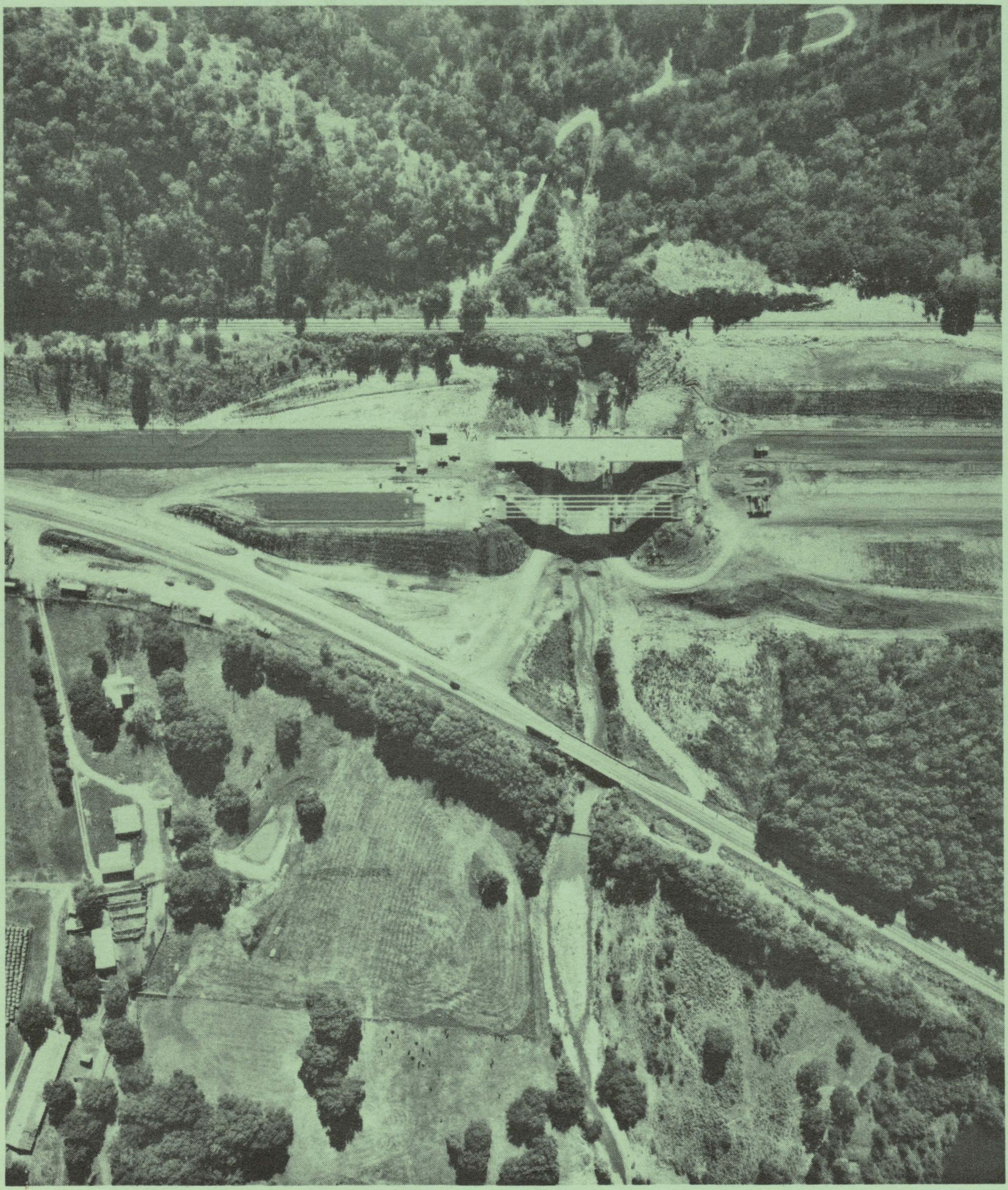
THE IMPACT OF HIGHWAY CONSTRUCTION ON A FRESH WATER STREAM

A DEMONSTRATION PROJECT



Research and Development Division
Oklahoma Department of Transportation
December 1988

THE IMPACT OF HIGHWAY CONSTRUCTION ON A FRESH WATER STREAM: A DEMONSTRATION PROJECT

By

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16. ABSTRACT

Oklahoma Department of Transportation (ODOT) commenced a demonstration study in 1976 to determine the impact of highway construction on a fresh water stream. A creek near a highway construction site along US-69 at Limestone Gap in northern Atoka County was selected. The testing sites along the streams in the area of construction were monitored for physical and chemical changes.

The sites were monitored by ODOT Research Division for a period of 11 years. A cost analysis was made to show approximate cost of conducting typical studies per year.

It was concluded that the construction activities used have no recognizable impact on fresh water streams, like Limestone Creek. It is recommended that highway construction contractors follow some guidelines to minimize erosion from construction sites. It is also recommended that similar studies be conducted in future construction areas where there is a potential for highway construction to impact on aquatic life or fresh water quality.

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PREFACE

This constitutes the final report of the research demonstration project 76-05-1 "The Impact of Highway Construction on a Fresh Water Stream".

Included in this report is a listing of the materials and methods required to perform the necessary tests which can estimate the effects of contaminating chemicals or sediments on the aquatic life of a clear perennial stream.

This publication represents an approach that may be used on other highway construction projects to estimate the possible impact of highway construction on small streams.

METRIC (SI*) CONVERSION FACTORS

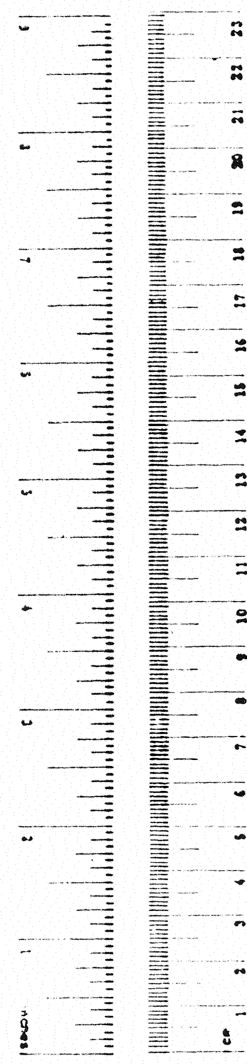
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

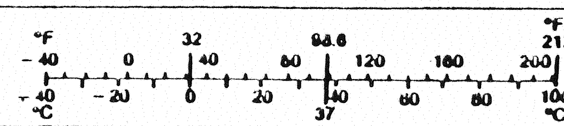
* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

EXECUTIVE SUMMARY

There is a continuous interaction between the highway environment and natural water resources. Each stage of the highway process namely; planning, location, right of way, design, construction, operation and maintenance has a potential effect on natural water resources.

Modern highway construction methods can cause large areas of cut and embankment soils to be exposed to erosion. Timely treatments of such exposed areas are necessary to reduce or eliminate the erosion-sedimentation process. Protection of stream water quality along highway construction sites constitutes an important aspect of improving total aesthetic environment.

The amount of soil necessary to cause adverse effects on aquatic life in Oklahoma streams is largely unknown.

Oklahoma Department of Transportation (ODOT) personnel conducted a demonstration study of the impact of highway construction on a fresh water stream, at Limestone Gap, in Atoka County, Oklahoma, from 1976 to 1987.

Chemical, physical and biological parameters were determined in order to test and observe the water quality of three testing sites along Limestone and Noname Creeks, above and below the construction zone at Limestone Gap.

It was determined from the analysis of chemical and physical test data obtained from the testing sites, that there was no evidence of pollution or excessive concentrations of heavy metals in the stream. No significant sedimentation was found upstream or downstream from the construction zone.

In terms of costs, it was estimated that an average monitoring cost per test site, per year is approximately $16,000. This of course, depends on the type of tests required, wages and salaries of personnel, type of equipment, and materials needed to conduct the tests.

It was recommended that highway construction contractors follow some guidelines to minimize erosion from construction sites. It was also recommended that similar studies be conducted in areas where there is a potential for construction activities to impact on stream water quality.

Portable field kits and on-site procedures are available that can give good indications of the magnitude of turbidity, sedimentation and chemical content.

This study indicates the degree of proficiency required of ODOT personnel to conduct necessary tests needed to determine stream water quality.

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INTRODUCTION

The modern transportation engineer has become increasingly concerned not only with safety and traffic, but with aesthetics enhancement and environmental protection.

This study is directed at one aspect of environmental protection which is the effect of construction practices on stream water quality. It involves a demonstration effort by the Research Division of the Oklahoma Department of Transportation (ODOT). It shows ODOT's ability to monitor, record and identify the impact that various highway construction activities have on a fresh water stream.

The construction of a highway tends to generate public concern as a possible cause of stream pollution. Such pollution could result in the following: fouled drinking water, stream turbidity, clogged navigation channels, spoiled fishing grounds, clouded reservoirs, plugged culverts and sedimentation (siltation).[1] This concern emerges because there is a continuous interaction between highway systems and the numerous water resources of an area.

There are three kinds of stream water pollution that are of immediate concern to highway engineers. These are physical, chemical and biological. One or a combination of these can occur in a particular area.

Physical pollution can occur in the form of sediment introduced by slope and runoff erosion from highway construction sites after rain storms. This affects stream water greatly by reducing light transmission in the water thereby affecting fish food sources. Highways under construction have been found to yield between 250 and 730 metric tons of sediment per hectare.[2] Construction activities like clearing, grading, blasting, excavating and pond draining may be the source of sediments. Such sediment is picked up by surface runoff and carried into the streams as silty or clayey suspended solids. Clay particles produce turbidity which could pose serious threats to aquatic life below construction sites. A stream filled with sediment may cause flooding, bank erosion, clogging of channels, silt coating of gills in young fish, burying of fish eggs, destruction of microinvertebrate habitat, damage to other elements of the aquatic ecosystem or general loss of aesthetic appeal.[3]

Chemical pollution in the form of dissolved minerals and heavy metals may have toxic effects on aquatic organisms within a stream environment. If the stream water contains large amounts of heavy metals such as lead, the effect can be devastating.

Dissolved minerals and heavy metals can be introduced into streams through application of herbicides and fertilizers from a farm area. It also could be introduced naturally from dissolved rock minerals. These minerals and heavy metals upon entry into the stream react with and deplete dissolved oxygen in water thereby, causing death of fish and other aquatic life.

Biological or bacteriological pollution of a stream can occur due to contamination from the use of herbicides and fertilizers, but this form of contamination is very rare in occurrence.[4] Since highway construction is increasingly being held responsible for the contamination of rivers, streams, lakes and ponds, it becomes necessary to determine the degree of impact of highway construction activities on a fresh water stream. The variables which influence or cause fresh water stream contamination must be recognized in order to develop mitigating measures.

OBJECTIVE

The objective of this study is to demonstrate ODOT's ability to determine the impact of highway construction activities on a fresh water stream. To accomplish this objective, procedures for testing and predicting the impact of highway construction were established by undertaking the following tasks:

1. Monitor water quality parameters at specific sites along the selected stream.
2. Determine the constituents contained in watershed runoff entering the streams prior to construction.
3. Identify significant pollutants, if any are observed.
4. Identify and document the presence of common microinvertebrates.
5. All data collected were to be classified, analyzed and the findings reported.
6. Determine the critical phases involved in the highway construction process that may have an impact on the quality of the stream water.
7. Establish an appropriate monitoring schedule.
8. Develop a procedure that ODOT can use to evaluate and select areas needing investigative effort, as it relates to highway construction practices.
9. Recommend the best management practices and operational guidelines for control and abatement of highway construction impact on a fresh water stream in Oklahoma.

The goal of this demonstration study is to incorporate useful water quality guidelines, findings or recommendations into the planning, design, construction and maintenance of highways.

SCOPE

This demonstration study involved testing and monitoring of two streams at Limestone Gap (Limestone and Noname Creeks) before, during and after highway construction.

A project manager and two technicians conducted the testing and monitoring activities.

Three sites were selected. Two sites were upstream and one was downstream from the construction zone. The two sites upstream were designated site 1 and site 2 respectively. Site 2 is closer to the construction. Site 3 is located downstream below the construction zone. Monitoring activities and testing focused on chemical, physical and biological parameters of the water. The demonstration study started at Limestone Gap in 1976 and ended in 1987 with 11 years of baseline data collected, interpreted and stored in a central computer data bank at ODOT. Recommendations are based on the results obtained from collected data.

DESCRIPTION AND LOCATION OF THE SITE

The area selected for the demonstration study was chosen because of the clarity of the stream water and the magnitude of the proposed highway construction work, which involved extensive clearing, blasting and a high embankment in the immediate vicinity of the stream. Other considerations such as accessibility to sampling sites, contributed to the final selection of the site. The place chosen for the demonstration is located approximately two miles north of Chockie, eight miles south of Kiowa along US highway 69 at a place called Limestone Gap in northern Atoka County, Oklahoma. Figure 1 shows the location of the demonstration site.

The construction project (MAF 249(43)) involves approximately eight miles of clearing, blasting, grading, drainage and surfacing work, beginning at Chockie and extending north to the Atoka-Pittsburg County line. At Limestone Gap, two major creeks met to form a confluence and cut into the 140 ft high limestone ridge to form a water gap. The two streams are Limestone Creek and Noname Creek on which testing sites 1 and 2 were located respectively. The population of Limestone Gap is essentially 0 in 1988, and the immediate area consists of rolling wooded lowlands surrounding the long sinuously winding limestone ridge. Most of the watershed is steeply rolling to mountainous with many areas consisting of up to 25 percent slopes.

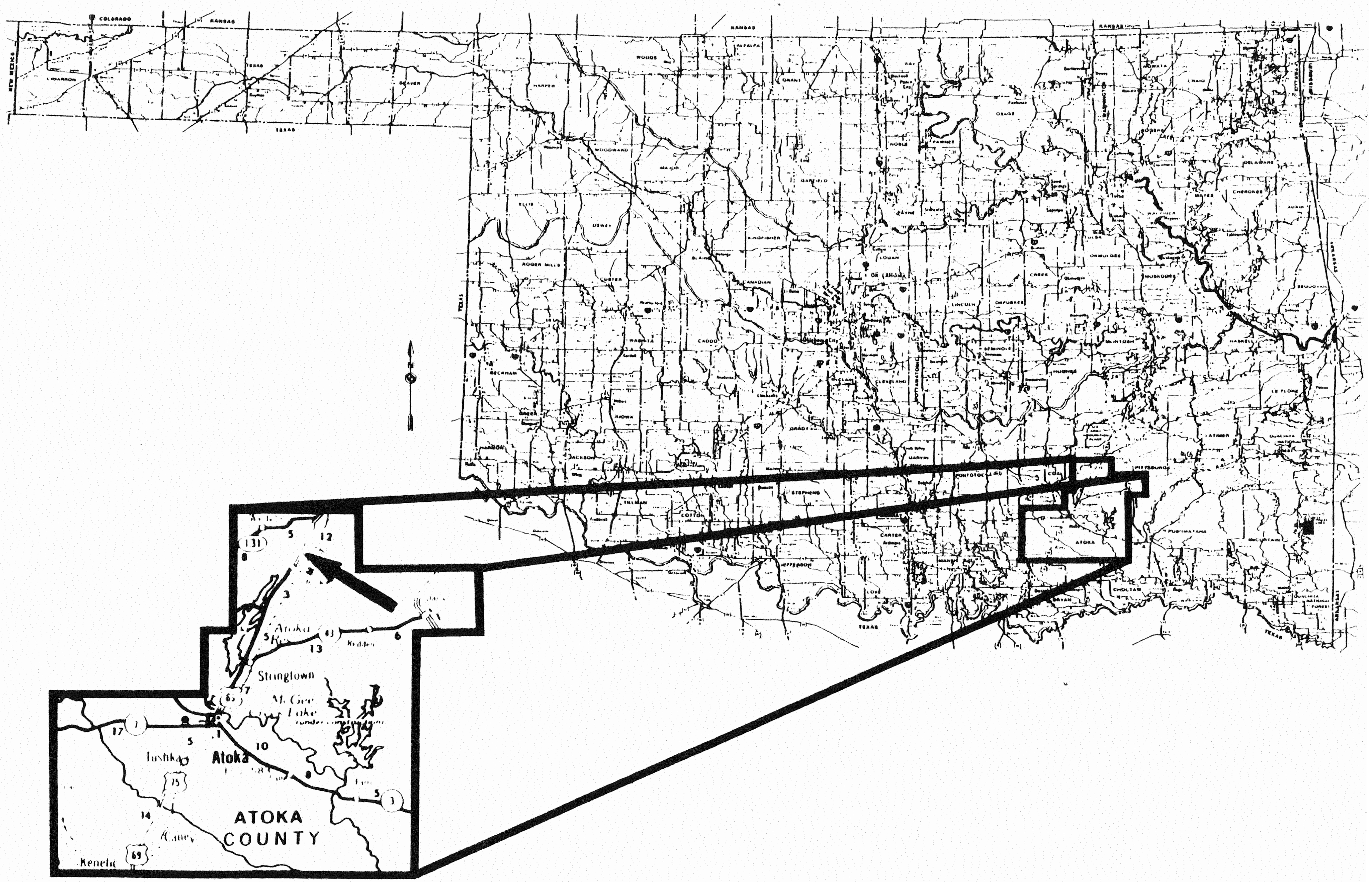

Figure 1. Project Location

GEOLOGY

Limestone ridge is a "hogback". It is geologically dated to be about 270 million years old. The ridge is composed of the Atoka and Wapanucka formations. The Wapanucka formation is exposed at Limestone Gap with its layers striking N54°E and dipping from 35° to 45° in a southeasterly direction. It's located in the S1/2 of NE1/4 of section 31, Township 2, North Range 13, East in Atoka County. Both the Missouri-Kansas-Texas railroad and US 69 traverse the area in a north-south direction.

Three distinct geological members formed the Wapanucka formation at Limestone Gap and they are: Chickachoc Chert, lower limestone and the middle shale members.[6]

Limestone ridge is significant geologically, because it represents the beginning of the frontal belt of the Ouachita Mountains. It is bounded on the west by the Choctaw fault and on the east by the Ti-Valley fault.[7] Figure 2 shows the regional geological setting of Limestone Gap in respect to the two major faults of the Ouachita frontal belt.

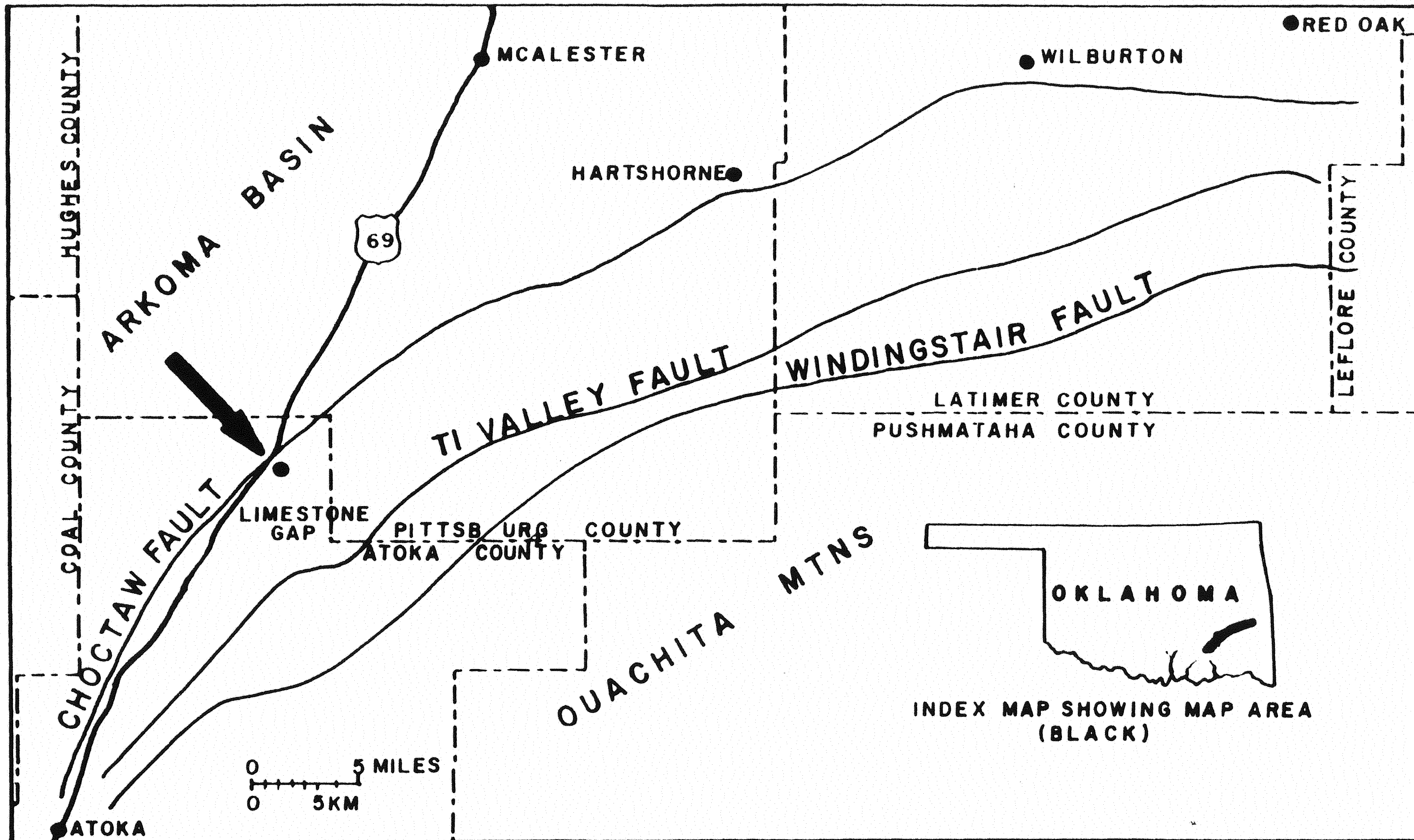

Figure 2. Regional Geologic Setting of Limestone Gap

Source: Grayson, Robert Jr., Ph.D Thesis University of Oklahoma, Geology Department (Modified by ODOT)

SOILS

The soils in the area may be divided into two categories. They are, the upland soils within the watershed and the alluvial soils along the streams.

The soil series in the area includes the Eram, Parsons, Rexor and Endsaw-Hector series. Approximately 127,000 yd^3 of these local clayey soils will be used as borrow for the fills.

Eram soils are associated with gentle slopes, and have a dark grayish brown clay loam surface about 10 in thick. They are found usually under tall native grasses mostly in weathered shale.

Parsons silt loam is associated with nearly level uplands. It has a very dark grayish brown silt loam surface layer about seven inches thick. It is mottled to a depth of about 25 in. Erosion hazard is severe where cultivated crops are grown, and the soil has medium potential for tame pasture and high potential for natural grass.

Rexor loam is associated with flood plains, with a characteristic brown loam surface layer about 10 in thick. The erosion hazard is slight and the soil has high potential for woodland, with flooding as the only hazard.

Endsaw-Hector soils are fine sandy loam soils that exhibit different properties. Endsaw's surface layer is dark grayish brown in color, with a thickness of four inches of fine sandy loam. Hector soils are brown with a three inch thick fine sandy loam surface layer. The erosion hazard rating for Endsaw-Hector soils is very severe where surface cover is removed, and the soils are on steep, 8 to 30 percent slopes. Outcrops of stone, steep slopes and shallow depth to rock are farming limitations.[7] Figure 3 shows the soil map of the area.

SOIL LEGEND

SYMBOL	NAME
21	CARNASAW-CLEBIT COMPLEX, 5 TO 8% SLOPES
22	CARNASAW-CLEBIT ASSOCIATION, MODERATELY STEEP 1/
23	CARNASAW-CLEBIT ASSOCIATION, STEEP 1/
28	DELA FINE SANDY LOAM
29	DENNIS LOAM, 1 TO 3% SLOPES
30	DENNIS LOAM, 2 TO 5%, ERODED
31	DENNIS AND ERAM SOILS, 2 TO 8% SLOPES, SEVERELY ERODED 1/
35	ENDSAW-HECTOR COMPLEX, 5 TO 8% SLOPES
38	ERAM CLAY LOAM, 3 TO 5% SLOPES
40	ERAM-TALIHINA COMPLEX, 5 TO 20% SLOPES
53	KITI-ROCK OUTCROP COMPLEX, 20 TO 45% SLOPES
57	PARSONS SILT LOAM, 0 TO 1% SLOPES
58	PARSONS SILT LOAM, 1 TO 3% SLOPES
61	REXOR LOAM
62	REXOR AND DELA SOILS 1/

1 ¾ ½ ¼ 0

5000 4000 3000 2000 1000 0

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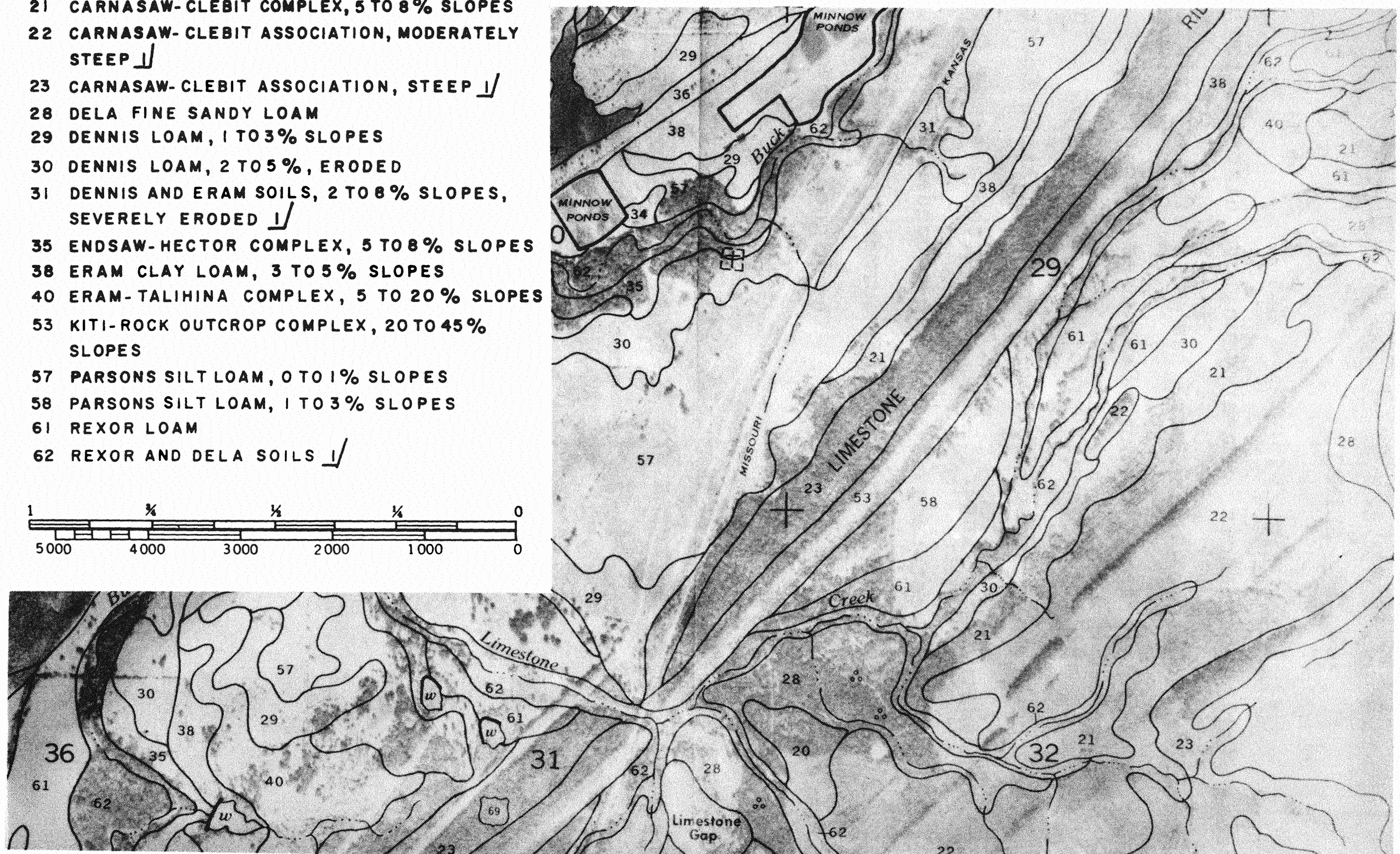


Figure 3. Soil Map of Limestone Gap

Source: Soil Survey of Atoka County, Oklahoma US Department of Agriculture, Soil Conservation Service

CLIMATE

Limestone Gap experiences a nearly uniform distribution of rainfall throughout the year. The area has most of the rainfall during the period of April through September when at least 61 percent or 25 in of the total annual precipitation occurs. This period is also the growing season for most crops in Atoka County.

Average temperature in winter is 43 °F, and the average daily minimum is 31°. The lowest temperature ever recorded was 2 °F.

Average snowfall is 3 in. The average summer temperature is 80° with average daily maximum of 92°. The highest temperature recorded was 110 °F.

Atoka County in general experiences some severe thunderstorms and tornadoes, but the storms are local and of short duration. The direction of prevailing wind is from the South, and the average windspeed is 13 miles per hour.[7]

MATERIALS AND METHODS

Materials used in conducting the demonstration at Limestone Gap included the following.

A. **Chemical Field Test-kit**, model DR18369B, manufactured by Hach Chemical Corporation. It was used to test the chemical properties of dissolved minerals and heavy metals in water samples. It includes necessary glassware, apparatus and reagents needed to perform all indicated tests shown in Table 1. Figure 4 shows the chemical field test-kit.

B. **Turbidimeter**, model 2100A manufactured by HACH Chemical Corporation. It was used to make direct measurements of suspended particles in a liquid using the Nephlometric Turbidity Unit principle. Figure 5 shows the Hach turbidimeter.

C. **Water Sampler**, model USDH 48-2142, it was used to obtain water samples from the stream. Figure 6 shows the water sampler and bottles.

D. **Hydrolab "digital"**, model 4000 manufactured by Hydrolab Corporation. It was used to test water temperature, pH alkalinity, specific conductance dissolved oxygen and dissolved solids. Figure 7 shows the Hydrolab and a pair of required wading boots.

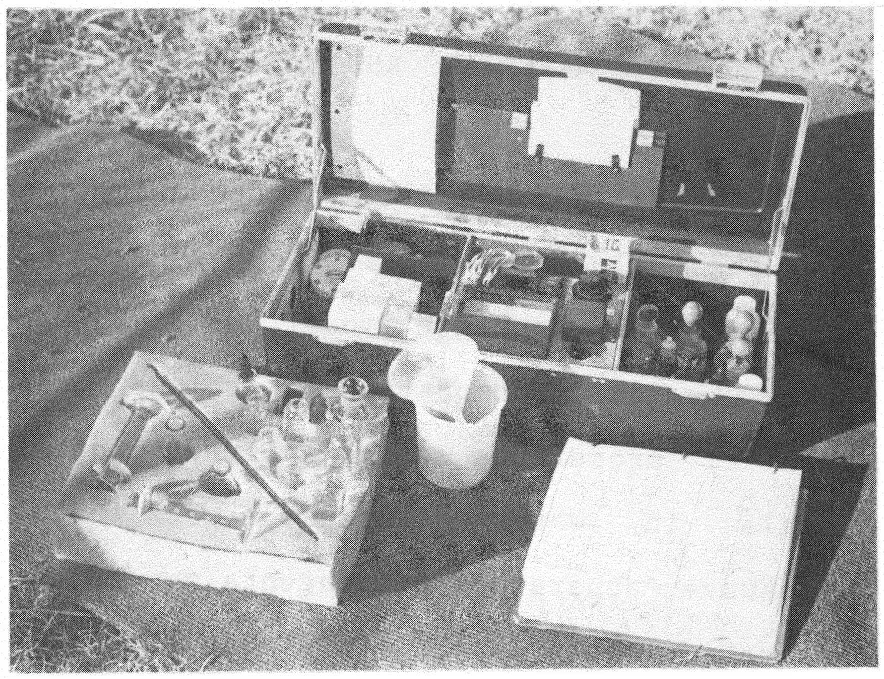


Figure 4. Hach Chemical Testing Kit

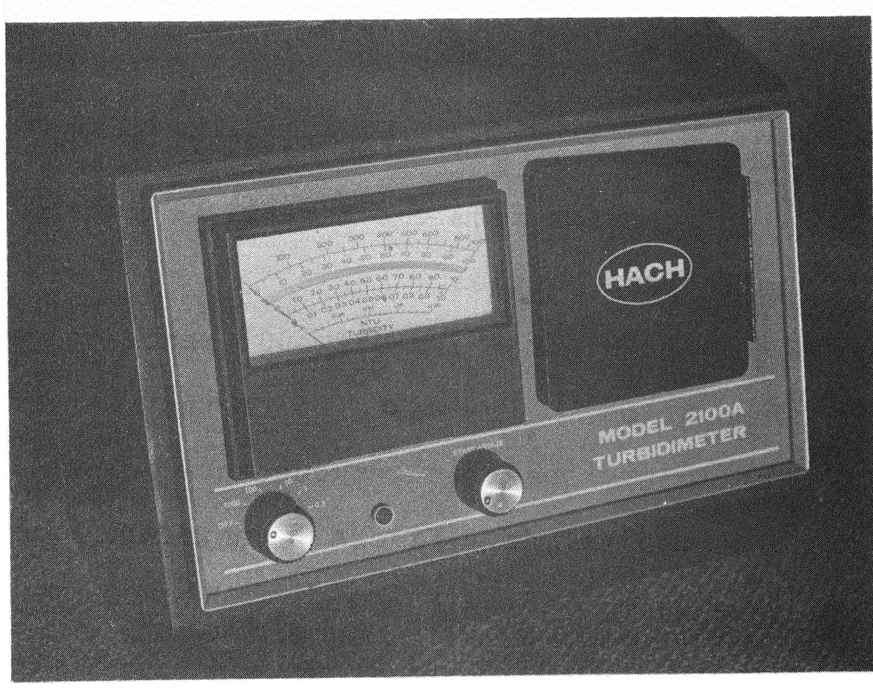


Figure 5. Turbidimeter

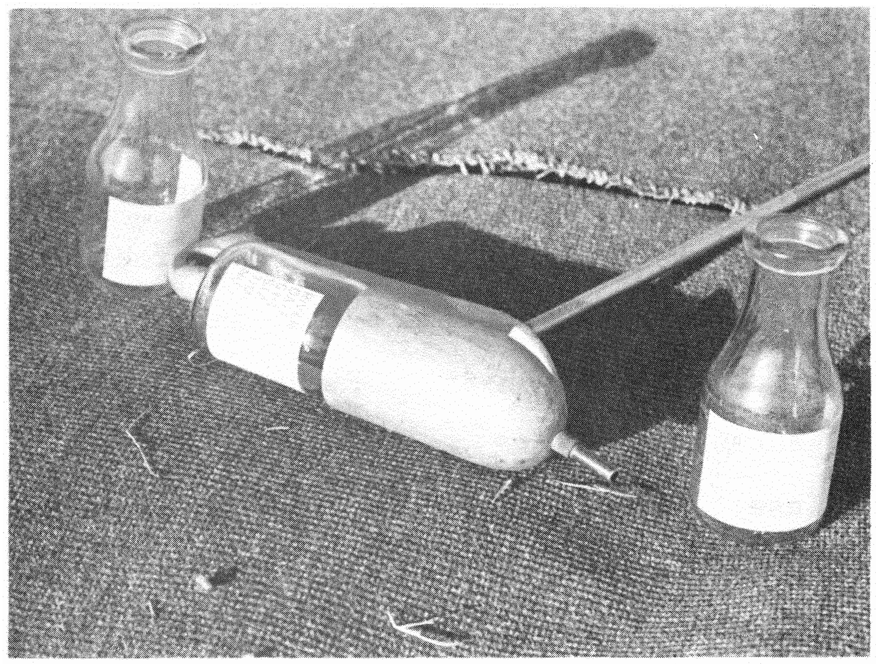


Figure 6. Water Sampler and Bottles

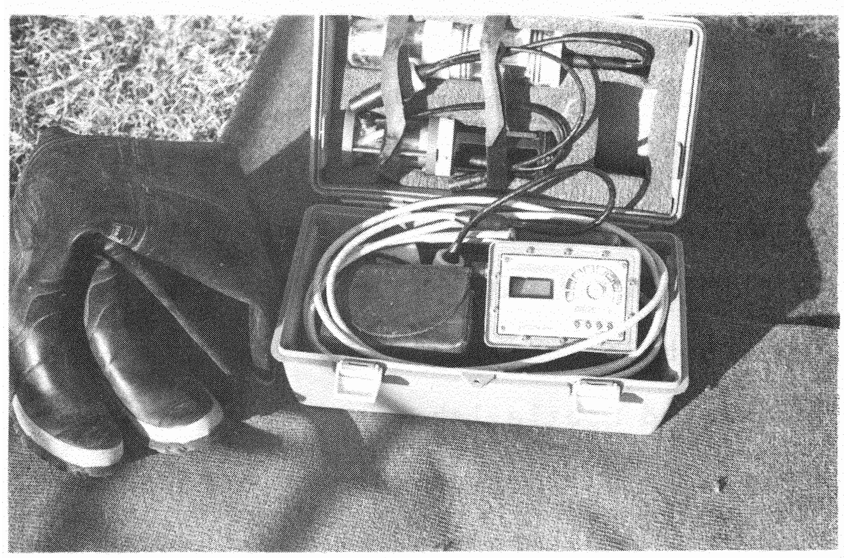


Figure 7. Hydrolab and Wading Boots

E. **Sediment Collector Plate**, was made by ODOT with a #10 screen placed across the top. It was used to collect settling stream sediment carried along the stream bottom. Figure 8 shows the sediment collector plate.

F. **Rain Gauge**, model 5-780, manufactured by Universal Raingauge. It registers the amount of rainfall on a clock driven chart. Figure 9 shows part of the rain gauge.

G. **Insect Trapping Net**, used to collect micro-invertabrae from the stream. Figure 10 shows the trapping net a brush and some plastic bottles used in preserving collected insect samples.

H. **pH Meter**, model SR-3058, manufactured by Chemtrix TU-40. It was used to directly measure the pH (acidity/alkalinity) of the water sample. Figure 10 shows the pH meter.

I. **Mobile-lab**, it's an RV converted into a mobile-lab. It's used to transport equipment and personnel to remote testing sites. All chemical tests are conducted inside the mobile-lab at the site. Figure 12 shows the RV converted mobile-lab.

J. **Binocular Microscope**, It was used to identify the aquatic insects collected at the sites. Figure 13 shows the microscope and associated tools.

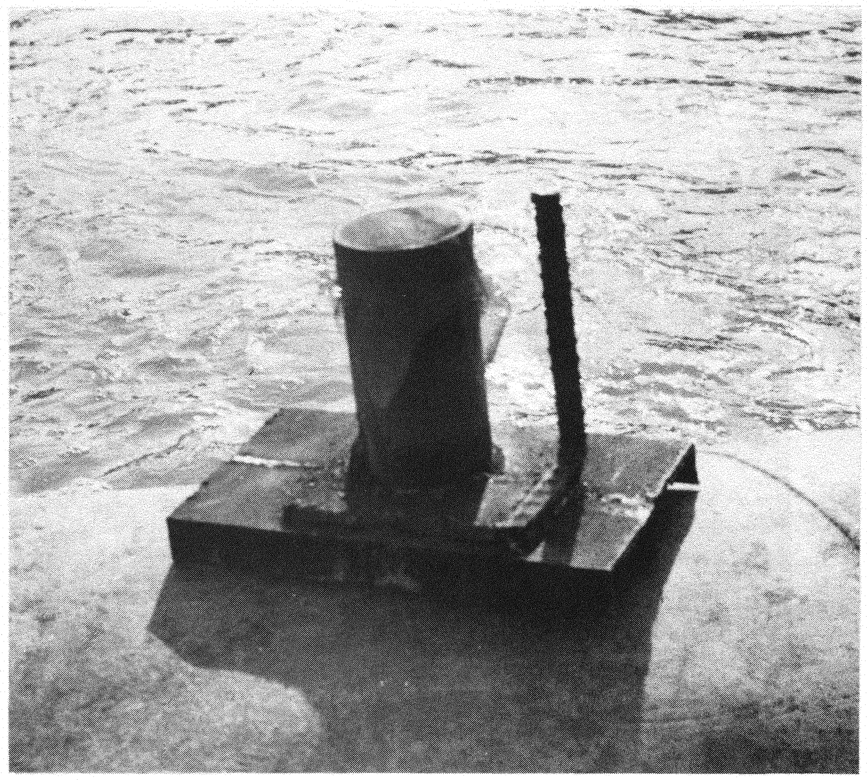


Figure 8. Sediment Collector Plate

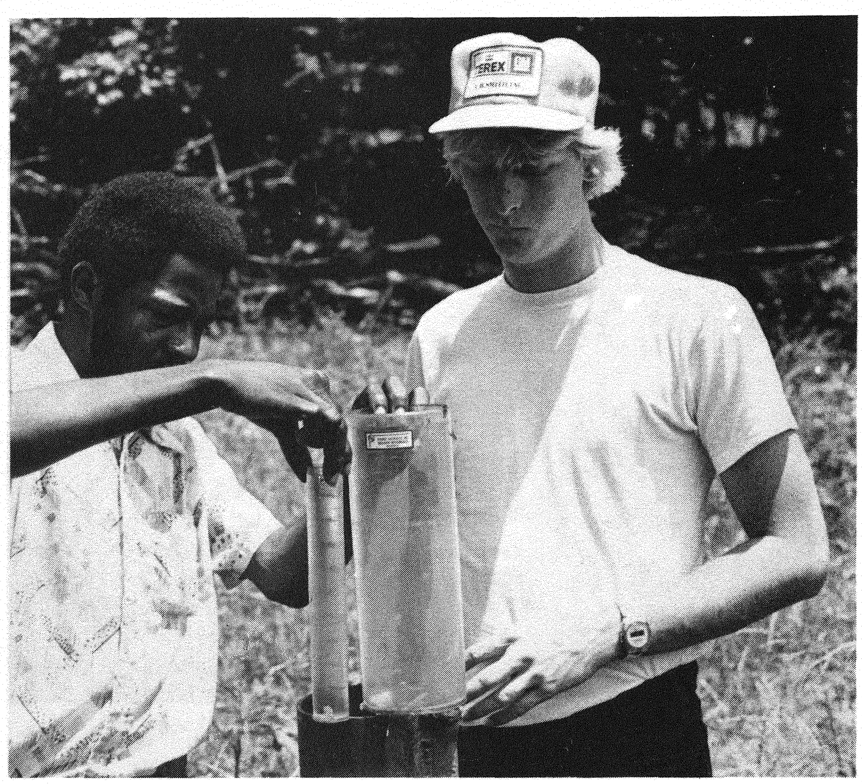


Figure 9. Rain Gauge

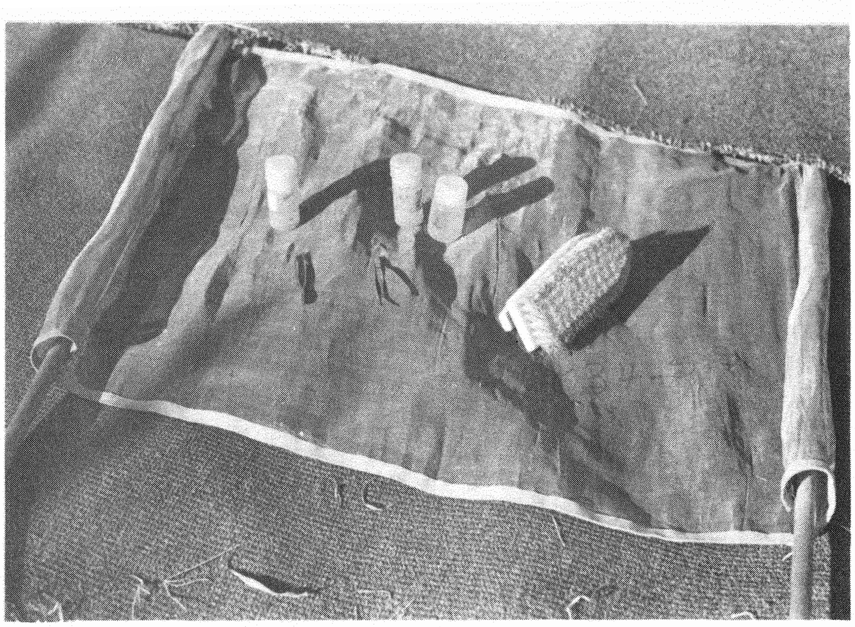


Figure 10. Aquatic Insect Trapping Net

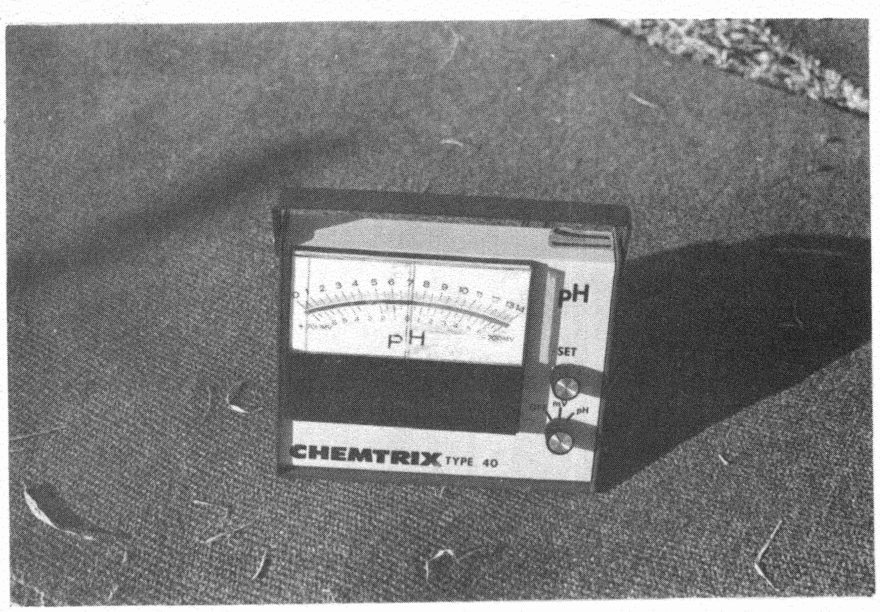


Figure 11. pH Meter

Figure 12. ODOT RV Mobile-lab

Figure 13. Binocular Microscope and Accessories

RESEARCH APPROACH

The monitoring activities at Limestone Gap were divided into three periods. These involved pre-construction, construction and post-construction activities. Monitoring stations were established along the stream channels so that comparative periodic sampling and testing could be performed. Two sites approximately 50 ft apart were established upstream from the construction zone. One site was located on Noname Creek and the other on Limestone Creek directly under the County bridge. These sites were selected in order to sample the stream quality before it passed through the construction zone.

A site approximately 250 yd downstream from the boundary of the construction area, under the US 69 bridge, was selected as a third monitoring site. This location was selected in order to observe the effects of the construction activities on the stream. Figure 14 shows the locations of the water quality monitoring sites.

A support activity involved monitoring the amount of rainfall at the site using an official recording raingauge. Stream monitoring activities began in 1976 but construction work did not start until 1984. Normally one year of water quality monitoring is needed prior to construction work, but due to the postponement of the construction work, several years of data were collected.

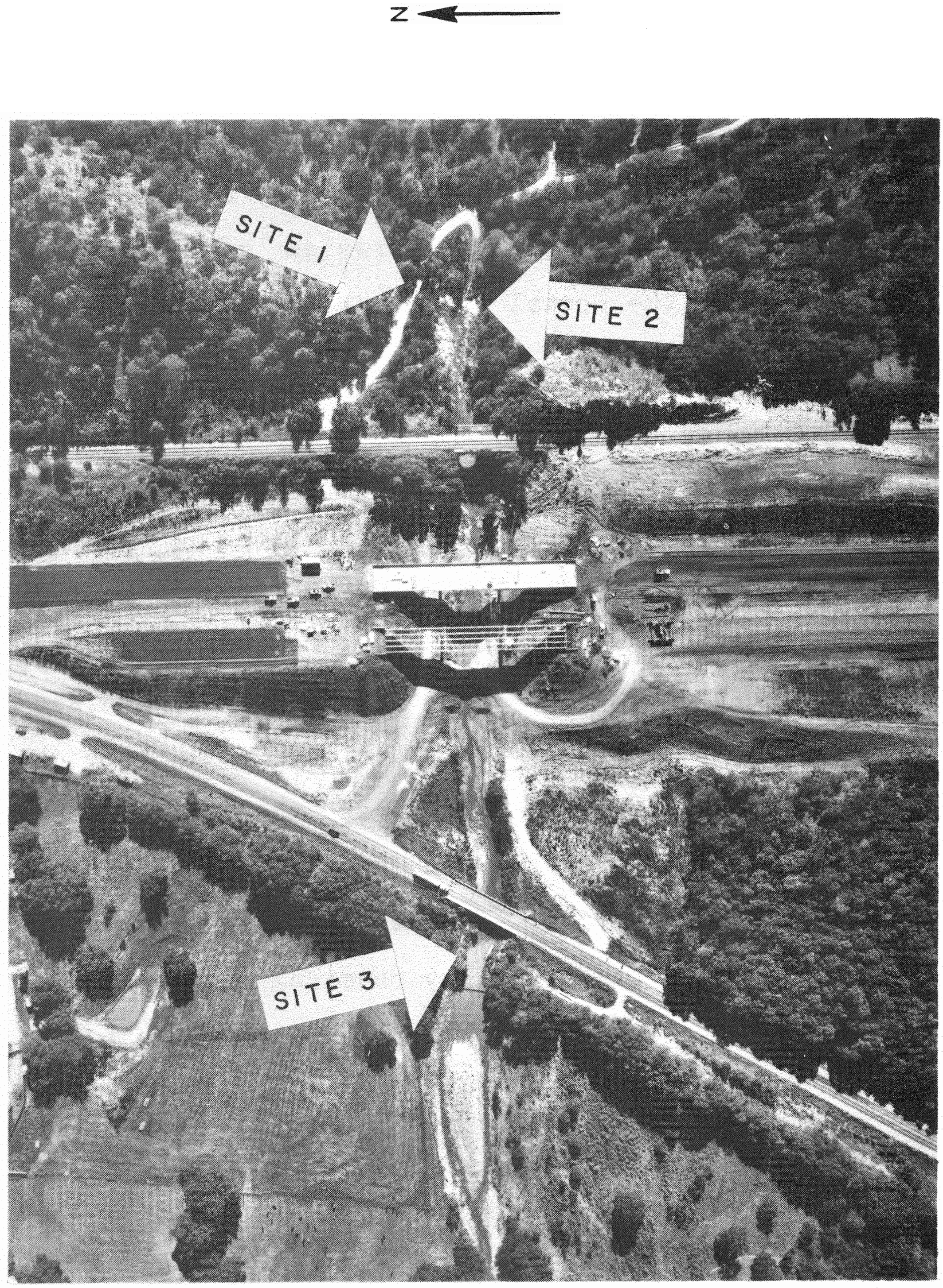


Figure 14. Water Quality Monitoring Sites 1, 2 and 3

Construction Activities

Construction activities included clearing, grubbing, grading, rock crushing, bridge and roadway construction. Each of these activities were carefully monitored and photographs were taken.

These activities were carefully monitored without imposing or suggesting any type of erosion mitigating ideas that might influence the normal practices of the contractor at the job site.

Chemical Sampling

Water samples were collected and tested at each of the sampling sites once every month.

Chemical tests were performed in accordance to the instructions in the Hach Manual, 11th Edition. Nineteen different chemical parameters were analyzed and tested before, during and after construction. All the chemical tests were performed in the field, at the site, inside the mobile laboratory, except when the portable Hydro-Lab is used. The Hydro-lab has to be immersed in 12 in or more of water. Table 1 shows the water quality chemical parameters tested at Limestone Gap.

TABLE 1

WATER QUALITY CHEMICAL PARAMETERS
TESTED AT LIMESTONE GAP

pH

Calcium (Ca^{+2})

Chloride (Cl^{-})

Chlorine (Cl_2)

Copper (Cu^{+})

Dissolved Oxygen

Dissolved Solids

Hardness

Iron (Fe^{+})

Magnesium (Mg^{+})

Nitrate (NH^{4})

Nitrate (NO_3^{-})

Nitrite (NO_2^{-})

Phosphate (PO_4)

Silica ($Si0_2$)

Specific Conductance

Sulfate (SO_4^{-})

Temperature

Turbidity

Biological Sampling

Fish: Species composition of the fish in the area were identified by the Oklahoma Fish and Wildlife Biological Laboratory, in Norman OK. It was determined that no endangered or threatened species were present in the creek.[8] Visual observations of small species and juvenile specimen were examined by obtaining and releasing some of the fish using small nets. The following species were determined to be present in Limestone Creek based on information from the Oklahoma Fish and Wildlife Biological Laboratory records, and confirmed by visual examination of samples obtained by ODOT personnel.

The fish found in Limestone Creek included the following species:

- Largemouth Bass
- Sunfish
- Bluegill Sunfish
- Green Sunfish
- Catfish
- Channel Catfish
- Blue Catfish
- Flathead Catfish
- Black bull head

Figure 15 shows the most common fish species in Limestone Creek.

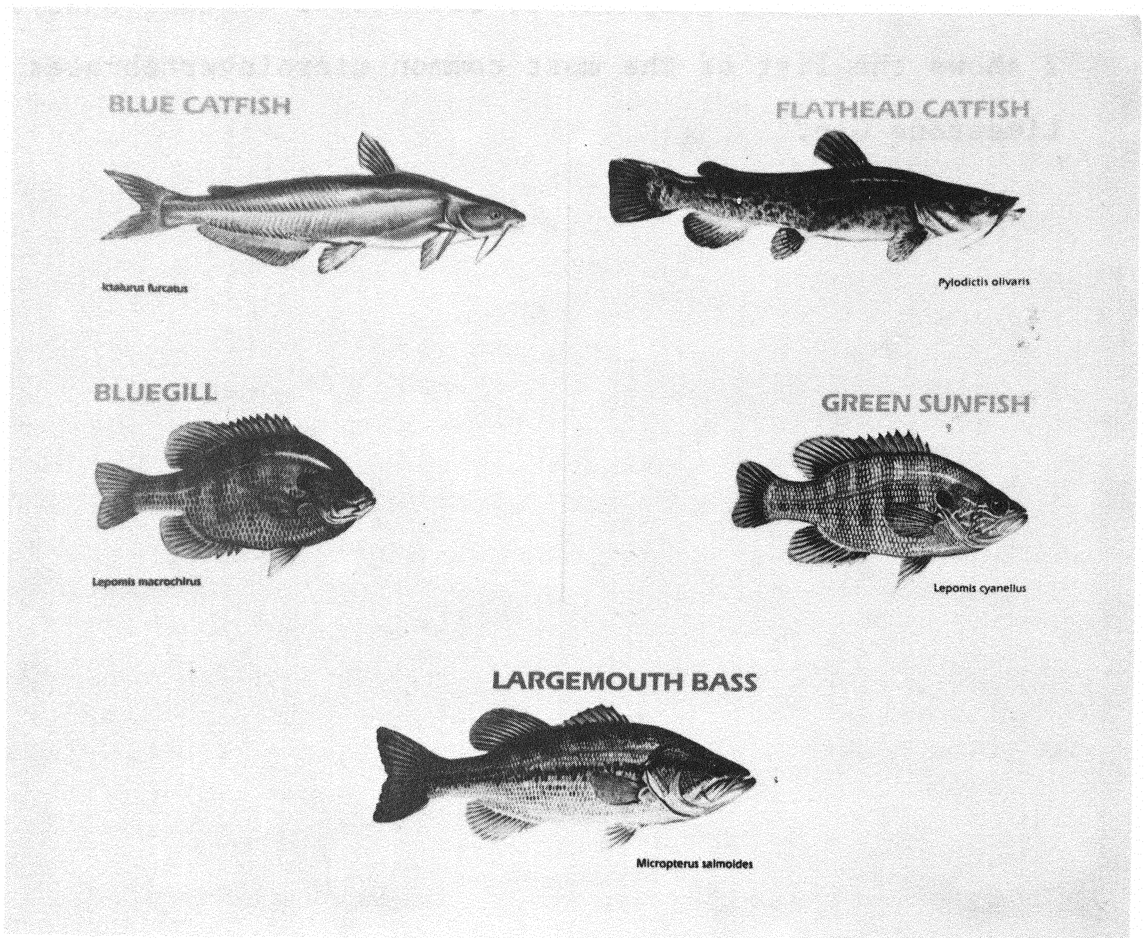


Figure 15. Common Fish Species in Limestone Creek

Microinvertebrates: Samples of microinvertebrates were obtained from each monitoring station by using insect trap nets.

The samples are preserved for laboratory identification in isopropanol. With the aid of a binocular microscope, these samples are identified, sorted and catalogued. The information was stored in the computer to facilitate further analysis. Table 2 shows the list of the most common microinvertebrates found at Limestone Gap.

TABLE 2

COMMON MICROINVERTEBRATES

FOUND AT

LIMESTONE GAP

Plecoptera

Trichoptera

Ephemeroptera

Coleoptera

Neuroptera

Odonata

Hemiptera

Crustacea

Mollusca

Annelida

Diptera

Note: The names above are phylogenetic and consist of both orders and phyla.

Vertebrates: Various typical species of birds, snakes, frogs, turtles lizards, along with beavers and raccoons were found to be abundant at Limestone Gap. No attempt was made to catalogue these groups. Figure 16 is a sketch of the general ecological habitat.

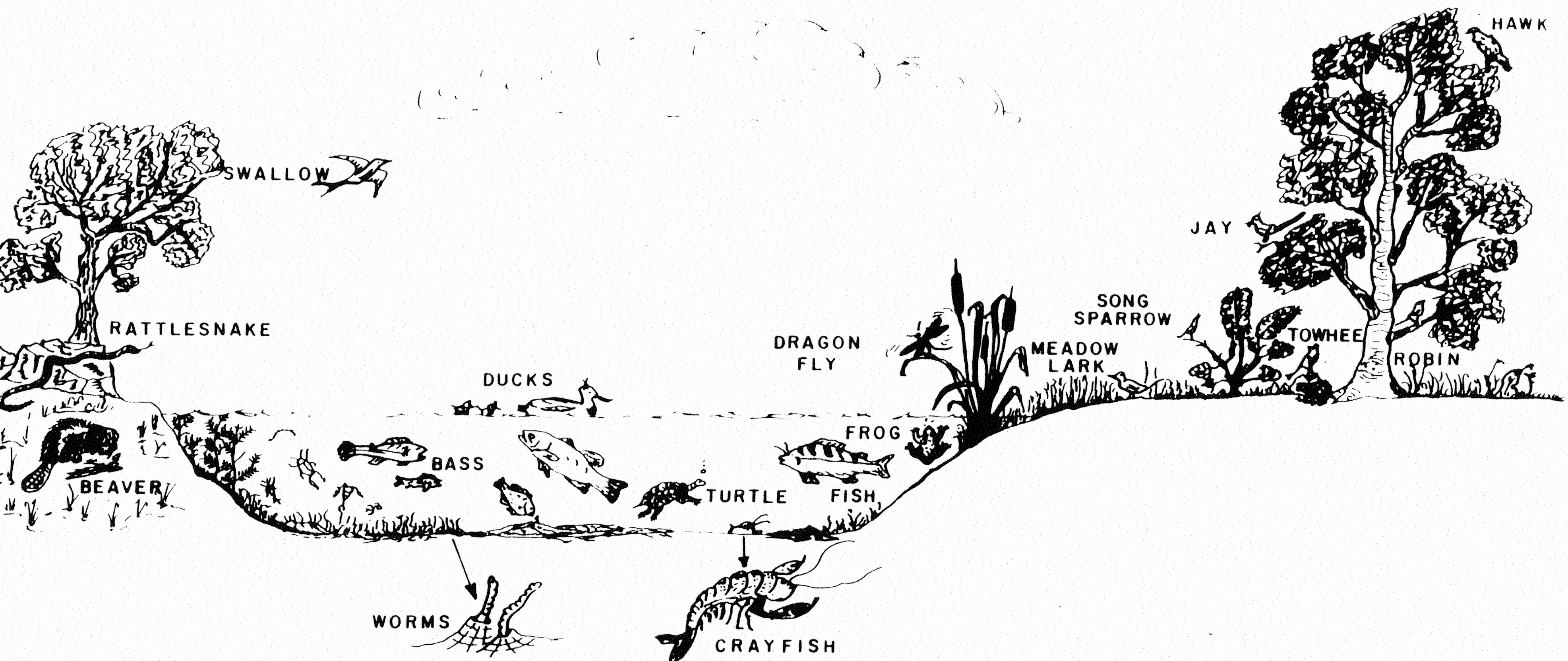


Figure 16. Aquatic and Ecological Habitat at Limestone Gap

Plants: A survey of the area prior to construction indicated that 75 percent of the area is covered by woodland. The common trees and shrubs in the area are:

Oaks

Willow

Pecan

Pine

Cedar

Cottonwood

Hackberry

Bois d'arc

In the immediate area of the construction zone, the area was covered mostly by tall grass species; e.g., Big Bluestem, Little Bluestem, Switch Grass and Indian Grass.

Physical descriptions of the general area were made and photographic records of the condition of the streams and surrounding environment were made before, during and after construction activities.

STREAM CHARACTERISTICS

Limestone Creek

This creek is a perennial stream with an average stream bed elevation of approximately 640 ft. The channel width is about 30 to 55 ft with an approximate length of 4.2 mi. Figure 17, 18 and 19 shows the cross section and the channel width for testing sites 1,2 and 3 respectively. The Limestone Creek channel bottom is rocky and gravelly with pools and riffles. Its banks are unstable, made up of fairly loose soil, shale and gravel. The stream is intermittently clogged at various points in the channel by natural debris such as rock, gravel and broken branches and fallen trees.

The gradient of Limestone Creek above the construction site is approximately 40 ft per mi and 15 ft per mi below the site. The drainage area is approximately 9 sq mi. The highest water level ever recorded was at an elevation of 650 ft or about 5 to 15 ft above the stream bed under the old US 69 bridge (site 3). When in flood, Limestone Creek can rise approximately 15 ft. Figure 20 shows a typical flood condition on Limestone Creek. Here, the water level is approximately 5 ft from the channel bottom under the old US 69 bridge.

A Q_{50} of approximately 7350 cfs and a Q_{100} of 8650 cfs with a V_{50} of 8.9 fps were calculated for Limestone Creek at site 3.

At the construction site, Limestone Creek was dammed by the contractor. Two 48 in corrugated culverts were placed parallel

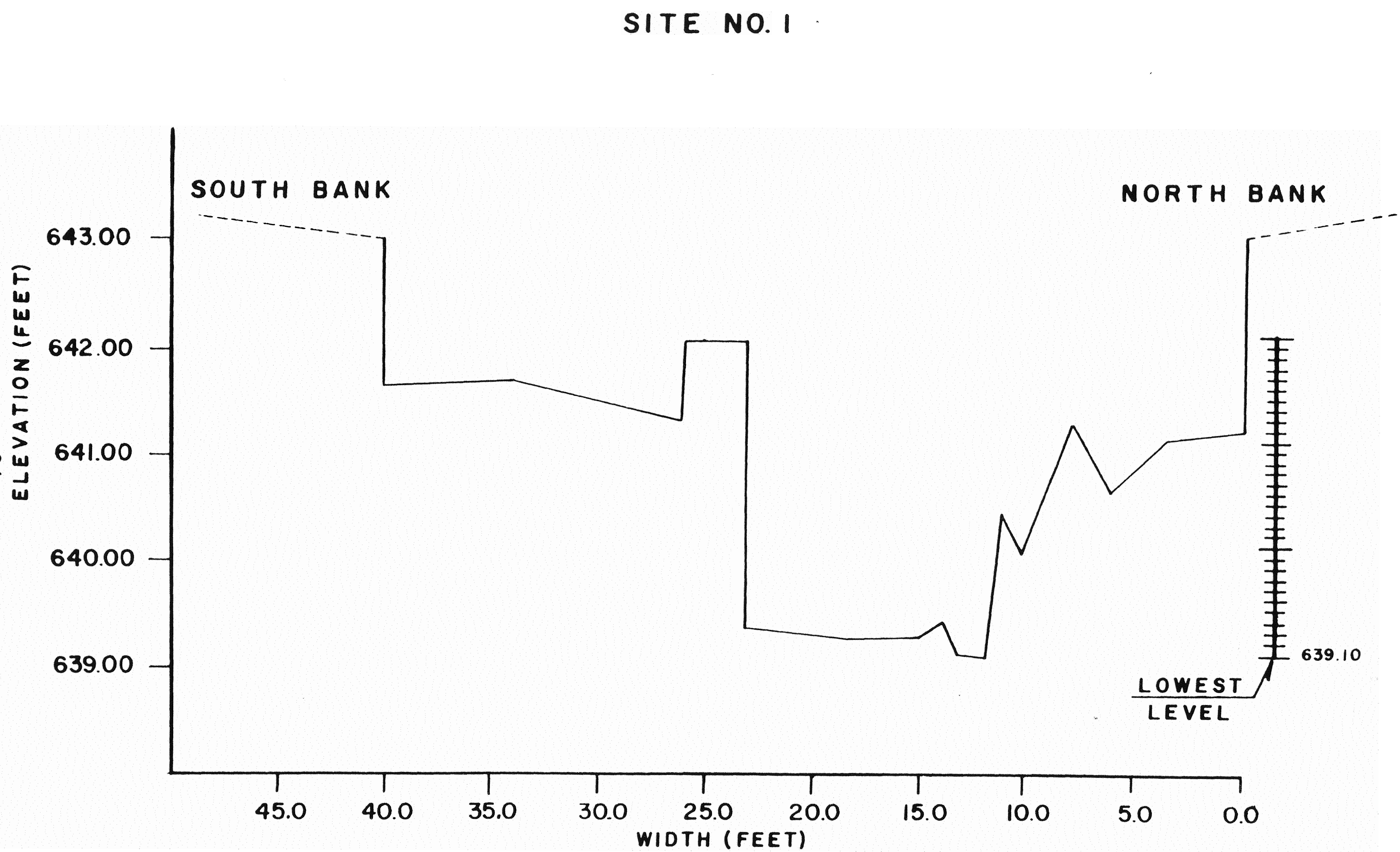


Figure 17. Cross Section of Limestone Creek, Site 1

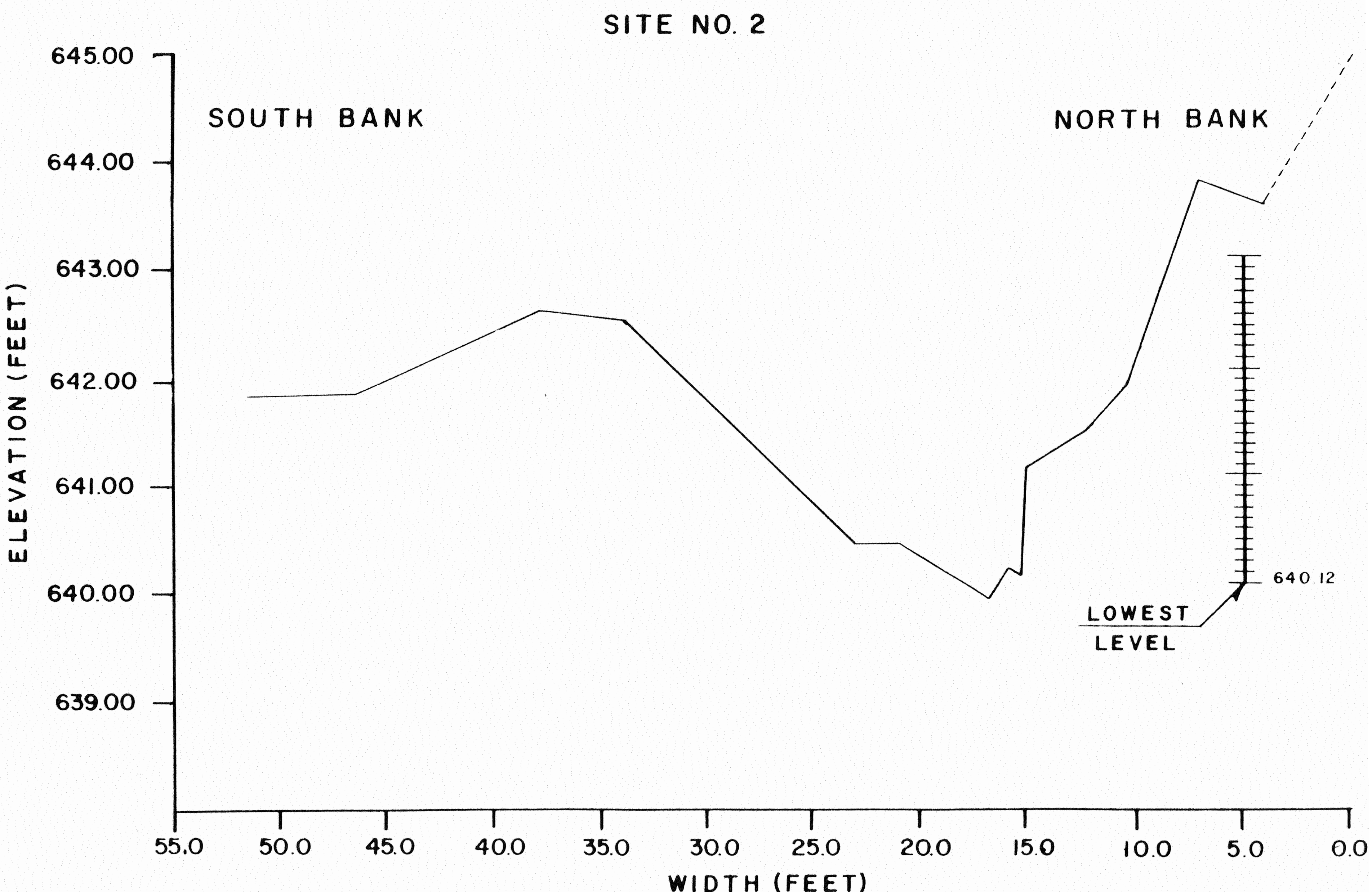


Figure 18. Cross Section of Noname Creek, Site 2

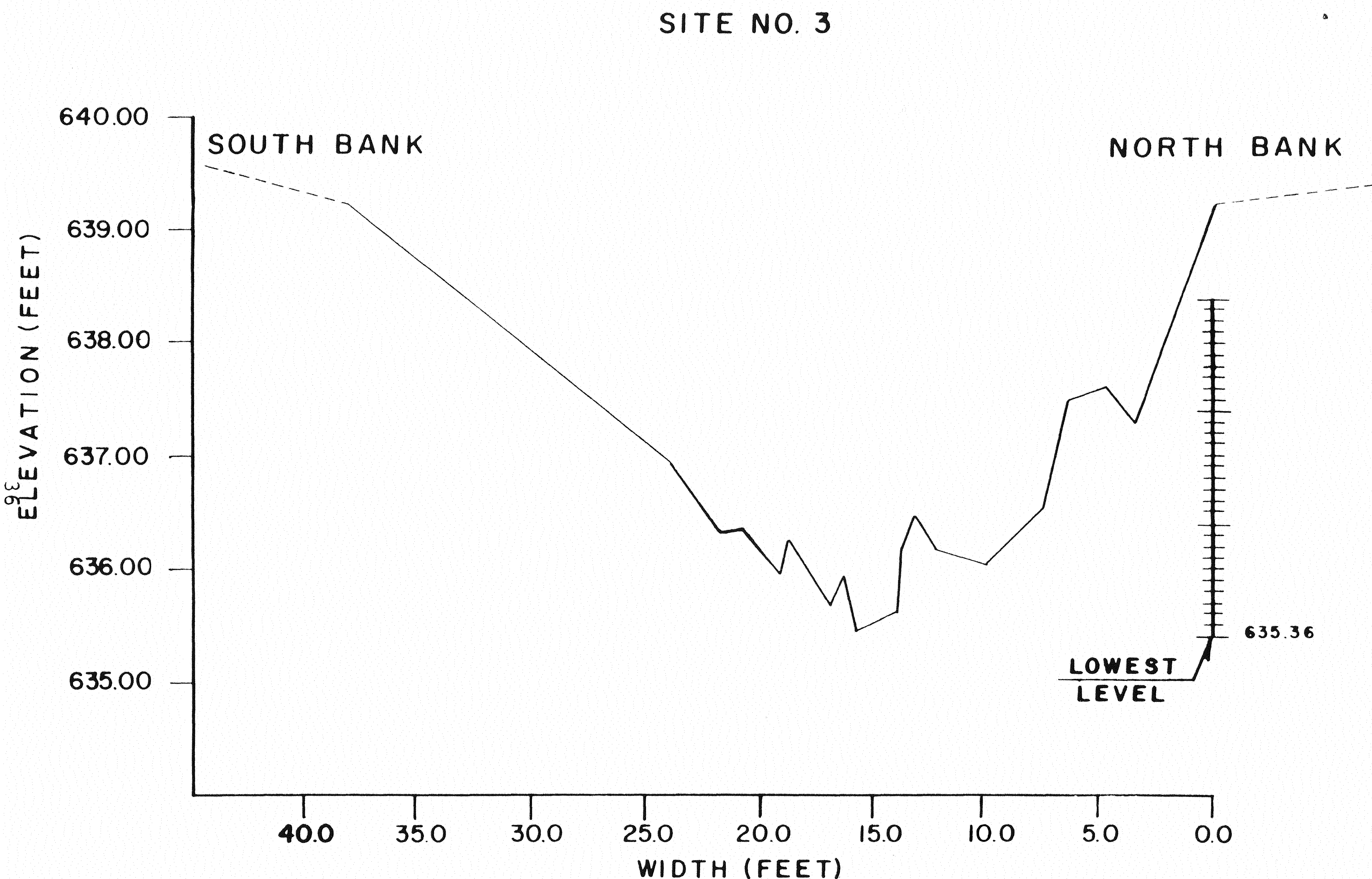


Figure 19. Cross Section of Limestone Creek, Site 3

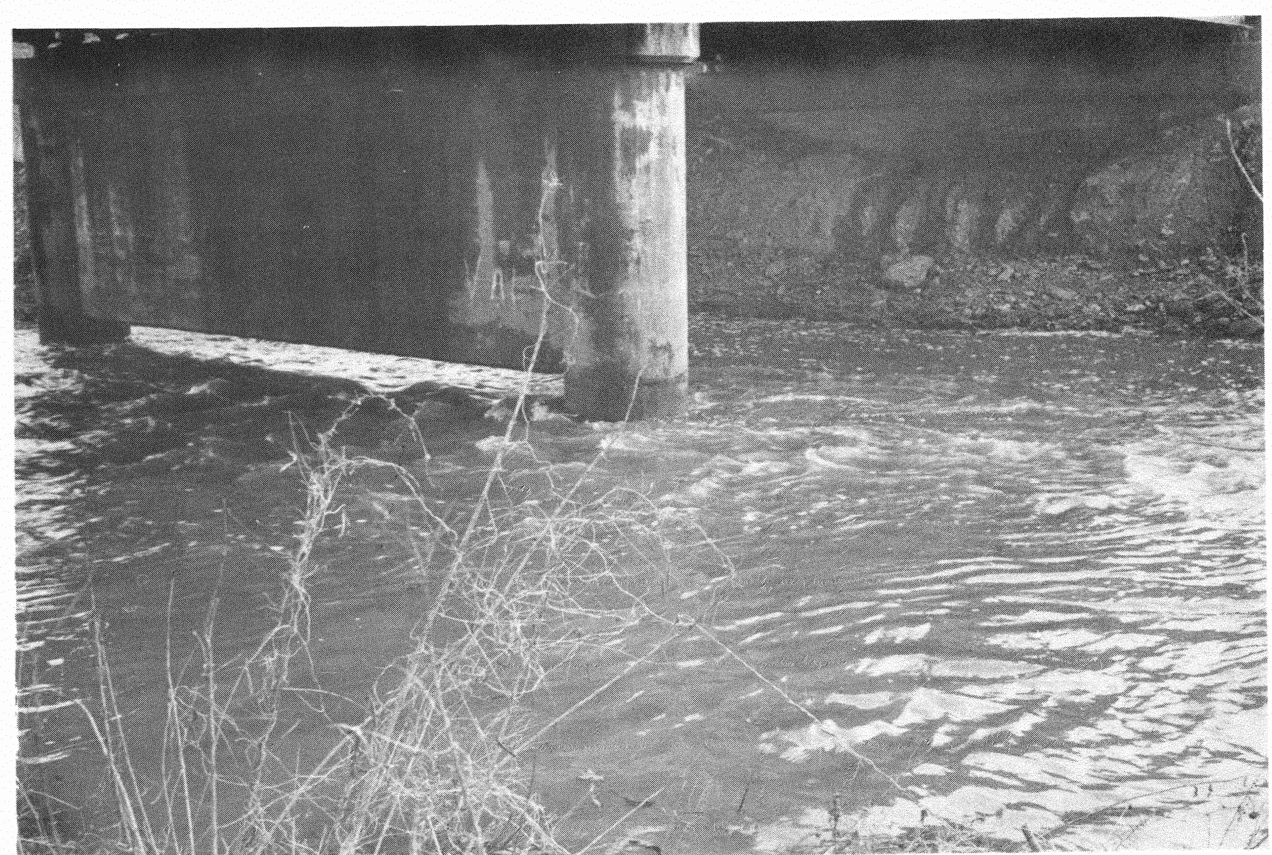


Figure 20. Low Flood Condition of Limestone Creek at Site 3

to the stream channel while a fill dyke was built over them to convey heavy trucks and equipment to and from the construction site. This installation created a water storage pond for the construction work at Limestone Gap. Figures 21 and 22 show the temporary dyke across Limestone Creek and the pump used to pump water from the pond.

Noname Creek

This creek is characterized by a low intermittent flow with a very shallow bottom channel with an approximate length of 3 1/2 mi. It has an average channel width of approximately 25 ft or less. The banks are very stable with presence of trees, shrubs and grass including protruding rock formations that provide stability along the channel. The gradient is approximately 25 ft per mi.

Figure 21. A View of Limestone Creek and the Temporary Dyke Looking East

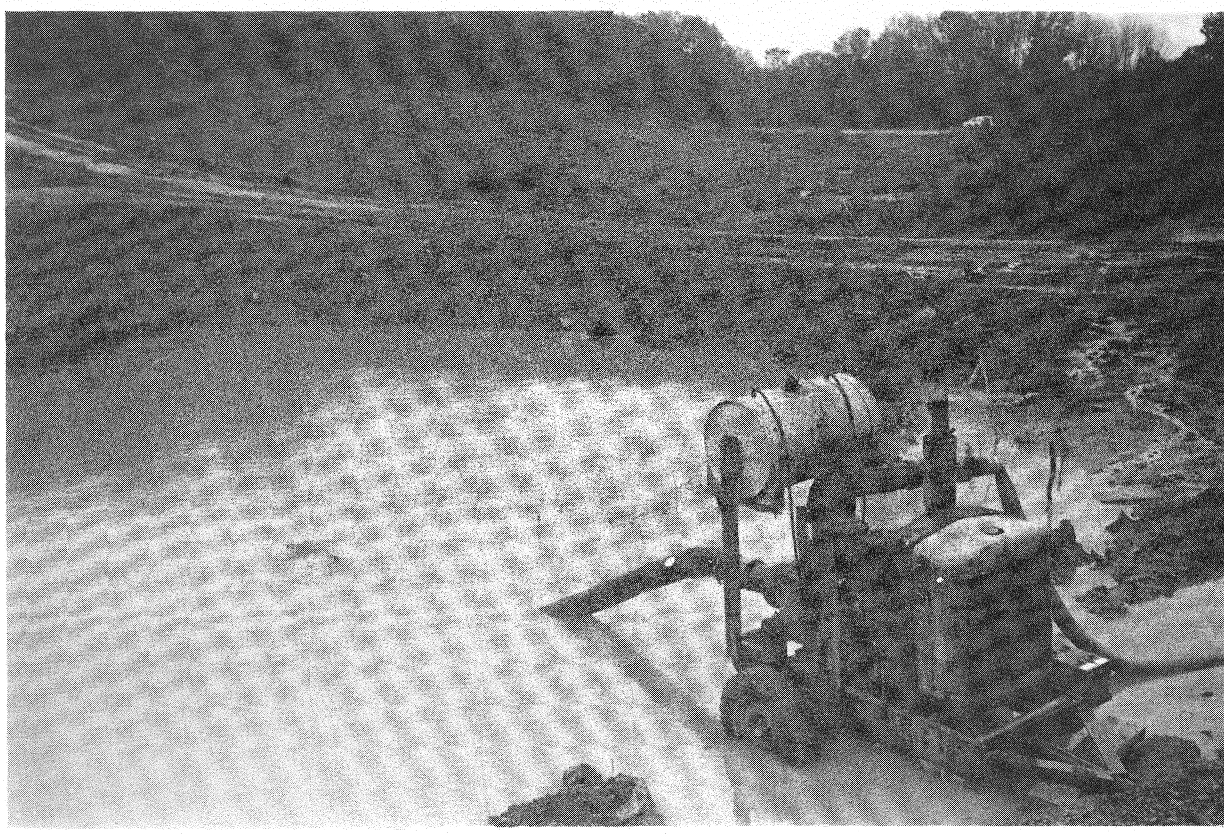


Figure 22. Limestone Creek Retention Pond With Water Pump

PRE-CONSTRUCTION

Monthly testing of the water quality and other monitoring activities of the various parameters began in the fall of 1976. Water samples were obtained and tested, aquatic insects and other microinvertebrates were collected and identified. Also, the fish species composition of the stream was determined and photographs also were taken of the general condition of the Limestone Gap area.

The pre-construction phase of research monitoring and testing activities ended in October of 1984, providing eight years of baseline data. Normally a year or two of baseline data would be adequate. Figure 23 shows the pre-construction condition along Limestone Creek.

Figure 23. Pre-construction Condition of Limestone Creek

CONSTRUCTION

The construction period represented the most critical period during which highway construction activities might influence the water quality of the stream.

Construction work on US 69 involved approximately eight miles of clearing grading and drainage. The contractor responsible for roadway construction was Nineteenth Seed and R.R. Tway (a joint venture). The bridge over Limestone Creek was built by Daryl Bond Construction Company from Yukon. Construction started in the fall of 1984, and ended in the fall of 1986.

The following were the three phases of construction activities at Limestone Gap:

1. <u>Clearing, Grubbing, Grading:</u> In November of 1984, clearing along the right-of-way started. It involved, using a bulldozer to clear the right-of-way, burning brush piles, removing stumps, draining ponds and other related activities.

   The clearing grubbing and grading operation started at the same time in all areas surrounding Limestone Creek. sediment collector plates were placed directly adjacent to disturbed areas where runoff entered the streams. An area approximately 1800 ft long by 400 ft wide was cleared along Limestone Creek alone. Figure 24 shows the cleared area along Limestone Creek.

Figure 24. Cleared Area Along Limestone Creek

2. Blasting and Rock Crushing: Blasting activities started on April 10, 1985. The contractor used the blasting technique of angle pre-splitting to produce a 1/2:1 slope in the area of the Gap where a new alignment was required.

This blasting technique of pre-splitting is significant because it reduces overbreakage, crushing and radial cracking of rock around the bore holes. It also prevents excessive flying debris. This reduced the amount of sediments that were introduced into the nearby stream. Blasting was completed in April of 1986. Figure 25 shows blasting at Limestone Gap.

A crusher plant was set up nearby. The dynamited limestone material was removed and crushed to specified sizes varying between 1/2 to 3/4 in. This crushed rock material was later used as aggregate base and fill material. It was estimated that approximately 160,000 yd^3 of crushed material was used while, 215,920 tons were recorded to have passed over the crusher scales. Figure 26 shows the crusher plant.

Figure 25. Blasting at Limestone Gap

3. Bridge and Roadway: Bridge work over Limestone Creek began on April 14, 1986 and ended on December 17, 1986. It involved construction of 0.051 mi twin bridges on drilled shaft piles. It was done simultaneously with roadway surfacing.

Runoff from fill materials used for the construction at the bridge approaches was monitored by placing several sediment collector plates along the stream and directly across from the bridge construction site. Figure 27 shows an ODOT researcher placing one of the sediment plates in the creek.

To prevent erosion, the bridge abutments were protected with rip-rap. The literature reviewed indicated that the impact of bridge construction on aquatic communities is minimal, but researchers at ODOT monitored this activity to see if there would be any impact at Limestone Gap.[9] Figure 28 shows roadway surfacing while Figure 29 and 30 show the completed new twin bridges across Limestone Creek.

Figure 27. Placement of Sediment Collector Plate

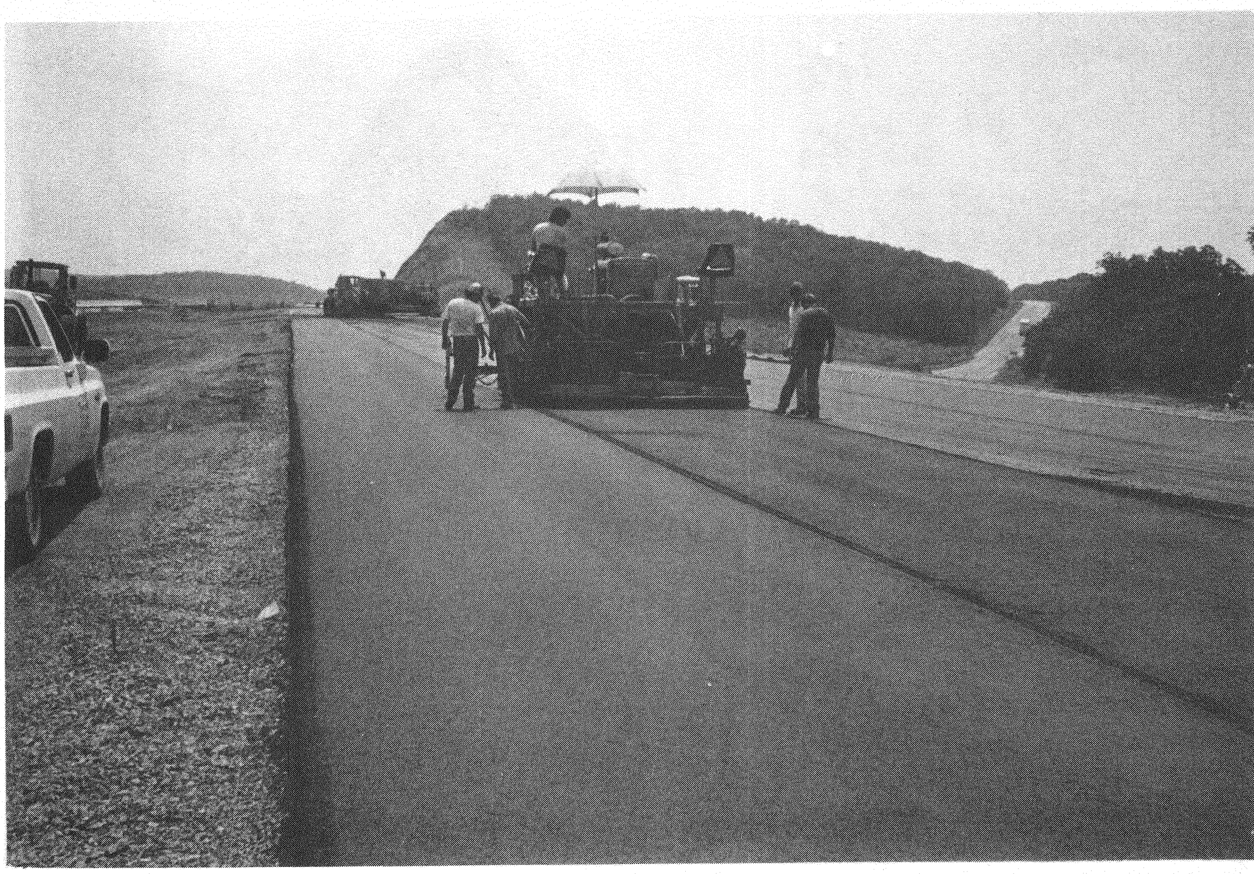


Figure 28. Roadway Construction at Limestone Gap

Figure 29. Completed New Twin Bridges at Limestone Gap

Figure 30. Limestone Creek and US 69 Looking South, 1988

4. Post Construction: Monitoring of water quality continued for a year after construction was completed.

Continual water quality and biological sampling was done since the time of initiation of the demonstration project. It continued through the construction period and a year after all construction work was completed.

The monitoring activities ended in December of 1987, a year after construction work was finished. In total, approximately 11 years of base data was collected for evaluation.

PROBLEMS

Limestone Creek is essentially a perennial stream that usually flows except in the driest part of July and August. The first problem encountered at the location, is the seasonal low flow of Limestone and Noname Creeks. When the water level is low, it is impossible to use the hydro-lab to test the water. In the hottest part of the summer, the creeks contain isolated pools of water. Some small fish (Sunfish, Blue Gills, etc.) are occasionally trapped in these isolated pools until the creeks are rejuvenated by fall rains.

During the rainy season, especially when there is a rainstorm the creeks are flooded. This makes it impossible to obtain water samples. Since proper water samples can only be obtained by wading across the stream, some monthly intervals went by without testing. Also, the use of the hydro-lab was precluded because of flooding.

Finally, researchers at ODOT entertained some reservations about the potential impact of the contractor practice of damming the stream to create a retention storage pond so that it could be used for construction purposes. However, there was no evidence to show that the impoundment adversely affected the quality of the streams or associated aquatic life.

DATA ANALYSIS

Data storage and analysis was facilitated by using a pre-written SAS computer program that enabled investigators to list, compare and analyze data from each test site.

Three areas were emphasized in analyzing the impact of highway construction on Limestone Creek. They were turbidity level, presence of aquatic insects and chemical concentrations.

Turbidity measurements were analyzed for periods before during and after construction to determine any changes.

The Turbidity plots of variation per year from 1976 through 1987 are shown in the graph in Figures 31, 32 and 33 for sites 1, 2 and 3. They show no detectable pattern of change of any significance.

The aquatic insects present were analyzed. Analysis of the composition and population of aquatic insects found indicated a variety of species in different proportions. These species varied in proportion depending on, the individual collecting the samples, the condition of the stream, and the season and number of samples collected.

The nymph and larvae forms of the orders; Plecoptera, Ephemoroptera, Trichoptera, and Diptera are the common fish food. Other types of fish food include the Stoneflies, Mayflies, Caddisflies, flies, gnats, midges, and mosquitoes seen near the streams. Usinger, says that in streams, Stone Fly nymphs, Mayfly nymphs, and Caddisfly larvae, as well as midge larvae serve as the staple diet of most fishes.[10]

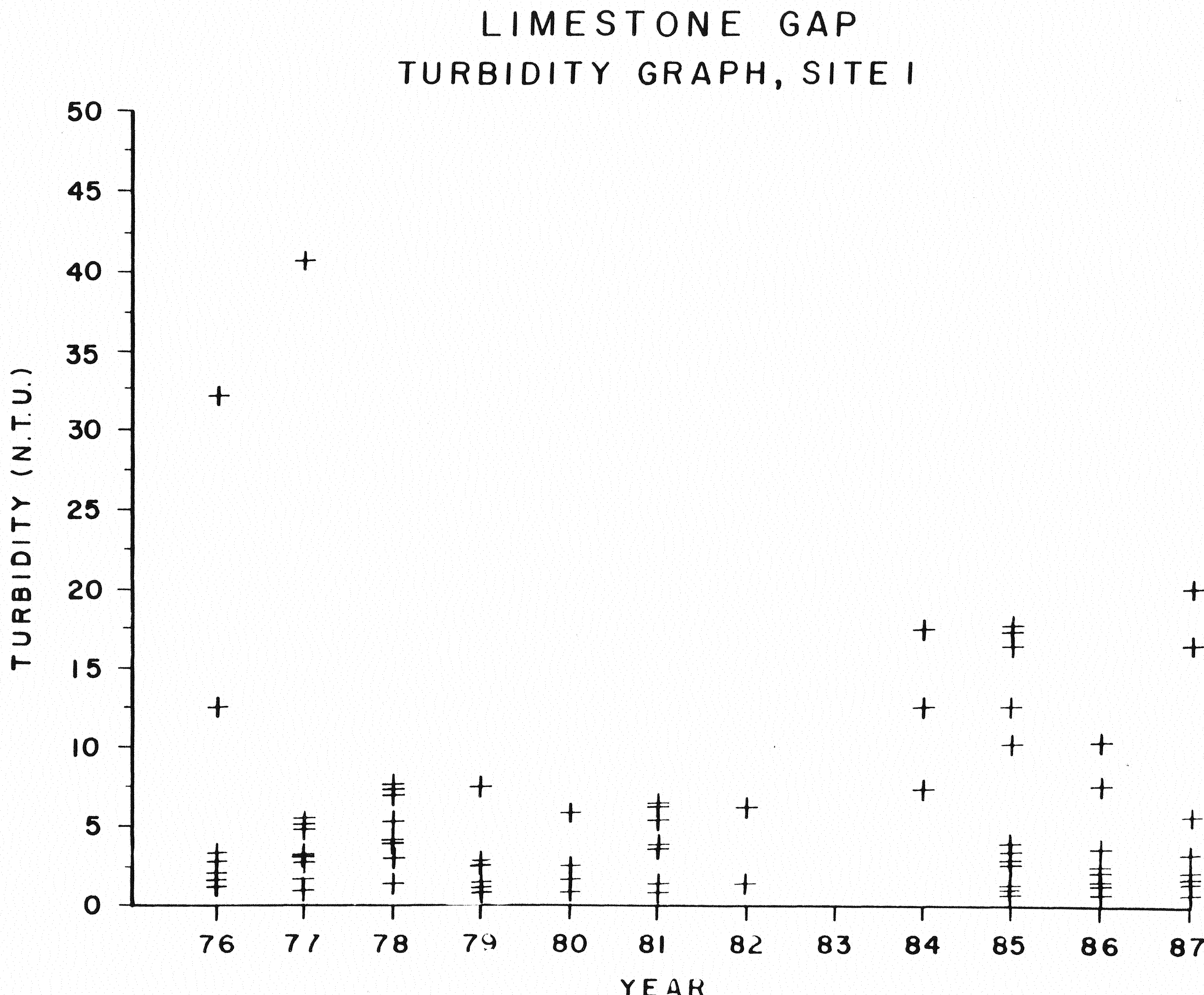


Figure 31. Turbidity Variation Plot from 1976 through 1987 for Site 1.

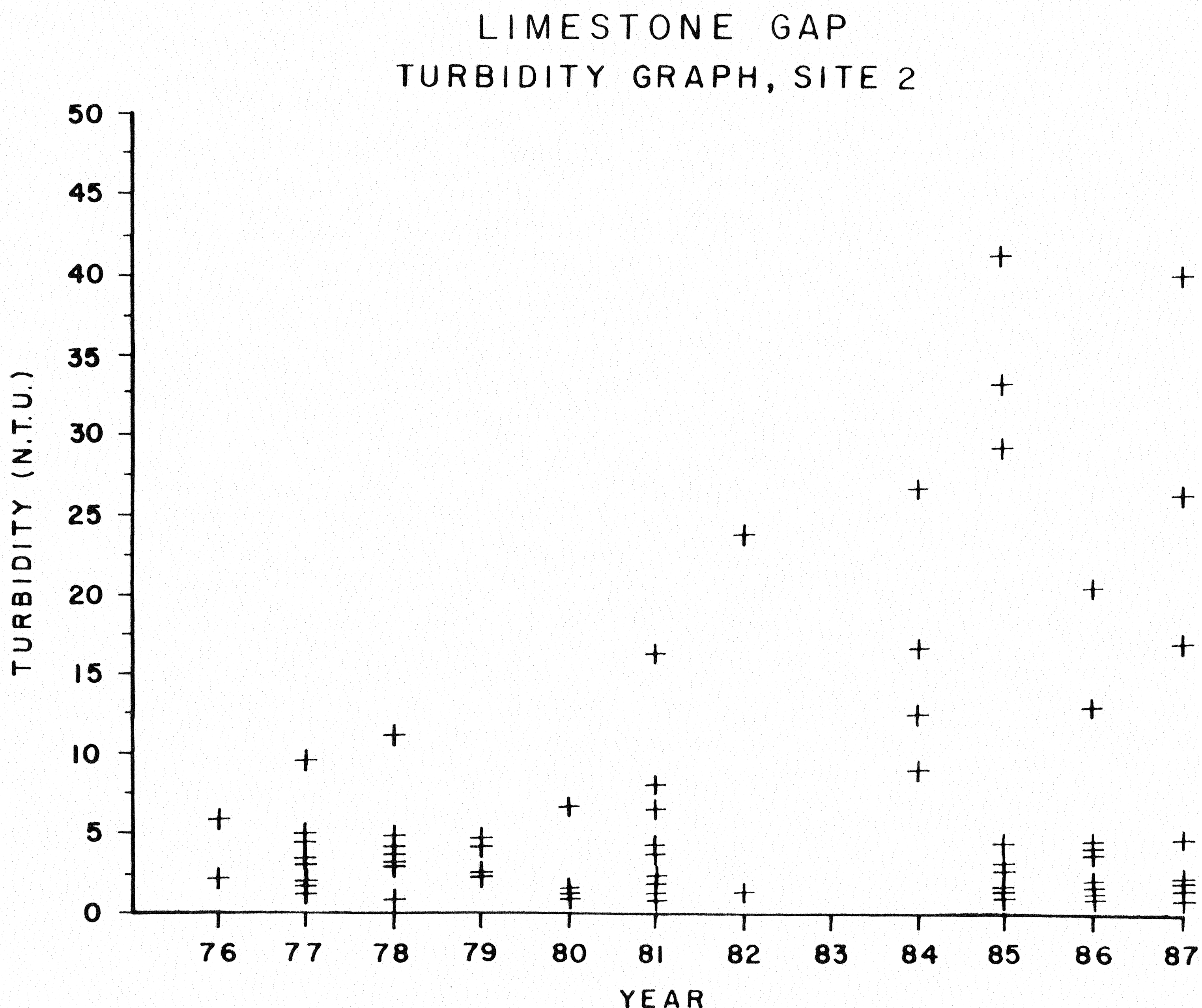


Figure 32. Turbidity Variation Plot from 1976 through 1987 for Site 2

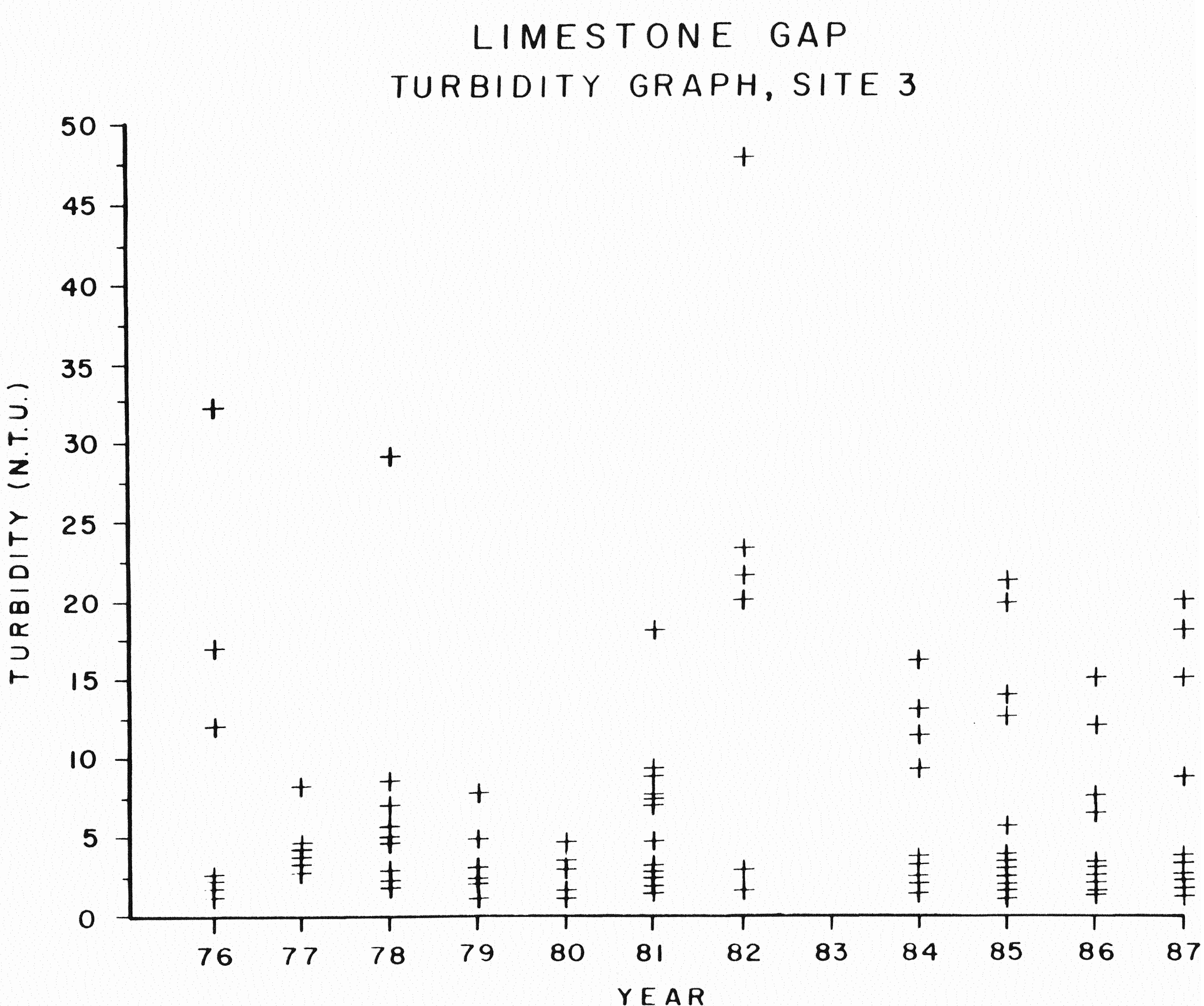


Figure 33. Turbidity Variation Plot from 1976 through 1987 for Site 3.

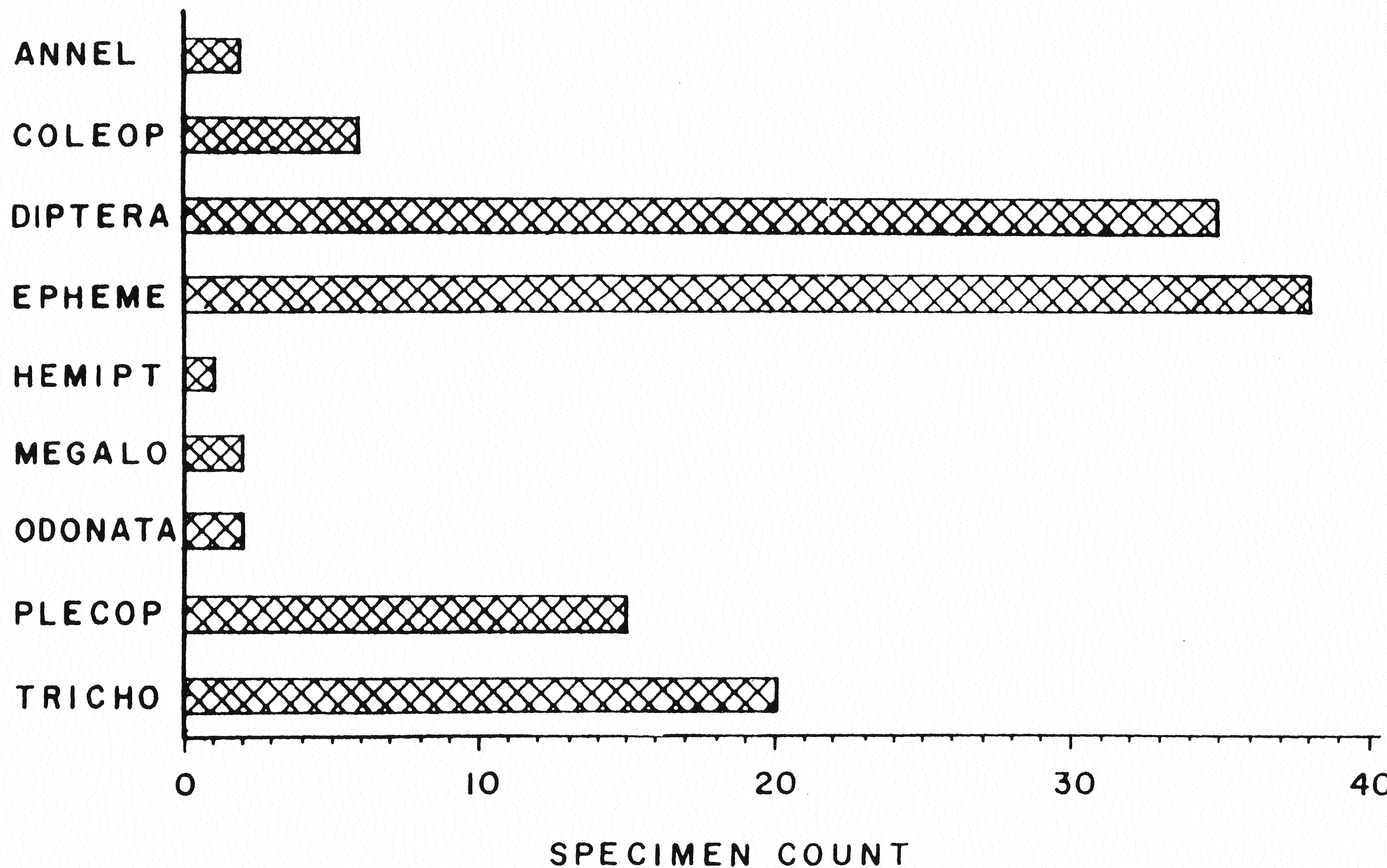
Tables 3 and 4 show the distribution of aquatic insects found at Limestone Creek. They show an increase in concentration of some aquatic insects for site 1 between the years 1980 and 1987. Similar results were found for site 2 and 3.

Standards for the allowable limits of dissolved chemical constituents were derived from the U.S. Geological Survey Water Data for Oklahoma and data from Oklahoma Water Resources Board (Water Quality Standards 1985).[11] Based on these standards, there was no evidence of pollution or excessive concentrations of heavy metals. Table 5 shows an overall average of water quality parameter values for rainfall, nearby creeks; e.g., Muddy Boggy Creek, and the three stream sites at Limestone Gap. It was evident from the data in Table 5 that site 2 shows a moderate increase in metals like Calcium, Magnesium, etc, compared to site 1 and site 3. This is expected since site 2 is closer to the blasting and construction site. More dissolved minerals from limestone are contained in site 2 than any other sites. A Pearson correlation coefficient analysis was performed on the variables comprising the base data. The relationship that existed between each variable is shown in Appendix Tables A-1 through A-6.

A survey of the stream bed indicated that no significant sedimentation had occurred upstream or downstream from the construction zone. Presently, there are some rock debris varying in sizes from 2 to 12 in in Noname Creek due to blasting while few scattered rock fragments can be found in Limestone Creek,

TABLE 3.

AQUATIC INSECTS AT
LIMESTONE CREEK SITE I, 1987



AQUATIC INSECTS AT
LIMESTONE CREEK SITE 1, 1980

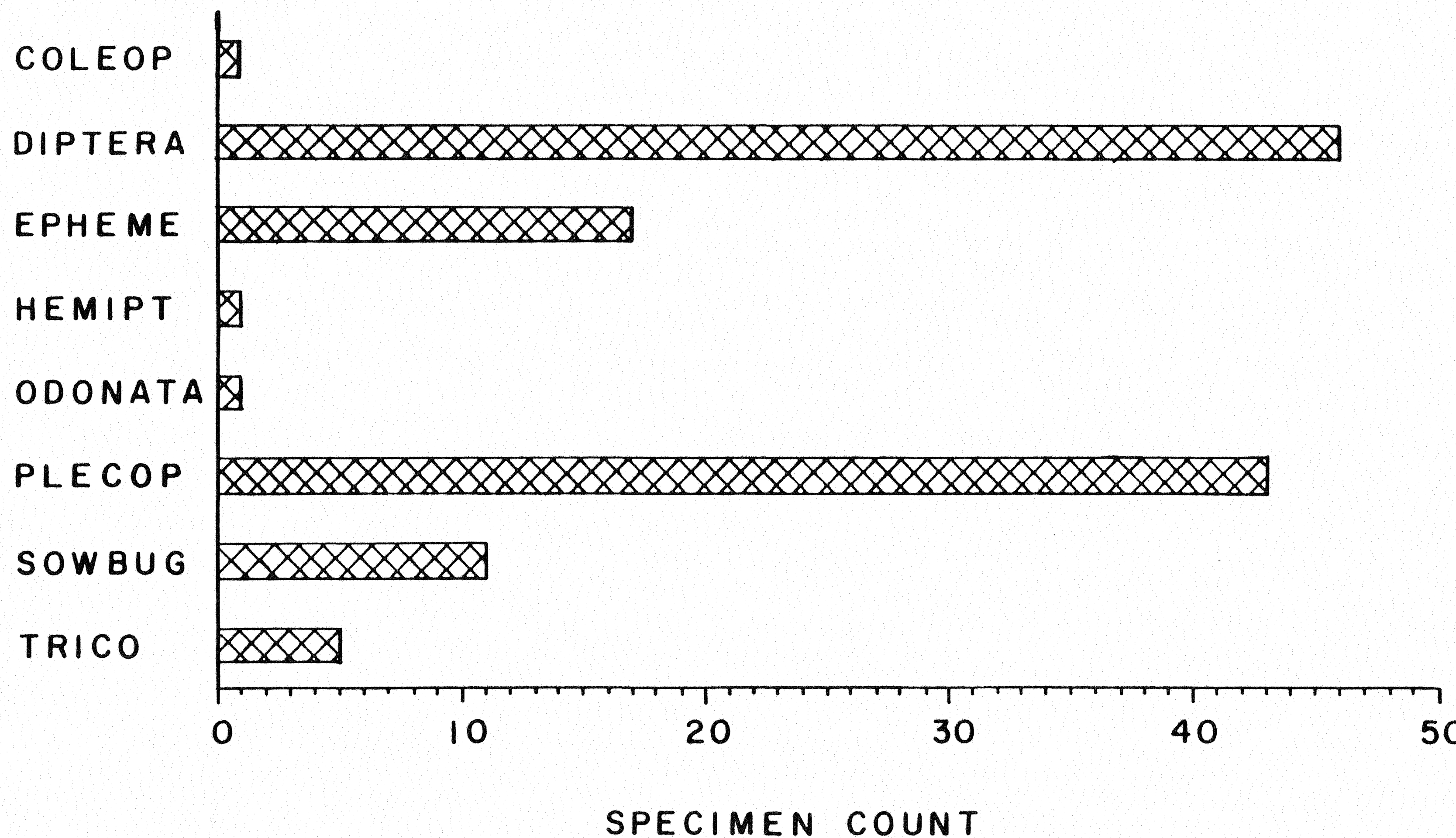


TABLE 5.
THE AVERAGE OF WATER QUALITY PARAMETERS OF LIMESTONE CREEK AND OTHER LOCAL WATER BODIES

PARAMETERS	WATER BODIES				
	RAINWATER	MUDDY BOGGY RIVER	LIMESTONE CREEK		
			Site 1 LS Creek	Site 2 Noname	Site 3 LS Creek
pH	*	7.3	7.4	7.5	7.4
Calcium (Ca^{+2})	10.0	30.0	69.9	151.5	99.3
Chloride (Cl^-)	5.0	15.0	26.4	22.3	26.4
Chlorine (Cl_2)	0.01	0.1	0.1	0.1	0.04
Copper (Cu^+)	0.3	0.01	0.1	0.3	0.2
Dissolved Oxygen	*	16.2	9.4	9.7	9.5
Dissolved Solids	*	*	182.2	331.3	241.8
Filterable Orthopos	0.03	0.03	*	*	*
Hardness	20.0	50.0	97.6	184.2	125.5
Iron (Fe^+)	0.1	0.8	0.1	0.2	0.1
Magnesium (Mg^+)	10.0	20.0	27.6	37.2	26.7
Nitrate (NH_4^-)	0.7	2.8	0.9	1.4	1.0
Nitrate (NO_3^-)	3.1	12.3	4.1	6.0	4.5
Nitrite (NO_2^-)	0.02	0.01	0.01	0.01	0.01
Phosphate (PO_4)	*	0.03	0.01	0.1	0.1
Silica (SiO_2)	1.0	4.0	7.1	6.4	6.8
Specific Conductance	*	59.0	206.3	371.5	283.6
Sulfate (SO_4^-)	1.0	14.00	33.4	78.03	48.5
Temperature °C	*	29.8	17.1	16.9	18.3
Turbidity	1.5	47.00	5.3	9.1	9.5

All concentrations are expressed in milligrams per liter except specific conductance (Umhos/cm) and turbidity (Nephlometric unit).

*Parameters not tested.

along with a slight scouring of stream bed materials midway downstream from the construction site. None of these create any obstacles to the normal stream channel flow or the aquatic life.

The average particle size distribution of sediments in the samples obtained from Noname and Limestone Creek bed upstream from the construction site was 20 percent sand, 30 percent silt and 50 percent clay, whereas the sediment at the construction zone contained approximately 40 percent sand, 20 percent silt and 40 percent clay.

Monitored sediment collection devices indicated no dramatic changes in the amount of sediment from site 1 and site 3, but site 2 has a slight increase in the amount of sediment.

Runoff from fills at the site of bridge construction did not produce any more sediment than that found in site 2. The amount of sediment collected in the plate at the bridge construction site is very minimal and lower than that found in site 3.

COST

On an average it will cost approximately $16,000 per site, per year to conduct a study of this nature. The cost for a study will vary depending on the following factors:

1) Number of monitoring sites
2) Number of times the tests will be conducted
3) Location of the site
4) Wages and salaries of personnel
5) Type of equipment and materials needed to conduct the tests.

Table 6 shows a schedule of the associated costs for a typical testing site involving a once a month testing schedule for one year.

Table 6

ESTIMATED ANNUAL COST

FOR

CONDUCTING WATER QUALITY TESTS*

Personnel		$ 8,400.00
Travel		$ 2,000.00
Equipment		$ 3,500.00
Materials		$ 1,500.00
	Total	$15,400.00

* Tests to be performed monthly at one site for one year.

CONCLUSION

At the end of this study the following conlusions were reached:

1. There was no physical, chemical or biological evidence to indicate that highway construction activities adversely affected the quality of the streams at Limestone Gap. (Limestone and Noname Creeks)
2. Higher concentrations of heavy metals and dissolved solids were found at site 2 "Noname Creek", which is near to the construction compared to sites 1 and 3. The amount was too insignificant to cause any damage to aquatic life or stream water quality.
3. Retention storage created during construction by building a temporary dyke across the stream had no noticeable adverse impact on the stream. Instead, it was probably effective in removal of some heavy metal compounds that were allowed to settle.
4. Existing highway practices and standards are adequate but precautionary measures still need to be taken. For instance, silt fences could be installed.

Three important goals were accomplished with the completion of the Limestone Gap demonstration project. They are as follows:

1. A rational method of assessing the impact of highway construction on water quality was established.

2. It was shown that technician training, to learn specific test procedures and develop sampling schedules to monitor the impact of various stages of construction on fresh stream water, is feasible.
3. It was not difficult for technicians to regularly test the required physical, chemical and biological parameters on a periodic basis, despite problems from weather and construction activities.

This demonstration serves as another step towards better understanding of man's involvement with the environment. It is an attempt on the part of ODOT, to show the maintenance of an ecological environment unblemished by "progress".

The results showed that a stream with the characteristics of Limestone Creek is not easily disturbed by an episode of normal highway construction activity.

The rocky, gravel ground cover of most of the slopes in the construction area helped to reduce erosion. The hard rock stream channel also helped in this area as the aesthetics of this type of stream channel are more difficult to disturb.

RECOMMENDATIONS

Usually erosion controlling measures are useful or required in areas of highway construction where there is potential for surface runoff into nearby streams.

It is recommeded that ODOT provide highway construction contractors with some guidelines to minimize erosion from construction sites. The following items are suggested.

1. Areas susceptible to erosion should be identified so that plans can be made as to the type, size and location of the erosion control measures.
2. Temporary or permanent diversion drainage ditches can be developed to handle runoff.
3. Sediment laden runoff can be collected by using silt fences, brush barriers or sediment basins.
4. Natural runoff on slopes above construction sites should be diverted such that it will not flow over the construction site.
5. The length of time any given area of construction work such as clearing, is laid bare to the elements should be minimized. Easily eroded soils should be protected from rain with excelsior mats or their equivalents.

Consideration for all the recommended erosion control measures are to be made prior to clearing or any other construction activity so that natural runoff can be directed to the drainage ditches, silt fences, sediment basins or other erosion control structures.

Finally, it is recommended that similar studies be conducted in areas where there is a potential for construction activities to impact on stream water quality or other ecological environments.

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APPENDIX A

STATISTICAL CORRELATIONS OF CHEMICAL CONSTITUENTS

STATISTICAL CORRELATIONS OF CHEMICAL CONSTITUENTS

The calculated means values for the chemical constituents at Limestone Gap varied from site to site and from one parameter to the next. Some of the variation could be explained by the fact that the total number of observations for each parameter varied from one site to the next. Appendix A-3 and A-4 show statistical summaries of the means for site 1, 2 and 3.

The correlations on the chemical parameters tested indicated a positive relationship between dissolved solids and the following: conductivity, hardness, calcium and magnesium.

Turbidity also has a positive correlation with dissolved oxygen, temperature, and nitrates.

Heavy metals like copper, calcium, magnesium and nitrates also have positive correlations for dissolved solids, conductivity, turbidity, chlorine and alkalinity. Figure A-1 shows a plot of the hardness against calcium for site 2. This figure indicates that most of the hardness is due to the presence of dissolved limestone ($CaCO_3$).

K E Y			
PARAMETER ABBREVIATION		PARAMETERS	UNIT OF MEASUREMENT
ALKA	=	pH	—
TEMP	=	Temperature (T)	°C
CL_2	=	Chlorine	mg/L
IRON	=	Iron (Fe^+)	mg/L
CLRIDE	=	Chloride (CL)	mg/L
COND	=	Specific Conductance	UMHOS/cm
SILI	=	Silica (SiO_2)	mg/L
NRIT	=	Nitrite (NO_2^-)	mg/L
NRAT	=	Nitrate (NH_4)	mg/L
NO_3	=	Nitrate (NO_3^-)	mg/L
DSOL	=	Dissolved Solids	mg/L
PHOS	=	Phosphate (PO_4)	mg/L
DOXY	=	Dissolved Oxygen	mg/L
TURB	=	Turbidity (Turb)	NTU
COPP	=	Copper (CU^+)	mg/L
CALC	=	Calcium (Ca^{+2})	mg/L
HARD	=	Total Hardness (TH)	mg/L
MAGN	=	Magnesium (Mg^+)	mg/L
SULF	=	Sulfate (SO_4^-)	mg/L

LIMESTONE GAP CREEKS
CHEMICAL CONSTITUENTS MEANS VALUES IN MG/L EXCEPT *

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
SITE=1									
ALKA *	73	7.44	1.05	4.50	9.20	0.12	543.05	1.11	14.16
CALC	86	69.94	48.45	10.00	210.00	5.22	6015.00	2347.35	69.27
COND *	67	206.30	118.78	25.00	679.00	14.51	13822.00	14107.67	57.57
DOXY	64	9.38	3.61	0.10	21.00	0.45	600.30	13.02	38.47
DSOL	63	182.16	95.02	40.00	460.00	11.97	11476.00	9028.75	52.16
HARD	86	97.56	61.21	30.00	250.00	6.60	8390.00	3746.32	62.74
MAGN	86	27.56	17.83	0.05	80.00	1.92	2370.05	318.05	64.71
NO3	84	4.05	3.02	0.88	11.40	0.33	340.19	9.11	74.54
NRAT	84	0.92	0.70	0.03	2.60	0.08	77.17	0.49	76.51
NRIT	82	0.01	0.01	0.00	0.03	0.00	0.67	0.00	68.96
TEMP *	73	17.07	6.77	3.50	29.20	0.79	1246.20	45.79	39.64
TURB *	88	5.27	6.61	0.01	41.00	0.70	464.15	43.73	125.38
SITE=2									
ALKA *	70	7.51	1.00	5.70	10.50	0.12	525.95	0.99	13.25
CALC	81	151.48	80.61	40.00	360.00	8.96	12270.00	6497.78	53.21
COND *	62	371.52	155.87	105.00	740.00	19.80	23034.00	24296.12	41.96
DOXY	58	9.74	2.47	4.90	15.10	0.32	565.10	6.11	25.38
DSOL	58	331.28	137.43	85.00	620.00	18.05	19214.00	18887.92	41.49
HARD	81	184.20	81.01	50.00	410.00	9.00	14920.00	6562.16	43.98
MAGN	78	37.17	21.76	10.00	110.00	2.46	2899.00	473.44	58.54
NO3	80	5.99	6.03	0.09	44.00	0.67	478.81	36.35	100.74
NRAT	80	1.35	1.47	0.02	11.00	0.16	107.77	2.15	108.92
NRIT	77	0.01	0.02	0.00	0.13	0.00	0.94	0.00	165.47
TEMP *	64	16.91	7.57	3.00	33.00	0.95	1082.30	57.37	44.79
TURB *	82	9.12	28.47	0.12	251.00	3.14	748.15	810.40	312.01
SITE=3									
ALKA *	97	7.36	1.17	0.00	9.60	0.12	714.10	1.37	15.93
CALC	114	99.26	67.22	0.20	260.00	6.30	11315.20	4518.78	67.73
COND *	87	283.62	146.40	25.00	763.00	15.70	24675.00	21431.56	51.62
DOXY	83	9.50	3.87	0.00	18.00	0.42	788.32	14.96	40.73
DSOL	84	241.76	109.81	38.00	560.00	11.98	20308.00	12058.71	45.42
HARD	114	125.47	74.11	0.10	290.00	6.94	14303.10	5492.12	59.07
MAGN	112	26.68	13.13	0.10	60.00	1.24	2988.10	172.28	49.20
NO3	112	4.47	3.15	0.13	12.30	0.30	500.26	9.90	70.45
NRAT	112	0.98	0.73	0.02	2.80	0.07	109.61	0.53	74.11
NRIT	110	0.01	0.02	0.00	0.10	0.00	1.54	0.00	142.24
TEMP *	92	18.26	7.06	3.60	33.30	0.74	1680.10	49.88	38.67
TURB *	117	9.45	22.71	0.70	190.00	2.10	1105.64	515.87	240.35

LIMESTONE GAP CREEKS
CHEMICAL CONSTITUENTS CORRELATION VALUES IN MG/L EXCEPT *

SITE=1

VARIABLE	N	MEAN	STD DEV	SUM	MINIMUM	MAXIMUM
ALKA*	73	7.43904110	1.05370532	543.05000000	4.50000000	9.20000000
CALC	86	69.94186047	48.44945326	6015.00000000	10.00000000	210.00000000
COND*	67	206.29850746	118.77570088	13822.00000000	25.00000000	679.00000000
DOXY	64	9.37968750	3.60850757	600.30000000	0.10000000	21.00000000
DSOL	63	182.15873016	95.01972738	11476.00000000	40.00000000	460.00000000
HARD	86	97.55813953	61.20719001	8390.00000000	30.00000000	250.00000000
MAGN	86	27.55872093	17.83402431	2370.05000000	0.05000000	80.00000000
NO3	84	4.04988095	3.01872809	340.19000000	0.88000000	11.40000000
NRAT	84	0.91869048	0.70290581	77.17000000	0.03000000	2.60000000
NRIT	82	0.00819512	0.00565126	0.67200000	0.00100000	0.03000000
TEMP*	73	17.07123288	6.76688176	1246.20000000	3.50000000	29.20000000
TURB*	88	5.27440909	6.61291199	464.14800000	0.00800000	41.00000000

LIMESTONE GAP CREEKS
CHEMICAL CONSTITUENTS CORRELATION VALUES IN MG/L EXCEPT *

SITE=1

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

	ALKA	CALC	COND	DOXY	DSOL	HARD	MAGN	NO3	NRAT	NRIT	TEMP	TURB
ALKA*	1.00000	0.06792	-0.12408	-0.05514	-0.12321	0.09047	0.13446	-0.40245	-0.40226	-0.25791	-0.07855	-0.00787
	0.0000	0.5736	0.3209	0.6678	0.3401	0.4531	0.2636	0.0006	0.0006	0.0299	0.5243	0.9481
	73	71	66	63	62	71	71	70	70	71	68	71
CALC	0.06792	1.00000	0.86709	-0.11829	0.89407	0.97431	0.62954	-0.16508	-0.16921	-0.08587	0.11233	-0.39000
	0.5736	0.0000	0.0001	0.3599	0.0001	0.0001	0.0001	0.1335	0.1239	0.4430	0.3510	0.0002
	71	86	65	62	62	86	86	84	84	82	71	86
COND*	-0.12408	0.86709	1.00000	-0.28074	0.93747	0.84866	0.60945	0.02650	0.01780	-0.18894	0.26717	-0.28853
	0.3209	0.0001	0.0000	0.0246	0.0001	0.0001	0.0001	0.8353	0.8889	0.1317	0.0288	0.0198
	66	65	67	64	63	65	65	64	64	65	67	65
DOXY	-0.05514	-0.11829	-0.28074	1.00000	-0.14787	-0.14918	-0.20117	0.04328	0.04513	0.13786	-0.51013	0.13571
	0.6678	0.3599	0.0246	0.0000	0.2595	0.2472	0.1169	0.7405	0.7298	0.2853	0.0001	0.2929
	63	62	64	64	60	62	62	61	61	62	64	62
DSOL	-0.12321	0.89407	0.93747	-0.14787	1.00000	0.87460	0.62848	-0.02217	-0.02903	-0.15328	0.07061	-0.29568
	0.3401	0.0001	0.0001	0.2595	0.0000	0.0001	0.0001	0.8654	0.8242	0.2343	0.5824	0.0196
	62	62	63	60	63	62	62	61	61	62	63	62
HARD	0.09047	0.97431	0.84866	-0.14918	0.87460	1.00000	0.78823	-0.14961	-0.14988	-0.06296	0.08691	-0.37028
	0.4531	0.0001	0.0001	0.2472	0.0001	0.0000	0.0001	0.1744	0.1736	0.5741	0.4711	0.0004
	71	86	65	62	62	86	86	84	84	82	71	86
MAGN	0.13446	0.62954	0.60945	-0.20117	0.62848	0.78823	1.00000	-0.06125	-0.05104	0.01581	-0.01347	-0.21108
	0.2636	0.0001	0.0001	0.1169	0.0001	0.0001	0.0000	0.5799	0.6447	0.8879	0.9112	0.0511
	71	86	65	62	62	86	86	84	84	82	71	86
NO3	-0.40245	-0.16508	0.02650	0.04328	-0.02217	-0.14961	-0.06125	1.00000	0.99390	0.40929	-0.15087	0.14277
	0.0006	0.1335	0.8353	0.7405	0.8654	0.1744	0.5799	0.0000	0.0001	0.0002	0.2125	0.1951
	70	84	64	61	61	84	84	84	84	80	70	84
NRAT	-0.40226	-0.16921	0.01780	0.04513	-0.02903	-0.14988	-0.05104	0.99390	1.00000	0.38119	-0.14947	0.16032
	0.0006	0.1239	0.8889	0.7298	0.8242	0.1736	0.6447	0.0001	0.0000	0.0005	0.2168	0.1452
	70	84	64	61	61	84	84	84	84	80	70	84
NRIT	-0.25791	-0.08587	-0.18894	0.13786	-0.15328	-0.06296	0.01581	0.40929	0.38119	1.00000	-0.11467	-0.00939
	0.0299	0.4430	0.1317	0.2853	0.2343	0.5741	0.8879	0.0002	0.0005	0.0000	0.3518	0.9333
	71	82	65	62	62	82	82	80	80	82	68	82
TEMP*	-0.07855	0.11233	0.26717	-0.51013	0.07061	0.08691	-0.01347	-0.15087	-0.14947	-0.11467	1.00000	-0.01666
	0.5243	0.3510	0.0288	0.0001	0.5824	0.4711	0.9112	0.2125	0.2168	0.3518	0.0000	0.8904
	68	71	67	64	63	71	71	70	70	68	73	71
TURB*	-0.00787	-0.39000	-0.28853	0.13571	-0.29568	-0.37028	-0.21108	0.14277	0.16032	-0.00939	-0.01666	1.00000
	0.9481	0.0002	0.0198	0.2929	0.0196	0.0004	0.0511	0.1951	0.1452	0.9333	0.8904	0.0000
	71	86	65	62	62	86	86	84	84	82	71	88

LIMESTONE GAP CREEKS
CHEMICAL CONSTITUENTS CORRELATION VALUES IN MG/L EXCEPT *

SITE=2

VARIABLE	N	MEAN	STD DEV	SUM	MINIMUM	MAXIMUM
ALKA*	70	7.51357143	0.99571260	525.95000000	5.70000000	10.50000000
CALC	81	151.48148148	80.60879467	12270.00000000	40.00000000	360.00000000
COND*	62	371.51612903	155.87213570	23034.00000000	105.00000000	740.00000000
DOXY	58	9.74310345	2.47238163	565.10000000	4.90000000	15.10000000
DSOL	58	331.27586207	137.43333862	19214.00000000	85.00000000	620.00000000
HARD	81	184.19753086	81.00716323	14920.00000000	50.00000000	410.00000000
MAGN	78	37.16666667	21.75866250	2899.00000000	10.00000000	110.00000000
NO3	80	5.98510000	6.02921577	478.80800000	0.08800000	44.00000000
NRAT	80	1.34 12500	1.46730546	107.77000000	0.02000000	11.00000000
NRIT	77	0.01224675	0.02026480	0.94300000	0.00100000	0.13000000
TEMP*	64	16.91093750	7.57462592	1082.30000000	3.00000000	33.00000000
TURB*	82	9.12378049	28.46744138	748.15000000	0.12000000	251.00000000

LIMESTONE GAP CREEKS

CHEMICAL CONSTITUENTS CORRELATION VALUES IN MG/L EXCEPT *

SITE=2

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

	ALKA	CALC	COND	DOXY	DSOL	HARD	MAGN	NO3	NRAT	NRIT	TEMP	TURB
ALKA*	1.00000	0.18340	-0.01463	0.10667	-0.14647	0.26516	0.30723	-0.25338	-0.23115	-0.14208	0.01944	-0.32607
	0.0000	0.1374	0.9109	0.4297	0.2769	0.0301	0.0121	0.0386	0.0598	0.2628	0.8798	0.0075
	70	67	61	57	57	67	66	67	67	64	63	66
CALC	0.18340	1.00000	0.74005	-0.43077	0.67095	0.94201	0.12463	-0.09991	-0.10177	0.09389	0.24925	-0.26606
	0.1374	0.0000	0.0001	0.0010	0.0001	0.0001	0.2769	0.3810	0.3721	0.4198	0.0527	0.0178
	67	81	59	55	56	81	78	79	79	76	61	79
COND*	-0.01463	0.74005	1.00000	-0.37349	0.83268	0.69364	0.25873	-0.18853	-0.21091	-0.09668	0.47470	-0.39273
	0.9109	0.0001	0.0000	0.0039	0.0001	0.0001	0.0499	0.1527	0.1088	0.4784	0.0001	0.0023
	61	59	62	58	58	59	58	59	59	56	62	58
DOXY	0.10667	-0.43077	-0.37349	1.00000	-0.32185	-0.37524	0.14906	0.24611	0.23263	-0.05595	-0.49170	0.06070
	0.4297	0.0010	0.0039	0.0000	0.0176	0.0048	0.2820	0.0701	0.0874	0.6936	0.0001	0.6628
	57	55	58	58	54	55	54	55	55	52	58	54
DSOL	-0.14647	0.67095	0.83268	-0.32185	1.00000	0.65115	0.20650	-0.09621	-0.12513	-0.08220	0.12945	-0.35259
	0.2769	0.0001	0.0001	0.0176	0.0000	0.0001	0.1304	0.4806	0.3582	0.5585	0.3328	0.0083
	57	56	58	54	58	56	55	56	56	53	58	55
HARD	0.26516	0.94201	0.69364	-0.37524	0.65115	1.00000	0.33144	-0.14715	-0.14249	0.06354	0.20632	-0.28793
	0.0301	0.0001	0.0001	0.0048	0.0001	0.0000	0.0030	0.1956	0.2103	0.5855	0.1106	0.0101
	67	81	59	55	56	81	78	79	79	76	61	79
MAGN	0.30723	0.12463	0.25873	0.14906	0.20650	0.33144	1.00000	-0.23441	-0.21744	-0.14054	0.00548	-0.13837
	0.0121	0.2769	0.0499	0.2820	0.1304	0.0030	0.0000	0.0415	0.0592	0.2324	0.9668	0.2333
	66	78	58	54	55	78	78	76	76	74	60	76
NO3	-0.25338	-0.09991	-0.18853	0.24611	-0.09621	-0.14715	-0.23441	1.00000	0.99370	0.03726	-0.10457	0.28661
	0.0386	0.3810	0.1527	0.0701	0.4806	0.1956	0.0415	0.0000	0.0001	0.7509	0.4225	0.0110
	67	79	59	55	56	79	76	80	80	75	61	78
NRAT	-0.23115	-0.10177	-0.21091	0.23263	-0.12513	-0.14249	-0.21744	0.99370	1.00000	0.03965	-0.08305	0.28415
	0.0598	0.3721	0.1088	0.0874	0.3582	0.2103	0.0592	0.0001	0.0000	0.7355	0.5246	0.0117
	67	79	59	55	56	79	76	80	80	75	61	78
NRIT	-0.14208	0.09389	-0.09668	-0.05595	-0.08220	0.06354	-0.14054	0.03726	0.03965	1.00000	0.10019	-0.02284
	0.2628	0.4198	0.4784	0.6936	0.5585	0.5855	0.2324	0.7509	0.7355	0.0000	0.4543	0.8458
	64	76	56	52	53	76	74	75	75	77	58	75
TEMP*	0.01944	0.24925	0.47470	-0.49170	0.12945	0.20632	0.00548	-0.10457	-0.08305	0.10019	1.00000	-0.15568
	0.8798	0.0527	0.0001	0.0001	0.3328	0.1106	0.9668	0.4225	0.5246	0.4543	0.0000	0.2349
	63	61	62	58	58	61	60	61	61	58	64	60
TURB*	-0.32607	-0.26606	-0.39273	0.06070	-0.35259	-0.28793	-0.13837	0.28661	0.28415	-0.02284	-0.15568	1.00000
	0.0075	0.0178	0.0023	0.6628	0.0083	0.0101	0.2333	0.0110	0.0117	0.8458	0.2349	0.0000
	66	79	58	54	55	79	76	78	78	75	60	82

LIMESTONE GAP CREEKS
CHEMICAL CONSTITUENTS CORRELATION VALUES IN MG/L EXCEPT *

SITE=3

VARIABLE	N	MEAN	STD DEV	SUM	MINIMUM	MAXIMUM
ALKA*	97	7.36185567	1.17255449	714.10000000	0.00000000	9.60000000
CALC	114	99.25614035	67.22185964	11315.20000000	0.20000000	260.00000000
COND*	87	283.62068966	146.39523132	24675.00000000	25.00000000	763.00000000
DOXY	83	9.49783133	3.86844648	788.32000000	0.00000000	18.00000000
DSOL	84	241.76190476	109.81217470	20308.00000000	38.00000000	560.00000000
HARD	114	125.46578947	74.10882196	14303.10000000	0.10000000	290.00000000
MAGN	112	26.67946429	13.12555542	2988.10000000	0.10000000	60.00000000
NO3	112	4.46664286	3.14662862	500.26400000	0.13200000	12.30000000
NRAT	112	0.97866071	0.72525298	109.61000000	0.02000000	2.80000000
NRIT	110	0.01399091	0.01990044	1.53900000	0.00100000	0.10000000
TEMP*	92	18.26195652	7.06240382	1680.10000000	3.60000000	33.30000000
TURB*	117	9.44991453	22.71278523	1105.64000000	0.70000000	190.00000000

LIMESTONE GAP CREEKS
CHEMICAL CONSTITUENTS CORRELATION VALUES IN MG/L EXCEPT *

SITE=3

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	ALKA	CALC	COND	DOXY	DSOL	HARD	MAGN	NO3	NRAT	NRIT	TEMP	TURB
ALKA*	1.00000	0.08055	0.03464	0.19334	0.03857	0.08118	0.00542	-0.27265	-0.29250	-0.11560	0.08951	-0.07530
	0.0000	0.4328	0.7515	0.0818	0.7292	0.4293	0.9584	0.0072	0.0038	0.2646	0.4042	0.4635
	97	97	86	82	83	97	95	96	96	95	89	97
CALC	0.08055	1.00000	0.84973	-0.40134	0.85418	0.98652	0.50987	0.00749	0.02440	0.35771	0.18610	-0.20397
	0.4328	0.0000	0.0001	0.0002	0.0001	0.0001	0.0001	0.9375	0.7984	0.0001	0.0757	0.0295
	97	114	87	83	84	114	112	112	112	110	92	114
COND*	0.03464	0.84973	1.00000	-0.52958	0.94847	0.84284	0.50315	-0.00439	0.02285	0.03012	0.34218	-0.22046
	0.7515	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.9680	0.8346	0.7843	0.0012	0.0402
	86	87	87	82	84	87	85	86	86	85	87	87
DOXY	0.19334	-0.40134	-0.52958	1.00000	-0.42917	-0.38243	-0.13033	-0.22270	-0.24585	0.11531	-0.29607	-0.02720
	0.0818	0.0002	0.0001	0.0000	0.0001	0.0004	0.2462	0.0443	0.0260	0.3053	0.0069	0.8072
	82	83	82	83	79	83	81	82	82	81	82	83
DSOL	0.03857	0.85418	0.94847	-0.42917	1.00000	0.86041	0.56532	-0.00240	0.01827	0.14021	0.15616	-0.24826
	0.7292	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.9828	0.8698	0.2090	0.1560	0.0228
	83	84	84	79	84	84	82	83	83	82	84	84
HARD	0.08118	0.98652	0.84284	-0.38243	0.86041	1.00000	0.63477	0.01576	0.03400	0.35685	0.13661	-0.20362
	0.4293	0.0001	0.0001	0.0004	0.0001	0.0000	0.0001	0.8690	0.7219	0.0001	0.1941	0.0298
	97	114	87	83	84	114	112	112	112	110	92	114
MAGN	0.00542	0.50987	0.50315	-0.13033	0.56532	0.63477	1.00000	0.06593	0.08411	0.20264	-0.12743	-0.11675
	0.9584	0.0001	0.0001	0.2462	0.0001	0.0001	0.0000	0.4938	0.3823	0.0337	0.2313	0.2202
	95	112	85	81	82	112	112	110	110	110	90	112
NO3	-0.27265	0.00749	-0.00439	-0.22270	-0.00240	0.01576	0.06593	1.00000	0.96391	0.12753	-0.02134	0.06890
	0.0072	0.9375	0.9680	0.0443	0.9828	0.8690	0.4938	0.0000	0.0001	0.1884	0.8409	0.4704
	96	112	86	82	83	112	110	112	112	108	91	112
NRAT	-0.29250	0.02440	0.02285	-0.24585	0.01827	0.03400	0.08411	0.96391	1.00000	0.13708	0.00479	0.09538
	0.0038	0.7984	0.8346	0.0260	0.8698	0.7219	0.3823	0.0001	0.0000	0.1572	0.9641	0.3171
	96	112	86	82	83	112	110	112	112	108	91	112
NRIT	-0.11560	0.35771	0.03012	0.11531	0.14021	0.35685	0.20264	0.12753	0.13708	1.00000	-0.26802	-0.02030
	0.2646	0.0001	0.7843	0.3053	0.2090	0.0001	0.0337	0.1884	0.1572	0.0000	0.0111	0.8333
	95	110	85	81	82	110	110	108	108	110	89	110
TEMP*	0.08951	0.18610	0.34218	-0.29607	0.15616	0.13661	-0.12743	-0.02134	0.00479	-0.26802	1.00000	0.00187
	0.4042	0.0757	0.0012	0.0069	0.1560	0.1941	0.2313	0.8409	0.9641	0.0111	0.0000	0.9859
	89	92	87	82	84	92	90	91	91	89	92	92
TURB*	-0.07530	-0.20397	-0.22046	-0.02720	-0.24826	-0.20362	-0.11675	0.06890	0.09538	-0.02030	0.00187	1.00000
	0.4635	0.0295	0.0402	0.8072	0.0228	0.0298	0.2202	0.4704	0.3171	0.8333	0.9859	0.0000
	97	114	87	83	84	114	112	112	112	110	92	117

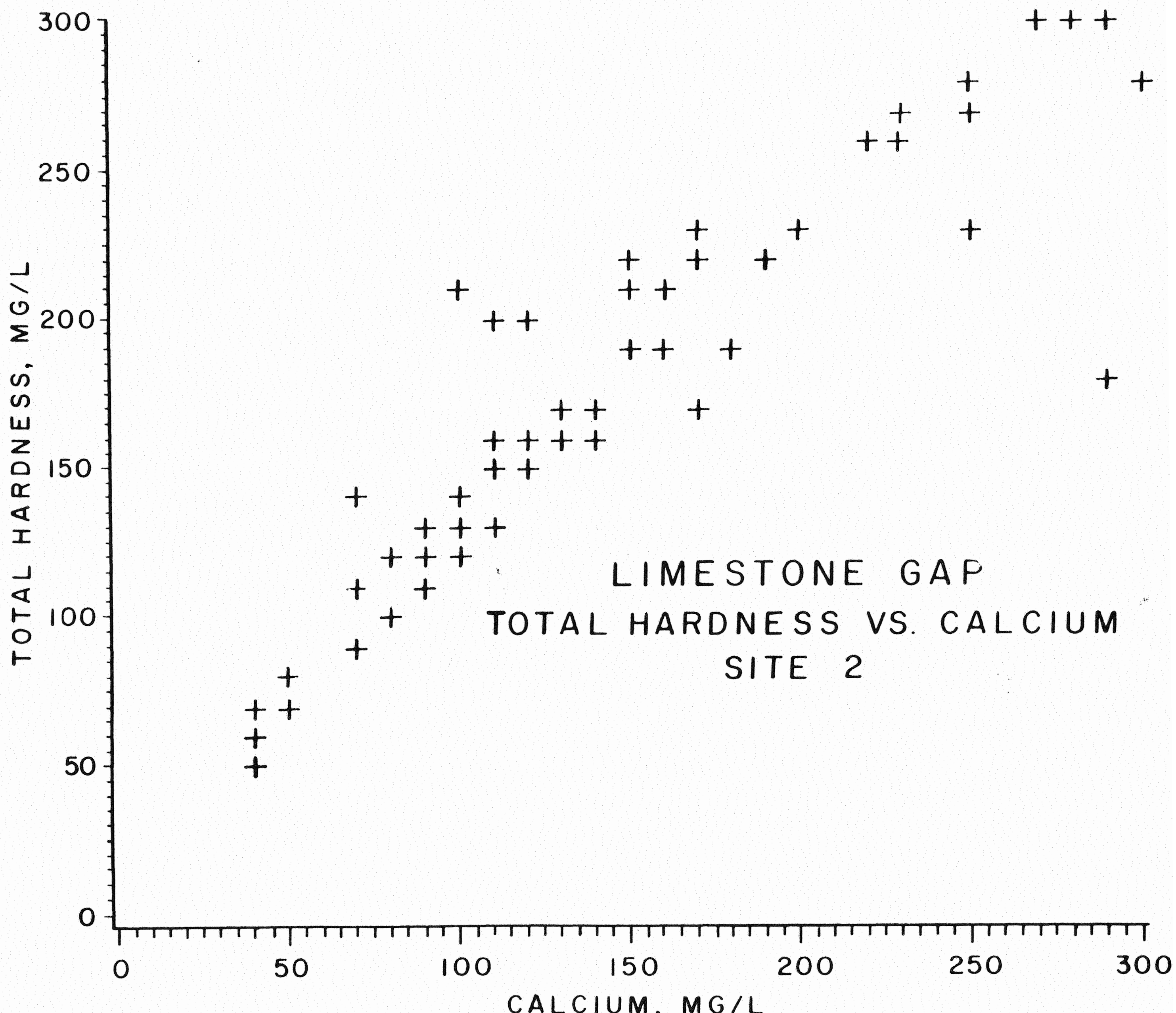

Figure A-1. A Plot of Hardness Against Calcium for Site 2.