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Impact of Urban Stormwater Runoff on the Water Quality of the Subsurface Lost River, Bowling Green, Kentucky

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Rice,

Donald E.

1982

IMPACT OF URBAN STORMWATER RUNOFF ON THE WATER QUALITY OF THE SUBSURFACE LOST RIVER, BOWLING GREEN, KENTUCKY

A Thesis
Presented to
The Faculty of the Department of Geography and Geology
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

by
Donald E. Rice
July, 1982

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IMPACT OF URBAN STORMWATER RUNOFF ON THE WATER QUALITY OF THE SUBSURFACE LOST RIVER, BOWLING GREEN, KENTUCKY

Recommended July 17, 1982
(Date)

Nicholas C. Crawford
Director of Thesis

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Wayne L. Hoffman

Approved September 24, 1982
(Date)

Elmer Gray
Dean of the Graduate College

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

IMPACT OF URBAN STORMWATER RUNOFF ON THE WATER QUALITY OF THE SUBSURFACE LOST RIVER, BOWLING GREEN, KENTUCKY

Donald E. Rice 81 pages

Directed by: Nicholas C. Crawford, Ronald R. Dilamarter, Wayne Hoffman

Department of Geography and Geology Western Kentucky University

Bowling Green, Kentucky is located in a distinctive karst region, characterized by subsurface drainage. The Lost River is a large subsurface stream which flows beneath the city. It receives much of the stormwater runoff from Bowling Green, since most of the city's runoff is directed underground. Significant pollutants in Bowling Green's stormwater runoff were identified from water quality test results of storm event grab samples, and a composite sample, of runoff entering the urban By-Pass Cave. Water quality test results were also obtained from storm event grab samples, and a composite sample, of the Lost River at the Blue Hole before it reached Bowling Green and at the Resurgence after it had passed beneath Bowling Green. Significant pollutant test results from the Blue Hole and Resurgence were analyzed to determine the impact of urban stormwater runoff on the water quality of the Lost River. Suspended solids were the only urban runoff pollutant identified as entering the Lost River in significant quantities. Animal waste, iron, and oil and grease were identified as stormwater runoff pollutants of the Lost River, but whose origin, either urban or rural, could not be conclusively determined from the available data.

CHAPTER I

INTRODUCTION

The Karst Environment of Bowling Green, Kentucky

Bowling Green, Kentucky is located in a distinctive karst region, the Pennyroyal Plain. The Pennroyal Plain, shown in Figure 1, is characterized by numerous sinkholes, and extensive, integrated subsurface drainage systems.

The Pennyroyal Plain originated as a consequence of the retreat of the escarpment leading to the adjacent Chester Cuesta (Mammoth Cave Plateau). It is believed that the retreat of this escarpment, known as the Chester Escarpment, is caused by gullying and vertical shaft formation (White et al., 1970). It is estimated that over 100 meters of overburden have been removed through these porcesses (Lehman, 1976). The 100 meter figure corresponds to the difference in relief between the Chester Cuesta and the Pennyroyal Plain. Since the retreat of the Chester Escarpment is considered an active process, the Pennyroyal Plain is still developing.

The most obvious karst features of the Pennyroyal are sinkholes, but perhaps the most significant features are the extensive integrated subsurface drainage systems. Associated with these subsurface drainage systems are sinking streams, caves, karst windows, and large springs. All of these karst features are found within Bowling Green, Kentucky, making it one of the few cities in North America that must concern

THE PENNYROYAL PLAIN OF KENTUCKY

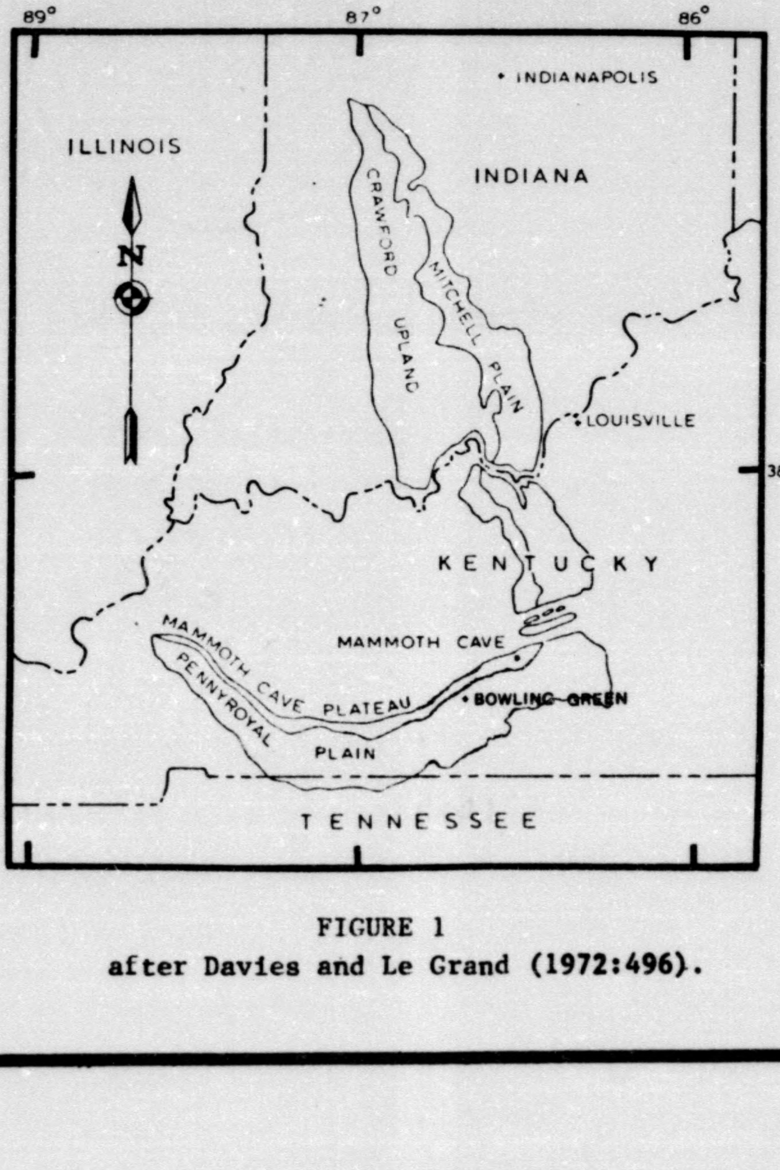

FIGURE 1
after Davies and Le Grand (1972:496).

itself with karst hydrology.

A prominent feature of the karst hydrology of Bowling Green is its major subsurface stream, the Lost River. The Lost River surfaces at a "blue hole" spring in the bottom of a large uvala, in south Bowling Green. The discharge of the spring at base flow is approximately 570 liters per second, but in times of heavy precipitation the discharge increases to over 11,300 liters per second. The Lost River flows approximately 125 meters across the floor of the uvala then enters Lost River Cave at the opposite end.

Lost River Cave is an extensive system with almost five kilometers of mapped passage and five known entrances. The cave is primarily a conduit for the Lost River, characterized by large trunk passage, as seen in Figure 2. Breakdown collapse prevents exploration about halfway through the Lost River's route beneath Bowling Green. The river resurges again at a large spring in Lampkin Park, approximately five kilometers north of its entry into Lost River Cave (George, 1973; Crawford and Beeler, 1980). From the Resurgence the Lost River joins Jennings Creek, which discharges into the Barren River. The Resurgence, Blue Hole, and the known and projected path of the Lost River are shown in Figure 3 (adapted from Crawford and Beeler, 1980). In Figure 3 Lost River Uvala corresponds to the Blue Hole, and Dishman Mill Rise corresponds to the Resurgence. The Lost River presents an excellent opportunity to investigate the impact of urbanization on karst groundwater quality, because comparisons of water quality before the Lost River enters Bowling Green, and after it has passed beneath Bowling Green, can be made at the Blue Hole and Resurgence, respectively.

Figure 2. Large trunk passage in Lost River Cave.

Pollution of the Karst Environment in the Bowling Green Area

Groundwater quality problems in Bowling Green are intensified by the karst environment. Pollutants from both diffuse and discrete sources are rapidly directed into Bowling Green's turbulently flowing subsurface streams. This type of groundwater system behaves much like surface streams, without the natural cleansing advantages of either. Karst groundwater flowing in discrete channels is ineffective in removing pollutants through the groundwater cleansing mechanisms of natural filtration and absorption (Aley, 1981). Turbulently flowing karst groundwater, unlike laminar flowing groundwater, rapidly transmits septic tank effluent to surface receiving water. This allows little time for the die off of any pathogenic bacteria present in the effluent.

The cleansing mechanism of absorption, natural filtration, and die off of pathogenic bacteria is ineffective in karst groundwater

ROUTE OF THE LOST RIVER, BOWLING GREEN, KENTUCKY

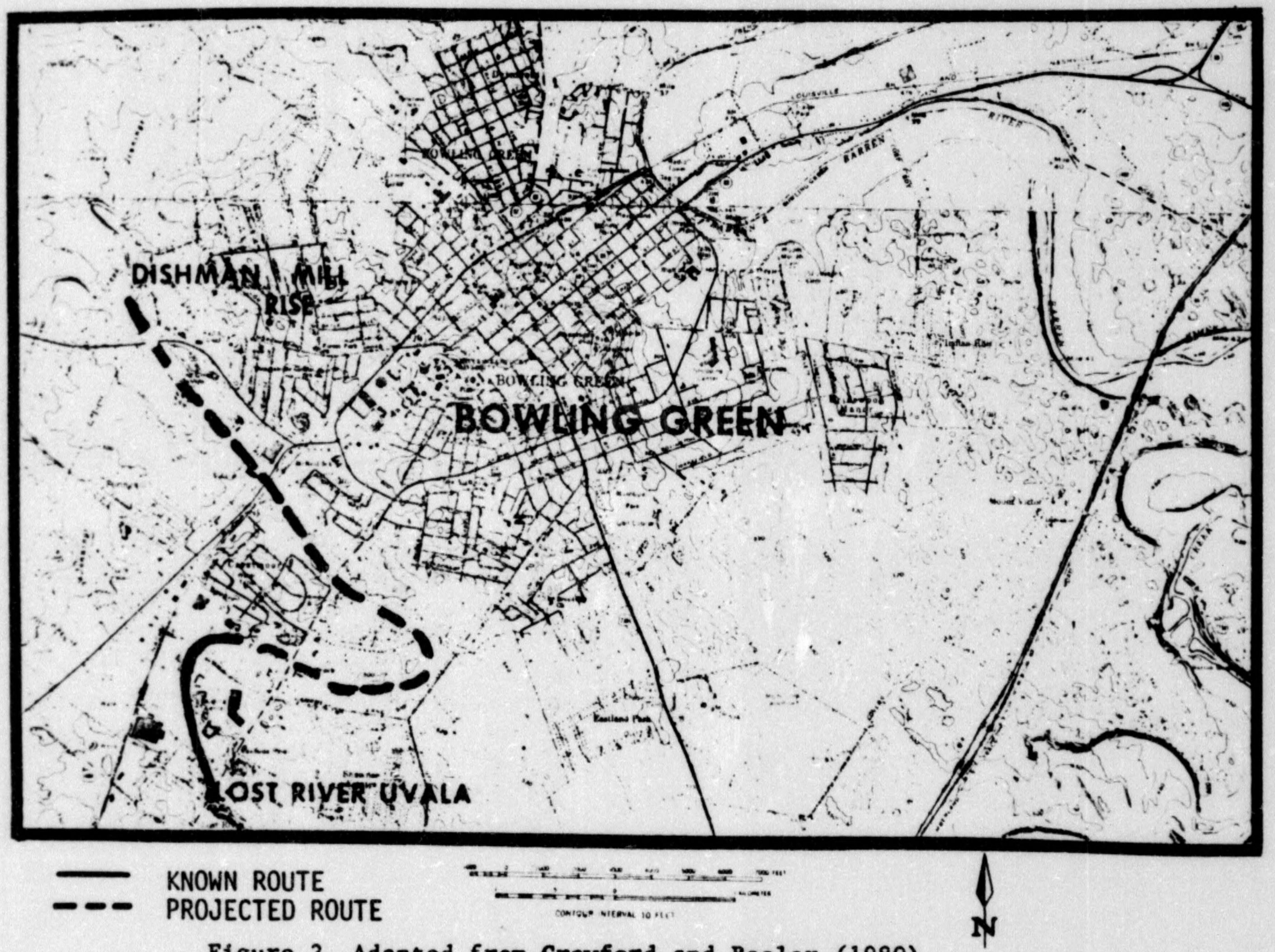

Figure 3. Adapted from **Crawford and Beeler** (1980)

because it generally behaves like a turbulently flowing surface stream. Yet various mechanisms that aid in the cleansing of surface streams are ineffective for karst groundwater. Aley (1981) points out that ultraviolet light is not present to aid in killing bacteria, and reoxygenation is less rapid in karst groundwater. These are of particular concern when oxygen demanding wastes, such as septic tank effluent and urban stormwater runoff, are present. The lack of natural cleansing abilities mentioned here make the karst groundwater of Bowling Green very susceptible to both point and nonpoint sources of pollution.

Dumping of waste in and around Bowling Green is too often characterized by the attitude "out of sight, out of mind." Sinkholes are commonly used by individuals for dumping garbage, trash, and sewage. Caves and sinkholes have also been used by industry for dumping of their waste. Several examples of this have been recorded. The Fields Meat Packaging Company of Bowling Green was ordered to stop dumping waste blood into a cave located beneath its plant, after it was discovered that the blood was reaching the Barren River (Elliot, 1976). Quinlan and Rowe (1977) cite severe pollution problems in Hidden River Cave, at nearby Horse Cave, Kentucky. Inadequately treated sewage effluent, containing high concentrations of heavy metals and organic waste, reaches Hidden River, within the cave, from two drainage wells into which the effluent is dumped. Hidden River resurges at thirty-seven springs along Green River, distributing the polluted water over a large area. Quinlan and Rowe (1977) also report the pollution of Smiths Grove's municipal drinking water supply by a creamery located eight kilometers from Smiths Grove, which dumped 310 metric tons of whey into a sinkhole. This resulted in Smiths Grove's municipal well water being unfit to drink for over a month.

These are examples of water pollution in urban karst resulting from deliberate indiscriminate dumping of waste. Water pollution problems in urban karst may also result from accidental or unrecognized dumping. The following examples illustrate this problem:

1. Septic tank effluent from homes in a subdivision south of Bowling Green was found to be rapidly draining into the Lost River. This was documented when dye dumped into a toilet reached the Lost River Blue Hole in only ten hours (Crawford, 1979).
2. A truck carrying sodium cyanide, potassium cyanide and copper cyanide overturned and burned on Interstate 65 near Cave City, Kentucky. If it had rained, or if firemen had not contained the runoff water used fighting the fire, cyanide in high concentrations would have quickly entered the subsurface drainage system through a nearby sinkhole (Daily New, June 5, 1980).
3. Sanitary sewer lines in Bowling Green have been laid in ditches which intersect tributaries of the Lost River. If leakage occurs the Lost River will be polluted with raw sewage.

These are examples of real and potential groundwater pollution problems in urban karst environments caused from accidental or unrecognized dumping. It is not an inclusive list, but it does represent pollution problems common to the urban karst of Bowling Green.

All examples presented thus far represent pollution problems resulting from discrete sources of pollution. A significant contribution to pollution of the subsurface waters of Bowling Green is made by urban stormwater runoff, which is a diffuse nonpoint source of pollution. The subsurface streams of Bowling Green, such as the Lost River, serve as natural storm sewers, with water directed to them through numerous sinkholes and swallets. Without urbanization the impact of storm runoff on water quality in this area would be insignificant. Urbanization in Bowling Green has created conditions that make stormwater runoff a potentially serious pollution problem.

Stormwater management practices involve two methods of directly injecting runoff into the karst aquifer. The first method involves directing runoff into natural karst catchments, including both sinkholes and swallets. Sinkholes, being depressions, naturally collect runoff. In Bowling Green stormwater is often routed into sinkholes through ditches and pipes. The Nahm Avenue Sink in Bowling Green receives stormwater runoff from fifty-five hectares (Daugherty and Trautwein, Inc., and G.R.W. Engineers, Inc., 1980). Increased flow to sinkholes also results from an increase in impervious area within their drainage basins. Swallets route surface streams to subsurface drainage systems. Within Bowling Green most surface streams are ephemeral, flowing only when stormwater runoff fills their channels. Man made channels direct runoff into cave entrances, which function as swallets, though no natural channels now lead to their entrances. For example, By-Pass Cave receives run-off from over thirty-two hectares.

The second method of directing stormwater runoff into the subsurface drainage system is accomplished through the use of dry wells. A dry well in Bowling Green is a well, usually eight to twelve inches in diameter, of variable depth, cased for only the first few feet, which is used only for delivering runoff to the subsurface drainage system. They are drilled wherever runoff collects (often in sinkholes), or where it is necessary to reduce surface flow of runoff. The capacity of dry wells depends on how effectively they intersect the subsurface drainage system. Over 300 dry wells have been drilled in Bowling Green (Crawford, 1980).

Statement of Purpose

The urban stormwater management practices described above result in not only a greater quantity of runoff being directed underground than would naturally occur, but also in water potentially rich in pollutants being directed underground. It is the purpose of this thesis to assess the quality of the water entering the Lost River drainage system and to determine the impact of Bowling Green's stormwater runoff on the water quality of the Lost River.

CHAPTER II

REVIEW OF LITERATURE

Introduction

The focus of this thesis is the pollution of karst groundwater by urban stormwater runoff. Urban stormwater runoff has been extensively investigated as to the type and sources of pollutants and its impact on surface receiving waters. The published research on urban runoff quality deals with nonkarst urban environments. The type of pollutants in urban runoff will not likely differ when karst and nonkarst terrains of comparable land use are compared. Therefore it is assumed that the types and sources of pollutants in urban stormwater runoff are comparable for karst and nonkarst terrains.

However it cannot be assumed that the impact of urban stormwater runoff is comparable for karst and nonkarst urban areas. The drainage system for runoff to receiving waters in the urban karst environment of Bowling Green is unique, therefore its impact may be unique. The literature concerning the impact of runoff in nonkarst urban areas was reviewed to determine how the impacts of stormwater runoff on the two environments compare.

Types of Urban Stormwater Runoff Pollutants

Consistently reported as the primary pollutants of urban runoff are suspended and settleable solids (Sartor and Boyd, 1972; Lager and Smith, 1974). Sartor and Boyd (1972:2) describe them as, "inorganic mineral-like matter, similar to common sand and silt." These pollutants alone do not represent a serious threat to surface water quality, as turbidity is the water quality parameter most affected. However, associated with the inorganic suspended and settleable solids in the runoff is a much smaller by mass, but often significant, amount of organic matter (Sartor and Boyd, 1972). Excessive organic matter in water results in a reduction of the oxygen supply available to aquatic life. Thus both inorganic and organic debris are considered to be pollutants in urban stormwater runoff.

Algal nutrients have been a water pollutant of serious concern in recent years. The nutrients occur in water usually as compounds of nitrogen and phosphorus (Hammer, 1975). An excess of the compounds has been reported in urban stormwater runoff by Lager and Smith (1974), Colston (1975), and Sartor and Boyd (1972). There are several serious problems that an excess of algal nutrients can cause. Eutrophication of a water body can occur due to the presence of these nutrients (Sartor and Boyd, 1972). Sartor and Boyd (1972) also mention two other problems that can result from excess algal nutrients in a drinking water supply. Methemoglobinemia, or blue baby disease, is a serious blood disease that can be contracted if infants drink water containing an excess of nitrites. An excess of phosphates in drinking water may interfere with coagulation of solids at a water treatment plant. Viewing these problems in terms of urban stormwater runoff, Sartor and Boyd (1972) point out that eutrophication and methemoglobinemia will not be problems unless the water is discharged into a standing body of water. Free flowing water prevents the continuous water pollution conditions necessary for the development of these two problems by dispersing any polluted slug of runoff entering it. However phosphate polluted runoff can cause temporary problems in coagulation of solids at a water treatment plant, even if discharged into free flowing water.

Incompletely investigated, but of potentially significant impact, is the presence of heavy metals in urban stormwater runoff. Shaheen (1975), Colston (1974), Lager and Smith (1974), and Sartor and Boyd (1972) all report the presence of heavy metals in urban stormwater runoff. The heavy metals lead, mercury, and chromium are known to be toxic to humans; but the degree of toxicity can be dependent on the chemical form of the heavy metal (Sartor and Boyd, 1972). Some heavy metals such as copper may be toxic to aquatic life, while having little impact on humans. However any heavy metal may be toxic to humans if ingested in high concentrations. This literature review reveals why heavy metals must be considered incompletely investigated with respect to urban stormwater runoff. It was stated that the degree of toxicity can be dependent on the chemical form of the heavy metal. Sartor and Boyd (1972:68) before presenting the results of their heavy metal tests of urban runoff point out that

> The toxic effect of a given metal on an aquatic environment is dependent upon a number of complex and rather poorly understood factors. One of the most important factors is the form of the particular metal. The data reported here are the total amounts of such metals present, without regard to their chemical/physical states (i.e., their balance, whether they are tied up into complex inorganic or organic compounds, etc.). Analyses of such materials should be performed as part of a more definitive future study. At this time it is possible only to consider the significance of finding such metals in their most toxic form, recognizing the dangers inherent in making such speculations. It is strongly urged that the

> conclusions drawn below be adequately qualified if ever quoted out of context.

This quotation illustrates a consistent problem with the testing of heavy metals in urban stormwater runoff: results cannot always be used to assess the toxic impact of the heavy metals.

An examination of the results of numerous urban stormwater runoff studies compiled by Huber (1979) confirms that heavy metals are consistently present in the runoff. Earlier, the difference in toxicity among heavy metals was mentioned, with lead and chromium being very toxic to humans. Because of their toxicity lead and chromium are often the only heavy metals tested for in urban runoff studies. When the presence or absence of other heavy metals is not known, it is impossible to accurately assess the effects in urban runoff. Potentially the effects could be severe, if not on humans then on other ecosystems which the runoff contacts. The prolific use of pesticides has contaminated virtually every aspect of the environment. The chlorinated hydrocarbon pesticides, such as DDT, DDD, and dieldrin, have been particularly damaging because of their widespread abuse and longevity in the environment. The presence of chlorinated hydrocarbons in urban stormwater runoff in significant concentrations has been reported by Shaheen (1975), Lager and Smith (1974), and Sartor and Boyd (1972).

In addition both Shaheen (1975) and Sartor and Boyd (1972) report finding significant concentrations of polychlorinated biphenyls (PCBs) in urban runoff. PCBs also have toxic effects on the environment like the chlorinated hydrocarbons, and like them they are widely distributed and long lasting in the environment (Sartor and Boyd, 1972).

Pathogens are of concern in any water pollution study. It is essential to know if water contains pathogens in sufficient quantity to be a threat to human health; consequently pathogens are a widely investigated water quality parameter of urban stormwater runoff. Hammer (1975) points out that testing for pathogenic bacteria in water is best accomplished by using coliform bacteria as indicator organisms for pathogenic bacteria. Colston (1974), Lager and Smith (1974), Sartor and Boyd (1972), Huber (1979) and Shaheen (1975) discuss the presence of coliform bacteria in urban stormwater runoff. Generally their conclusions indicate that coliform bacteria do occur in significant quantities in urban stormwater runoff. However Sartor and Boyd (1972) note that it is difficult to predict from urban runoff data the levels of coliform in receiving water because of their generally rapid die off.

The last pollutant included in this examination of urban stormwater runoff pollutants is salt, a seasonal pollutant. Salt used in highway deicing has been reported as a common abundant pollutant of urban runoff. The major threat of salt in urban runoff is creating a salty taste in receiving water that is used as a drinking water supply. Drinking water is not polluted until high concentrations of chlorides from salt are present in it. Drinking water standards limit chlorides to a maximum of 250 milligrams per liter (Hammer, 1975).

Sources of Urban Stormwater Pollutants

Literature has not often concerned itself with the sources of urban runoff pollutants. Two obvious sources, the road and motor vehicles, were investigated by Sartor and Boyd (1972). They reported that roads contribute a sizable quantity of suspended sediments in urban runoff. Motor vehicles represent a cornucopia of urban runoff pollutants. The contribution of motor vehicles to urban runoff pollution includes leakage of fuel, lubricants, hydraulic fluids, and coolants; fine particles worn from tires, clutch and brake linings; particulate exhaust emissions; dirt, rust and decomposing coatings; and vehicle components broken off by vibration or impact (Sartor and Boyd, 1972). Shaheen (1975) also cites motor vehicles as a source or pollutants, indicating that 100 percent of lead in urban runoff is from this source.

Independent Variables Affecting Quantities of Pollutants in Urban Stormwater Runoff

Urban stormwater runoff studies have been limited in their examination of the source of pollutants. A more significant contribution from these studies is their examination of the independent variables that affect the quantity of pollutants present in the runoff. Colston (1974) was especially concerned with the different variables associated with urban stormwater. Specifically he lists discharge and time from storm start as the significant independent variables affecting stormwater quality. Colston found that the amounts of pollutants increase with discharge and decrease as time from storm start increases. The latter is more commonly referred to as the first flush effect. Colston indicated that the independent variables of land use in an urban drainage basin, and elapsed time from the last storm, surprisingly did not have a significant effect on the quantity of pollutants in urban stormwater runoff.

Lager and Smith (1974), like Colston (1974), report the first flush effect as being responsible for higher concentrations of pollutants in urban runoff. However they dispute another of Colston's findings by reporting that land use variation in an urban drainage basin does have a significant effect on the concentration of pollutants in runoff. They further contradict Colston by reporting that higher concentrations of pollutants in urban runoff can be expected after prolonged dry periods. High rainfall intensity was another independent variable which Lager and Smith identified as increasing the quantity of pollutants in urban runoff. They also listed a negative independent variable that would result in lower quantities of pollutants in urban runoff. A storm which is near the end of a series of closely spaced storms will generate runoff with lesser quantities of pollutants than the earlier storms, since pollutants will have been washed away--with little chance to reaccumulate.

Shaheen (1975) considered the time it takes for pollutants to accumulate in an urban drainage basin. He reports that the accumulation of deposits on roadways levels off after several days. Shaheen confirms the existence of the first flush effect and also supports Lager and Smith's (1974) view that high rainfall intensity increase the quantity of pollutants in urban runoff; in fact high rainfall intensity may produce a second peak of pollutant concentration equal to or surpassing the peak obtained by the first flush effect.

The independent variables Sartor and Boyd (1972) examined dealt with the quantity of pollutants present at any given site. They conclude that the quantity is dependent on several variables: the elapsed time since the site was last cleaned (either intentionally or by rainfall), surrounding land use, local traffic volume and character, and street surface type and condition.

Impact of Pollutants in Urban Stormwater Runoff

Having examined the type, source, and independent variables affecting pollutants in urban stormwater runoff, the literature review must include one more aspect: its impact. Wullschleger et al. (1976:4) point out that the independent variables which affect the quantity of pollutants in urban runoff prevent an accurate description of typical urban runoff quality. They state

> The many variables which can affect the quality of storm generated discharges, such as time between occurrences, rainfall amount, intensity and duration, and drainage area surface conditions make the use of the term "typical" to describe the quality of storm generated discharges a nuisance.

Yet often in assessing the impact of urban runoff, urban runoff quality is typified based on averages of some pollutant quantities.

Using data from several cities, Sartor and Boyd (1972) calculated hypothetical storm averages of pollutant quantities in urban runoff for a hypothetical city of specified characteristics. According to their data urban runoff contains significant concentrations of some pollutants, when compared to raw sanitary sewage. However both the hypothetical nature of the data they present, and that it does not account for dilution of urban runoff by receiving waters, must be considered when examining the relevance of their data to the actual impact of urban runoff.

Black, Crow and Eidsness, Inc. (1971) give a specific analysis of urban runoff impact. They observed that the pollution impact upon the South River of Atlanta, Georgia, from individual high frequency storms is more severe than that from storms of low frequency: "less dilution, more pollution." This is an example of the shock load impact of urban runoff. When the amount of urban runoff pollutants entering receiving waters is viewed on a yearly basis their impact may appear minimal. However the shock load impact of urban stormwater runoff coming from individual storms may result in high concentrations of pollutants entering receiving waters, causing significant pollution, like that reported by Black, Crow and Eidsness, Inc. Shaheen (1975) concludes that urban runoff imposes a significant pollution load on receiving waters on a shock load basis.

Karst Groundwater Problems in Bowling Green

The other area of literature relevant to this thesis, besides urban stormwater runoff, concerns karst groundwater problems in the Bowling Green area. Knowledge of problems affecting karst groundwater in Bowling Green is helpful in understanding the background for, and possible interactions with, urban runoff pollution.

The most significant research on karst groundwater in Bowling Green has been done by Crawford, with stormwater flooding of sinkholes one of his primary concerns (Crawford, 1981a). He reports that the flooding results when subsurface streams are unable to transmit all the runoff received from sinkholes during floods. This problem is pronounced in the urban environment of Bowling Green because of a high percentage of impervious area and an urban runoff drainage system that delivers a large quantity of runoff to the subsurface streams.

Crawford (1981b) also discusses urban runoff in Bowling Green. He states that pollutants are carried by urban runoff into caves serving as storm sewers. Though this is destructive to the cave environment, he points out that it is unfeasible to try to prevent this because the subsurface drainage system here is a natural feature of Bowling Green's karst environment. Efforts, he believes, should be focused on reducing pollution from urban stormwater runoff.

Lambert (1976) discusses some pollutants which present problems in

Bowling Green's karst environment. Gasoline leaks in underground tanks have resulted in dangerous concentrations of gasoline fumes in nearby homes. Fumes were probably coming up through drains or foundation cracks into the basements, from gasoline present in the natural subsurface drainage channels beneath the homes. Crawford (1981b) also reports similar incidents, and the potential for underground explosions, like those which occurred in Louisville, Kentucky's sewer system in 1981. Lambert (1976) mentions karst groundwater pollution problems resulting from improperly placed septic tanks, a problem documented by Crawford (1979). Inadequate well construction and leaking sewer lines were also mentioned by Lambert as problems.

Kaurish and Rowe (1972), in examining the water quality in the Barren River drainage basin, found a tributary of the Barren River to be very polluted. They conclude that Whiskey Run Creek in Bowling Green is badly polluted, with industrial discharges and urban stormwater runoff the primary sources of pollution. Significantly they make a statement with which this author strongly agrees (Kaurish and Rowe, 1973:55), "the impact of the runoff from Bowling Green city streets should be investigated."

Reports by Elliott (1976) and Tucker (1980) provide data on pollutant quantities present in the Lost River drainage system in Bowling Green, during base flow. Tucker (1980) has reported the only data on heavy metals in the Lost River. She found no pollution by heavy metals in the urban Lost River or its tributaries.

In a study designed to examine methane production in Bowling Green's caves, Elliott (1976) also examined some water quality characteristics. He found that the Lost River, both at the Blue Hole and

Resurgence, was not polluted by organic material as measured by the five day biochemical oxygen demand test. However three tributaries to the Lost River were found to be polluted by organic material. He reports algal nutrients in the Lost River in quantities sufficient to contribute to eutrophication. Fecal and total coliform tests done for Elliott's study produced counts almost double those acceptable for surface water standards for public water supplies. Clearly according to Elliott's data Lost River has pollution problems other than urban stormwater runoff.

CHAPTER III

STUDY AREA

The Lost River Drainage Basin

The study area for this thesis is that area of Bowling Green, Kentucky and vicinity, that drains into the Lost River between the Blue Hole and Resurgence. The Lost River drainage basin, including its urban portion, is shown in Figure 4 (after Crawford and Beeler, 1980). Physiographically Bowling Green is located within the Pennyroyal Plain. The climate of Bowling Green is humid subtropical, averaging 120 centimeters of precipitation per year.

An explanation of the hydrogeology of the urban Lost River is given by Crawford (1981b). The Lost River Cave has developed in the lower Ste. Genevieve and upper St. Louis limestones. It is perched on top of the Lost River Chert which is located near the top of the St. Louis formation. As it flows under Bowling Green the Lost River follows the down dip of the Lost River Chert. An underwater survey indicated the Lost River may be perched on the Lost River Chert even at the Resurgence. The subsurface drainage network that feeds the Lost River is developed in the Ste. Genevieve Limestone, which outcrops at the surface in the Bowling Green area. This network is characterized by shallow subsurface streams, often only four to six meters deep (Daugherty and Trautwein, Inc. and G.R.W. Engineers, Inc., 1980). It is believed that the subsurface drainage network is grossly dendritic in pattern, with the Lost

River being the highest order stream of the network.

Urban Stormwater Runoff in the Lost River Drainage Basin

Urban stormwater runoff enters the Lost River through swallets, sinkholes and dry wells. Crawford in a report by Daugherty and Trautwein, Inc. and G.R.W. Engineers, Inc. (1980) discusses dry wells in the Nahm Avenue Sink area. Most dry wells in this area have a water level that is approximately nine meters below the level of known underground streams in the same area. Crawford believes that the water level in the dry wells represent the level of the local water table. Since only a minimal amount of runoff water would be able to enter the groundwater supply during a storm, Crawford postulates that the dry wells function by filling with stormwater almost to the top of the uncased wells, where the water finds enlarged bedding plane openings which direct water into shallow cave systems. It is reasonable to assume that any functioning dry well which does not terminate in a subsurface conduit will drain stormwater in this manner.

That the subsurface drainage network delivers water to the Lost River between the Blue Hole and Resurgence is supported by the presence of a double peak in the stage height of the Lost River at the Resurgence during a storm. The first peak is believed to result from stormwater runoff entering the Lost River between the Blue Hole and the Resurgence, with the second peak being caused by stormwater runoff coming from agricultural land south of the city. The other more compelling evidence is that the discharge of the Lost River at the Resurgence is approximately twelve percent greater than the discharge of the Lost River at the Blue Hole. This obviously is a consequence of underground streams, such as those of By-Pass Cave and Nahm Avenue Sink, entering the Lost River at it flows beneath Bowling Green.

The By-Pass Cave stormwater runoff drainage basin is relevant to this thesis because it is contained entirely within the urban Lost River drainage basin and, therefore, contributes urban stormwater runoff to the Lost River (Daugherty and Trautwein, Inc., and G.R.W. Engineers, Inc., 1980). It is a shallow cave containing a stream tributary to the Lost River, well above the level of the Lost River. Stormwater runoff is directed into By-Pass Cave by three pipes whose combined capacity influences the development of flood conditions. The route of the stormwater runoff within the cave can be seen by examining Figure 5. Runoff flows through the cave in the single passage that leads from the entrance to the large room in the back of the cave. There it joins with the stream coming from the lower level passage. The stream then flows through breakdown, eventually to join the Lost River.

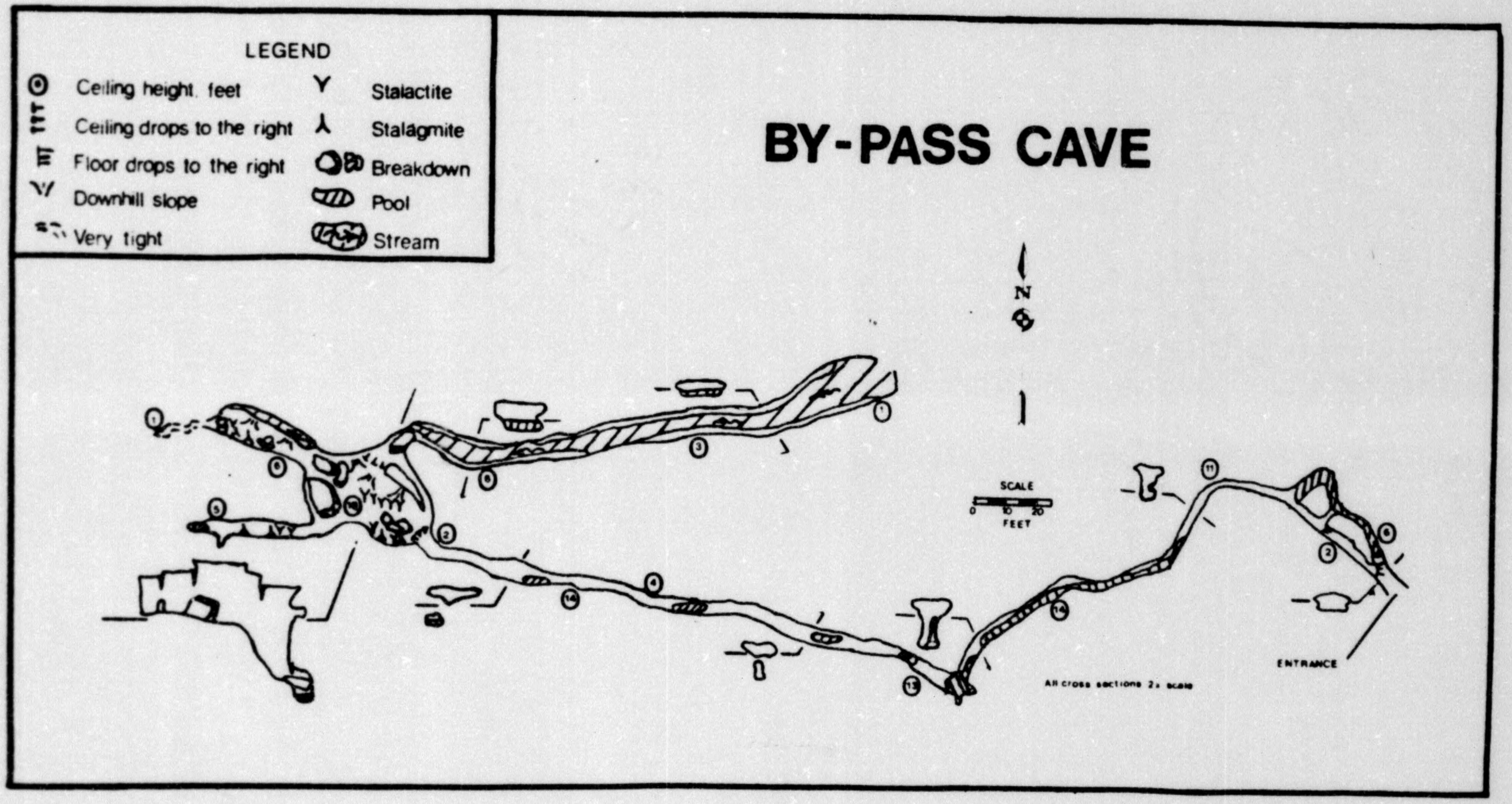
BY-PASS CAVE
LEGEND
Ceiling height, feet
Ceiling drops to the right
Floor drops to the right
Downhill slope
Very tight
Stalactite
Stalagmite
Breakdown
Pool
Stream
N
SCALE
0 10 20
FEET
ENTRANCE
All cross sections 2x scale

Figure 5

CHAPTER IV

HYPOTHESIS

This thesis is an investigation of the type, quantity, and impact of stormwater runoff pollutants entering the urban Lost River. The surfacing of the Lost River at the Blue Hole, and its subsequent route beneath Bowling Green to the Resurgence, allows a determination of these factors through the use of temporal comparisons. The type and quantity of pollutants present in the Lost River can be checked at the Blue Hole before it enters Bowling Green, and at the Resurgence after the Lost River has passed beneath Bowling Green. When such comparisons are made for a storm event, the type and quantity of pollutants that urban stormwater runoff delivers to the Lost River can be determined.

The hypothesis of this thesis is based on this type of comparison. The hypothesis is as follows: due to the introduction of pollutants into the Lost River beneath Bowling Green by urban stormwater runoff, the Lost River Resurgence will have a significantly higher concentration of urban stormwater runoff pollutants than the Lost River Blue Hole.

CHAPTER V

RESEARCH DESIGN

Method of Data Collection

The Method of Data Collection and the Method of Analysis which follow describe the planned procedure for testing the hypothesis. Water samples were collected from three sites - the Lost River Blue Hole, the Lost River Resurgence, and the entrance to By-Pass Cave. Runoff entering By-Pass Cave was tested to determine which pollutants are present in high concentrations in Bowling Green's urban stormwater runoff. If the hypothesis were to be accepted, then significantly higher concentrations of these pollutants would be detected at the Resurgence than at the Blue Hole.

The three sites were sampled during storm events. Samples were collected by Manning automatic water samplers. At the Blue Hole and By-Pass Cave entrance, samples were taken hourly from the beginning of the storm, until the end of the storm, or twenty-four hours, whichever came first. At the Lost River Resurgence samples were taken starting twenty-two hours after the beginning of the storm event. This figure is based on the measured flow through time from the By-Pass Cave entrance to the Lost River Resurgence.

Flow through time from By-Pass Cave entrance to the Lost River Resurgence was determined utilizing data collected from a quantitative dye trace. Rhodamine WT dye was injected at By-Pass Cave entrance at the beginning of a storm event, and samples were taken hourly at the

Resurgence starting shortly after the dye was injected. The data obtained from this dye trace are presented graphically in Figure 6. Twenty-two hours was considered to be the approximate time for for dye, and thus pollutants, to reach the Resurgence in high concentrations from By-Pass Cave. This figure is somewhat arbitrary since both the discharge of stormwater into By-Pass Cave and the discharge of the Lost River influences flow through time.

During sampling, the discharge from each location, at the time each sample was taken, was determined. The discharges at the Blue Hole and Resurgence were determined by the use of records from automatic stage height recorders and rating curves. At the By-Pass Cave entrance discharge was determined utilizing the data from automatic stage height recordings of the stormwater runoff as it passed through a ninety degree V notch weir, constructed just in front of the cave entrance.

The discharge at the time of sampling from each site was used in a sampling procedure for composite samples. Wullschleger et al. (1976) in describing a methodology for the study of urban stormwater runoff pollutants state that grab samples are insufficient for characterizing the average quality of stormwater runoff. Further they note that because of the interaction of the independent variables involved, no sampling procedure can obtain a truly representative sample from a storm generated discharge; however some sampling procedures will obtain a more representative sample than others. The sampling method they recommend is to obtain a sample composed from samples taken at constant time intervals, with the volume of sample used in the compositing being proportional to the discharge at the time the sample was taken. This compositing method was utilized for this thesis. The composite sample was compiled from

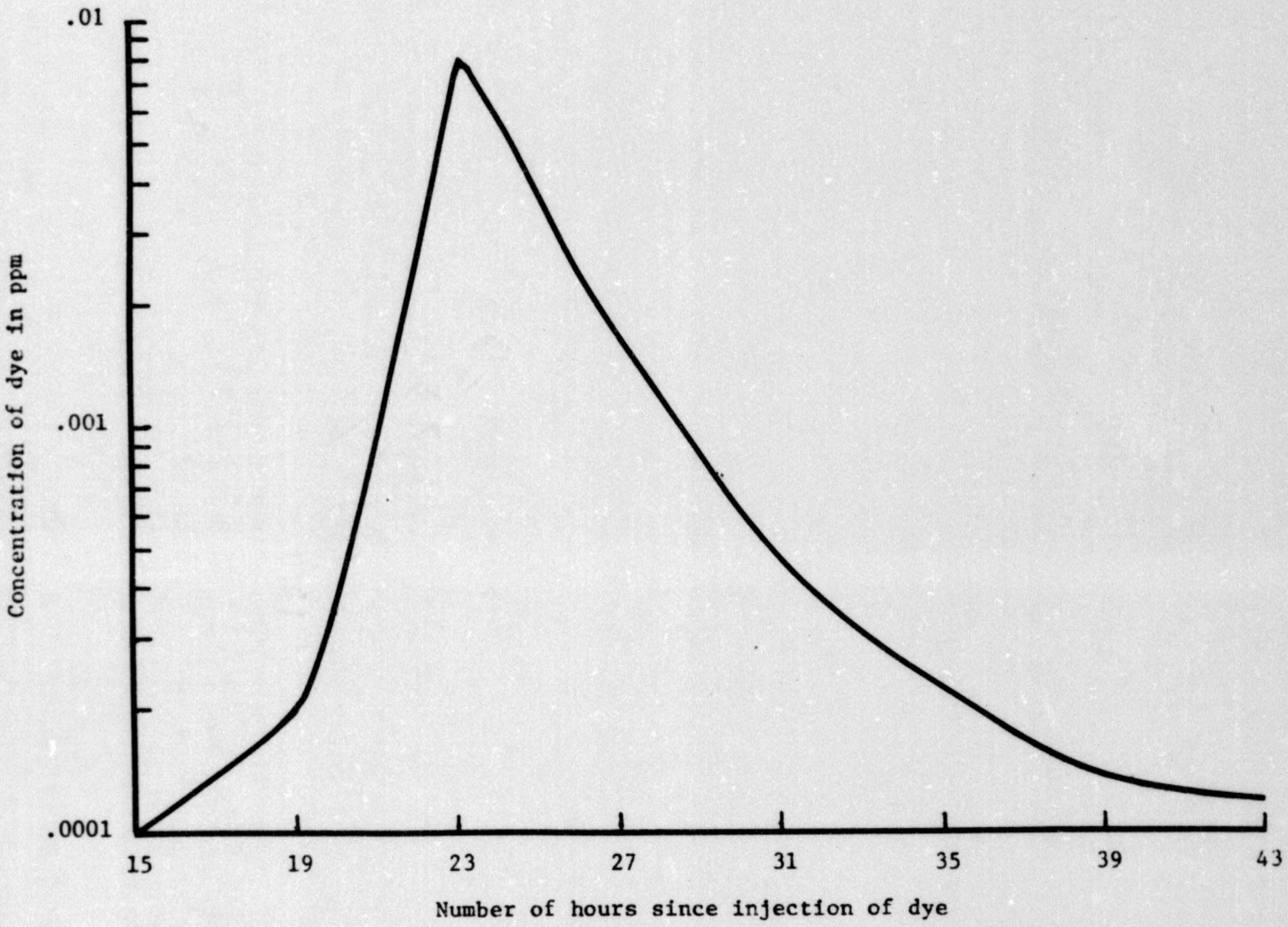

Figure 6. Quantitative dye trace, By-Pass Cave to Lost River Resurgence

the hourly samples taken during the storm event. The percentage of hourly sample volume used in compositing was obtained by dividing the discharge at the time the sample was taken, by the highest discharge during an hourly sampling.

Wullschleger et al. (1976) also list those water quality tests which should be run on composited samples. They base their list on comparability to other stormwater runoff studies, and a literature review to determine potential pollutants present in stormwater runoff. The water quality tests conducted on samples for this thesis were based primarily on those tests recommended by Wullschleger et al. Water quality tests performed are as follows:

1. As general pollution indicators - pH, turbidity, total dissovled solids, suspended solids and conductivity.
2. As an indicator of pollution by oxygen demanding wastes - Biochemical oxygen demand, five day test (BOD_5).
3. As indicators of nutrient pollution - Total Kjeldahl nitrogen, ammonia nitrogen and total phosphorus.
4. As indicators of pollution by pathogens - fecal coliform and fecal streptococcus.
5. As indicators of pollution by heavy metals - cadmium, chromium, iron, lead and mercury.
6. As indicators of pollution by petroleum products - oil and grease.

Three exceptions to the use of composite samples for these tests were made. This is a result of their incompatibility with samples obtained by automatic water samplers. The three tests are fecal coliform, fecal streptococcus, and oil and grease. Samples for these tests were obtained from discrete grab samples.

The By-Pass Cave drainage basin was considered in this thesis to be representative of those drainage basins that discharge into the urban Lost River. Information was collected on land use and size of the By-Pass Cave drainage basin in order to facilitate detailed analysis of pollution in the basin and to facilitate comparisons with other urban Lost River subbasins and drainage basins of other urban stormwater runoff studies.

Method of Analysis

The Blue Hole, Resurgence and By-Pass Cave were to be sampled as weather and budget permitted; therefore, selection of storms sampled would not be random. A minimum of four storm events were to be sampled to assure statistical validity. Unfortunately, due to the unexpected suspension of 208 funding, it was not possible to sample four storm events as planned.

The Blue Hole, Resurgence and By-Pass Cave were to be sampled during the same storm events, using the procedure described in the previous section. The means of the test results from the storm events sampled at By-Pass Cave were to be used to determine significant pollutants. A significant pollutant is defined as any pollutant whose mean from stormwater runoff tests of samples taken at By-Pass is in excess of surface water criterion for public water supplies. Significant pollutants were to be those used to test the hypothesis.

Means of significant pollutants obtained from storm event samples were to be computed for Lost River Blue Hole and Lost River Resurgence samples. Then the means of significant pollutants from Lost River Blue Hole were to be compared to their corresponding means from the Lost River Resurgence. A test was to be used to determine if there was a significant difference between the means, using the 0.01 significance level. On the basis of the results from the tests of significant pollutants means the hypothesis would then be accepted or rejected for each significant pollutant.

CHAPTER VI

RESULTS

Introduction

Due to the unanticipated budgetary restraints previously mentioned, only one storm event was sampled and tested as planned. The use of the test for comparing sample means was therefore eliminated, since no means were obtained. The hypothesis therefore was not tested.

Data were obtained as planned from one storm event. Also results of tests from storm event grab samples and dry weather grab samples were obtained. All of these data were utilized to examine and identify pollution problems from Bowling Green's urban stormwater runoff. For storm event grab samples and dry weather samples not all tests listed in the Method of Analysis section in Chapter V were run, and for both several additional tests were used. Information was obtained as planned for land use and size of the By-Pass Cave drainage basin.

Dry Weather Results

Tests results from grab samples obtained during dry weather are presented in Table 1 for the Lost River Blue Hole, and in Table 2 for the Lost River Resurgence. Computed means are considered to be from samples which are as representative as possible. The test results from six grab samples taken over a seven month period were used to calculate the means, although the time of sampling was not random, but done as budget permitted.

TABLE 1

DRY WEATHER WATER QUALITY TESTS, LOST RIVER BLUE HOLE

Test	Date						Mean
	9/8/80	9/19/80	9/25/80	11/6/80	1/19/81	3/25/81	
Water Temperature ^{o}C	16.0	15.5	15.5	14.5	13.9	14.0	14.9
Conductivity micromhos	420	440	420	460	440	360	423
pH	7.10	7.00	7.40	7.00	7.65	7.40	7.16
Dissolved Oxygen mg/l	. . .	9.6	8.8	8.5	9.0	8.8	8.9
BOD_5 mg/l	0.9	0.4	0.5	1.0	1.5	7.0	1.8
NH_3 Ammonia mg/l	<.01	<.01	<.01	<.01	<.01	<.01	. . .
Orthophosphate mg/l	.064	.072	.060	. . .	.110	.030	.067
Fecal Coliform colonies/100 ml	30	120	480	66	20	112	138
Fecal Streptococcus colonies/100 ml	80	110	1	26	. . .	90	61
Cadmium mg/l	. . .	. . .	. . .	. . .	<.01	. . .	. . .
Chromium mg/l	. . .	. . .	. . .	. . .	<.05	. . .	. . .
Copper mg/l	. . .	. . .	. . .	. . .	.02	. . .	. . .
Iron mg/l	. . .	. . .	. . .	. . .	1.28	. . .	. . .
Lead mg/l	. . .	. . .	. . .	. . .	<.10	. . .	. . .
Manganese mg/l	. . .	. . .	. . .	. . .	.08	. . .	. . .
Nickel mg/l	. . .	. . .	. . .	. . .	<.01	. . .	. . .
Zinc mg/l	. . .	. . .	. . .	. . .	.005	. . .	. . .

TABLE 2

DRY WEATHER WATER QUALITY TESTS, LOST RIVER RESURGENCE

Test	Date						Mean
	9/8/80	9/19/80	9/25/80	11/6/80	1/19/81	3/25/81	
Water Temperature °C	16.0	16.0	16.5	14.6	13.0	14.0	15.0
Conductivity micromhos	440	460	460	480	460	370	445
pH	. . .	7.40	6.85	8.10	8.00	7.70	7.60
Dissolved Oxygen mg/l	7.9	8.5	8.5	8.2	9.2	8.6	8.5
BOD_5 mg/l	0.7	1.0	0.4	0.8	1.2	8.6	2.1
NH_3 Ammonia mg/l	<.010	<.010	.018	<.010	<.010	<.010	. . .
Orthophosphate mg/l	.105	.098	.126	. . .	.110	.070	.102
Fecal Coliform colonies/100 ml	570	600	900	500	114	650	222
Fecal Streptococcus colonies/100 ml	160	500	800	52	. . .	82	319
Cadmium mg/l	. . .	. . .	. . .	. . .	<.01	. . .	. . .
Chromium mg/l	. . .	. . .	. . .	. . .	<.05	. . .	. . .
Copper mg/l	. . .	. . .	. . .	. . .	.01	. . .	. . .
Iron mg/l	. . .	. . .	. . .	. . .	.11	. . .	. . .
Lead mg/l	. . .	. . .	. . .	. . .	.10	. . .	. . .
Manganese mg/l	. . .	. . .	. . .	. . .	.01	. . .	. . .
Nickel mg/l	. . .	. . .	. . .	. . .	<.10	. . .	. . .
Zinc mg/l	. . .	. . .	. . .	. . .	1.104	. . .	. . .

Storm Event Grab Sample Results

Grab samples were obtained during two storm events at the Blue Hole, Resurgence and By-Pass Cave. Test results from the nine grab samples taken during the two storm events are presented in Tables 3, 4, and 5 for the Blue Hole, Resurgence and By-Pass Cave, respectively. It needs to be emphasized that these are grab samples taken during storm events. No attempt was made in the collecting of the samples to compensate for flow through time of the urban stormwater runoff to the Lost River Resurgence.

Of the two storm events sampled at the Blue Hole and Resurgence the first one ran from November 14 to November 18, 1980. The other storm event was from May 18 to May 19, 1981. Grab samples were taken six times during the November storm event. They were taken twice during and once immediately after the May storm. Grab samples at By-Pass Cave were obtained for the November storm and for one on January 20, 1981.

Means were not computed for test results of storm event grab samples at any location (with the exceptions of fecal coliform and fecal streptococcus, which are considered in Chapter VII). The storm event grab samples taken at each location cannot be assumed to be random. As described in the literature review there are many independent variables that affect urban stormwater runoff quality. These make it impossible to assume a storm was representively sampled when only grab samples were used. Therefore obtaining means was unjustified, both for all storm events, and for individual storm events.

Storm Event Composite Sample Results

The storm event from May 18 to 19, 1981, was also sampled using the planned compositing procedure, with a sample composited for each of the

TABLE 3

STORM EVENT WATER QUALITY TESTS, GRAB SAMPLES, LOST RIVER BLUE HOLE

Test	Date	11/14/80	11/15/80	11/17/80	11/17/80	11/17/80	11/18/80	5/18/81	5/19/81	5/20/81
	Time	12:30	15:00	10:30	13:50	17:30	11:15	16:30	14:40	16:30
	Precipitation cm	1.47	.30	5.31	5.31	5.31	.08	6.98	2.11	trace
Water Temperature °C		14.0	14.0	13.5	13.5	13.0	12.5	. . .	. . .	. . .
Conductivity micromhos		460	460	520	460	360	360	406	229	307
pH		7.10	7.20	7.68	7.35	7.25	7.30	7.30	7.00	6.90
Turbidity NTU		. . .	. . .	. . .	. . .	. . .	. . .	15	. . .	44
Total Dissolved Solids mg/l		. . .	. . .	. . .	. . .	. . .	. . .	270	228	244
Suspended Solids mg/l		. . .	. . .	. . .	. . .	. . .	. . .	60	486	171
Dissolved Oxygen mg/l		8.1	. . .	10.2	. . .	9.9	9.8	. . .	. . .	. . .
COD mg/l		. . .	. . .	. . .	. . .	. . .	. . .	2.2	32.9	12.8
BOD_5 mg/l		0.74	1.40	2.39	2.40	2.16	1.22	0.10	1.00	0.10
Total Kjeldahl Nitrogen mg/l		. . .	. . .	. . .	. . .	. . .	. . .	0.2	1.2	0.5
NH_3 Ammonia as N mg/l		.0100	.0121	.6650	.2210	.0980	.0190	.1600	.1000	.1000
Total Phosphorus mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.140	.525	.190
Orthophosphate mg/l		0.123	0.079	0.319	0.510	1.040	2.850	. . .	. . .	. . .
Fecal Coliform colonies/100 ml		78	104	1,000	. . .	6,300	27,400	. . .	20,600	10,700
Fecal Streptococcus colonies/100 ml		14	30	2,000	24,300	. . .	. . .	. . .	38,700	12,000
Cadmium mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.001	.001	.001
Chromium mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.004	.016	.007
Iron mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.944	5.100	3.560
Lead mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.015	.024	.012
Mercury mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.0001	.0001	.0002

TABLE 4

STORM EVENT WATER QUALITY TESTS, GRAB SAMPLES, LOST RIVER RESURGENCE

Test	Date	11/14/80	11/15/80	11/17/80	11/17/80	11/17/80	11/18/80	5/19/81	5/19/81	5/20/81
	Time	12:30	14:30	11:15	14:30	18:00	10:50	8:00	17:30	18:00
	Precipitation cm	1.47	0.3	5.31	5.31	5.31	0.08	6.98	2.11	trace
Water Temperature ^{o}C		14.8	15.0	14.0	13.5	13.0	14.5	. . .	. . .	. . .
Conductivity micromhos		460	440	420	340	300	340	217	242	303
pH		7.60	7.75	7.60	7.15	7.45	7.15	6.90	7.10	7.10
Turbidity NTU		. . .	. . .	. . .	. . .	. . .	. . .	420	. . .	57
Total Dissolved Solids mg/l		. . .	. . .	. . .	. . .	. . .	. . .	214	22.8	234
Suspended Solids mg/l		. . .	. . .	. . .	. . .	. . .	. . .	1,091	576	193
Dissolved Oxygen mg/l		8.55	. . .	9.20	10.30	10.20	8.75	. . .	. . .	. . .
COD mg/l		. . .	. . .	. . .	. . .	. . .	. . .	5.5	31.4	13.3
BOD$_5$ mg/l		.75	.27	1.32	1.83	1.64	1.79	1.20	1.00	.1C
NH$_3$ Ammonia as N mg/l		.0124	.0204	.0271	.0212	.0405	.0900	.1700	.1000	.1000
Total Kjeldahl Nitrogen mg/l		. . .	. . .	. . .	. . .	. . .	. . .	4.20	1.20	.51
Total Phosphorous mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.980	.570	.200
Orthophosphate mg/l		.065	.147	.217	.312	.355	.300	. . .	. . .	. . .
Fecal Coliform colonies/100 ml		640	170	2,100	8,100	5,900	33,800	. . .	21,400	5,200
Fecal Streptococcus colonies/100 ml		10	56	3,600	3,800	500	. . .	. . .	13,900	13,600
Cadmium mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.001	.001	.001
Chromium mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.036	.022	.008
Iron mg/l		. . .	. . .	. . .	. . .	. . .	. . .	5.66	5.43	3.52
Lead mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.053	.027	.019
Mercury mg/l		. . .	. . .	. . .	. . .	. . .	. . .	.0047	.0002	.0001

TABLE 5

STORM EVENT WATER QUALITY TESTS, GRAB SAMPLES, BY-PASS CAVE

Test	Date	11/14/80	11/17/80	1/20/81	1/20/81
	Time	13:30	10:00	17:30	20:45
	Precipitation cm	1.47	5.31	0.99	0.99
Water Temperature ^{o}C		15	7	. . .	. . .
Conductivity micromhos		220	34	930	175
pH		7.55	7.82	. . .	. . .
Dissolved Oxygen mg/l		8.0	. . .	. . .	. . .
Total Dissolved Solids mg/l		. . .	. . .	679	134
BOD_5 mg/l		102	7.32	. . .	. . .
NH_3 Ammonia as N mg/l		.510	.069	. . .	. . .
Orthophosphate mg/l		. . .	.145	. . .	. . .
Chlorides mg/l		. . .	. . .	209	21.8
Fecal Coliform colonies/100 ml		4,200	1,800	1,000	2,600
Fecal Streptococcus colonies/100 ml		13,600	10,900	5,800	9,300
Cadmium mg/l		. . .	. . .	.01	.01
Chromium mg/l		. . .	. . .	.07	.07
Copper mg/l		. . .	. . .	.20	.10
Iron mg/l		. . .	. . .	8.2	1.42
Lead mg/l		. . .	. . .	1.60	.25
Manganese mg/l		. . .	. . .	.48	.08
Zinc mg/l		. . .	. . .	1.076	0.230

three sites. The composite sample test results are presented in Table 6. At By-Pass Cave water samples were taken starting at the beginning of the storm at hours, May 18, 1981. Samples were taken hourly for the next twenty-four hours.

Discharge was determined by using the relationship between discharge and stage height of the stormwater runoff as it passes through a ninety degree V notch weir. An automatic stage height recorder provided continuous data on the height of the pool behind the weir.

To obtain discharge using a weir, the head of the water above the apex of the V notch was calculated by subtracting height from bottom of pool to the apex, from stage height (Figure 7 shows the head of the water at By-Pass Cave during the storm). Knowing the head, discharge was then calculated using a table from Hammer (1975). The amount of sample used for compositing was then determined by using the relationship

$$V = \frac{400Q}{8400}$$

where V is the volume of sample to be used for compositing in milliliters, Q is the discharge at the time the sample was taken in gallons per minute, 400 is the volume of the sample taken by the automatic water sampler in milliliters, and 8,400 is the maximum discharge in gallons per minute calculated during the sampling.

The compositing procedure at the Blue Hole and Resurgence, first needed a stage height rating curve of stage height versus discharge. Figure 8 is the stage height versus time hydrograph for the Lost River at the Resurgence, during the May 1981 storm event. Figures 9 and 10 give the rating curves for the Blue Hole and Resurgence, respectively. These curves were drawn from available discharge data. Using these

TABLE 6

STORM EVENT WATER QUALITY TESTS, COMPOSITE SAMPLES

Test	Date	5/18-19/81	5/18-19/81	5/19-20/81
	Location	By-Pass	Bluehole	Resurgence
	Precipitation cm	9.12	9.12	0
Conductivity micromhos		126	298	284
pH		6.6	7.0	6.8
Turbidity NTU		. . .	230	220
Total Dissolved Solids mg/l		136	238	236
Suspended Solids mg/l		116	629	1,256
NH_3 Ammonia as N mg/l		.10	.10	.10
Total Kjeldahl Nitrogen mg/l		.61	1.80	. . .
Total Phosphorous mg/l		.250	.725	.750
COD mg/l		37.0	43.3	56.5
BOD_5 mg/l		4.1	4.1	2.4
Cadmium mg/l		.001	.002	.002
Chromium mg/l		.002	.025	.007
Iron mg/l		1.24	5.52	5.28
Lead mg/l		.096	.042	.05
Mercury mg/l		.0050	.0047	.0002

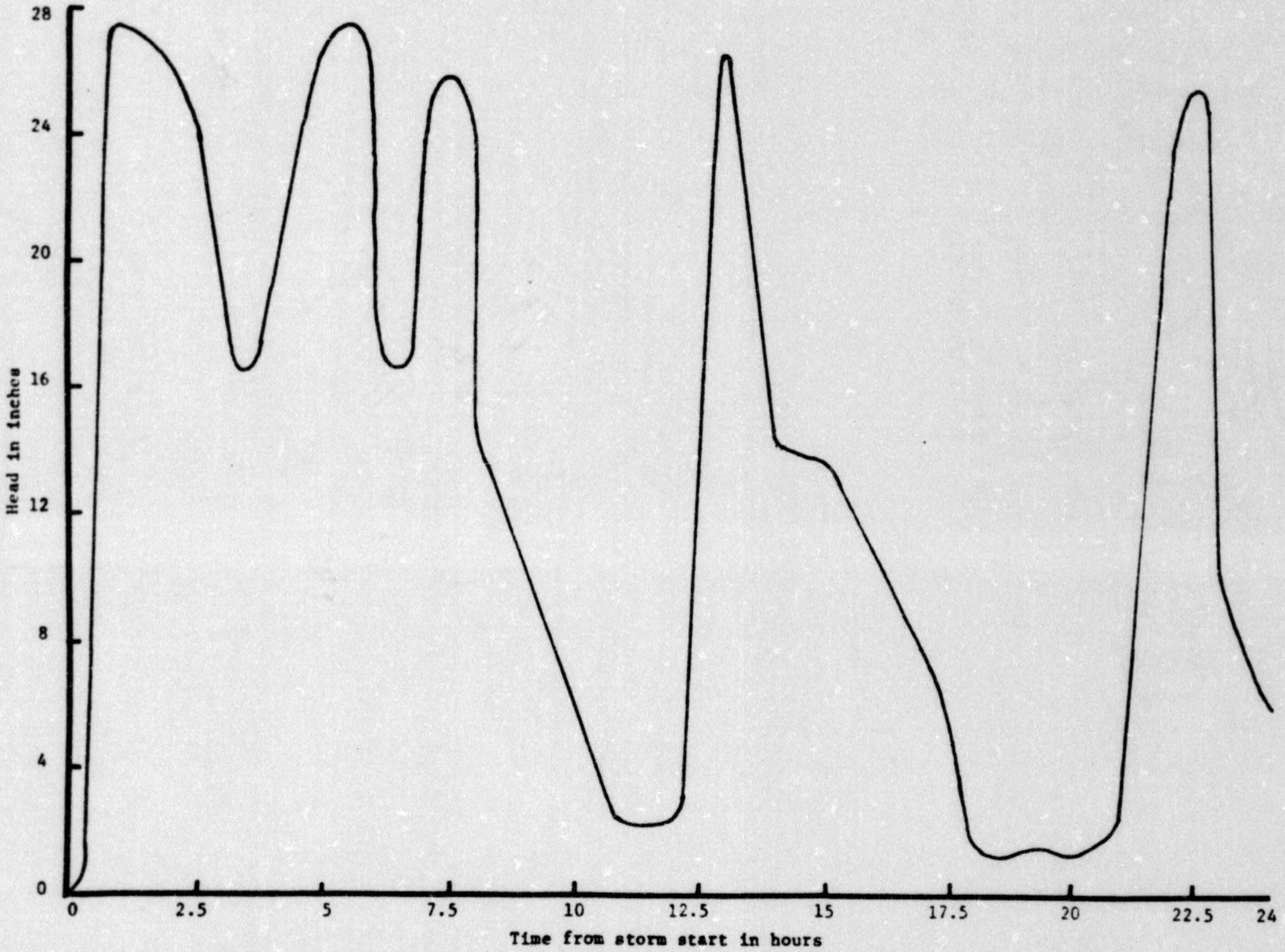

Figure 7. Head of water above weir apex, By-Pass Cave, May 18 to May 19, 1981

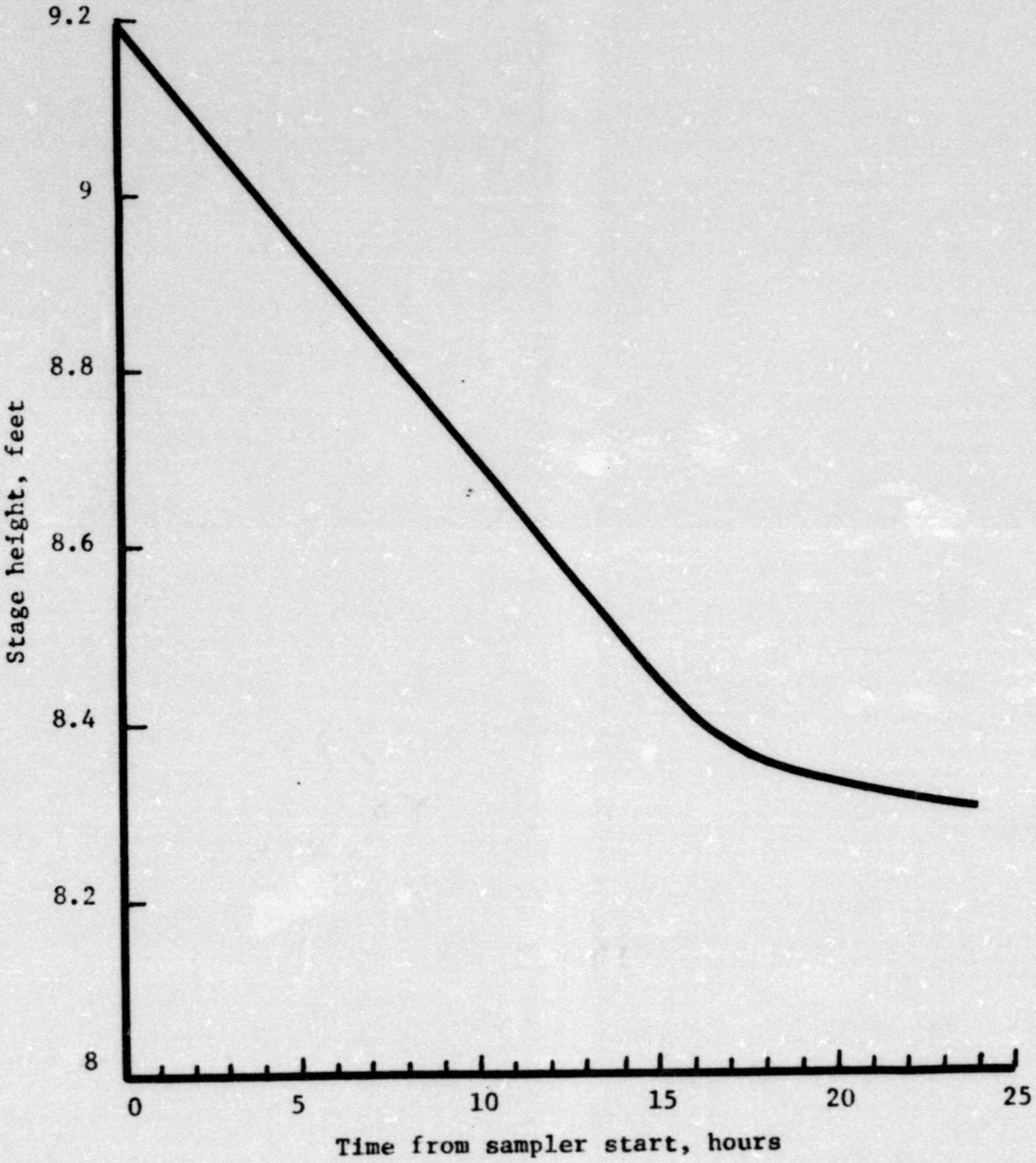

Figure 8. Hydrograph for Lost River Resurgence, May 19-20, 1981

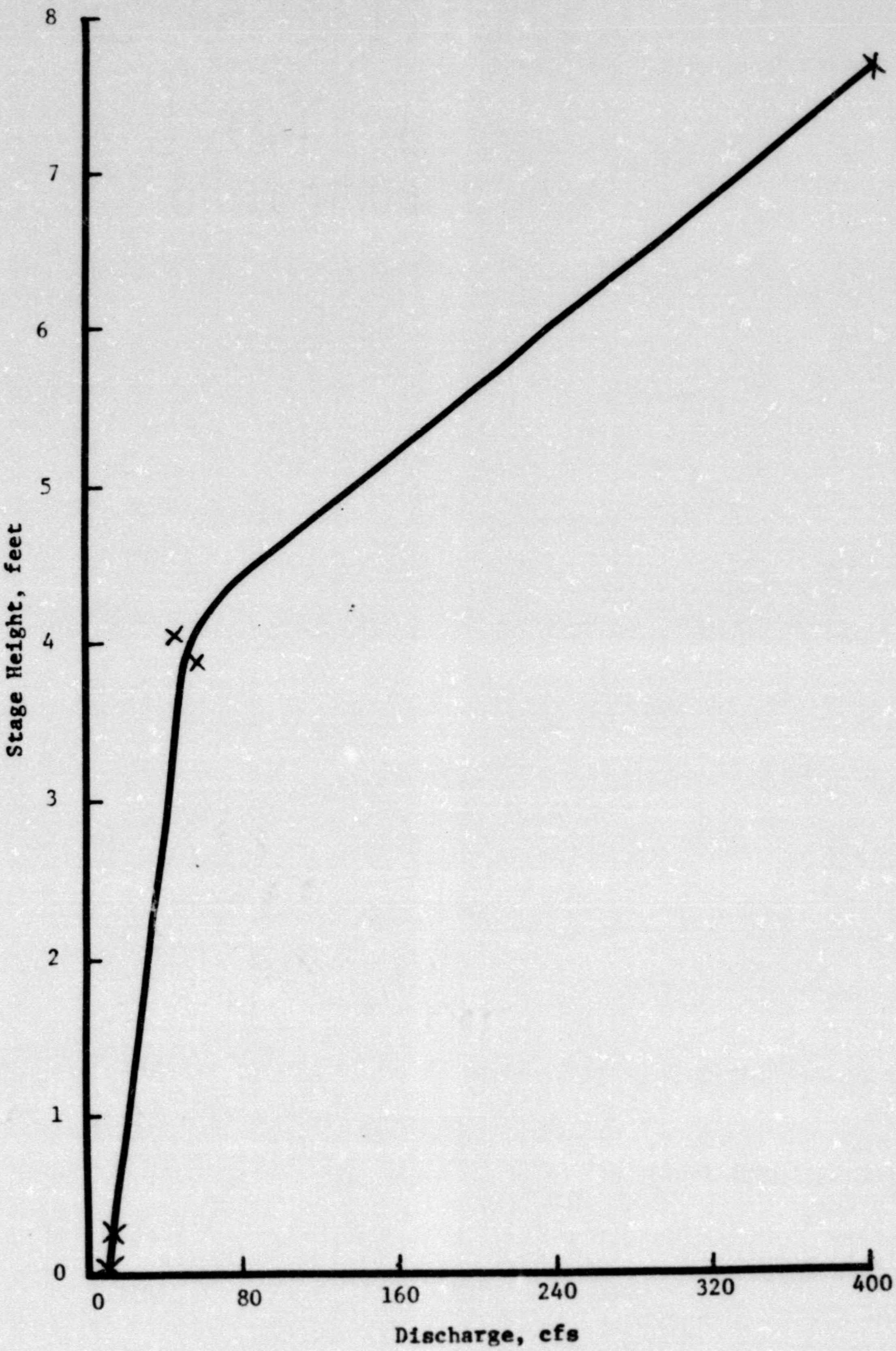

Figure 9. Lost River Blue Hole Rating Curve

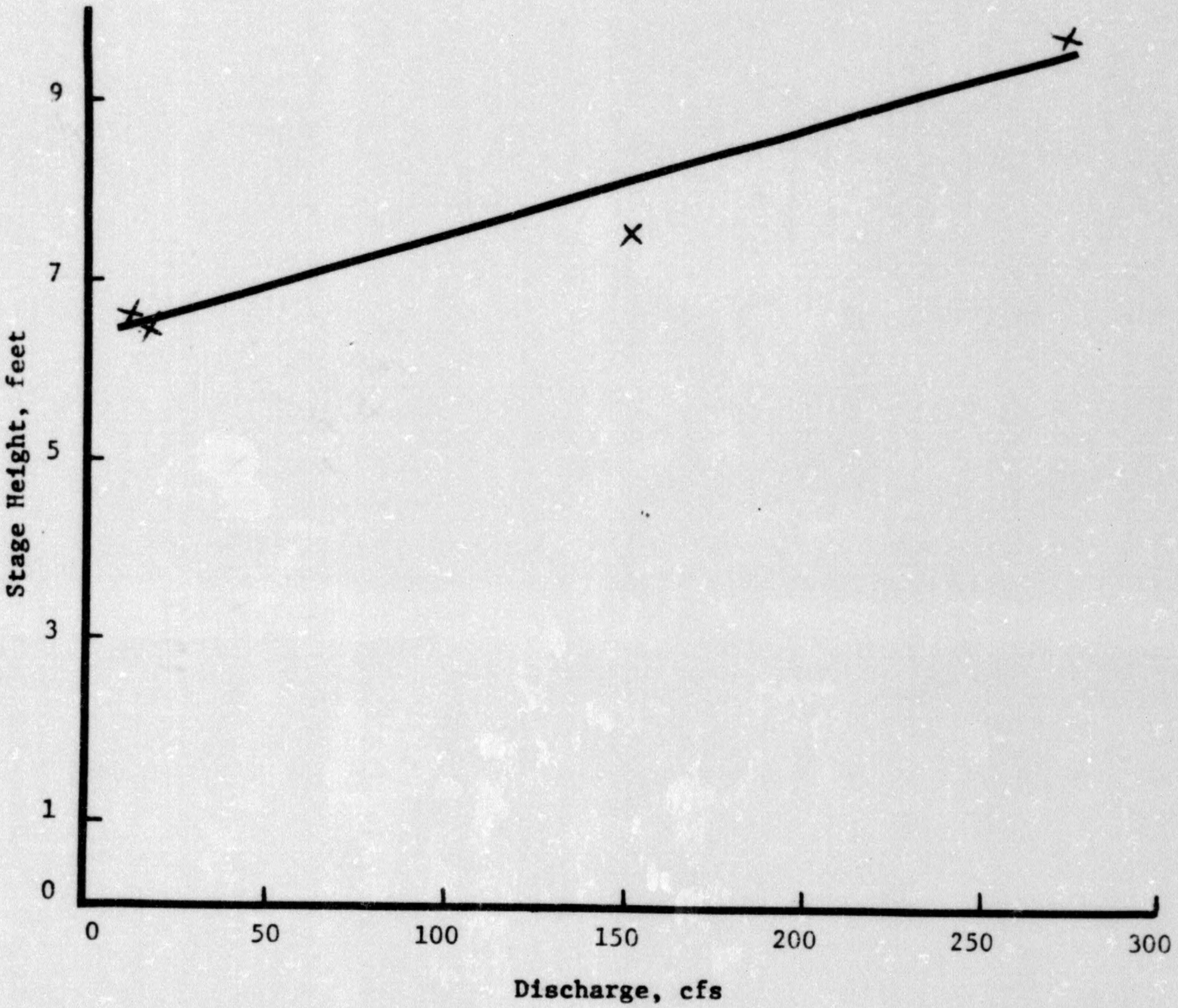

Figure 10. Lost River Resurgence Rating Curve

curves, discharge at the time each sample was taken was computed as planned for the Resurgence. The formula used in compositing at Lost River Resurgence was

$$V = \frac{400Q}{238}$$

where V is the volume of sample in milliliters used in compositing, Q is the discharge in cubic feet per second at the time the sample was taken, 400 is the volume in milliliters of the sample taken by the automatic water sampler, and 238 is the maximum discharge in cubic feet per second during the sampling period.

At the Lost River Blue Hole it was necessary to use a variation of the compositing procedure because of a malfunction of the stage height recorder there. With no record of stage height during the entire sampling period, discharge could not be determined at the time each sample was taken. Therefore an alternate method was used for obtaining percentages of the sample for compositing. The method made use of turbidity. It was known by observation that the stage height at the time sampling was started was .5 feet. Twenty-five and one half hours later the stage height was 5.8 feet. With the knowledge that the stage height had already peaked at the Resurgence by this time, it was assumed that the Blue Hole had peaked also, and somewhat earlier than the Resurgence. Therefore the 5.8 feet stage height was on the downward leg of the hydrograph. It was noticed that the earlier samples were clear, increased to a peak of turbidity after about fifteen hours, then began clearing. It was assumed this rise and fall of turbidity represented the rise and fall of the stage height. Stage height and thus discharge were substituted for by relative turbidity values. The percentage of the sample used in compositing was approximately proportional to its relative turbidity, with one-hundred percent of the sample with the greatest turbidity being used, and only ten percent of the sample with the lowest turbidity being used. The compositing procedure for the Blue Hole was essentially a visual process. Although the method was probably more representative than if all samples were combined to make a composite sample, it cannot be considered as accurate as the compositing procedure used at By-Pass Cave and the Resurgence.

It should be noted that at the time sampling began at the Resurgence (11:30 AM, May 19, 1981) the stage height of the Lost River there had already peaked. This indicates that the flow through time of the Lost River from Blue Hole to Resurgence was faster than twenty-three hours. It is possible that the runoff from By-Pass Cave also flowed to the Resurgence in less than twenty-three hours, since it is expected that runoff would cause an increase in stage height and would closely correspond to the flow through time of the Lost River between the Blue Hole and Resurgence. This would mean that flow through time of urban stormwater runoff was not adequately compensated for, and the peak runoff, and thus the peak concentration of pollutants; was not sampled.

CHAPTER VII

ANALYSIS

Analysis of Dry Weather Results

The hypothesis of this thesis was not sufficiently tested, therefore it could neither be accepted or rejected. However the data obtained for this thesis were utilized to determine which urban stormwater pollutants were present in the Lost River and what impact these pollutants have on the Lost River.

When the dry weather data from Tables 1 and 2 are examined, it is obvious that there are much higher concentrations of fecal coliform and fecal streptococcus at the Resurgence, than is found at the Blue Hole. The test results of two of the five samples, and the mean of all fecal coliform tests at the Resurgence, exceeded the surface water criteria for public water supplies of 2,000 colonies per 100 milliliters of sample. The fecal coliform to fecal streptococcus ratio for the Lost River Resurgence dry weather samples is presented in Table 7. Guidelines published by the U.S. Environmental Protection Agency for interpreting this ratio state that when the ratio is greater than four, pollution from human waste is indicated; when it is between two and four, pollution from predominantly human waste is indicated. Two of the five ratios from Table 7 indicated pollution from only human wastes, and another two indicated pollution predominantly from human waste. Only one ratio was indicative of pollution from other than human wastes. It was concluded from

TABLE 7

RATIO OF FECAL COLIFORM TO FECAL STREPTOCOCCUS DRY WEATHER SAMPLES, LOST RIVER RESURGENCE

Date	FC/FS
9/8/80	3.6
9/19/80	2.2
9/25/80	0.7
11/6/80	48.0
3/25/81	7.9

fecal coliform and fecal streptococcus tests and their ratios that the Lost River at the Resurgence is polluted by human wastes. The pollution occurs during dry weather and enters the Lost River between the Blue Hole and the Resurgence. It is probable that the source of the human waste is septic tank effluent.

The only pollutant found to be polluting the Lost River during dry weather was human waste. No other pollutants were present in great enough quantities to present a problem. Surface water criteria for public water supplies were exceeded only by fecal coliform and fecal streptococcus at the Resurgence.

Analysis of By-Pass Cave Storm Event Grab Sample Results

The By-Pass Cave drainage basin was considered representative of those stormwater runoff drainage basins that are tributary to the Lost River within the study area of this thesis. The total area of the drainage basin is 30.31 hectares. Commercial land use occupies 11.7 hectares, or thirty-nine percent of the drainage basin. Residential land use constitutes 18.62 hectares, or sixty-one percent of the drainage basin.

Four grab samples of runoff entering By-Pass Cave from two storm events were analyzed for various water quality parameters. In addition two grab samples were taken to accompany the composite samples, because certain tests were incompatible with the compositing procedure. The grab sample data from By-Pass Cave given in Table 5 indicate the presence of some pollutants in high quantities and also illustrate the first flush effect.

While there are no surface water criteria for public water supplies for biochemical oxygen demand, the 102 milligrams per liter of BOD_5 from the November 14, 1980 grab sample was more than triple the U.S. Environmental Protection Agency secondary treatment sewage effluent standard. According to this standard the arithmetic mean for biochemical oxygen demand (five day) for a sampling period of thirty consecutive days shall not exceed thirty milligrams per liter. The decrease of BOD_5 to 7.32 milligrams per liter 68.5 hours later in the storm was interpreted as the result of the first flush effect. The test results for ammonia followed the same pattern as BOD_5. The November 14, 1980 grab sample from By-Pass Cave had 0.51 milligrams per liter of ammonia. However later in the storm ammonia, like BOD_5, dropped to only 0.069 milligrams per liter. The first ammonia test result exceeded the surface water criterion of 0.5 milligrams per liter.

Fecal coliform and fecal streptococcus did not show a consistent first flush response from the By-Pass Cave grab samples. Just the opposite occurred during the January 20, 1981, storm, when samples early in the storm produced results much lower than those from samples later in the storm. All grab sample results for fecal coliform and fecal streptococcus were high. There are no surface water criteria for fecal streptococcus, but three of the five fecal coliform tests from By-Pass Cave exceeded the surface water criterion for fecal coliform of 2,000 colonies per one hundred milliliters of sample (the fifth test result for fecal coliform, obtained from a grab sample to accompany the composite sample of May, 1981 is reported in Table 8). All fecal coliform to fecal streptococcus ratios were between 0.2 and 0.3, indicating pollution from animal waste.

The By-Pass Cave grab samples from the January 20, 1981, storm demonstrate the first flush effect. The first sample was taken at the onset of the storm. The second was taken three hours and fifteen minutes later. Of the thirteen water quality tests run on both samples nine showed an obvious first flush effect. Two showed no difference, and fecal coliform and fecal streptococcus both increased in the later sample.

The grab samples from the January 1981 storm were tested for pollutants that were different than those tested from grab samples of the November 1980 storm. These included heavy metals, chlorides, total dissolved solids, and oil and grease. The results of the tests not only demonstrated the first flush effect, but also revealed the presence of some pollutants in high concentrations in the urban stormwater runoff entering By-Pass Cave. Surface water criterion for public water supplies is a maximum of 0.05 milligrams per liter hexavalent chromium. Total chromium of 0.07 milligrams per liter was measured in both samples. This cannot be considered in excess of the surface water criterion because it is not known what percentage of total chromium is hexavalent chromium. However it is in excess of the drinking water standard of 0.05 milligrams per liter total chromium.

Lead like chromium is a poison affecting the internal organs of the human body (Hammer, 1975). Lead was found in very high concentrations in the two grab samples from the January 1981 storm. The result of the lead test from the early sample was 1.6 milligrams per liter, which is thirty-two times higher than the surface water criterion for lead of 0.05 milligrams per liter. While the later sample contained only 0.25 milligrams per liter lead, it is still five times greater than the surface water criterion.

Surface water criteria for iron and manganese are expressed as milligrams per liter of filterable iron and manganese. As the grab samples were tested for total iron and manganese, the test results are not comparable with these criteria. Both test results from the January 1981 storm were high for both samples, and both also showed the first flush effect. They did exceed drinking water standards of 0.3 milligrams per liter iron and 0.05 milligrams per liter manganese. The presence of iron and manganese in the urban runoff is not as serious as that of lead and chromium. The former are objectionable in a public water supply because of brownish colored stains imparted to laundry, and a bittersweet taste attributed to iron.

A trace of snow was on the ground when the January 20, 1981, storm began. It was decided that weather conditions were appropriate for this testing for chlorides coming from the salt used to de-ice highways. An initial chloride reading of 209 milligrams per liter and a consequent high conductivity reading (from chloride ions) of 930 micromhos were obtained. While these readings are high, the chloride reading was still below the limit of 250 milligrams per liter set by surface water criteria for public water supplies.

Oil and grease are pollutants associated with motor vehicles. The Kentucky Department of Highways (personal communication, 1981) estimated 22,000 to 25,000 vehicles per day drive by By-Pass Cave on U.S. highway 31-W By-Pass. Therefore it was expected oil and grease would be present in the runoff entering By-Pass Cave. And indeed significant quantities of oil and grease were found in two grab samples of runoff entering the cave. Data on oil and grease are reported in Table 8. On January 20, 1981, the grab sample taken at the onset of precipitation contained 29.5

milligrams per liter, an extremely high value. The result of the sample taken May 18, 1981, five hours from the start of the storm, was 6.8 milligrams per liter. The surface water criterion for public water supplies is that oil and grease be virtually absent. Obviously oil and grease tests of runoff entering By-Pass Cave were greatly in excess of this criterion.

Total dissolved solids were tested for in grab samples from the January 20, 1981, storm. Again the first flush effect was demonstrated. The result of the total dissolved solids test in the earlier sample was 679 milligrams per liter; for the later sample it was 134 milligrams per liter. With the surface water criterion for total dissolved solids being 500 milligrams per liter, it is not clear whether total dissolved solids are a consistent pollutant of the runoff entering By-Pass Cave.

It was the original intent of this thesis to use composite samples to determine the significant pollutants to be used in testing the hypothesis. This approach was not possible; however, By-Pass Cave grab sample data were analyzed to determine which might be significant pollutants. The test results indicated the heavy metals chromium, lead, iron, manganese, and oil and grease. In addition first flush test values for ammonia, BOD_5, and total dissolved solids were high enough to indicate significant pollutants.

Analysis and Comparison of Blue Hole and Resurgence Storm Event Grab Sample Results

Whereas the original purpose of testing samples from By-Pass Cave was to determine significant pollutants, the original purpose of testing samples from the Lost River Blue Hole was to establish pollutant means to compare with means from the Lost River Resurgence. Since the necessary composite samples were not tested, this comparison was not possible. Grab sample data from the Blue Hole were used to establish a basis of comparison for stormwater runoff pollutants at the two sites. Grab samples were taken on eight occasions from two storm events. The results of the water quality tests from these grab samples are in Table 3.

The purpose of obtaining this storm event data was not to establish stormwater runoff pollutants for the Lost River. Any runoff pollutant present at the Blue Hole would originate outside the study area. It is interesting to note, though, the very high quantities of fecal coliform and fecal streptococcus found in the later stages of the two storms. These values included a high for fecal coliform of 27,400 colonies per 100 milliliters of sample, and a high for fecal streptococcus of 38,700 colonies per 100 milliliters of sample. Missing values made determination of ratios possible for only three of the six samples where either fecal coliform or fecal streptococcus exceeded 1,000 colonies per 100 milliliters of sample. Two of the ratios indicated pollution from animal waste, and one indicated pollution predominantly by livestock or poultry waste in mixed pollution. More importantly, none of the three ratios indicated pollution from human waste.

Iron was the only other water quality parameter tested from grab samples at the Blue Hole which was consistently in excess of the drinking water standard of 0.3 milligrams per liter. The results of the grab samples from May 18, 19 and 20, 1981 were 0.944, 5.1 and 3.56 milligrams per liter iron respectively.

Examination of data from the Blue Hole needs to be coupled with data from the Resurgence. It was by comparing the results of storm event water quality tests from these two locations that urban stormwater pollutants of the Lost River were identified. Data for grab sample storm event water quality tests from the Lost River Resurgence are given in Table 4. Table 8 presents data on some grab samples that were taken in conjuction with the May 1981 composite samples from the Resurgence, Blue Hole and By-Pass Cave (except for one sample from January 20, 1981 from By-Pass Cave that was tested for oil and grease).

Grab sample storm event water quality test results from the Blue Hole and Resurgence were compared. Tests corresponding to significant pollutants from By-Pass Cave were examined. The significant pollutants were fecal coliform, chromium, lead, iron, manganese, and oil and grease.

The test results for chromium at the Resurgence were consistently higher than those at the Blue Hole, though results at neither location were in excess of the surface water criterion for chromium. The test results for iron were also consistently higher at the Resurgence, and iron content at both the Resurgence and Blue Hole was well in excess of drinking water standards. The results for lead were again higher at the Resurgence, and there was one sample that exceeded surface water criterion for lead. No tests were conducted for manganese at either location, so comparison for this water quality parameter is not included.

Comparing fecal coliform and, consequently, fecal streptococcus as well involved comparing both the quantities reported and the ratios these provided. A total of eight storm event grab samples were tested for fecal coliform and fecal streptococcus at the Blue Hole and ten at the Resurgence (the data for the two extra samples is reported in Table 8). Several times for both the Resurgence and Blue Hole the tests for fecal coliform or fecal streptococcus were subject to error in laboratory procedure, and results are not reported. Although there were eight and

TABLE 8

STORM EVENT WATER QUALITY TESTS, GRAB SAMPLES, FOR FECAL COLIFORM, FECAL STREPTOCOCCUS, AND OIL AND GREASE

Test	Date	5/18/81	5/19/81	5/20/81	5/19/81	1/20/81	5/18/81	5/19/81
	Time	16:30	11:30	11:30	20:00	17:30	17:15	12:00
	Location	Bluehole	Resurgence	Resurgence	Resurgence	By-Pass	By-Pass	By-Pass
Oil and Grease mg/l		4.6	. . .	. . .	3.5	29.5	6.8	. . .
Fecal Coliform colonies/100 ml		...	. . .	9,300	...	. . .	...	9,200
Fecal Streptococcus colonies/100 ml		...	41,900	17,700	...	. . .	...	34,400

ten grab samples tested from the Blue Hole and Resurgence, respectively, ratios are not available for all grab samples tested.

At the Blue Hole and Resurgence grab samples used to test for fecal coliform and fecal streptococcus were obtained from only two storm events. Originally it was intended that means of the test results be calculated using grab sample data from a minimum of four storm events. Means were still calculated for fecal coliform and fecal streptococcus results, because of the number of samples tested and the diverse nature of the results. It must be noted however that these means represent no more than the average of the samples tested. Insufficient numbers of storm events were sampled for these means to be a representative sample of storms in Bowling Green. The means for Lost River Resurgence were 11,301 colonies per 100 milliliters of sample for fecal coliform and 10,563 colonies per 100 milliliters of sample for fecal streptococcus. The means for the Lost River Blue Hole were 9,455 colonies per 100 milliliters of sample for fecal coliform and 11,006 colonies per 100 milliliters of sample for fecal streptococcus. There does not appear to be any clear cut difference between the means of the Blue Hole and Resurgence for fecal coliform and fecal streptococcus. All four means were high, indicating pollution by pathogenic bacteria.

The ratios of fecal coliform to fecal streptococcus were too inconsistent in the November 1980 storm to draw any conclusions on the origin of the waste polluting the Lost River. In the May 1981 storm both ratios from the Blue Hole, and three of the four ratios from the Resurgence, were less than 0.7, indicating pollution by animal waste. The fourth ratio from the Resurgence of 1.54 does not have a clear interpretation. It is suggested by the guidelines used to interpret these ratios that when a ratio between one and two is obtained additional samples be tested.

The data from the May 1981 storm indicate pollution from animal waste at the Resurgence and Blue Hole. Storm event data from By-Pass Cave showed the same results. However, dry weather data from the Resurgence and Blue Hole indicate that the Lost River is polluted by human waste. It appears that stormwater runoff is introducing significant quantities of animal waste into the Lost River upstream from the Blue Hole. It is not clear what effect urban stormwater runoff has on the presence of fecal coliform and fecal streptococcus in the Lost River. The data from By-Pass Cave do show that high quantities of both are present in urban runoff. It is possible that counts of fecal coliform and fecal streptococcus would be much lower at the Resurgence if they were not present in urban runoff. Die-off of fecal coliform and fecal streptococcus is rapid and may occur in the Lost River between the Blue Hole and Resurgence. Urban stormwater runoff may be replenishing the supply. This is only speculation; further study is needed to determine die-off rates and replenishment sources for fecal coliform and fecal streptococcus in the Lost River.

Oil and grease constitute other significant pollutant whose grab sample results from the Blue Hole and Resurgence were compared. Only one grab sample from each location was tested. The results of these tests, presented in Table 8, show that oil and grease concentration was lower at the Resurgence than at the Blue Hole. This is surprising because high values for oil and grease from the runoff entering By-Pass Cave indicate that runoff could cause a significant increase in oil and grease values in the Lost River. Also surprising from the oil and grease tests was the 4.6 milligrams per liter result from the Blue Hole. Such a high value was expected from the urban Lost River drainage basin, but the Blue Hole drains primarily a rural area. The results cannot be considered conclusive, with only the results of one test from one storm event available for each location. Variances in concentration caused by time of sampling may have generated misleading results. Additional storm event samples need to be tested to generate more conclusive results.

The last water quality parameter from the Blue Hole and Resurgence storm event grab samples which merited comparison was suspended solids. Suspended solids were consistently higher, sometimes more than double in concentration, at the Resurgence. Suspended solids results from grab sample tests had a range of values of 60 to 171 milligrams per liter at the Blue Hole. At the Resurgence the range was from 193 to 1,091 milligrams per liter suspended solids. There exist no surface water criterion or drinking water standards for suspended solids. A limit of thirty milligrams per liter suspended solids for an arithmetic mean of a thirty day sampling period has been set by the U.S. Environmental Protection Agency for treated sewage effluent. This is an arithmetic mean, not a single value limit. The limit of thirty milligrams per liter suspended solids is used in this thesis arbitrarily, in view of the lack of any other available limit. Suspended solids, especially sediment, may naturally occur in streams in excess of this limit. Dune and Leopold (1978:714) recognizing this point out that "Under what conditions, then, sediment should be considered a pollutant is a matter of definition." Their definition (1978:714) is: "In general suspended load may be considered a pollutant when it exceeds natural concentrations and has a detrimental effect on water quality." It would have been preferable to use the mean of dry weather tests for suspended solids at the Resurgence as the criterion for pollution by suspended solids. In lieu of this, it was arbitrarily decided to use values in excess of thirty milligrams per liter suspended solids to indicate pollution. By this criterion grab samples from both the Blue Hole and Resurgence indicated pollution by suspended solids, with pollution being greater at the Resurgence.

In summary, comparisons of storm event grab sample water quality tests from the Blue Hole and Resurgence were made, based on significant pollutants from By-Pass Cave storm event grab sample water quality tests. The only exception was suspended solids, for which no data were available at By-Pass Cave. Of the comparisons made chromium, iron and lead were all consistently higher at the Resurgence, with iron being the only water quality parameter found to be consistently in excess of the drinking water standards.

The comparison of fecal coliform counts from the two locations produced ambiguous results. The results for oil and grease were high at both the Resurgence and Blue Hole, but the higher value was at the Blue Hole; additional storm event samples should be tested to see if this pattern is a consistent one. Suspended solids were found to exceed an arbitrarily chosen pollutant criterion at both the Blue Hole and Resurgence, with the Resurgence having consistently higher concentrations of suspended solids.

Analysis of By-Pass Cave Storm Event Composite Sample Results

Having completed the examination and comparison of grab sample storm event water quality tests, the composite sample water quality tests were next considered. The data from these tests are presented in Table 6. Following the original intention of this thesis, the data from By-Pass Cave was first examined to determine significant pollutants.

The composite sample storm event tests for By-Pass Cave revealed very few results indicative of significant pollutants. Iron at 1.24 milligrams per liter, and lead at 0.096 milligrams per liter were both in excess of their drinking and surface water criteria of 0.3 and 0.05 milligrams per liter respectively. Therefore iron and lead were considered significant pollutants. There is no surface water criterion for mercury, but drinking water standards, which generally reflect surface water criteria, limit mercury to 0.002 milligrams per liter. The concentration of mercury in the composite sample from By-Pass Cave was 0.005 milligrams per liter. Using drinking water standards as a reference, mercury was considered a significant pollutant. The composite sample result from By-Pass Cave for suspended solids was 116 milligrams per liter. The concentration exceeds the limit of thirty milligrams per liter used in this thesis to indicate pollution from suspended solids. The four significant pollutants, as determined by test results of the By-Pass Cave composite sample were iron, lead, mercury and suspended solids.

Analysis and Comparison of Blue Hole and Resurgence Storm Event Composite Sample Results

The composite sample results of tests from the Blue Hole and Resurgence, corresponding to significant pollutants from the By-Pass Cave composite sample, were compared. Comparisons for iron from these two locations showed no distinct difference in their results. With 5.53 and 5.28 milligrams per liter iron for the Blue Hole and Resurgence respectively, the drinking water standard of 0.3 milligrams per liter iron was exceeded. While the concentrations of iron found in the Lost River were high, iron is not a toxic water pollutant; it is only of aesthetic concern in drinking water supplies. So results for iron are not interpreted as revealing the presence of a dangerous water pollutant in the Lost River. With the concentration at the Resurgence actually slightly lower than that of the Blue Hole, it appears that urban stormwater runoff is not affecting the concentration of iron in the Lost River.

In comparing the concentrations of lead found in the composite samples from the Blue Hole and Resurgence, a slight increase was noted at the Resurgence. Lead was found in a concentration of 0.042 milligrams per liter at the Blue Hole and 0.05 milligrams per liter at the Resurgence. With an increase of only 0.008 milligrams per liter at the Resurgence, the higher concentration of lead there cannot legitimately be attributed to urban stormwater runoff. Surface water criterion for lead is 0.05 milligrams per liter which was equaled at the Resurgence but not exceeded. It is highly probable though that first flush runoff temporarily causes the Resurgence to significantly exceed this limit. Lead is toxic and would cause significant, though temporary, toxic pollution of the Lost River.

The comparison of composite sample results for mercury from the Blue Hole and Resurgence show a decrease in concentration at the Resurgence. The Blue Hole mercury concentration of 0.005 milligrams per liter exceeded the drinking water standard of 0.002 milligrams per liter mercury. It appears from this data that urban stormwater runoff is not increasing the concentration of mercury in the Lost River. Actually it appears to have a diluting effect, thus reducing the concentration of mercury at the Resurgence. More composite sample comparisons are needed for confirmation, since the composite sample result of 0.005 milligrams per liter mercury from By-Pass Cave seems to contradict this finding. It would seem from the By-Pass Cave data that urban stormwater runoff should at least maintain the concentration of mercury in the Lost River, not reduce it. This trend is especially important to define because of the toxicity of mercury. It also should be pointed out that it is not known if stormwater runoff is introducing mercury, into the Lost River upstream of the Blue Hole. No tests for mercury were run in dry weather on Lost River water samples to determine if mercury is present during base flow. It seems likely that stormwater runoff is carrying this pollutant to the Lost River, but it cannot be confirmed from available data.

The only significant pollutant revealing a large increase between the Blue Hole and Resurgence was suspended solids. Composite sample results for suspended solids at the Blue Hole were 629 milligrams per liter, at the Resurgence 1256 milligrams per liter. With suspended solids nearly doubled in concentration at the Resurgence, it appears that urban stormwater runoff does significantly increase the amount of suspended solids in the Lost River. A complicating factor, though, is that the By-Pass Cave composite sample produced a result of only 116 milligrams per liter suspended solids. There does not appear to be a sufficient concentration of suspended solids in urban stormwater runoff to account for the increase of greater than 600 milligrams per liter suspended solids between the Blue Hole and Resurgence. For the most accurate results, samples used to test for suspended solids should be depth integrated across an entire cross section of the stream being sampled. Grab samples were obtained for the suspended solids test in this manner, but it was not possible for composite samples, since it was not consistent with the use of an automatic water sampler. It is particularly suspected that the nonintegrated composite sample from By-Pass Cave would be affected, because the intake for the automatic water sampler was located behind the weir. The weir ponds up water behind it allowing some suspended solids to settle. Indeed a large pile of sediment accumulated behind the weir in the year after it was installed. It is possible that settling of suspended solids reduced their concentration found in the By-Pass Cave composite sample. Ideally depth integrated samples should be taken from a cross section of the runoff channel before it is ponded by the weir. However because the flow of the runoff is contained within a storm sewer pipe this is not possible. With the increase so dramatic in composite sample test results for suspended solids between the Blue Hole and Resurgence, and the consistently higher concentrations at the Resurgence of suspended solids measured in grab samples, it is concluded that urban stormwater runoff causes a significant increase in suspended solids in the Lost River. This is concluded despite the lower concentrations of suspended solids from By-Pass Cave composite samples. Both samples greatly exceeded the limit of thirty milligrams per liter suspended solids used in this thesis to indicate pollution from suspended solids.

Composite sample test results for the four significant pollutants, as determined by results from the By-Pass Cave composite sample, have been examined. Comparisons of these results showed that of the four (iron, lead, mercury and suspended solids) only suspended solids showed an increase at the Resurgence due to urban stormwater runoff. The concentrations of iron and lead were not appreciably different between the Blue Hole and Resurgence, and mercury was reduced in concentration at the Resurgence.

Summary of the Analysis of Test Results

All water quality data from dry weather grab sample and composite sample water quality tests have been reviewed. An examination of dry weather water quality tests revealed that the only pollutant present in high concentrations in the Lost River during dry weather flow was human waste. With high ratios of the indicator organisms fecal coliform and fecal streptococcus present only at the Resurgence, it appears human waste is entering the Lost River between the Blue Hole and Resurgence.

By-Pass Cave storm event grab sample test results were used to determine significant pollutants. These results revealed chromium, iron, lead, fecal coliform, and oil and grease were significant pollutants. The significant pollutant storm event grab sample test results from the Blue Hole and Resurgence were then compared. Additionally storm event grab sample test results for suspended solids were compared because of their high concentrations at both locations. No grab sample results were available from By-Pass Cave to identify suspended solids as a significant pollutant. The comparisons for chromium and lead showed consistently higher results at the Resurgence, but they both were found in low concentrations at each location. Iron was consistently higher at the Resurgence but high concentrations were found at each location. Fecal coliform counts did not appear to differ appreciably in concentration at either location, but the concentration of fecal coliform was very high at each location. It was concluded that the source for fecal coliform (and fecal streptococcus) was upstream of the Blue Hole. Oil and grease concentration was found to be lower at the Resurgence, but the concentration of oil and grease exceeded the surface water citerion at both locations. Suspended solids were much higher in concentration at the Resurgence, but greatly exceeded the limit for suspended solids used in this thesis even at the Blue Hole.

Composite sample test results were examined in the same manner as those from grab samples. Significant pollutants identified from By-Pass Cave composite sample test results were iron, lead, mercury and suspended solids. Composite sample results showed little difference in iron concentrations at the Blue Hole and Resurgence, but concentrations were very high at each location. Lead also did not differ much in concentration between the Blue Hole and Resurgence but was low in concentration at each location. The concentration of mercury dropped at the Resurgence. The concentration of mercury at the Blue Hole was high but had dropped enough by the time the Lost River had reached the Resurgence to be of no concern.

Dry weather, grab sample and composite sample data were examined for consistent trends. Iron and lead were identified from both By-Pass Cave grab and composite sample test results as significant pollutants. The only consistent trend in results for these two water quality parameters at the Blue Hole and Resurgence was their concentrations. Iron was consistently high, exceeding drinking water standards, and lead was consistently below surface water criterion for public water supplies. Iron and lead did not show a consistent pattern of increase, decrease, or equality in concentration between the two locations.

Suspended solids were identified as a significant pollutant only from composite sample test results. Suspended solids were consistently higher in concentration at the Resurgence. The composite samples yielded higher concentrations of suspended solids than did grab samples. This finding may have resulted from using improper sampling technique for suspended solids in the composite sample.

Fecal coliform, fecal streptococcus, and oil and grease were sampled only by the grab sample method, since composite sampling was inconsistent with the laboratory procedure for testing of these water quality parameters. The one reliably consistent trend observed in these tests was the high concentrations they all showed at both the Blue Hole and Resurgence.

Limitations of Storm Event Data

Besides the desirability of having more composite and grab sample data, there is one aspect limiting the reliability of the data used in this thesis that warrants attention. Grab sample data represent pollutant concentrations at the time of sampling. Sufficient grab samples taken during the rise and fall of the hydrograph will show the rise and fall of pollutant concentrations, though pollutant concentrations will peak before the hydrograph does because of the first flush effect. If the May 1981 Blue Hole grab sample data from Table 3 are examined it can be seen that there was a rise, followed by a drop in concentration. This pattern is found in eight of the twelve water quality parameters tested from all three grab samples taken during the May 1981 storm event. The first of these samples was taken four hours after the beginning of the storm. When the grab sample data for the May 1981 storm event from the Resurgence was examined a conflicting pattern became evident. Nine of the twelve water quality parameters tested for in all three of the grab samples from this event decreased in concentration. Indicating only the downward leg of pollutant concentrations were sampled. It seems probable then that with the peak pollutant concentrations not sampled at the Resurgence, the observed pollutant concentrations were lower there than if sampling had included the rise and fall of pollutant concentrations.

Composite sampling also suffered from inaccuracy. Composite sampling at the Blue Hole was begun at the onset of the storm. It was started twenty-three hours later at the Resurgence, which was three and one half hours after taking the first grab sample from the Resurgence. Also it was known that by the time composite sampling was initiated at the Resurgence, the hydrograph of the Lost River there had already peaked. Since pollutant concentrations usually peak before a hydrograph does, this is further evidence that the peak of pollutant concentrations was not sampled. The composite sampling procedure at the Blue Hole was accurately carried out. However at the Resurgence it is probable that high pollutant concentrations, including the peak, were not sampled. Therefore pollutant concentrations from the composite sample at the Resurgence would be lower than if the full range of pollutant concentrations had been sampled. It is now apparent that the sampling at the Resurgence should have begun much sooner than the time of twenty-three hours from storm start. One method that could be utilized to accurately compensate for flow through time in the future would be to start sampling all locations at the onset of the storm, injecting dye in the stormwater runoff entering By-Pass Cave when sampling is begun there. When dye is detected in the sample at the Resurgence, use that sample as the beginning on the samples used for compositing there, being sure the same number of samples are used for compositing at each location.

CHAPTER VIII

CONCLUSIONS

Stormwater Runoff Pollutants of the Lost River

Examination and comparisons of the data obtained for this thesis resulted in identification of pollutants of the Lost River that originate in stormwater runoff. It was concluded that significant quantities of pathogenic bacteria are being introduced into the Lost River by stormwater runoff. This conclusion is supported by the high quantities of the indicator organisms fecal coliform and fecal streptococcus found at the Blue Hole and Resurgence. The ratios of fecal coliform to fecal streptococcus identify the source of the pathogenic bacteria as animal waste. The results indicated that the animal waste entered the Lost River upstream of the Blue Hole.

Another pollutant category identified from the testing of storm event samples of the Lost River was oil and grease. It is probable stormwater runoff is introducing this pollutant into the Lost River, but without dry weather samples for comparison this process cannot be verified. Whatever the method of delivery to the Lost River, oil and grease were found in sufficient concentrations in the Lost River to pollute it. Insufficient data prevents determination of the role urban stormwater has on the concentration of oil and grease in the Lost River but a pollutant present in high concentrations at the Blue Hole and Resurgence is of less concern since it does not have a health impact. Iron was high in concentration in both grab and composite samples from the Blue Hole, Resurgence and By-Pass Cave.

The Impact of Suspended Solids

The one pollutant contributed by urban stormwater runoff that definitely impacts the Lost River was suspended solids. Concentrations of suspended solids were high at both the Blue Hole and Resurgence but unquestionably in much greater concentration at the Resurgence. This is directly attributed to urban stormwater runoff.

The impact of high concentrations of suspended solids introduced by urban stormwater runoff into the Lost River is not obvious. In a drinking water supply suspended solids are a nuisance because they must be filtered out. Since the Lost River is not used as a drinking supply, suspended solids are not of great concern. In a surface stream suspended solids may interfere with the ecology of the stream, both by interfering with the life cycles of stream biota and by increasing the turbidity of the stream, which reduces the rate of photosynthesis in the stream. It is possible that suspended solids are interfering with the ecology of the Lost River. The ecological environment of the Lost River has two distinct divisions: cave and noncave. Obviously, decreased photosynthesis is not of concern in the cave environment. It is beyond the scope of this thesis to speculate on any other possible impact the high concentrations of suspended solids in the Lost River may have on either its cave or noncave ecological environment, other than to state that there exists potential for it to be adversely affected.

In discussing the potential impact on a stream when its natural concentrations of suspended solids is altered Dunne and Leopold (1978:715) state, "It is the change from natural conditions that usually causes difficulties, often unforeseen." One of these "unforeseen difficulties" that may be of great impact within the urban Lost River drainage basin is the plugging of the subsurface drainage system. With high amounts of suspended solids being found in the Lost River, it is probable there are equally high amounts of solids that do not remain suspended, but settle to the bottom of the drainage channel. These solids, more commonly referred to as sediment, will not greatly effect the subsurface Lost River, since it is contained in a large conduit, but its tributaries may become clogged.

Most of Bowling Green's stormwater runoff is directed into small tributaries in the subsurface drainage system, which confine the runoff within limestone conduits. If these become clogged, runoff will cause flooding on the surface around the area where it is directed into the subsurface including areas around dry wells, sinkholes and swallets. In Bowling Green the areas around such inputs are frequently developed--containing homes, businesses, or industry--so any flooding within these areas is potentially serious.

In fact flooding such as that described above does occur within Bowling Green. It has been the subject of much research (for example, see Crawford, 1981a, 1981b, 1980; Daugherty and Trautwein, Inc. and G.R.W. Engineers, Inc., 1980; and Booker Associates, 1978). Crawford (1980:5), in discussing urban karst flooding states:

> ...there is some evidence that soil erosion from agricultural landuse, urban stormwater runoff, and construction sites is clogging many of the sinks and drainage wells. Sediment forty to fifty feet deep is often found stacked up in drainage wells. What about the sediment that reaches the karst aquifer under Bowling Green? Is it being deposited in the small conduits of the underlying limestone, clogging them, and thus contributing to the sinkhole flooding problems of this karst landscape?

Sedimentation of subsurface conduits is by no means the only cause of such flooding, but it is believed that unless the quantity of suspended and settleable solids in Bowling Green's urban stormwater runoff is reduced, the magnitude and occurrence of flooding within Bowling Green will increase.

The weir at By-Pass Cave demonstrated the presence of sediment in urban stormwater runoff, as well as a possible solution to the problem. Before the weir was constructed at By-Pass Cave, the swallet there had a bedrock floor. One year after the construction of the weir a large quantity of sediment had collected behind the weir. The weir ponds up the runoff until it has reached the height where it can pass through the V notch. Once this height is reached the flow of the runoff is impeded only slightly, but velocity is reduced enough to allow some of the suspended load in the runoff to settle out. The solution that this points to is the use of retention reservoirs and sediment traps to provide an opportunity for the solids in stormwater runoff to settle on the surface instead of the subsurface. The use of flood retention reservoirs and sediment traps is not a new idea. Crawford (1980) points out that in Bowling Green flood retention reservoirs must now accompany any new construction involving a change in land use. Besides storing runoff to prevent or reduce flooding, flood retention reservoirs would allow the settling of some suspended solids in the runoff. Crawford points out that the effectiveness of flood retention reservoirs in Bowling Green is often greatly impaired because one or more dry wells are usually drilled in the bottom of the reservoir, allowing rapid entry of stormwater runoff into the subsurface drainage system. Crawford (1980:4) states:

> If the retention reservoirs did not have drainage

> wells, stormwater runoff would sink slowly into the soil, thus filtering out sediment, trash, and other pollutants associated with urban stromwater runoff.

In most of the older developed areas of Bowling Green flood retention reservoirs do not exist, and it would not be economically feasible to install them. Small sediment traps around each dry well in these areas, however, could be installed at a reasonable cost, and be reasonably effective in reducing the concentrations of suspended and settleable solids in urban stormwater runoff. The size of these traps is best determined by field research, but it is estimated one having a volume of one cubic meter would be adequate. It should be emphasized that dry wells within the sediment traps should be cased to the top of the trap, so that stormwater runoff must fill the trap before it can flow into the dry well (this is also true for dry wells in flood retention reservoirs). Little runoff can be contained within such a sediment trap, but it is expected that the first flush of polluted runoff for most storms will be contained long enough to allow settling to reduce its load of suspended solids.

Loadings Obtained from the By-Pass Cave Storm Event Composite Sample Test Results and their Significance

No pollutant of the Lost River other than suspended solids was identified, from data presented in this thesis, as originating in urban stormwater runoff. However the presence of contradictory data for some pollutants, indicates at least the possibility of their presence in urban stormwater runoff. These pollutants are chromium, lead and mercury. Further research needs to be done to determine if these pollutants are present in urban stormwater runoff in sufficient quantities to cause pollution of the Lost River. Because these pollutants are very toxic it is especially important to establish whether the Lost River is being impacted by urban stormwater runoff containing chromium, lead and mercury.

Though suspended solids were the only pollutant in urban stormwater runoff identified as having a significant impact on the Lost River, it is possible that further testing of composite samples would identify additional urban runoff pollutants that have a significant impact on the Lost River. Also, the impact of the first flush effect on the Lost River merits further investigation. The first flush of urban stormwater runoff is probably introducing high quantities of pollutants into the Lost River, causing temporary, but significant, pollution of the Lost River.

An estimate of the total quantity of pollutants transported by urban runoff during a storm was obtained by calculating pollutant loadings for that storm. Loadings are a measure of the weight of pollutants per unit area. Loadings were calculated for the May 18 to May 19, 1981, storm using the By-Pass Cave composite sample test results. The composite sample results were used because it was believed they were representative of pollutant concentrations from the entire storm event.

To calculate loadings the By-Pass Cave composite sample test results were divided by 30.31 hectares, the area of the By-Pass Cave drainage basin. Results were thus expressed in milligrams per liter per hectare. These quantities were then multiplied by the volume of runoff entering By-Pass Cave, calculated using data from the graph of the head of the water above the weir at By-Pass Cave (Figure 7). This volume was 14,403,269 liters. The resulting milligrams per hectare were converted to grams per hectare, which represent the loadings of pollutants for the storm. The loadings represent the average concentration in each hectare of the By-Pass Cave drainage basin. The calculated loadings are given in Table 9. Also included in Table 9 is the total amount of pollutants, in grams, delivered to By-Pass Cave during the storm. The data in Table 9 reveals some interesting figures. It is significant to note that while data from the Resurgence indicated no serious pollution from the toxic heavy metals, there were still high, though diluted, quantities present in the runoff entering By-Pass Cave. The highest amount was 1,381.2 grams of lead in the By-Pass Cave runoff.

Almost two metric tons of total dissolved solids were in the runoff entering By-Pass Cave. Suspended solids totaled over 55 kilograms in the runoff entering By-Pass Cave, even though results showed low concentrations of suspended solids due to improper sampling technique. With this large quantity of suspended solids generated from just over thirty hectares in one storm, it is easier to believe the subsurface drainage network may be becoming plugged with them.

The one other thing that the loadings emphasize is that there are pollutants in urban stormwater runoff. Pollutants such as lead, chromium and mercury may not be present in high enough concentrations in the Lost River to be pollutants of it, but significant quantities are present in urban stormwater runoff; it is just that the Lost River is large enough to be able to dilute them. Where less diluted, urban stormwater runoff will pollute the karst aquifer of Bowling Green.

Recommendations for Reduction of Pollution from Urban Stormwater Runoff

Besides the recommendations for reducing the pollution caused by suspended solids in urban stormwater runoff that have already been made, what else can be done in Bowling Green, if further investigation reveals

TABLE 9

SELECTED LOADINGS FROM THE BY-PASS CAVE COMPOSITE SAMPLE

Test	g/hectare	Total grams to By-Pass Cave
Total Dissolved Solids	64,625.20	1,958,859.7
Suspended Solids	55,118.97	1,670,744.9
Total Phosphorus	117.45	3,560.0
BOD_5	1,946.80	59,010.7
Cadmium	.47	14.2
Chromium	.93	28.5
Iron	589.33	17,863.6
Lead	45.57	1,381.2
Mercury	.96	71.9

serious problems associated with urban stormwater runoff? In many other cities the storm sewer flow is combined with sanitary sewer flow, and the combined flow is treated at the municipal waste water treatment facility. In Bowling Green there exists no integrated storm sewer system, and it would be prohibitively expensive to install one now, especially because of the shallow depth to bedrock and the nature of the karst topography. There are several things, however, that may be done to clean up urban stormwater runoff. Flood retention reservoirs especially, and to a lesser extent sediment traps, will collect other pollutants besides suspended solids. Crawford (1981a) states that an effective method for dealing with highly polluted urban stormwater runoff in Bowling Green would be to collect it in flood retention reservoirs feeding it slowly over a period of days into the sanitary sewer system, or perhaps treating it on site. This procedure should be followed especially for any surface areas, such as heavily commercialized or industrialized areas, that contribute high quantities of pollutants to urban stormwater runoff.

Besides these measures there is only one other economically feasible method of reducing pollutants in stormwater runoff in Bowling Green. This method is street sweeping. Street sweeping, if it is of the vacuum type, will remove pollutants accumulating on city streets. If the streets are scrubbed with water, pollutants will not be kept out of the subsurface drainage system, since water would only flush pollutants into it. Current street sweeping practices in Bowling Green are to clean city streets one to two times per week with a vacuum type street sweeper adaptable only to streets with curbs. No state highways, such as U.S. Highway 31-W By-Pass, that pass through Bowling Green are cleaned by street sweepers.

Summary

This thesis has examined the presence and impact of pollutants in urban stormwater runoff on the Lost River of Bowling Green, Kentucky. Also some pollutants associated with nonurban stormwater runoff were identified. In addition, identification was made of several heavy metals that may be polluting the Lost River. The significant findings of this thesis are as follows:

1. The only pollutant of the Lost River that definitely can be attributed to urban stormwater runoff is suspended solids.
2. The first flush effect was documented for runoff entering By-Pass Cave.
3. Urban stormwater runoff entering By-Pass Cave is very polluted. Of particular significance were the high concentrations of chromium, lead and mercury found in the runoff entering By-Pass Cave.
4. Stormwater runoff introduces animal waste into the Lost River.
5. Iron is a stormwater runoff pollutant of the Lost River.
6. Oil and grease is a stormwater runoff pollutant of the Lost River.

These findings are based on data collected for this thesis. It is believed additional study of stormwater runoff within the Lost River drainage basin can better define the source of stormwater runoff pollutants and provide more conclusive evidence on the impact of urban stormwater runoff on the Lost River.

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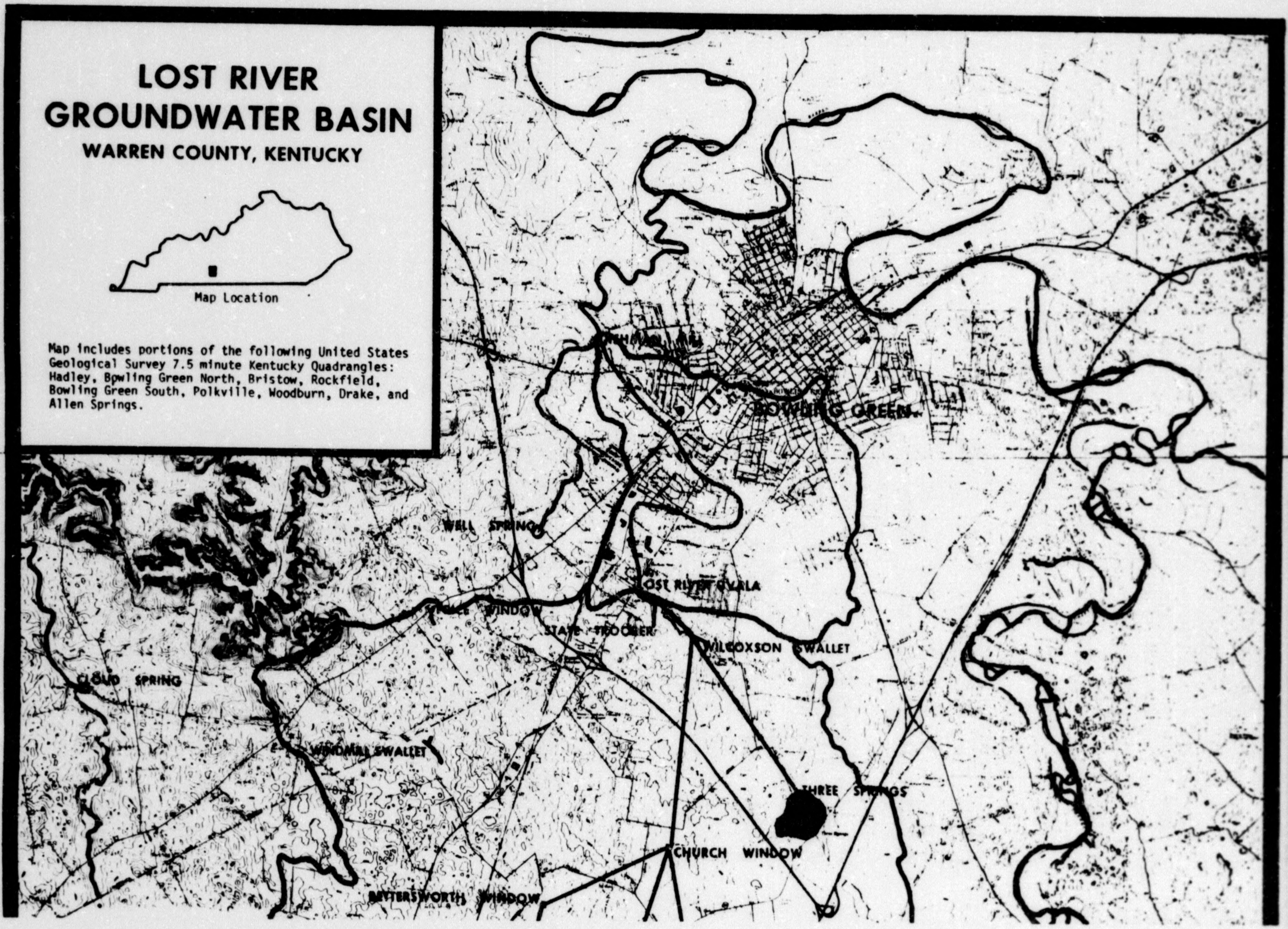
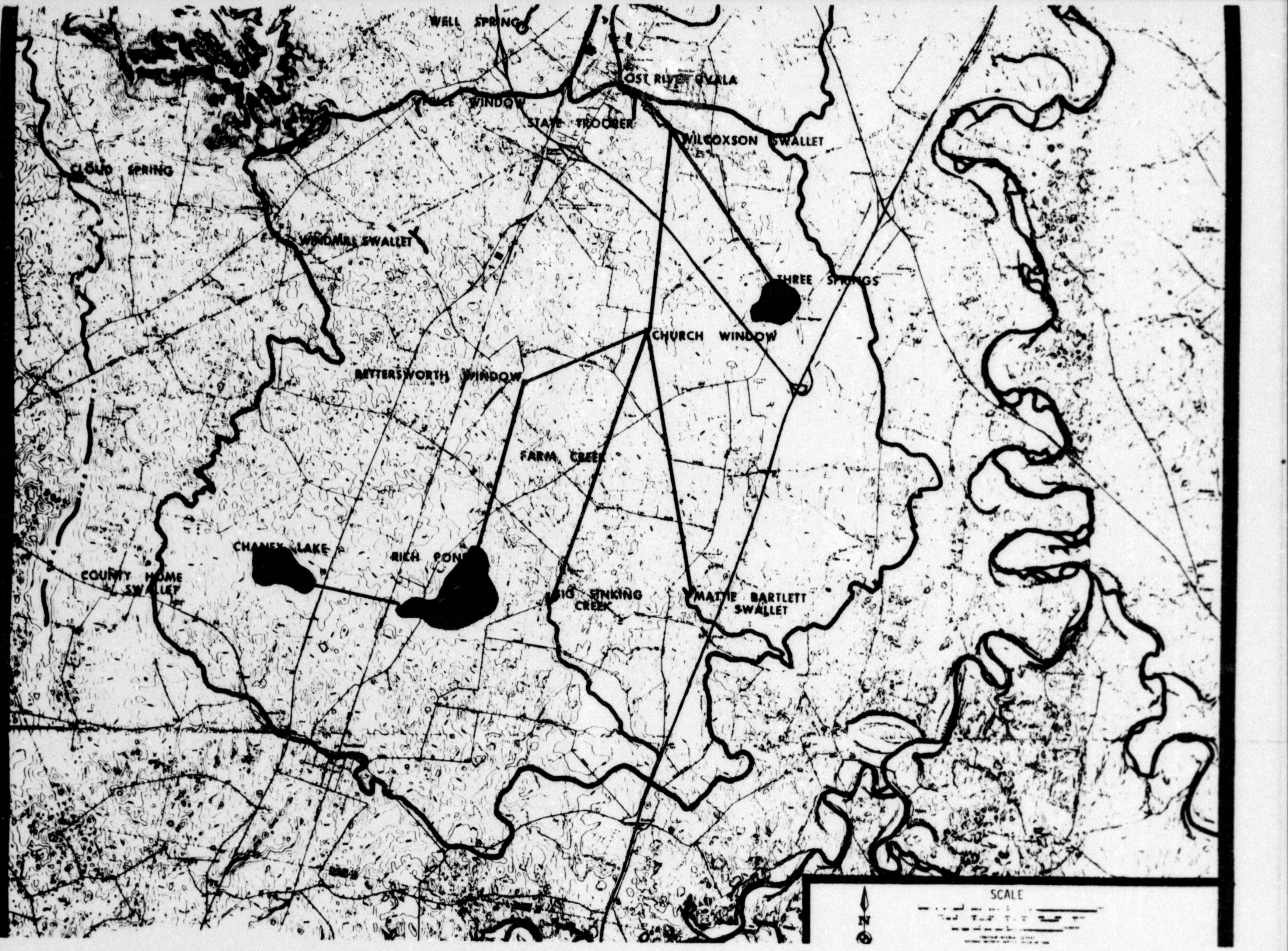


LOST RIVER GROUNDWATER BASIN

WARREN COUNTY, KENTUCKY

Map includes portions of the following United States Geological Survey 7.5 minute Kentucky Quadrangles: Hadley, Bowling Green North, Bristow, Rockfield, Bowling Green South, Polkville, Woodburn, Drake, and Allen Springs.


WELL SPRING
LOST RIVER OVALA
WINDOW
STATE TROOPER
WILCOXSON SWALLET
CLOUD SPRING
WINDMILL SWALLET
THREE SPRINGS
CHURCH WINDOW
BETTERSWORTH WINDOW
FARM CREEK
CHANEY LAKE
RICH POND
COUNTY HOME SWALLET
BIG SINKING CREEK
MATTIE BARTLETT SWALLET
SCALE
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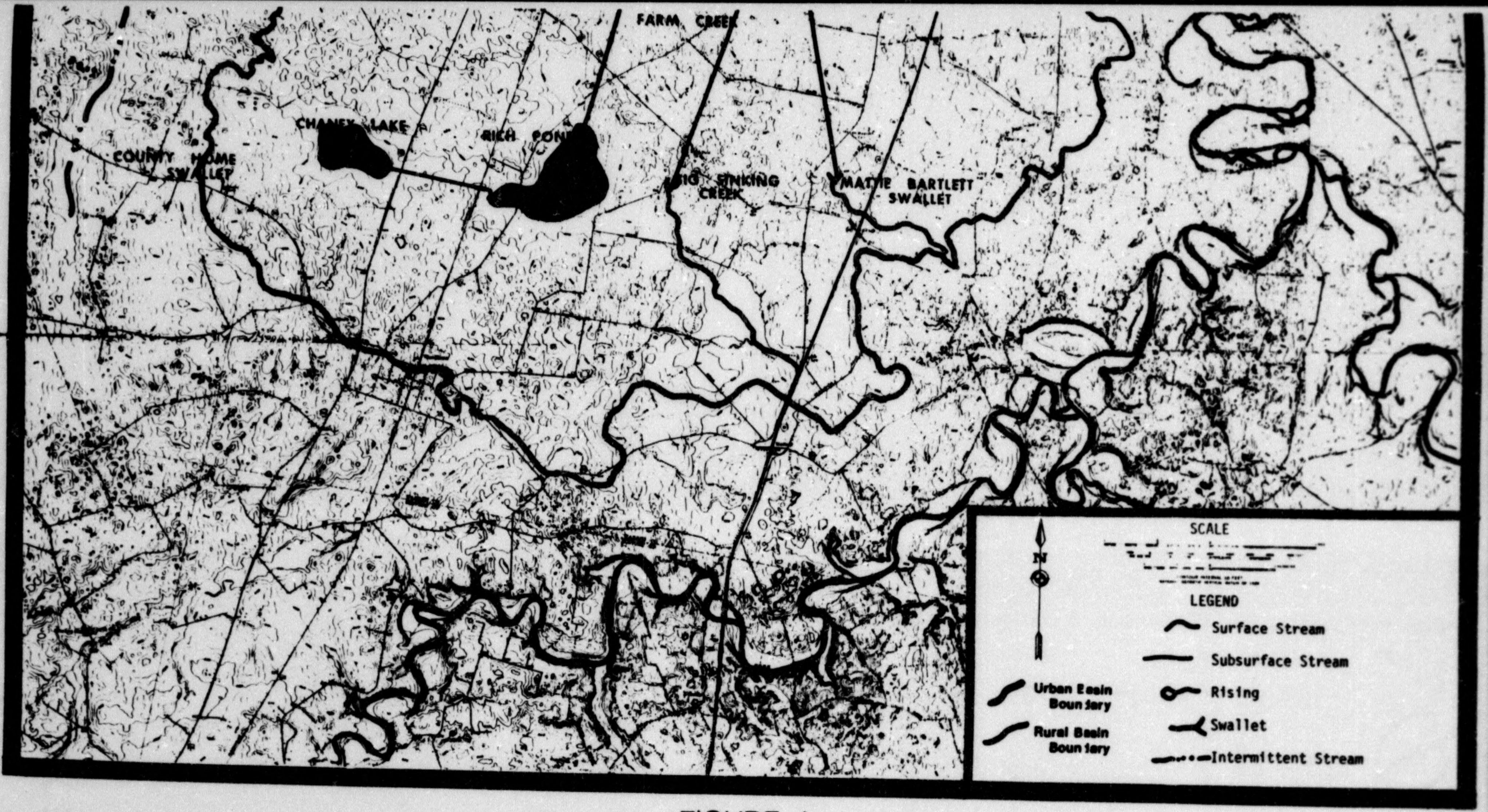
FARM CREEK
CHANEY LAKE
RICH POND
COUNTY HOME SWALLET
BIG SINKING CREEK
MATTIE BARTLETT SWALLET
SCALE
N
LEGEND
Surface Stream
Subsurface Stream
Rising
Swallet
Intermittent Stream
Urban Basin Boundary
Rural Basin Boundary

FIGURE 4