11-1978

Limnological Observations of Sugar Creek, Lincoln County, Missouri

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November, 1978

Department of Biology, Lindenwood College

St. Charles, Missouri

INTRODUCTION

Today, while looking at my log book, I notice that April 10, 1978 is the official beginning of my stream study. Back in the Fall of 1977, I decided to do a stream study for the culminating project required by Lindenwood IV. Then, it was a vague idea of sloshing around in some creek while making chemical water tests, noting obvious life forms, gathering and identifying these life forms and noting the geology of the stream's valley and channel. All of this was supposed to lead to an accurate description of "Said" creek as my culminating project. "Said" creek had not been chosen at that time. Comfortable in my ignorance of the enormity of the task before me, I put off my choice until Winter Trimester.

As the trimester progressed, I studied ecological principles as they applied to streams and reached a saturation point which was not caused by standing in water too long--it was time to start field studies. The choice of Sugar Creek in Cuivre River State Park was made because I had waded it many times before and had some curiosity concerning its life forms and its water's source. For example, I had noticed that the creek as it flows through the picnic area has a large volume compared to the upper reaches of the creek which is nearly dry during the summer and fall. No tributary carrying a large volume comes into the creek between the upper reaches and the picnic area. Where did all this water come from? What kinds of fish were here besides the blue gill and suckers I had seen on my previous wading-fishing expeditions?

On April 10, 1978, I drove up to Sugar Creek in the park to get permission to use the creek for study. I talked to the park manager and received permission to proceed with my study. That day the creek was running fast, high, and cold--not inviting for wading-type activities from an enthusiastic "creeker" like myself. I told myself as I left that weather conditions would surely change soon. They did change. The rain increased.

On April 11, I began my geological studies of the area by ordering a topographic map of the Elsberry, Missouri Quadrangle. I discovered when it came that it wasn't detailed enough and the roads had been changed since the map was made.

During April and May, in between heavy rains, I began to make short visits to the creek to gather water samples for chemical testing. My enthusiasm was beginning to dampen. Gray skies overhead, a sharp, cold wind whipping at my back, a creek running fast and bankful made me wonder if my creek would ever return to its placid state that I knew.

The end of May brought sunny skies. The creek began to show a few exposed gravel bars, attached algae began to grow in the shallow parts; I could step into the water without an involuntary, sharp inhalation escaping from my lips. The end of May and the first week in June was the time for making real progress on chemical and physical water tests at Sites 1-9. In the middle of June, I began to seine the creek for fish, gather bottom samples for invertebrates and record plants seen in the water. Each trip to the creek was and still is a new experience. As the summer progressed, the creek's current slowed, the water warmed, and more life became apparent. At the end of June and now in November, much of the creek bed is dry. The water disappears in long stretches of its channel only to appear again in a pool with no apparent connection to the stream. I am given a new panorama of conditions on each visit.

The dynamic nature of this stream has me in awe; I realize that my investigations illustrate only a few of the ecological principles I have learned from books. My culminating project--this stream study--gives me field practice in using the tools of the biologist-limnologist, but often falls short of answering the many questions I have about this stream. For example: How much of the water is runoff? How much is ground water? Are there other reptiles in this creek along with the common banded watersnake I see so regularly?

I am fortunate to have first enjoyed Sugar Creek as a wader and nature observer. Questions arose then. Why does the lower part of the creek appear as alternating quiet pools and active riffles? What species of algae make up those long streamers attached to rocks? Is this water polluted? Why is this stream so much like a clear Ozark stream? I attempt to answer these questions and others in my paper. Questions come to me anew as I wade this stream. For example: What is the seasonal variation of dissolved gases in the creek? Do nitrates fluctuate seasonally and/or after a heavy rain? What are the temperature variations of the stream at certain depths, times of day, and seasons? These are a few of the questions I have not answered. Perhaps it is best to leave those for others.

The following paper begins with a METHODS AND MATERIALS section which gives a brief description of the methods and materials I have employed to investigate the physical, chemical and biological conditions at each site. A DATA section follows. The first part of the data concerns the geology of the entire length of Sugar Creek. It includes length, gradient, rock stratigraphy, and a short description of the geologic features of each site, and short geologic history of the area which explains some of the creek's present features. The second part of the data section concerns the chemical factors investigated at each site: the presence of certain elements, ions, and compounds in the water and a brief explanation of the possible sources of these chemicals. The amounts of these chemicals are found in tables given at the end of each discussion. The third section of data deals with the obvious life forms found in the stream's water. They are reported as obvious surface plants, bottom plants, plankters, invertebrates, and vertebrates. A short discussion of the "fitness" of the physical and chemical conditions of the stream for certain species of plants and animals is included in the SUMMARY section. The SUMMARY section includes a statement characterizing Sugar Creek as a lotic environment, but a lotic environment unique in some ways, to its locality.

METHODS AND MATERIALS

Measurement of length. Total length of the creek was ascertained through the use of a geometric compass and topographic maps of the area.[1,2] The geometric compass was set to the scale of the maps (.1" = .1 mile). Consecutive marks were drawn on the creek as shown on the maps. The marks were counted and converted to miles.

Measurement of gradient. The altitude of the area where the creek begins was determined through the use of two topographic maps.[3] After finding the altitude of the area near the mouth of the creek, the latter altitude was subtracted from the former and the difference in altitude was divided by the total length in miles, giving an average gradient.

Measurement of width and depth at each site. The following method for finding width and depth is applicable only in creeks shallow enough to wade. A string was tied to two stones--one at each end. At the site, the rock tied to one end was thrown across the stream to the edge of the water. The other rock was anchored to the opposite side of the creek after the string was pulled taut. A wader equipped with a yard stick followed the string across and every three feet, the wader inverted the yardstick to measure the depth.

Measurement of velocity. A small stick, a watch with a second hand, and a tape measure were used to measure velocity. A 25' length of water was measured off using a tape measure. Two sticks were placed, one at each end of the 25' measure. The stick was dropped into the water and timed as it traveled 25'. The distance was divided by the total time in seconds to give velocity.

Methods of water collection. The water sample for dissolved oxygen (D. O.) was always collected first. It was collected in its calibrated glass bottle. The empty sample bottle was stoppered and lowered underwater by hand. The stopper was removed while it was underwater. The bottle filled, and if any bubbles were in the bottle, they were removed by tapping the bottle. The stopper was inserted while the bottle was underwater. The second water sample for other chemical tests was dipped from the surface with a glass jar.

Methods of chemical water testing. A field water testing kit model DR-EL, made by Hach Chemical Company was taken to each site to do water testing. Tests for dissolved oxygen, iron, nitrate, nitrite, phosphates, total hardness, calcium, magnesium, pH, total alkalinity, and turbidity were performed as outlined in the Methods Manual[4]. Carbon dioxide was measured indirectly using total alkalinity and pH values. The pH corresponded to a table value. This table value was multiplied by mg/liter total alkalinity to give mg/liter carbon dioxide. This method is found in the Handbook of Common Limnological Methods.[5]

Methods of capturing biological specimen. With the exception of Site 5 and Site 6, each site was seined to capture any fish, amphibians, crayfish, insects and reptiles. An 11' seine was dragged through the site by two persons. Seining was impossible at Site 5 and Site 6 because of their small size and rock-filled bottoms. Fish, amphibians, and insects were captured by dip net or by hand at these sites.

Obvious surface plants. The obvious surface plants were algae. These plants were gathered by hand at two sites, a deep pool, Site 1, and a riffle, Site 2. The water samples from Site 1 and Site 2 were introduced into Ehrlenmeyer flasks which contained three types of media (BBM, VSW and BBM + extra Calcium) for growth.[6]

Bottom samples. Bottom samples were taken by two methods. The first method utilized a Peterson dredge. This dredge was used in loose gravel, mud and sand bottoms at Site 1, Site 3, Site 4, and Site 8. The dredge was dropped into the bottom and brought to the top by a rope attached to the dredge. The contents were put through a series of graded sieves. If any life was found, it was put into a 10% formalin solution for preservation. The second method of bottom sampling employed a two pound coffee can which was pushed down into the sediment to a depth of one inch. A metal plate was pushed under the one inch of sediment in the can before bringing it to the surface. This method was used at Site 2, Site 5, Site 6, Site 7, and Site 9. The contents were put through the series of graded sieves and any life found was placed in a 10% formalin solution.

DATA

The Geology of Sugar Creek

Sugar Creek flows down part of the southwestern flank of the Lincoln fold in Lincoln County, Missouri. (See Figure 1, p. 9) The U.S. Geological Survey quadrangle map of the Elsberry Missouri Quadrangle made in 1934 shows the upper section of the creek from T50N R1W, section 36 to T50N R1W, section 7 to be intermittent. Intermittent is used to indicate a stream which does not flow over the surface of the channel at all times of the year. A walk to various sites at certain times verifies that this is the case. As mentioned in the INTRODUCTION of this paper, much rainfall causes this stream to run fast and high. At these times, the creek occupies the entire channel. Runoff from the areas above the creek's source is the major source of water in the rainy seasons. As summer progresses, the creek is often dry in long stretches of its channel, but at irregular intervals, the water reappears in pools. During this season, the major source of water is ground and spring water. The lower portion of the creek, T49N R1E, sections 18 and 19, is the only portion which flows all year.

Sugar Creek is a consequent stream, that is, "a stream whose pattern is determined solely by the direction of slope of the land."[7] Consequent streams often flow over massive, flat-lying rock formations and have a tree-like branching of its tributaries called dendritic drainage. The slope down which Sugar Creek flows is called the Lincoln Fold. This important geologic feature is an asymmetrical anticline approximately 165 miles long. (See Figure 2) This fold began its evolution during Ordovician times approximately 500,000,000 years ago. It continued to fold, fault and uplift during Silurian, Devonian and Mississippian times approximately 350,000,000 years ago. Toward the end of Mississippian times, this fold reached its maximum structural development, and since then has been subject to massive erosion by runoff

Figure 1: Sugar Creek drains the southwestern flank on the Lincoln Fold.

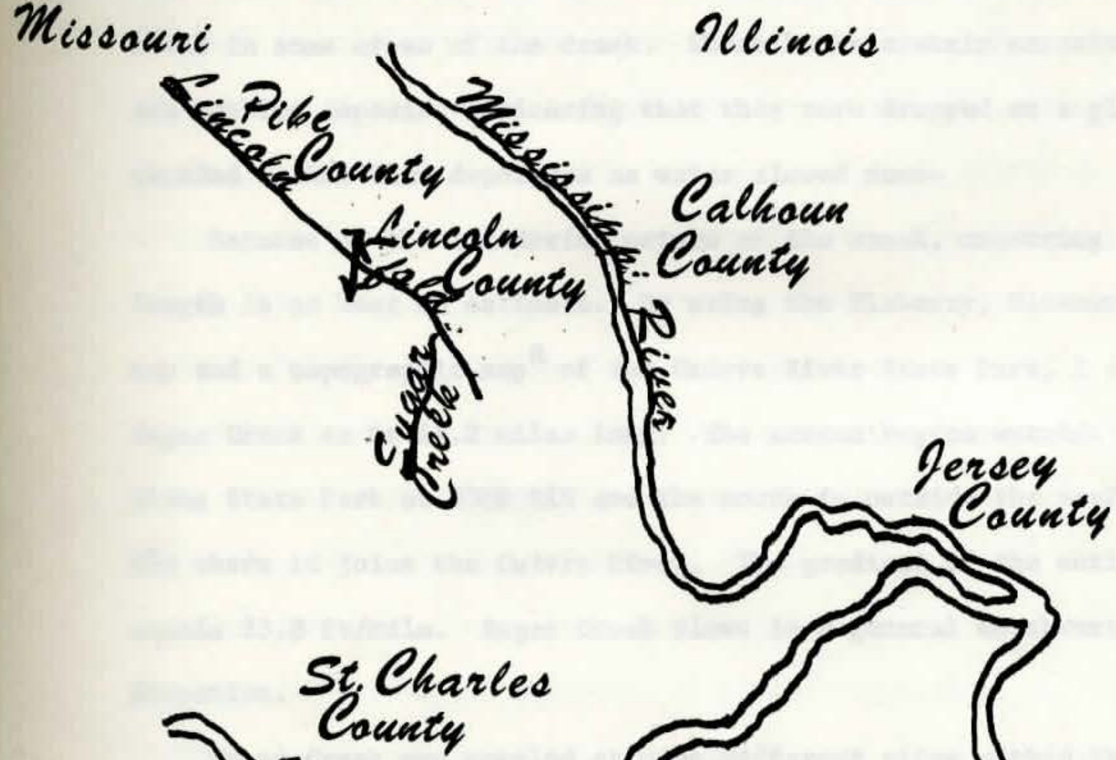


Figure 2: A cross section through an anticline showing the axial plane and its marking on a geologic map.

waters. This runoff caused the rock strata to be eroded down to the Osagean series of rock strata called the Burlington-Keokuk limestones. These limestones are the present bedrock exposed in the valley cut by Sugar Creek as it flows through the Cuivre River State Park. The chert nodules found in this type of limestone make up the gravel and cobbles found in the channel of Sugar Creek. Crinoid and Brachiopod fossils are commonly found in the gravel bars and rock cliffs along Sugar Creek. Evidence of glaciation during the Ice Ages is found in the mud-clay banks found in some areas of the creek. These banks contain unsorted gravel and cobbles deposits indicating that they were dropped as a glacier receded rather than deposited as water slowed down.

Because of the meandering nature of the creek, measuring miles of length is at best an estimate. By using the Elsberry, Missouri Quadrangle map and a topographic map[8] of the Cuivre River State Park, I estimated Sugar Creek to be 14.2 miles long. The source begins outside Cuivre River State Park at T50N R1W and the mouth is outside the park at T46N R1E where it joins the Cuivre River. The gradient of the entire stream equals 23.8 ft/mile. Sugar Creek flows in a general southwesterly direction.

Sugar Creek was sampled at nine different sites within the boundaries of Cuivre State Park. I chose the sites after looking over a topographic map of the Park and noted that the Park was five sections wide. I included one, and sometimes two sites per section. After wading the creek in a section, I chose a shallow site and a deeper site. All sites are marked on a three page map found in Appendix A. The sites are numbered 1-9 proceeding downstream from the source and going toward the mouth. Sites selected for study included a variety of widths, depths, channel bottoms, and velocities in order to illustrate a variety of stream environments. (See cross sections of each site on pages 15 and 16) A brief description of each site follows.

Sugar Creek at Site 1 is a wide, deep pool. The creek has worn through some layers of Burlington limestone on the east side leaving shelf-like rock layers exposed. On the west side of the creek is a steep mud bank (five feet high) which has large cobbles embedded in it--probably a glacial till deposit which has been covered by a forest-made soil. There is a small riffle leading into the pool. The bottom is sandy with a gravel bar in the middle of the channel. The bottom of the channel on the east side is boulder-strewn. The gravel in the middle was probably brought in by high water and deposited as the water flowed into this deeper, quieter water. This occurs because as water slows down, it drops out its heaviest particles. Except during spring and early summer, when much runoff comes through here, the water seeps into the pool from a spring upstream. Very little surface velocity occurs during most of the year (less than .01 ft/sec). After leaving Site 1, the water area narrows greatly and occupies only a small part of its rock-lined channel.

Site 2 is a narrow riffle at the Highway KK bridge. Water flows through this narrow channel rapidly (1.09 ft/sec). Increased velocity is probably a factor of narrowing of the channel at this site. The deeper side of the channel is boulder-lined and the shallow side is a gravel bar. Between Site 2 and Site 3, a small tributary comes into the creek on the west side. The water remains shallow, but at Site 3 it suddenly becomes a deep pool.

Site 3 is a wide section of the creek. The banks on both sides are steeply sloping--a gravel-sand bank approximately four feet from the water's surface on the east bank and a shelf-rock cliff approximately four feet high on the west bank. The water moves through Site 3 with a slow velocity. (.05 ft/sec). This is caused by greater size of the channel. At the end of Site 3, the creek makes a sharp bend and follows one, and at times two channels. The water in one channel, usually the west, disappears underground. Further downstream, the amount of water in the east channel increases. This must be due to the percolation of ground water from the higher areas upstream. The channel between Site 3 and Site 4 is wide and shallow with a few deeper pools (approximately two feet deep).

Site 4 is a deep pool of quiet water. A ravine leads into the creek on the east bank, but no water comes from this ravine except during and after a heavy rain. This site has a steep mud, cobble-embedded bank approximately five feet high on the east side and a gravel bar on the west side. The water is actively washing out the mud bank and fallen trees are in the lower end of this pool. The channel has a sand-mud bottom which is easily disturbed by walking through it. There are some large cobbles which have fallen in from the mud bank. Measuring velocity of the water is difficult because the water moves so slowly (.09 ft/sec) and wind often interferes with the measurement by blowing the stick upstream. The creek makes a sharp bend at the end of Site 4 and ends in a deep pool at Site 5.

The channel bed is wide at Site 5, but most of the water is in a narrow, deep pool on the west side of the channel. Large boulders, cobbles and tree roots from a large tree fill this pool. There is no current visible at Site 5 because the water ceases to flow over the channel's surface. Between Site 5 and 6, the creek bed has been dry since approximately June 14, 1978. An occasional pool is present because of ground water seepage into the depressions in the channel. During and after a heavy rain, this entire channel is filled with runoff water from surrounding hilly area.

Site 6 is a dry gulch with a small pool of spring water on the east side. A very uneven bottom, holes and high gravel bars characterize this site. There are large boulders which have fallen in from cliffs found on the east side of the channel. The west side of the channel is covered with a thin layer of forest-made soil. The spring pool is approximately three feet deep, but no current is visible because the water leaves the pool by seepage into the ground.

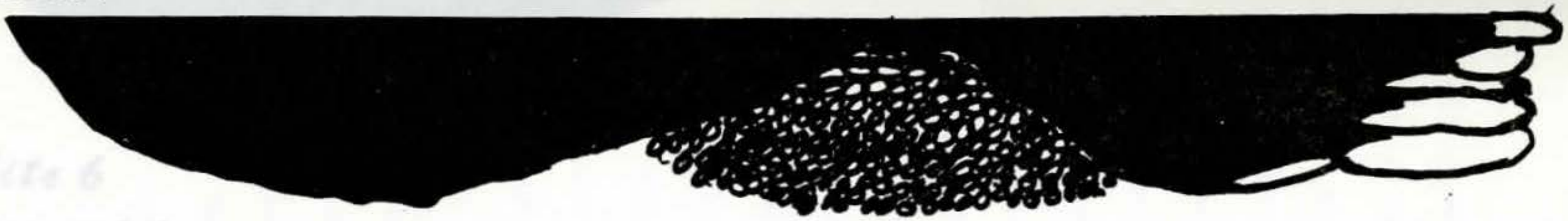
Site 7 is a large, rounded, shallow pool with an outlet ending in a riffle. The bottom of the channel is coarse sand with gravel and large areas of bare, jointed rock. The velocity is slow (approximately .02 ft/sec). The valley carved by the creek is deep. One hundred foot high hills are on both sides of the creek. Between Sites 7 and 8, the creek is a series of pools which end in riffles. This area appears to be sloping steps caused by the gradually descending channel filling in with gravel and fallen logs at narrow parts of the stream.

The creek bends sharply at Site 8 and is partially dammed by several large fallen trees. This site is a deep pool of quiet water known locally as the "swimming hole". A riffle is on the east side of the trees. The creek bank on the west is a 20 foot high Burlington limestone cliff and on the east it is a gravel bar. The bottom is sand-mud and gravel with large boulders near the cliff. The velocity was difficult to measure because wind interfered with the measurement by blowing the stick upstream, but an approximate measurement of .01 ft/sec was made.

Site 9 is at the end of two riffles below the Highway 147 bridge at the picnic ground in Cuivre River State Park. The water is very shallow (1-6 inches) on the west side as it goes over the gravel bar, but the east side is deeper (approximately 2½ feet). The velocity is .38 ft/sec. Both banks are low (approximately three feet). The east bank is exposed rock and soil layers and the west bank is a gravel bar. The bottom is sandy-gravel.

A general characterization of the flow of this creek would be that the creek flows intermittently between Site 1 and Site 6, but flows continually above Site 7 to the mouth of the creek. The water does not occupy its entire channel most of the year, but the creek has worn away enough of the overlying rock layers to be in the water table causing a constant, but slow seep of water. During the rainy seasons of the year, the creek carries much runoff from the rocky hills surrounding this creek.

Site 1



Site 2

Site 3

Site 4

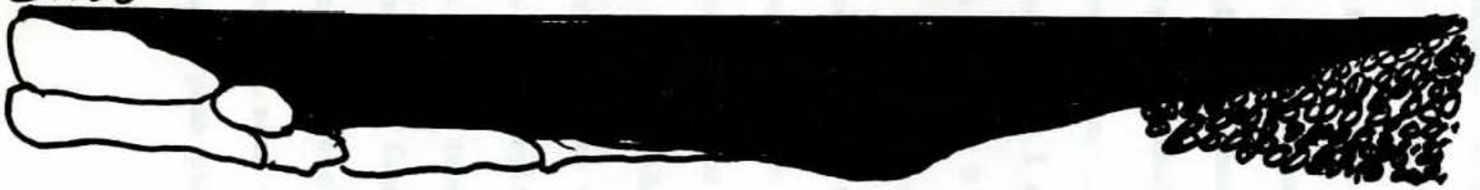
Scale .25 in = 1 ft

Site 5

Site 6
dry gulch

Site 7

Site 8



Site 9

CHEMICAL AND PHYSICAL FACTORS

Dissolved Oxygen. One of the key chemical tests made on water in Sugar Creek was the test for dissolved oxygen. In order for a stream to support living organisms in its water dissolved oxygen must be present. Generally less than three mg/liter dissolved oxygen is considered to be detrimental and sometimes lethal to most populations of aquatic organisms.[9] Dissolved oxygen is the source of oxygen necessary for the respiratory activities of all aquatic plants and animals, and is necessary for decaying processes which occur in the stream.

Oxygen in the atmosphere at 0 degrees C and 1 atmosphere pressure equals .27 g/liter. Oxygen dissolved in water at 0 degrees C and 1 atmosphere pressure equals .0146 g/liter. It is apparent that oxygen is not very soluble in water, but the amount is vital to aquatic life.

Dissolved oxygen gets into stream water by two main processes: aeration, either through riffles or through surface agitation by wind blowing across the surface of water and as a byproduct of photosynthesis of aquatic plants. Dissolved oxygen leaves stream water by respiratory activities of aquatic plants and animals, by decaying processes, through loss due to lessened solubility of O_2 at higher temperatures of water and through oxidation of various mineral substances found dissolved in water.

The following table shows the amounts of dissolved oxygen found at each site. The samples were not taken at the same time of day, but all were taken during daylight hours--a time of peak photosynthetic activity.

TABLE 1

Site	Trial 1 mg/liter	Trial 2 mg/liter	Trial 3 mg/liter	Avg.
1	6	6	8	6.7
2	11*	10*	9	10.0
3	11*	10*	11*	10.7
4	13**	11*	11*	11.7
5	11**	11**	9*	10.3
6	8	9*	8	8.3
7	12*	11*	12*	11.7
8	8	8	8	8.0
9	9	11	9	9.7

All values presented in the table indicate that the water in Sugar Creek has an adequate dissolved oxygen supply for the support of aquatic organisms. The values which have an asterisk indicate supersaturation at the temperature of the water when samples were taken. Supersaturation of dissolved oxygen can be caused by increased photosynthetic activity. A double asterisk indicates a probable collection or measuring error since the values seemed high for the type of site. Still water, unless an algal bloom is occurring, should have no more than 8 mg/liter.

Carbon dioxide. The atmosphere in rural areas rarely contains more than 52 mg carbon dioxide per liter air. Carbon dioxide is a very soluble gas in water, but in streams it usually does not exceed 10 mg/liter of water.[10]

Carbon dioxide is important to life in the stream because it is a necessary substance for photosynthesis in plants--exceptions being certain algae and higher plants which directly utilize bicarbonates. Carbon dioxide has a relationship to the amount of oxygen which can be absorbed on the hemoglobin molecule in fishes' blood--the higher the concentration of carbon dioxide, the lower the amount of oxygen absorbed.

Carbon dioxide enters the water by aeration of water due to riffles or wind blowing over the surface, ground water coming into contact with much decomposing material in the soil, decomposing organic material in the stream bottom, respiration of plants and animals in the stream, reactions of carbonate and bicarbonate, mainly limestone, with organic or inorganic acids.

Carbon dioxide leaves the water by photosynthesis of aquatic plants, formation of marl, agitation of water, and evaporation of water.

The following table, TABLE 2, presents the amounts of carbon dioxide found at each site. The alkalinity, and pH which are explained in later sections, are found in this table because they were used to calculate free carbon dioxide.

All water samples were taken during daylight hours, which are times of high photosynthetic activity. The tests for pH and alkalinity were performed at each site. Later, the calculation of free carbon dioxide was made using the graph mentioned in the METHODS section of this paper.

TABLE 2

Site	Alkalinity in mg/liter	pH	CO_2 in mg/liter
1	260	8.6	1.04
2	240	8.6	.96
3	230	8.6	.92
4	230	7.6	9.2
5	250	8.4	1.5
6	220	7.9	4.4
7	220	7.6	8.8
8	250	8.0	4.0
9	230	8.0	3.7

The greatest source of error in this method of free carbon dioxide is in determining the pH. For example, an error of .1 unit of pH can cause an error of 2 to 4 mg/liters carbon dioxide if the pH range is between 7.0 and 7.3 and the total alkalinity is 100 mg/liter.[11]

pH. "The pH of a solution is a measure of its hydrogen ion activity and is the logarithm of the reciprocal of the hydrogen ion concentration."[12] The pH scale is 0-14. The pH of most natural waters range from 4-9. pH changes from 7, the neutrality point, are the result of reactions of weak acids and strong base salts, or of strong acids and weak base salts. The gases, ammonia, carbon dioxide, and hydrogen sulfide also change the pH. Most natural waters in this area are slightly alkaline--the pH is over 7.0 but under 9.0. This alkalinity is due to dissolved carbonates and bicarbonates from limestone and dolomite.

The importance of pH values is that often they are one of the limiting factors of the distribution of aquatic plants and animals. pH tests were performed on Sugar Creek so that free carbon dioxide could be determined by the method described. TABLE 2 on page 20 shows the pH values for each site. As can be seen from the data, none of the sites indicated an acidic condition of the water. This is consistent with the description of most surface waters in this area.

Alkalinity. Alkalinity of a stream's water is the capacity to accept protons. The compounds or ions which cause the shift from neutrality towards alkalinity are (1) hydroxide, (2) carbonates, and (3) bicarbonates. When total alkalinity is determined, these three ions are summed. When testing for alkalinity, the first indicator used is phenolthalein. When this indicator does not show a purple color, it is assumed that there are no hydroxide or bicarbonate ions in the water sample contributing to its alkalinity. Therefore, the alkalinity value is due to the bicarbonate ions. This was the case for water in Sugar Creek.

Alkalinity is important in that it determines the pH. A high hydroxide value could indicate contamination and/or water treatment chemicals. Total alkalinity values in most natural waters range from 45 to 200 mg/liter.[13] Sugar Creek had higher readings than 200 mg/liter at all sites. One possible explanation is that the ground water percolation through massive limestone and dolomite beds of this area is dissolving large amounts of calcium carbonate and carrying the dissolved material into the stream.

Total hardness, Calcium and Magnesium. The test for total hardness is a measure of the total amount of calcium and magnesium ions expressed as mg/liter calcium carbonate. Calcium and magnesium are important to the normal growth and survival of aquatic plants and animals. For example, pH is related closely to the amount of bicarbonates of calcium and magnesium, and the alkalinity in this creek is equal to the amount of bicarbonate, therefore; the hardness being equal to the alkalinity may be a limiting factor for distribution of certain populations of plants and animals because it determines pH. A second important factor is that certain algae depend on these bicarbonates for a supplemental supply of carbon dioxide. Also, calcium salts are used in aquatic organisms; shells, bones and teeth. Magnesium is an essential ion to the chlorophyll molecule found in all green plants.

Calcium and magnesium ions enter the water of a stream from ground water as carbonic acid in ground water reacts with carbonate rocks (mainly limestone and dolomite) forming the soluble carbonate, calcium bicarbonate.

Calcium and magnesium ions leave the stream's water as aquatic plants and animals produce marl (calcium and/or magnesium carbonate), as plants take up magnesium or as water evaporates, leaving the carbonate residue which precipitates.

TABLE 3 shows total hardness, calcium, magnesium, and alkalinity at each site in ppm (ppm is the same as mg/liter).

TABLE 3

Site	Alkalinity ppm	Total Hardness ppm	Calcium ppm	Magnesium ppm
1	260	260	220	40
2	240	240	200	40
3	230	220	200	20
4	230	230	190	40
5	250	250	200	50
6	220	220	190	30
7	220	220	200	20
8	250	250	210	40
9	230	230	200	30

Hardness values expressed as mg/liter calcium carbonate can range from 0 to hundreds of mg/liter. Concentrations of calcium in waters from limestone areas range from 30 to several hundreds mg/liter.[14] Magnesium concentration in water often ranges from 5 to 50 mg/liter.[15] As can be seen from values given in the table above, the amounts of calcium and magnesium are high. This is explained by the types of rock through which this water flows (limestone and dolomite).

Iron. Iron, although it ranks next to aluminum in abundance in the Earth's crust, is usually found in alkaline surface waters in concentrations less than 1 mg/liter.[16] Iron may be found in either the ferric (Fe^{+++}) or the ferrous (Fe^{++}) state. Iron is important in that it is a limiting factor for certain aquatic plants. If water contains more than 5 mg/liter iron, growth of aquatic plants is seriously hindered.[17] Aquatic plants grow best when the iron content is .2-2 mg/liter.[18]

Iron enters a stream's water by being dissolved in ground water as iron-containing minerals are leached from the rock layers through which the ground water flows.

Iron leaves the water as certain bacteria called iron bacteria act on the ferrous state. They oxidize it to the ferric state where it becomes hydrated and precipitated, forming yellow-orange gelatinous deposits.

Refer to TABLE 4 for the amounts of iron found at each site. Notice that the water of Sugar Creek carries less than 1 mg/liter iron. This fact is consistent with the description of the water of an alkaline surface stream.

TABLE 4

Site	Iron mg/liter
1	.05
2	.05
3	.05
4	.05
5	.05
6	less than .05
7	less than .05
8	.05
9	.05

<u>Inorganic nitrogen compounds</u>. Inorganic nitrogen compounds found in water are nitrate, (NO_3-), nitrite, (NO_2^-), and ammonia, (NH_3). In unpolluted waters, the inorganic nitrogen compounds usually are 1 mg/liter or less.[19] The two inorganic nitrogen compounds tested for in Sugar Creek were nitrate and nitrite. These will be considered separately in the discussion, although TABLE 4 shows the amounts of both ions found at each site.

Nitrate is the most highly oxidized state of nitrogen found in water. The world average concentration of nitrate in water is .30 ppm.[20] It is important in that it is the form of nitrogen that is used directly by most plants in their uptake and utilization of nitrogen for protein synthesis. It is also the end-product of the decomposition of organic nitrogen-containing molecules (proteins and amino acids).

Nitrate enters the stream's water through runoff as the water picks up decayed proteins in the watershed. Ground water can also contain nitrate because it has run through areas which have much decayed organic matter. In the stream itself, bacterial action on nitrites add to the nitrate content of the water. Nitrate concentration is usually small, less than .3 ppm in an unpolluted stream.[21]

Nitrite is the second highest oxidation state of nitrogen. It is found in quantities less than .1 mg/liter in unpolluted streams.[22] It is important because it can be utilized directly by certain aquatic plants in protein synthesis and also because it has a toxic effect on many aquatic plants and animals if the concentration exceeds .1 mg/liter.[23]

Nitrite gets into stream water by nitrite bacterial action on ammonia and denitrifying bacterial action on nitrates which are in the water.

Nitrite leaves stream water by the action of nitrate bacteria on nitrites or by the action of denitrifying bacteria changing nitrite to ammonia. Plant up-take of this substance also reduces the concentration.

TABLE 5

Site	Nitrate in ppm	Nitrite in ppm
1	5.98	.02
2	2.00	.01
3	.995	.005
4	1.00	0.0
5	1.00	0.0
6	5.99	.01
7	4.96	.04
8	7.97	.03
9	2.995	.005

<u>Phosphates</u>. Phosphates in water are present in two forms: organic phosphates (meta, poly, and ortho) and inorganic phosphates (poly and ortho). The phosphate tested for in Sugar Creek was orthophosphate. Orthophosphates are usually the ions of phosphoric acid, and at the pH of this stream (mildly alkaline), the phosphate salt is more probably calcium phosphate.[24]

The importance of all types of phosphates to the aquatic community is that phosphates are used in the synthesis of ADP and ATP, the energy-transformers of all living cells and in the nucleic acids, DNA and RNA.

The primary natural source of phosphates in water is the leaching of rocks containing phosphates. Other sources are decaying organic matter, domestic sewage, manmade fertilizers and detergents.

Phosphates leave stream water by being used by plants during periods of high biological activity, chemical precipitation of the salt, and by adsorption on clay particles.

The values for orthophosphate in TABLE 6 are given in ppm. No upper limits for orthosphosphate have been determined for flowing streams, although for total phosphates, a value of 100 micro grams/liter, or .1 ppm, has been used as a guide by the EPA. This is believed to be a value which prevents excess plant growth. The values shown in my table indicate that orthophosphates are equal to .1 ppm and in two cases, Site 4 and Site 5, exceed .1 ppm. This might be due to agricultural runoff of fertilizers into the stream, since there is cultivated land on both sides of the creek.

Refer to TABLE 6 for the orthophosphate values found in Sugar Creek.

TABLE 6

Site	Orthophosphate in ppm
1	.1
2	.1
3	.1
4	.2
5	.2

TABLE 6 (continued)

6	.1
7	.1
8	.1
9	.1

Turbidity. Turbidity is a term which refers to the opaqueness produced in water by suspended particles. These particles may be organic detritus, clay, plankton, silt or other colloidal particles. If the turbidity is high, the amount of light which can penetrate the water is much reduced. This reduction of light influenced the photosynthetic activity of the plankton and other bottom aquatic plants.

In moving streams, turbidity is often a problem because the stream picks up particles as it flows over bare land surfaces (exceptions being bare rock, gravel or sand). During flood times, the faster current causes more dirt and silt to wash into the main stream. A slow moving stream may be turbid because of an algal bloom.

Turbidity was measured in Formazin Turbidity Units. The reading for demineralized water equalled 0. Five hundred is the highest value for water which allows visible light transmittance. TABLE 7 shows the values for the water at each site along Sugar Creek.

TABLE 7

Site	Formazin Turbidity Units
1	10
2	10
3	10
4	20
5	55
6	20
7	10
8	0
9	0

THE BIOTIC COMMUNITY OF SUGAR CREEK

The biotic community of Sugar Creek refers to all living organisms found in this stream habitat. Not all plants and animals could be found and identified in this study, therefore, the data reports only the obvious surface plants, the obvious bottom plants, the obvious plankters, the obvious invertebrates, the obvious vertebrates.

Obvious surface plants. The obvious surface plants of Sugar Creek are algae, members of Divisions CHLOROPHYTA, CYANOPHTA, and CHRYSOPHTA. Algae, although simple in structure because they have no leaves, roots or stems, are the energy "fixers" of the stream. In the process of photosynthesis, the algae trap the radiant energy of the sun in their protoplasm, which in turn, is eaten by the heterotrophs of the stream. Early this spring, few algae were visible on the surface because of the high water, but as summer approached, long streamers (at times 20 feet in length) of green algae began to appear on the partially submerged rocks. In the riffles, these streamers were attached at one end to the submerged part of the rocks, while the remainder of the plant floated on the surface downstream. This type of alga was Cladophora, a genus of the division Chlorophyta, the green algae. Upon microscopic examination of pieces of Cladophora, it was seen that Cladophora was a substrate for other algae. For example, the diatom, Navicula and the green algae Spirogyra were frequently seen on the branched filaments of Cladophora.

In the quiet pools of water, free-floating algae were not macroscopically obvious until the middle of the summer. When a sample of water was taken from Site 1, a quiet pool, no alga filaments could be seen in the water. A drop from this sample was placed in three types of growth media and allowed to grow for three weeks. At the end of three weeks, many surface algae were found in the cultures. TABLE 8 lists all genera identified and the site where each is found. There was considerable duplication of genera in the two sites, but it should be noted that at Site 2, a riffle, fewer algae were found.

TABLE 8

Genus	Site 1	Site 2
Cladophora	x	x
Chlorococcum	x	x
Chlorella	x	
Chroococcus	x	
Closterium	x	
Chlamydomonas	x	
Cosmarium	x	
Oedogonium	x	x
Oscillatoria		x
Spirogyra	x	x
Stigeoclonium	x	
Tetraspora	x	
Ulothrix	x	x

Obvious bottom plants. The obvious bottom plants in Sugar Creek are the diatoms belonging to Division CHRYSOPHYTA and certain algae belonging to CYANOPHYTA, and CHLOROPHYTA. The riffle areas in the sites tested had long, green streamers of algae on the submerged rocks. As mentioned in the previous section, this alga was mainly Cladophora. In all areas which had boulders or cobbles on the bottom, many diatoms were present. The diatoms form a slippery surface on the rocks. TABLE 9 presents all of the bottom plants identified.

TABLE 9

CHRYSOPHYTA	CYANOPHYTA	CHLOROPHYTA
Navicula	Rivularia	Spirogyra
Gomphonema	Nostoc	Cladophora
Achnanthes		Stigeoclonium
Diatoma		
Cymbella		
Fragilaria		

The above listing of genera is not reported by site because of the repetition of genera. The diatoms, blue green and green algae often become plankters (free-floating organisms) when the current increases after a rain. The scouring effect of the water along the bottom loosens bottom plants and transports them downstream, where they may be attached anew.

The importance of the bottom organisms is that they participate in the important function of photosynthesis, as do the surface plants. They are also a main food supply for larger zooplankton, and invertebrates such as Mollusca, and insect larvae.

Plankters. "The plankters are those organisms that, because of their size or immobility or both, are at the mercy of water movements."[26] Plankton of Sugar Creek were studied incidently as bottom plants, surface plants and bottom animals. No separate studies using a plankton net were employed due to lack of time. Because plankton in a lotic environment settle to the bottom or attach to some substrate very rapidly, one would not expect to find many plankters in the stream's water. I did find some plankters in the water sample I took out at Site 1. See TABLE 8, page 31. Other organisms found at various sites are listed below in TABLE 10.

TABLE 10

Crustaceans	Rotifers	Protozoans
Daphnia	Philodina	Paramecium
Macrothrix	Rotaria	Chlamydomonas

Obvious invertebrates of Sugar Creek. The obvious invertebrates found in Sugar Creek were found attached to submerged logs, rocks and other vegetation, crawling on the bottom of the channel, or buried in the bottom sediments of shallow or deep sites. Two common insects found on the water's surface are listed below.

Invertebrates play an important role in the biotic community of Sugar Creek in that they are consumers of plant life, and are a food source for larger and faster animals. It must be noted that most of the invertebrates were captured in the shallow areas sampled. TABLE 11 gives the common name and the genus of each organism identified and the area where it is most commonly found.

TABLE 11

Genus and Common Name	Area where found
Physa snail	log and bottom rocks
Cambarus crayfish	crawling on bottom rocks in riffles and gravel areas
Gammarus scud	bottom sediments such as mud and sand
Ablabesmyia midge larva	bottom sediments of sand and mud
Isogenus stonefly nymph	bottom sediments of sand and mud
Gerris water strider	surface of water
Hydrophilus water scaventer beetle	surface of water

The obvious vertebrates of Sugar Creek. These animals represent the highest trophic level in the stream. Although some of the vertebrates such as the tadpoles are herbivorous, most are omnivorous, and some like the common banded water snake are carnivorous. Because of their size and motility, vertebrates are the organisms most easily noticed and identified. The areas of the stream where most of the vertebrates seemed to be concentrated were the shallow riffle areas. Some vertebrates such as the Green Sunfish, and the Orangethroat Darter were able to survive drought by living in the small pools of water at Site 5 and 6. The deeper areas of the stream such as Sites 1, 3, and 8 were the home of the larger Bluegill, Green Sunfish, Largemouth Bass. Sugar Creek has at least 15 different species of fishes and minnows, two species of frogs, and one species of reptile. TABLE 12 lists all of the vertebrates seen and identified.

TABLE 12

Species and Common Name	Location
FISH	
Semotilus atromaculatus Creek Chub	Site 8
Pimephales notatus Bluntnose Minnow	Site 8
Capostoma anomalum Central Stoneroller	Site 1, 8
Notropis umbratilis Redfin Shiner	Site 1, 8
Notropis lutrensis Red Shiner	Site 8
Notropis chrysocephalus Striped Shiner	Site 8
Notropis stramineus Sand Shiner	Site 1
Catostomus commersoni White Sucker	Site 7, 8
Lepomis macrochirus Bluegill	Site 1, 3, 4, 5, 6, 8
Ethestoma spectabile Orangethroat Darter	Site 1, 2, 8, 9
Cottus carolinae Banded Sculpin	Site 1, 8
Fundulus catenatus Northern Studfish	Site 8

TABLE 12 (continued)

Ictalurus melas Black Bullhead	Site 1
Lepomis cyanellus Green Sunfish	Site 3, 5
Micropterus salmoides Largemouth Bass	Site 1, 3
AMPHIBIANS	
Rana palustris Pickerel Frog	Site 2, 7, 9
Rana catesbiana Bullfrog	Site 7
REPTILES	
Natrix sipedon Common banded water snake	Site 1, 9

SUMMARY

Sugar Creek is a lotic environment. Lotic environments are inland waters in which the entire body of water moves continuously in a definite direction. Lotic waters have certain characteristics, they are: a variation of bottom sediments, suspended load as a function of velocity, a variety of velocities within the width and length of the stream, supply of dissolved gases often high or near saturation in unpolluted stream, dissolved solids usually high, pH range small due to current mixing the water, nitrates in low concentration and variable due to runoff, organisms adapted to current.

Sugar Creek flows in a general southwesterly direction down a slope with an average gradient of 23.8 ft/mile. The velocity range was wide (.01 ft/sec to 1.09 ft/sec). The highest velocity occurred during a time of increased runoff; and the lowest velocity occurred in a pool which has ground water as its major source of water.

In areas which had a slow velocity--less than 1 ft/sec, the bottom sediments contained fine sand, silt and some detritus. The areas which had a velocity greater than 1 ft/sec had gravel and cobble bottom sediments.

Because Sugar Creek has runoff water from bare rock areas, from forest-covered soil areas, and because much of the water comes from springs, the water is relatively clear. The average turbidity is 15 FTU. Recall that 0 FTU is the value for demineralized water. There were areas with higher turbidity than the average (15 FTU) such as Site 4 which had a silt bottom, and Site 5 which was a stagnant pool of water.

The dissolved gases, oxygen and carbon dioxide, were found to be variable, but definitely well within the limits of tolerance for most aquatic organisms. Some of the variations, especially the oxygen, were due to the amount of photosynthetic activity being done by the algae at the time of collection.

The dissolved solids reported as calcium, magnesium, and total hardness are high in Sugar Creek. The pH range is 7.6 to 8.6. This pH is descriptive of a slightly alkaline stream. The amounts of iron found in Sugar Creek (.05 mg/liter) are consistent with the description of a slightly alkaline stream. The alkalinity of the water in Sugar Creek is the same as the hardness value at each site; thus showing that the minerals causing alkalinity were mainly bicarbonates, natural occurring substances in a limestone area. Some of the nitrate values are higher than the recognized value (.03 mg/l world average) for unpolluted water. This would indicate that there is probably agricultural pollution getting into the stream. The orthophosphate values for the water in Sugar Creek cannot be judged because of lack of standards.

Many of the organisms living in Sugar Creek are adapted for living in current. The green alga Cladophora is common to slow moving streams. This alga as well as, Stigeoclonium, and Ulothrix is often found in clear, slow moving streams attached to submerged rocks or logs in riffle areas. The algae which are attached to rocks in the riffle areas are adapted to the current by having holdfast organs. The quiet pools in Sugar Creek make a well-suited environment for Oscillatoria, Tetraspora, Chlorella, and Oedogonium.

Within the filaments of the algae live the epiphytic organisms such as Philodina and Rotaria of the Rotifers, and Daphnia of the Crustaceans. These organisms and others serve as a food source for animals such as the Golden Shiner, Red Shiner, and Orangethroat Darter. Certain of the fishes and minnows are often seen in the riffles. These are the Central Stone-roller, feeding on the bottom rocks, Red Shiner, found near the surface, the quick swimming white suckers, feeding on the bottom, Orangethroated Darter, also a bottom feeder.

Certain of the pools of Sugar Creek are not flowing, Sites 5 and 6 have the fish which are more tolerant of stagnant conditions. The Green Sunfish, Black Bullhead, Golden Shiner, Creek Chub, and Fathead Minnow are fish which can survive in pools of water remaining as the main creek dries up. They are found in these pools.

The large permanent pools of Site 1, 3, 4, and 8 have the larger species of fish in them. Commonly found at these sites are the Large-mouth Bass, the Bluegill, the Banded Sculpin, the Green Sunfish. The Largemouth Bass and the Bluegill are voracious eaters and leave the deep water to prey on smaller organisms found in the shallow riffle areas adjoining the pools.

Species of invertebrates found in the bottom sediments were few. This lack of diversity cannot be explained by poor water quality. The water in Sugar Creek had adequate dissolved gases, and most minerals and nutrients were adequate. Perhaps this is a wrong observation due to the difficulty of capturing the bottom organisms. Certain species such as Isogenus, a Stonefly Nymph, and Ablabesmyia, midge larva, are found in lotic environments.

The creeks in the Prairie Region of the state are usually slow moving, with sand-mud bottoms and fairly turbid water. Sugar Creek is slow moving, but remarkably clear and somewhat cold. The highest temperature recorded at any site was 23 degrees Centigrade. The gravel bars, cold temperature and clarity of the water make Sugar Creek resemble an Ozark stream more than a typical Prairie Region stream of Missouri. Most species of fish found here were fish common the the area with the exception of one possible range extension, the Northern studfish.[26]

Thus we have Sugar Creek, an environment showing all the physical characteristics of a lotic environment.

It appears to be different, but closer observation shows that its life forms are typical of its area, the North Central Prairie Region.

EPILOGUE

This culminating project, entitled, Limnological Observations of Sugar Creek, Lincoln County, Missouri, has been more than an assigned project with its accompanying report. After I determined that the assignment was to be a stream study, I was able to realize a rare opportunity--the chance to investigate some casual observations I had about a favorite stream.

These investigations were not intended to be interpreted as scientific data. To do that would have required that all chemical, physical, and biological tests be controlled. They were not. Rather, these investigations were intended to be observations made with certain tools of the biologist-limnologist. Accuracy of data was striven for. Pertinent literature was read to understand each factor investigated. Tests were repeated when I doubted the results. This happened often. Each correction I was required to make gave me better insight in how best to utilize the equipment. Not all observations reported were done with sophisticated scientific equipment. Methods used for determining depth, width, and velocity were simple requiring only string, a stop watch, and a yard stick or tape measure.

The writing of this report caused me to review the pertinent literature of stream ecology, to think over possible causes for certain results, to relate the physical, chemical, and biological data I found in this stream.

Lastly, I gained the peace of mind which comes from being outdoors in a favorite place. This clear, and always cool stream was a pleasure to wade. There was an abundance of life to keep me watching. Seeing a new species was always exciting, but trying to predict its presence in the same spot another day made collection a gamble. As summer progressed, the amount of flow decreased causing the creek to change in appearance. These changes made the creek more interesting.

Reluctantly, I stopped my field studies. The creek is nearly dry now, but I know next spring it will flow clear, fast, and cold, repeating its cycle.

FOOTNOTES

1. Missouri Geological Survey, Rolla, Missouri, Elsberry Missouri Quadrangle Map, 1934

2. Missouri Geological Survey, Rolla, Missouri, Troy Missouri Quadrangle Map, 1972

3. Ibid. 1 and 2

4. Methods Manual, Hach Model DR-EL, Hach Chemical Company, Ames, Iowa. (n.d)

5. Lind, Owen T., Handbook of Common Methods in Limnology, 1974 pages 49-50

6. Mattox, Karl R, Bold, Harold C., Phycological Studies, 1962, page 10

7. Longwell, Chester R., Flint, Richard T., Introduction to Physical Geology, 1963, page 192

8. Missouri Division of Natural Resources, Division of Parks and Recreation, Cuivre River State Park Base Map, Oct. 27, 1976

9. Lind, Owen T. page 59

10. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 1971, p. 86

11. Ibid. page 87

12. Lind, Owen T. page 44

13. Ibid. page 51

14. Ibid. page 80

15. Lind, Owen T., page 58

16. Standard Methods for the Examination of Water and Wastewater, page 187

17. Smith, Gilbert M. The Freshwater Algae of the United States, 1950, pg. 16

18. Ibid. page 16

19. Reid, George L., Ecology of Inland Water and Estuaries, page 185

20. Ibid. page 187

21. Ibid. page 187

22. Standard Methods for the Examination of Water and Waste water, 1971, page 240

23. Ibid, page 240

24. Lind, Owen T. p. 64

25. Reid, George L., p. 200-201

26. Lind, Owen T. p. 81

27. Schuette, Bruce, List of Fishes found in Big Sugar Creek, 1978

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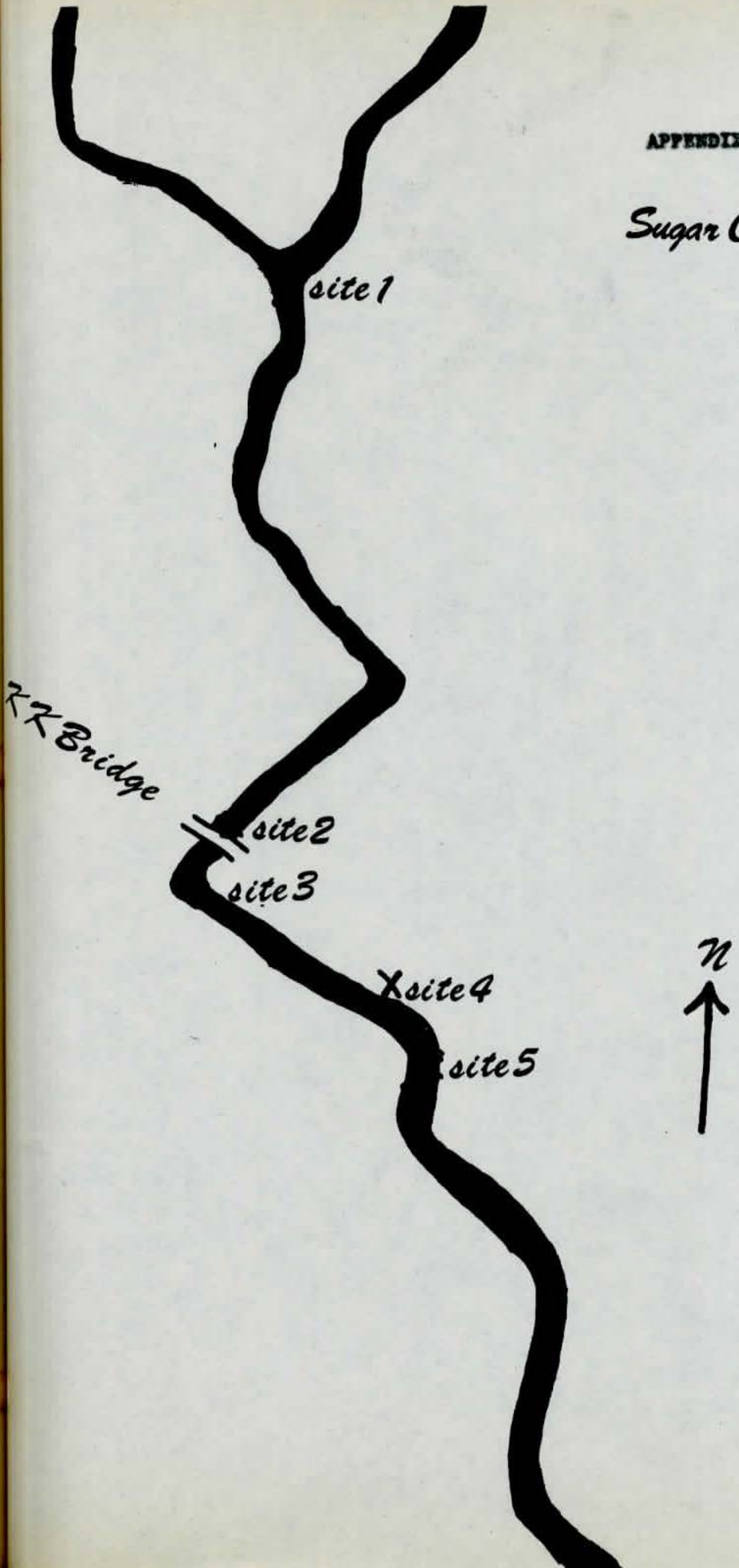
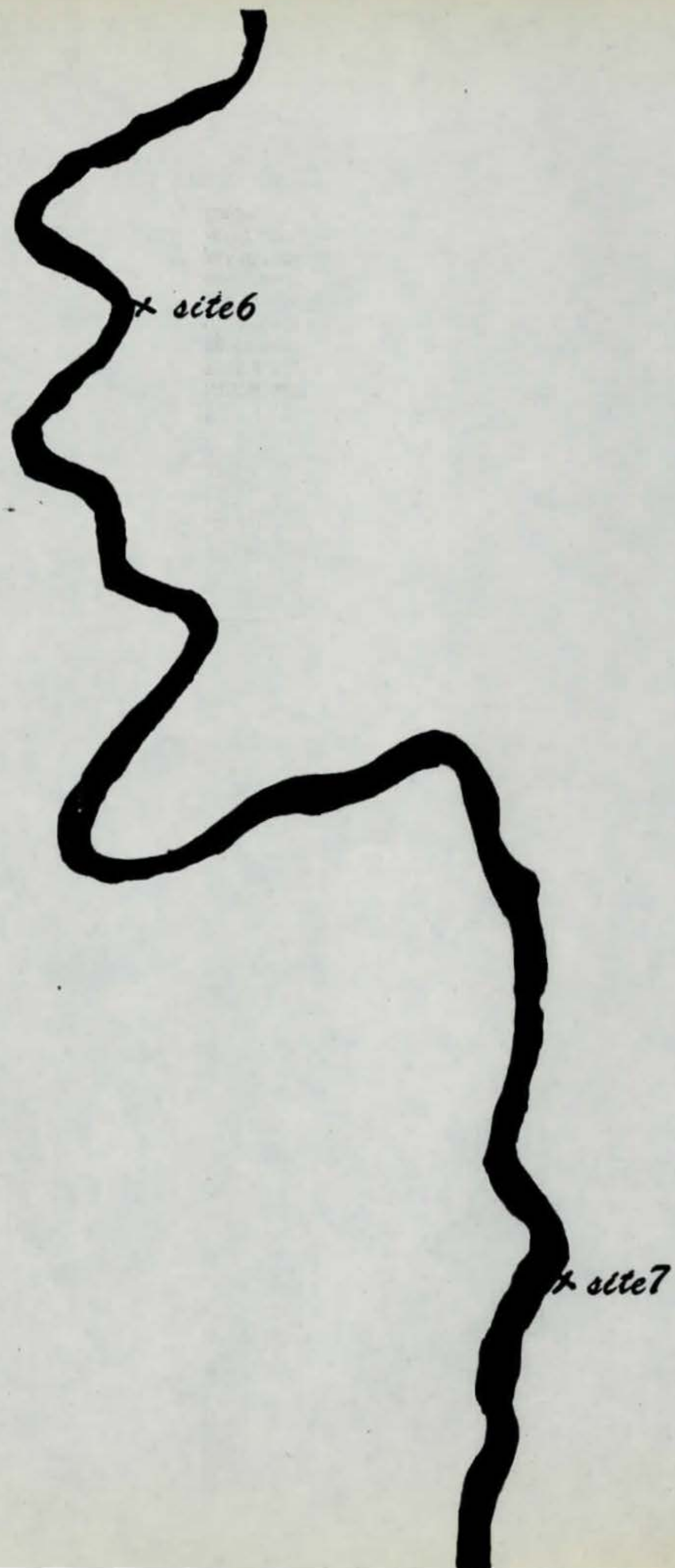
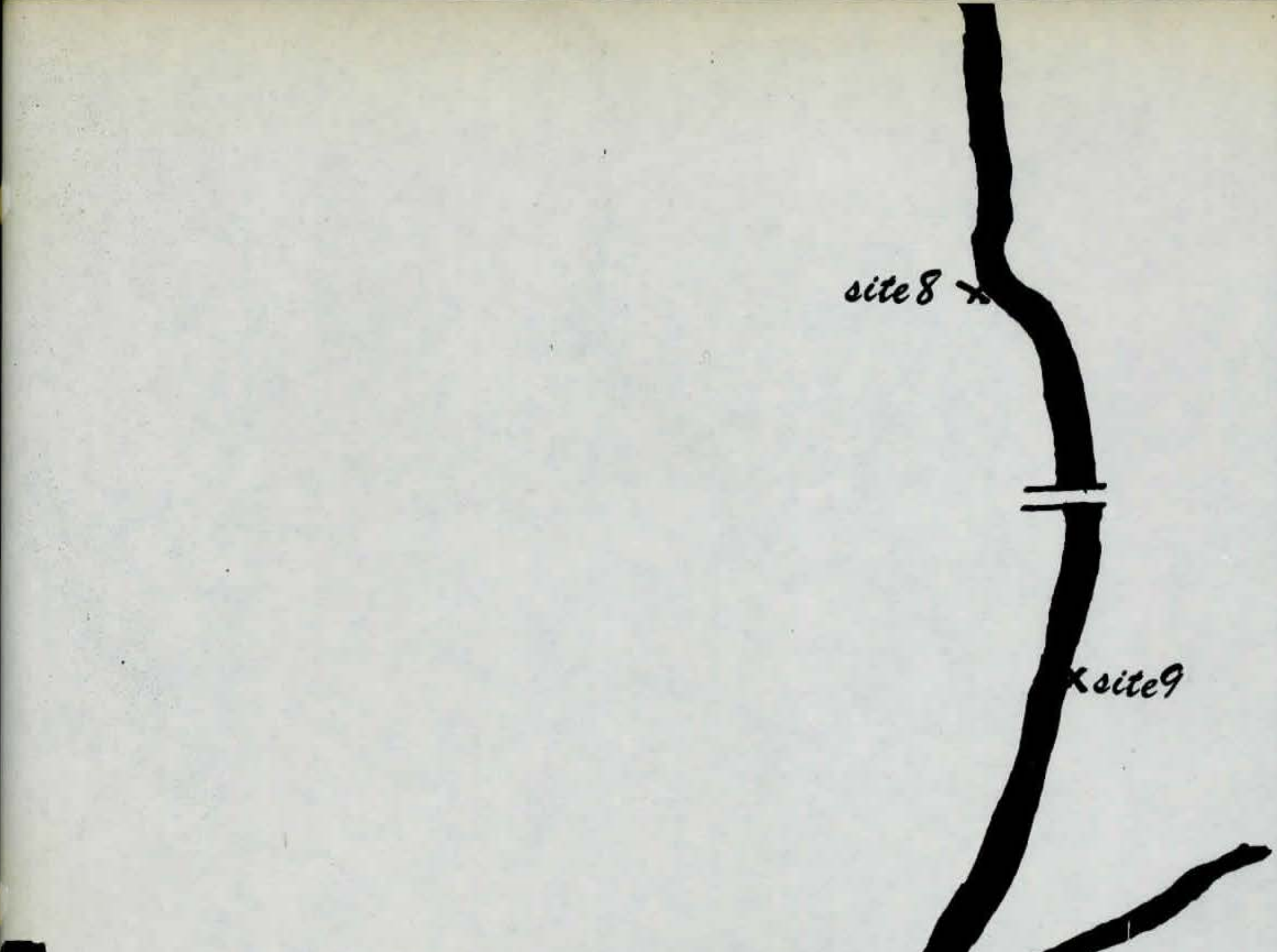
APPENDIX A

Sugar Creek




site6
site7


site 8
site9
Little Sugar Creek
Cuivre River