m.i.d. of less than 200 mm., while at Cairo, Illinois, Memphis, Tennessee, Greenville, Mississippi and New Orleans, Louisiana, the m.i.d. was consistently less than 175 mm. and for many samples smaller than 150 mm. The addition of the waters of the Missouri River complicates the determinations of the effects of erosion silt on light penetration into the waters of the lower Mississippi because the Missouri River was known as a muddy river even before the white man took over Kansas, Nebraska, and the Dakota as the natural erosion in the upper Yellowstone region has long been severe. However, the present erosion silt loads due to uncontrolled erosion for which man is largely responsible have reduced the m.i.d. of the Upper Mississippi, *i.e.*, the Mississippi above the mouth of the Missouri, from a range between 6,000 and 20,000 mm. to one between 150 and 2,000 mm. with the average less than 300 mm.

Similar changes have taken place in the Tennessee River which many river pilots living today remember 20 to 25 years ago as a relatively clear stream even after heavy rains. July 20 to August 30, 1932, the writer examined 496 samples from the Tennessee River between Paducah, Kentucky and Hiwassee Creek above Chattanooga, Tennessee. The millionth intensity depth for these samples averaged 1,000 mm. with 42 per cent of the samples less than 350 mm. although the river was low and rains few, yet at Paducah, Kentucky as has already been pointed out this river during very low water frequently had a m.i.d. of 20,000 mm.

As these enormous changes in light penetration depths charged to erosion silt might be due in part to substances in solution many samples from typical localities were forced through a colloidal filter (Whatman No. 40 filter paper filled with celloidin) under 80 pounds pressure. This procedure gave sparkling clear filtrates containing the dissolved substances and the light transmission through the filtrate was compared with that through the original unfiltered water. The millionth intensity depths of both filtered and unfiltered samples are given for a few river waters of high turbidity, as typical; Mississippi River, Keokuk, Iowa, unfiltered 235 mm., filtered 34,000 mm.; Mississippi, Memphis, Tennessee, 188 mm., 8,000 mm.; Missouri River, Boonville, Missouri, 115 mm., 8000 mm.; Black Warrior River, Demopolis Alabama, 645 mm., 17,104 mm.; Tombigbee River near Tuscaloosa, Alabama, 323 mm., 6,869 mm.; and Mobile River near Mt. Vernon, Alabama, 764 mm., 68,800 mm. It may be seen from these figures that, freed of the erosion silt, the waters of these very muddy rivers were of a clearness comparable to that of the clear streams from protected areas, *i.e.*, the erosion silt load had not changed the amount of natural organic detritus carried by the stream, nor increased to any extent the quantities of dissolved substances interfering with the transmission of light. Any rise in dissolved colored substances in river waters was found primarily as the result of introduction of organic wastes, as in Hastings Pool and Lake Pepin, where the organic pollution from the Twin Cities gave the water a distinct brownish color.

As the significance of the millionth intensity depth in showing the screening out of light by erosion silt in river water, depends upon a maintained and relatively uniform turbidity from surface to bottom as great as that of the sample, whenever possible m.i.d. determinations were made on water from different depths, supplemented with measurements of the rate of clearing due to the settling out of the silt. From several thousand m.i.d. readings at various depths two statements may be made. First, the vertical distribution of erosion silt, after the scourings and heavier particles of sand are removed, is fairly uniform in the water of flowing rivers with a tendency toward increased turbidity near the bottom in the slower parts of the stream; and second, in impounded waters back of power dams if the water be deep enough and the current slow enough to allow thermal stratification in summer, there is a marked stratification of erosion silt in the deeper waters.

Readings every 12 hours together with various readings at all hours of the night and day on the m.i.d. of Lake Keokuk, Mississippi River, from samples at the surface (0.5 meter) and bottom (8.5 meters) levels for 40 consecutive days (July and August, 1932) involving over 340 observations show that the suspended silt is quite uniformly distributed at all times throughout this body of water, which has a current of 3 to 4 miles per hour, a maximum depth of approximately 9 meters, and no thermocline. During period mentioned the m.i.d. varied from 88 mm. to 1,548 mm., with 47 per cent of the surface readings and 54 per cent of the bottom readings less than 380 mm. Even the deep holes of rivers showed this rather uniform distribution of the suspensoids. Off Tower Rock near Grand Tower, Illinois the surface m.i.d. of the Mississippi River on September 8, 1931, was 129 mm., decreased progressively to 119 mm. at the 30 meter level and rose to 124 mm. at the bottom, 33 meters. At Pan Eddy in the Tennessee River on August 31, 1931, the surface m.i.d. was 548 mm., and decreased gradually to 500 mm. at 39 meters, the bottom. No thermal stratification of water was found either at Tower Rock or Pan Eddy.

In various of the deeper power dam lakes, created by impounding rivers, as Lake Wilson, Tennessee River, and Lake of Ozarks, Osage River, a very definite stratification of the erosion silt load however was observed. In these river lakes stream flow and depth are such that during the summer months there is definite thermal stratification of the water, with a well defined thermocline. In Lake Wilson during July and August extending from the surface to approximately the 18 meter level there is an upper mass of water in which the temperature declines gradually as the depth increases. This mass of water, the hyperlimnorrheum, flows steadily downstream. Below the hyperlimnorrheum is second mass of water between the 18th and 21st meter levels, a true thermocline in which the temperature of the water drops abruptly. The water in the thermoclinal zone does not flow appreciably. A third mass of water extends below the thermocline, *i.e.*, from approximately the 21st meter level to the bottom of the lake. This mass of water is quiet during the summer and is a true hypolimnion. A set of m.i.d. determinations at Sta. 385 in Lake Wilson on August 24, 1931, will suffice to show the vertical distribution of silt in these three masses of water. The surface m.i.d. on that day was 1,147 mm., decreased progressively to 1,070 mm. at the 15 meter level, and rose to 1,127 mm. at the 18 meter level, the bottom of the hyperlimnorrheum. At the 21st meter level, the lower limit of the thermocline, the water had cleared so that the m.i.d. was 4,143 mm. and from the 24th meter level to the bottom, 33 meters, the water was sparkingly clear with a m.i.d. of 7,860 mm. The abrupt change in water temperature and correlated change in water viscosity in the thermocline produced this stratification, so that during the warm summer months in several of these deep power dam lakes the writer has found a warm muddy river, the hyperlimnorrheum, flowing over a cold, clear lake, the hypolimnion, with very little mixing in the thermocline.

Settling out studies of river waters carrying various quantities of erosion silt showed that with the exception of the scourings, *i.e.,* the heavy particles of sand found particularly in water where the current was swift, the finer erosion material remained suspended for hours even in water which was undisturbed, *i.e.,* the m.i.d. was still greatly reduced by the erosion silt after 48 to 96 hours settling. As settling out curves have been plotted for various river waters by hydrographic engineers, the rates of settling need not be discussed here, but the present studies have brought out the fact that the very fine suspensoids, *i.e.* those which are the last to settle out and therefore those which would remain suspended were the water subject to even slight agitation, are very effective in screening out light in river water. A detailed case of the clearing of water by settling and the corresponding rise in the m.i.d. may be taken as typical of several hundred determinations of this sort. At Pharrs Island, near Clarksville, Missouri, the surface m.i.d. of the Mississippi River water on August 24, 1932 was 157 mm. After standing 1 hour the m.i.d. rose to 176 mm.; after 2½ hours to 221 mm.; after 20 hours to 421 mm.; after 48 hours to 1,009 mm.; and after 96 hours to 1,639 mm. The silt still remaining therefore at the end of 20 hours settling reduced the m.i.d. of the water (as shown by filtration samples) from 15,000 mm. to 421 mm. and at the end of 96 hours to 1,639 mm., *i.e.,* even after 96 hours of undisturbed settling, a condition which would rarely occur in the river, the silt load reduced the light entering the surface of the water to one-millionth of its surface intensity in approximately the first 1.5 meters as compared with 15 meters for this same water without its silt load. In many cases the colloidal clays carried by inland stream waters maintained effective screens against light penetration for even longer periods than in this average sample from the Mississippi River. These suspensions, however, could be quickly discharged by adjusting the water to a pH of 8.8 to 9.1, an alkaline condition not found in normal river water.

Penetration of Colored Light of Various Wave Lengths into Waters Carrying Erosion Silt

As the physiological and biological effects of light vary with the wave length, the selective action of erosion silt against light entering river water was studied both by spectrographic photographs of light transmitted through waters carrying erosion suspensoids and by the measurements of the transmission of colored light through such samples, as recorded by the photoelectric apparatus. In both cases the light transmission of each of the various pieces of glass apparatus and screens (Corning Glass for colors) was standardized spectrographically against the helium spectrum as photographed on the same plate.

Selective penetration studies showed that waters carrying large loads of erosion silt transmitted in general more red light than light of the shorter wave lengths, with a maximum transmission in the scarlet-orange zone, *i.e.*, light of wave lengths between 6,600 and 5,850 A. U. However this differential in favor of the red rays was not large, especially in less turbid waters, so that the major effect of the suspended erosion silt is that of an opaque screen, regardless of the color of the light. The high selectivity of clear ocean water and distilled water favoring the transmission of light between 4,700 and 5,500 A. U., the bluish and yellowish greens (Shelford, '29; Pietenpol, '18), was not found in water carrying even a small amount of erosion silt. In fact some muddy waters, possibly as the result of dissolved substances, seemed slightly selective against the blue green light. The various findings on the penetration of colored light into river waters containing erosion silt were checked and verified by studies of light penetration through prepared suspensions in distilled water of white adobe clay, red clay and black humus and through similar suspensions of muds dredged from the bottoms of Lake Wilson, Lake Keokuk and Lake Pepin at points where extensive deposits of erosion silts were found. These tests showed that the color of the soil was practically a negligible factor, in determining the color of light transmitted through waters containing erosion silt, except for possibly a small amount of selective reflection of light from the silt particles in very dilute suspensions. The erosion silt particles, therefore, screen out the light very largely as opaque objects regardless of their own individual color.

Spectrographic photographs of light transmitted through river water carrying erosion silt confirmed the findings on light penetration into such waters as stated above. Figure I gives spectrographic photographs of Missouri River water before and after filtering and of unfiltered water from the Hinkson River, a small Missouri stream flowing over a limestone bed but through farm land. These photographs show a differential in favor of the red end of the spectrum.

TEMPERATURE ADJUSTMENT OF SILT-LADEN WATER

The heating and cooling rates of water carrying erosion silt as compared with distilled water was determined for various samples in standardized two-liter pyrex flasks immersed in electrically controlled constant temperature water baths. When desired the fluid inside the flask was kept in motion by a motor driven glass stirrer making approximately 150 r.p.m. The data from these heating and cooling tests, when expressed graphically gave curves for the rates of heat transmission and heat radiation in waters carrying erosion silt that were essentially the same as those for distilled water (with of course a slight allowance for the small amounts of electrolytes present in the river waters) if the water samples were constantly and sufficiently agitated. However, if the samples were undisturbed the stratification of the erosion silt particles as they began to settle out or otherwise rearrange themselves definitely interferred with heat transmission and produced a skew lag in both the warming and cooling curves of waters carrying erosion silt as compared with distilled water. Temperature affects the metabolism of aquatic organisms and alters various physical and chemical factors,

TABLE I. *Cooling and heating of water from Coal Creek, near LaFollette, Tennessee, April 25, 1934*

Minutes after immersion	Unagitated			Agitated	
	Distilled water in degrees C.	Coal Creek		Distilled water in degrees C.	Coal Creek unfiltered [2] in degrees C.
		Filtered [3] in degrees C.	Unfiltered [2] in degrees C.		
start	19.7	19.7	19.7	37.0	37.0
2	22.8	22.8	22.0	35.0	35.0
4	26.6	26.6	25.2	32.0	31.9
6	29.5	29.4	28.0	30.2	30.0
8	31.5	31.5	29.7	29.0	28.8
10	33.0	32.9	31.2	28.0	28.0
12	34.0	34.0	32.3	27.4	27.4
14	34.8	34.7	33.0	26.9	27.0
16	35.4	35.3	33.7	26.5	26.6
18	35.9	35.8	34.2	26.2	26.3
20	36.2	36.2	34.6	25.9	26.0
22	36.4	36.3	35.0	25.8	25.8
24	36.6	36.6	35.3	25.6	25.6
26	36.7	36.7	35.6	25.4	25.5
28	36.8	36.8	35.8	25.4	25.4
30	36.9	36.9	36.0	25.3	25.3
40	37.0	37.0	36.5	25.3	25.3
	Bath temperature 37°C.			Bath temperature 20° C.	

[2] m.i.d. 614 mm. as taken from stream.
[3] m.i.d. 17,000 mm. after passing through colloidal filter.

FIG. 1. Spectrographic photograph showing light transmitted through water carrying erosion silt.

A = Helium spectrum. The wave lengths of the more conspicuous lines are given in Angstrom Units at bottom of figure. 1 minute exposure.

B = Hinkson River water, unfiltered. Sample taken near Columbia, Missouri, November 23, 1931, m.i.d. 1,846 mm. 30 seconds exposure.

C = Open light. 30 seconds exposure.

D = Empty flask. 30 seconds exposure.

E = Missouri River water, unfiltered. Sample taken near Boonville, Missouri, November 23, 1931, m.i.d. 84 mm. 20 minutes exposure, sample shaken every 2 minutes to maintain complete suspension.

F = Missouri River water, filtered. Same sample as "E," after passing through colloidal filter, m.i.d. 8,000 mm. 30 seconds exposure.

as dissolved oxygen, in the waters of the stream, so there are several applications of the findings from these heating and cooling tests, particularly to river lakes. As has already been pointed out in the larger river lakes as Lake Wilson, during the summer there is a large band of warm water, the hyperlimnorrheum, carrying the silt load of the river, and flowing on top of the clear cold water of the hypolimnon. The blanket of silt carried by the hyperlimnorrheum in view of these heating and cooling data, must alter the rate of heat exchange between the surface waters and those in the deeper parts of these river lakes. In table I a typical set of these data from studies of samples from Coal Creek, a small tributary of the Clinch River near LaFollette, Tennessee, are presented.

Erosion Silt and the Electrolytes of River Waters

As has been pointed out under the discussion of light penetration into waters carrying erosion silt, the amounts of soluble substances in the filtrates after passing river waters through colloidal filters were small, and bore no very definite relation to the amount of erosion material present in the original sample. Variations in the amounts of soluble, colorless substances determined either as electrolytes by means of a standard specific conductance cell containing platinum electrodes and operating with a micro-hummer and telephone receiver, or specifically by the various analytical procedures as amounts of the salt were also independent of the erosion silt. The work on electrolytes in connection with erosion silt may be summarized quite briefly therefore although the electrolytes were frequently of much importance in stream pollution studies. The average specific conductance of relatively unpolluted river waters carrying erosion silt varied from 388 to 133 mho at 25° C.,[2] the usual value for the larger streams being near 290 mho, and the conductance of the whole river water, *i.e.,* river water carrying erosion silt was essentially the same as the conductance of the same sample of water after the erosion silt was removed by a colloidal filter. After sudden heavy rains the specific conductance of the river water usually fell, and never increased although the erosion silt load and consequently the turbidity rose greatly. These observations indicate that, under the existing conditions of erosion, rains and high waters add proportionately more insoluble material (erosion silt) than soluble electrolytes. Consequently following rains or high waters the available mineral salts in the water and the light penetration are both reduced in the river lakes as Lake Keokuk, Lake Pepin and Lake Wilson. A definitely correlated decrease in the plankton per unit volume of the water was noted at such times.

In connection with the salt complex of river water it may be noted that the erosion silt particles in most river waters were quickly discharged and precipitated when the pH of the surrounding water was adjusted to 8.8 to

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[2] These values are times 10^{-6}.

9.1, and that the erosion silt was found to have a slight buffer value against acids, particularly in regions where there were limestone outcrops.

Erosion Silt as Affecting Bottom Conditions

Blanketing of Stream Bottom

The effects of rapid blanketing of stream bottoms by layers of silt which smother out the existing fauna before it can readjust are well known. The sedentary biota suffers particularly during these sudden inundations of erosion material following floods and high waters, although many of the mobile species are affected either directly or indirectly through the loss of food supplies. The magnitude of some of the silt deposits and their effects on fisheries and fresh-water mussels in the Mississippi and Tennessee systems have already been discussed (Ellis, '31 a and b). However to determine the specific effects of slowly deposited silt under controlled conditions over 2,000 fresh-water mussels representing 18 of the common species were carried in a set of experiments conducted in the raceways at the U. S. B. F. Station at Ft. Worth, Texas. Special bottoms of measured sand or gravel were laid in these raceways and optimum conditions for mussels established at the start. Above these prepared bottoms wooden lattice-work trays were constructed so that mussels could be held at various levels in the same water, subject to the same silt deposits as the mussels in the gravel or sand at the bottom of the raceway, except that silt could not accumulate around or over the mussels in the trays. The raceways were supplied with running water from Lake Worth, an unpolluted, impounded portion of the Trinity River which carries a moderate load of very fine erosion silt, chiefly adobe clay with very little organic matter. The average turbidity of the water in the raceways represented a m.i.d. of 800 to 1,200 mm., *i.e.*, the water was not overloaded with silt. The current in the raceways was reduced so that conditions of silting comparable to those in the quieter portions of normal streams were maintained. The individual mussels were marked and the entire series inspected once or twice weekly.

These experiments, extending over some fourteen months, showed that most of the common fresh-water mussels were unable to maintain themselves in either sand or gravel bottoms when a layer of silt from one-fourth of an inch to one inch deep was allowed to accumulate on the surface of these otherwise satisfactory bottom habitats, although other individuals of these same species held in the lattice-work crates a few inches or feet above the bottom thrived in this same water. Daily analyses of the water at various levels in these raceways showed that the high mortality of the mussels on the bottom was induced by the silt covering and was not due to low oxygen, pH, carbonates or other water conditions. The Yellow Sand-shell, *Lampsilis teres*, a sand inhabiting species was the most readily killed by silt deposits, and the Three-horned Warty-back, *Obliquaria reflexa*, the Maple Leaf, *Quadrula*

quadrula, and the Monkey-face, *Quadrula metanevra,* were among the more resistant. However, the mortality rapidly approached 90 per cent or more for all species when the silt layer began to permanently cover the sand or gravel. On the other hand the mortality of the mussels in the crates was very low.

Laboratory experiments with fresh-water mussels in water carrying heavy loads of erosion silt (this material being kept in suspension by automatic glass stirring devices) showed that erosion silt interfered with the feeding of fresh-water mussels. The mussels in the muddy water remained closed a large per cent of the time, 75 to 95 per cent, while mussel in silt-free water but subject to the same current influences as those in the erosion silt tests were closed less than 50 per cent of the time. When mussels opened in water carrying large amounts of erosion silt, an excessive secretion of mucous was produced and this served in part to remove the silt which tended to settle into the mantle cavity. Mussels dying in silt laden water always contained deposits of silt in the mantle cavity and frequently in the gill chambers.

Retention of Organic Matter and Other Material by Erosion Silt

By a laking process organic particles and other substances in the river water are carried to the bottom as the silt settles out, and water-logged objects at the bottoms of streams are quickly covered by layers of silt, especially in the quieter waters. As a result organic matter, either from the natural detritus in the stream or from other sources, and trades wastes, as chemical and gas factory effluents, are carried to the bottom of the streams by erosion silt. Often these substances brought down with the silt are incompletely decomposed or are chemically unsaturated, so that subsequently large demands are made on the oxygen supply of the river water or noxious compounds are formed in these mud deposits. These hazards to aquatic life exist to some extent even in streams relatively free from erosion silt but are greatly augmented by the accumulation of material and the reduction of oxidation for which the silt blanket is responsible. The extent of the organic deposit held by erosion silt may be seen from some analyses of muds dredged from Lake Keokuk and Lake Pepin. These muds carried from 9.25 to 12.66 per cent organic material and from 0.286 to 0.457 per cent nitrogen by Kjeldahl determination in terms of dry weight. Erosion mud taken from surface run-off streams usually carried less than 1 per cent organic matter. Water analyses demonstrated low oxygen, high carbon dioxide and often relatively high sulphur content (as hydrogen sulphide or other sulphide derivatives) in water samples taken from near the bottom of these same river-lakes, above the layers of silt mixed with organic wastes, and bacteria counts made by the plate method showed that erosion silt deposits were much richer in bacteria than either the river water above these deposits, or the adjacent bottom areas of sand or gravel.

Laboratory experiments, verified these findings, for small amounts of finely divided organic material when mixed with erosion silt created an oxygen demand in the surrounding water, which oxygen demand was maintained 10 to 15 times as long as the oxygen demand created by the same amount of organic material when mixed with fine sand. These experiments also demonstrated that disturbances in the pH and carbonate balances were also sustained over much longer periods when the organic material was carried down by erosion silt than when deposited with sand.

SUMMARY

1. Erosion silt alters aquatic environments, chiefly by screening out light, by changing heat radiation, by blanketing the stream bottom, and by retaining organic material and other substances which create unfavorable conditions at the bottom.

2. The present erosion silt loads of our inland streams have reduced the millionth intensity depth for light penetration from 15,000 mm. to 34,000 mm. or more, to 1,000 mm. or less, the summer average for the Mississippi River (1934) above Alton, Illinois being less than 500 mm.

3. Erosion silt in river water acts chiefly as an opaque screen to all wave lengths of visible light, but in very muddy waters a small differential was found favoring the transmission of scarlet-orange light.

4. Erosion silt alters the rate of temperature change in river waters. This is particularly significant in deep river lakes where thermal stratification of the water produces a stratification of the silt load, a warm muddy river, the hyperlimnorrheum flowing over a clear, cold lake, the hypolimnion, during the summer months.

5. Excepting the very quiet portions, erosion silt is quite uniformly distributed throughout the waters of rivers even in very deep holes, and in those river lakes in which there is no thermal stratification.

6. Erosion silt does not materially alter the salt complex or the amount of electrolytes in river waters.

7. Experimental studies demonstrated that layers of fine silt from one fourth of an inch to one inch thick produced a very high mortality among fresh-water mussels living in gravel or sand beds, and in water which was otherwise favorable.

8. The amount of organic material carried to bottom with erosion silt ranged from 8 to 12 per cent of the dry weight of the mud on the bottom of Lake Pepin and Lake Keokuk.

LITERATURE CITED

——. 1933. Standard methods for the examination of water and sewage. *Ed. 7. Amer. Pub. Health Assoc., New York, N. Y.*

Bailey, R. W., C. L. Forsling, and R. J. Becraft. 1934. Floods and accelerater erosion in northern Utah. *U. S. Dept. Agri. Misc. Pub. 196.*

Bates, C. J., and O. R. Zeasman. 1930. Soil erosion, a local and national problem. *Wisconsin Agri. Exp. Stat. Research Bull. 99.*

Bennett, H. H., and W. R. Chapline. 1928. Soil erosion a national menace. *U. S. Dept. Agri. Cir. 33.*

Ellis, M. M. 1931a. A survey of conditions affecting fisheries in the upper Mississippi River. *U. S. Bureau of Fisheries Circular 5.*

——. 1931b. Some factors affecting the replacement of the commercial fresh-water mussels. *U. S. Bureau of Fisheries Circular 7.*

——. 1934. A photoelectric apparatus for turbidity and light penetration measurement. *Science* **80**: 37–38.

Pietenpol, W. B. 1918. Selective absorption in the visible spectrum of Wisconsin lake waters. *Trans. Wisc. Acad. Sci., Arts and Let. 19.*

Shelford, V. E. 1929. Laboratory and Field Ecology. *Baltimore.*