Research Report
KTC-03-30/SPR237-01-1F

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EVALUATION OF METHODS TO PROTECT WATER QUALITY IN KARST AREAS: PHASE I

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Evaluation of Methods to Protect Water Quality In Karst Areas: Phase I

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16. Abstract

The primary focus of this report is two-fold; to provide a literature review on what has been previously learned about highway runoff in relation to karsts aquifers and to characterize a karsts highway site in Kentucky that can be used to evaluate a variety of best management practices. From research findings, the main sources of pollutants in highway runoff came from vehicles, atmospheric fallout, and precipitation. The behavior of pollutants and their interaction with the environment can dictate where they will be found and how to best minimize their effects. Although it would seem that traffic volumes would greatly influence the accumulation of pollutants on roadways, past studies have not proven this. Instead, no clear relationship between traffic and water quality has been reported. Removal processes such as air turbulence (both natural and the result of vehicles) limit the accumulation of solids and other pollutants on road surfaces, thereby obscuring the relationship between the traffic volume and runoff loads. Of the various precipitation characteristics, intensity was found to have the greatest impact on the type and quantity of pollutants found in highway runoff. This was expected due to the greater velocity traveled by runoff during high rain intensity events which does not allow suspended particles a chance to settle out and often results in greater friction along the runoff travel routes. In all experiments previously conducted, highway paving material appears to have minimal impact. Of the best management practices examined, vegetated controls received the highest recommendation because of their wide adaptability, low costs, and minimal maintenance requirements.

Water quality testing results from the location off I-65 South demonstrated very low levels of select pollutants, when compared to national averages. The existing vegetative controls in the highway median and along the drainage paths are considered to be effective at mitigating a large quantity of runoff from reaching the drainage point into sinkhole.

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EXECUTIVE SUMMARY

The primary focus of this report is two-fold; to provide a literature review on what has been previously learned about highway runoff in relation to karsts aquifers and to characterize a karsts highway site in Kentucky that can be used to evaluate a variety of best management practices.

From research findings, the main sources of pollutants in highway runoff come from vehicles, atmospheric fallout, and precipitation. Vehicles often collect pollutants from parking lots, urban roadways, construction sites, farms and dirt roads and then deposit them on highways during a rain event. The behavior of pollutants and their interaction with the environment can dictate where they will be found and how to best minimize their effects. For example, certain metals have a significant correlation with solids particles which can be effectively reduced in runoff through a filtration process whereas nutrients are more often found in the dissolved phase. Although it would seem that traffic volumes would greatly influence the accumulation of pollutants on roadways, past studies have not proven this. Instead, no clear relationship between traffic and water quality has been reported. This is true for both average daily traffic and the number of vehicles during a storm. Removal processes such as air turbulence (both natural and the result of vehicles) limit the accumulation of solids and other pollutants on road surfaces, thereby obscuring the relationship between the traffic volume and runoff loads. Of the various precipitation characteristics, intensity was found to have the greatest impact on the type and quantity of pollutants found in highway runoff. This was expected due to the greater velocity traveled by runoff during high rain intensity events which does not allow suspended particles a chance to settle out and often results in greater friction along the runoff travel routes. In all experiments previously conducted, highway paving material appears to have minimal impact. Of the best management practices examined, vegetated controls received the highest recommendation because of their wide adaptability, low costs, and minimal maintenance requirements.

Presented in the site characterization report is background information on a highway intersection receiving runoff that drains to a sinkhole located approximately 50 yards away. The site was observed between April and October of 2002. Water quality testing results from the location demonstrated very low levels of select pollutants, when compared to national averages. The existing vegetative controls in the highway median and along the drainage paths are considered to be effective at mitigating a large quantity of runoff from reaching the drainage point into sinkhole. One interesting finding of this study was the relatively small amount of runoff drainage from the highway that reached the sinkhole as compared to other runoff sources. The sinkhole appeared to receive a large quantity of runoff from an adjacent parking lot, which was also observed to drain at a much faster rate.

LIST OF ABBREVIATIONS

ADP	Antecedent Dry Period
ADT	Average Daily Traffic
BMP	Best Management Practice
COD	Chemical Oxygen Demand
PAH	Polycyclic aromatic Hydrocarbons
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
LNAPL	Light Non-Aqueous Phase Liquids

Metals:

Zn	Zinc
Cd	Cadmium
As	Arsenic
Ni	Nickel
Cu	Copper
Fe	Iron
Pb	Lead
Cr	Chromium
Mg	Magnesium
Hg	Mercury

INTRODUCTION

Finding ways to mitigate nonpoint source pollutants is a growing concern for many state agencies as a result of the increased pressure from the U.S. EPA for improved surface and groundwater quality. In Kentucky, the situation is compounded by the fact that 55% of the state is underlain by mature karst. Karst landscapes are areas of limestone or other soluble bedrock where dissolution and erosion have produced direct paths to underground aquifers. Therefore, runoff from impervious areas such as roadways and buildings is able to evade natural filtration by topsoil and is flushed directly into sinkholes, springs, and underground caves. This results in the contamination of ground and surface water, which are the primary sources of drinking water in Kentucky. Many underground aquifers especially in Western Kentucky are also unique habitats for endangered species of wildlife. This study focuses on a sinkhole that drains highway runoff into the Mammoth Cave aquifer, a sensitive underground habitat.

Recent studies have suggested that highway runoff from interstate roadways may be a significant contributing factor in the pollution of karst aquifers. In particular, highway runoff may contain high concentrations of heavy metals, which are toxic to aquatic life, and often accumulate due to the fact that they do not readily degrade in the environment. Other pollutants such as oil, gasoline, and suspended solids are also of concern and may threaten aquatic habitats and pose potential health hazards to the public.

Managing and protecting groundwater sources within karst areas are not simple tasks. In order to determine which best management practices are most applicable to a particular highway site, background studies which characterize the highway design features, operating conditions, maintenance practices, and drainage system are all needed. It is also necessary to understand the types of contaminants coming from highway runoff and their effects on the surrounding environment.

This report is the first of a three-phase study to identify appropriate best management practices for future implementation along highways in Kentucky that are located in karst terrain. The goals of the study are to develop a generalized approach for evaluating highway runoff impacts on water quality, provide models to analyze highway sites for potential groundwater impact, and identify treatment requirements based on the effectiveness of proposed best management practices. The report includes a literature review of past and current research findings on the causes and impacts of highway runoff in karst aquifers. This document also provides background information on a highway site in Kentucky chosen to implement and evaluate a variety of best management practices.

LITERATURE REVIEW

BACKGROUND

With the passage of the amendments to the Clean Water Act in 1987, states were required to identify water bodies in which water quality standards could not be met without the control of nonpoint source pollutants, and to establish management programs for these bodies of water (Chapter 26, Subchapter III, Section 1329). Such sources include the regular use and maintenance of roads and highways, which cause an accumulation of pollutants on the impervious surface from oil, tires, dust, grease, and other materials to be washed into receiving waters through rain events. Therefore, activities associated with the operation and maintenance of highways and roads are subject to state regulations and programs addressing nonpoint source pollution. At this time however, there are no water quality regulations to control runoff from Kentucky highways, except from construction activities. While it has been suggested that highways are minor contributors of water pollution compared to other land uses (FHWA, 1997), relatively little research has been focused specifically on the subject of karst aquifers and their pollutant sources. In particular, highway runoff may have a more significant impact on groundwater quality in karst terrains, where soils may be thin or nonexistent and where groundwater recharge occurs directly through fractures, sinkholes, and sinking streams. The combination of polluted runoff with the potential re-suspension of pollutant laden sediments previously deposited makes control and delay of the hydrologic pulse through this system critical for control.

SOURCES OF POLLUTANTS IN HIGHWAY RUNOFF

Major sources of pollutants on highways include vehicles, dustfall, and precipitation. Other possible sources, which occur less frequently, include accidental spills, roadway maintenance practices such as sanding or deicing, and the use of herbicides on highway right-of-ways.

Vehicles are both a direct and indirect source of pollutants on highways (Barett, et al., 1998). As a direct source, vehicles contribute pollutants from normal operation and frictional parts wear. It has been reported that virtually all of the carbon monoxide, nitrogen oxide, and lead compounds emitted into the air come from vehicle exhaust (Ball et al., 1991). Vehicle exhaust also accounts for about 65% of the hydrocarbons, with the remainder derived from crankcase blowby and evaporation from the carburetor. The wear of automotive components and corrosion of bodywork contributes to increased pollutant loadings, especially heavy metals. Pollution generated by the leaking of brake fluid, antifreeze compounds, transmission fluid, engine oil, and grease is directly deposited onto the highway surfaces. Tire wear contributes oxidizable rubber compounds and zinc oxides. The multiple types of pollutants that are directly associated with vehicles, each with differing fate and transport mechanisms, makes for a potentially difficult problem to analyze and quantify.

Indirect pollutants are solids that are acquired by the vehicle for later deposition, often during storms (Asplund et al., 1980). These solids are transported from locations such as parking lots, urban roadways, construction sites, farms, and dirt roads. In one study, it was shown that more than 95% of solids on a given highway originated from sources other than the vehicles themselves (Shaheen, 1975).

Atmospheric sources of pollution are another major contributing factor to the pollutant load found in highway runoff. Typically deposition occurs by precipitation during storms or by dustfall during dry periods. Dustfall occurs continuously as natural and human activities release fine particles into the ambient air. Surrounding land use therefore has an important effect on the amount and types of pollution in dustfall. It has been shown that highways in or near urban areas have significantly higher levels of pollutant loading than those in rural areas (Driscoll, 1990). Typical dustfall concentrations for various U.S. cities range from 17 to 170 Mg/km^2/month (10 to 100 tons/mi^2/month) (Gupta et al., 1981).

Highway maintenance practices have also been shown to have an adverse affect on water quality. The proximity of the maintenance activities to a body of water increases the likelihood of adverse effects. The type of materials and methods used in the activities may also affect the impact. This includes such things as the use and disposal of: toxic components, materials containing nutrients, decomposable organic materials, and materials that could change the turbidity, pH, or suspended or dissolved solids content of the receiving body of water. Sanding and deicing during the winter months has also been shown to increase the loadings of suspended and dissolved solids to receiving waters. In a study conducted by Jones et al. (1992), it was found that road salt was very damaging to roadside vegetation because it decreased aeration and water availability in the soil. It was also found to be a major source of the metals nickel and chromium. The tolerance of animals to salt water was found to generally be much higher than that of plants. The higher salt concentrations in ground and surface waters were rarely found to be a problem for animals. The use of herbicides to control weeds and brush can have a much more devastating impact on aquatic life. Herbicides are toxic to aquatic animals although not to the same degree as insecticides (Kramme et al., 1985). Studies have shown that the majority of pollutants deposited along roadways can be found within 3 feet of the curb (Little and Wiffen, 1978).

FACTORS AFFECTING HIGHWAY RUNOFF QUALITY

During wet weather, the primary removal mechanism of pollutants found on highways is stormwater runoff. Not all pollutants emitted by vehicles however, end up on roadways. In a report by Hamilton et al. (1987) it was found that the mass of metal deposited greatly exceeds the mass removed by rainwater for all metals. Hewitt and Rashed (1990) reported that only 8% of the lead emitted by vehicles was removed in runoff, while 6% was deposited in soils adjacent to the roadway and 86% was dispersed by the atmosphere away from the vicinity of the road.

Many factors appear to influence the quality of stormwater runoff from highways, including traffic volume, precipitation characteristics, drainage characteristics, highway surface type, and the nature of the pollutants themselves. Traffic speed and braking, climate conditions, age and condition of vehicles, regulations regarding vehicle emissions, vegetation types on highway right-of-ways and accidental spills, may also affect the extent of pollutant accumulation. Complex interactions between these variables tend to obscure simple correlations between individual variables and water quality. As a result, water quality testing on highway runoff often produces inconsistent results.

It would appear that traffic volume would influence the accumulation of pollutants on the highway surface. However, vehicle disturbance can also remove solids and other pollutants from highway lanes and shoulders (Kerri, et al., 1985), and the impact of traffic volume on pollutant accumulation can be obscured. The results of several reports indicate that there is only a slight dependence of the quality of stormwater runoff on average daily traffic (ADT). Urban high-traffic sites are considered to be those sites where ADT > 30,000 while non-urban traffic flow has an ADT < 30,000. In a study done by Driscoll et al. (1990), it was found that runoff concentrations were two to four times higher from urban high-traffic sites (ADT>30,000) than from non-urban low traffic (ADT<30,000) sites. However, regression analysis of the data from the urban site indicated no strong or definitive relationship between ADT and pollutant level. This study and many others have indicated very little correlation between the water quality parameters being tested and traffic density. It has been suggested however that several additional traffic factors might influence runoff qualities. These include vehicular mix (percentage of trucks/cars), congestion factors, level of service, and vehicular speed.

Precipitation characteristics include the number of dry days preceding the event, the intensity of the storm and the storm duration. Research pertaining to an increase in pollutants associated with a greater number of antecedent dry days between storm events has provided mixed results. Colwill et al. (1984) determined that antecedent dry period (ADP) and the traffic flow during the time between storms only affected the concentrations of soluble pollutants. They found that the concentration of suspended solids and total lead released were instead principally influenced by rainfall intensity and total volume discharged. Other studies have found an association between ADP and the mean concentration of dissolved lead, dissolved copper, and particulate phase lead. However, no correlation for the concentration of dissolved Cd, particulate phase Cu, particulate phase Cd, or individual polyaromatic hydrocarbon concentration was evident. Other studies have found that ADP is relatively unimportant. Horner et al. (1979) found that the correlation was not strong enough to predict total suspended solids loadings from ADP.

From all the reported results however, it can be inferred that rainfall does effectively remove pollutants from the road surface and that a short antecedent period will result in lower pollutant loads. However, variations in the rate of deposition of pollutants on the road surface and removal processes such as air turbulence, volatilization, and oxidation reduce the correlation between pollutant load and longer antecedent dry periods.

Intensity has been found to have a much larger impact on the type and quantity of pollutants in runoff. This is due in large part to the fact that many pollutants are associated with particles, which are more easily mobilized in high intensity storms. In a study done by Hoffman et al (1985), the higher concentrations of hydrocarbons, lead, and suspended solids corresponded with the periods when the runoff had the highest flow rates. Many other studies have shown a positive correlation between load rates and storm intensity. Rainfall intensity has also been found to be important in explaining seasonal differences in removal rates of sediment from road surfaces. Higher intensity storms occurring in the summer result in increased sediment loadings and particle size ranges (Ellis and Harrop, 1987).

Another precipitation characteristic, runoff volume, seems to have less effect on pollutant concentration but is important in determining the total load to the receiving water. Longer storms that produce more rainfall, dilute highway runoff, and lower the concentration of contaminants. However, the loading of pollutants (total mass transported) is generally higher in longer storms, as the transport of at least some constituents continues throughout the duration of the event. Many solids and other pollutants that accumulate on the pavement and in the gutter between storms are quickly washed off, but vehicles and atmospheric fallout continue to release pollutant constituents (Kerri, et al., 1985).

Higher concentrations of pollutants are often observed in the first runoff from a storm. This is known as the “first flush” phenomenon. The “first flush” is the result of an initial washing away of pollutants that have accumulated on the pavement surface when a storm begins. As the storm continues, available pollutants are depleted and concentrations decline. Numerous studies have confirmed this theory.

The effect of highway paving materials (asphalt vs. concrete) on the quality of highway runoff appears to be minimal. Most studies have found that highway surface type is relatively unimportant compared to such factors as surrounding land use. It has also been reported that the type of collection and conveyance system for highway runoff (storm sewer, grassy swale, etc.) has a greater effect on runoff quality than pavement type.

POLLUTION CHARACTERISTICS

Water quality analysis on road surface runoff has indicated that the concentration and behavior of the pollutants depend to a large extent on whether the pollutants are in a dissolved or particulate form. The existing data indicates that heavy metals, oil and grease, TOC, and COD are often attached to solid particles and that the pollutant concentrations are generally higher in the smaller size fractions (Revitt and Ellis, 1987; Pitt and Amy, 1973). Particulate size can play a very significant role in the transport of the associated pollutant. For example, finer grains have lower settling velocities and remain in runoff longer than larger particles. Research by Harrison and Wilson (1985) also indicates that particle-associated elements show a more complex temporal variation related to storm intensity and the movement of large-grained sediment through drainage systems.

Metals are predominately washed from highways after adsorption upon particulate materials such as bituminous road surface wear products, rubber from tires, and particulates coated with oils. The degree of association with solids varies between different metals. Dissolved metal fractions found in runoff are small for lead, zinc, and iron (Gupta, et al., 1981). In a study performed by Gupta et al. (1981), individual metal loadings tested for statistical correlation with solids loadings showed very different results. Lead was found to have a significant correlation with solids at a 99% confidence limit for six out of six sites. Zinc, iron and cadmium were correlated at five of the six sites, copper and chromium at four sites, and mercury at only one (Gupta et al., 1981). Lead was also reported as the metal most associated with particulates by Hewitt and Rashed (1992). Once attached to solids particles, lead does not easily degrade. Although the use of lead as a gasoline additive was phased out many years ago, lead contaminated soils and river sediments have persisted (Science Daily, 2000). Intense storms often cause solids particles in river beds to become re-suspended in the steam flow. Other pollutants found primarily in the particulate phase and/or showing a strong correlation with solids include PAH's, TOC, COD, and extractable organics.

Nutrients are more likely to be found in the dissolved rather than the particulate phase. Many studies have supported this finding. Organic lead also tends to be primarily dissolved. The first flush phenomenon is especially true for dissolved components, which have been observed to contain higher concentration of pollutants.

Concentration and loadings of highway runoff constituents have been reported in several studies, and the data from individual reports as summarized by Driscoll et al. (1990) are presented in Table 1. The data includes the range of averages for each pollutant, but does not reflect the maximum or minimum concentrations reported. To explain the wide range of values presented in the table, several factors must be considered, including the processes involved in the deposition and transport of the pollutants.

In 1990, Driscoll et al. reported that the most important general factor influencing pollutant loads in highway runoff is surrounding land use. In this study, significant differences were found in highway runoff quality between urban areas and in rural areas. Although traffic densities are significantly different for these two categories of land use, the study concluded that there was no clear correlation with ADT and the pollutants found. Therefore, the study concluded that the principal difference between urban and rural areas in relation to pollutant loads is atmospheric quality. Unusual local factors can also influence the quality of runoff. Examples of such factors include high solids loading resulting from the eruption of Mount St. Helens (Asplund et al., 1980) and high zinc concentration in runoff at a site adjacent to a smelter (Driscoll et al., 1990).

EFFECTS OF HIGHWAY RUNOFF

There are many factors that determine the extent and importance of highway runoff effects on pollutant loads. The type and size of the receiving body, the potential for dispersion, the size of the catchment area, and the biological diversity and sensitivity of the receiving stream are just a few of these factors. Like hydrological effects, water quality effects are highly site specific. Different types of receiving water bodies react differently to the loading of pollutants. The processes that control the transport and fate of pollutants in lakes and reservoirs differ from those in rivers, streams, and aquifers. Typically lakes are analyzed on an annual or seasonal basis since they respond to cumulative pollutant loads delivered over an extended period of time. The most common environmental issue in lakes is the overstimulation of aquatic life as a result of the lake receiving too many nutrients. Streams on the other hand, respond more to individual events, since runoff produces a pulse of contamination, which moves downstream and is well removed by the time the next storm occurs. In general, the most common concern in streams is suppression of aquatic life by toxic effects of heavy metals (Driscoll, 1990). This could especially be a problem in karst aquifers where very sensitive ecosystems exist and groundwater movement is comparable to stream flow. The amount of dilution that highway runoff receives is dependent on the relative size of the receiving stream. In addition, the type of water body and its designated beneficial use determine which sets of pollutants will have the most significance.

There have been many studies investigating the potential impacts of various pollutants found in highway runoff. Particulates and sediments in runoff have been found to cause problems by decreasing flow capacity in drainage ways, reducing storage volume in ponds and lakes, smothering benthic organisms, decreasing water clarity, and interfering with the respiration of small fish. Furthermore, toxic materials often are absorbed and are transported by suspended solids. These toxins include metals, hydrocarbons, chlorinated pesticides, and PCBs. They can present both acute and chronic threats to receiving water organisms.

WATER QUALITY IMPACTS ON KARST AQUIFERS

Although many studies have addressed the impacts of stormwater and highway runoff on surface water, relatively little attention has been directed towards assessing its impact on groundwater, especially in karst areas. Dissolution of bedrock in karst areas results in a terrain characterized by sinkholes, sinking streams, and underground streams and springs. Groundwater in these settings is more susceptible to contamination because surface water may pass directly into the subsurface with little or no filtration by soil. Sensitive subterranean ecosystems may be also be affected by the karst groundwater as it migrates through the fractures and conduits. As a result of karst groundwater typically flowing through relatively large fractures within the bedrock, it may transport contamination rapidly from points of recharge (such as sinkholes) to distant cave streams, water wells, springs, and surface streams. Discharge rates of karst groundwater through springs and a resurgent cave are comparable to those values found for surface streams. Unlike groundwater movement through a granular aquifer that is measured in meters per year, the movement of karst groundwater may be measured in kilometers per day.

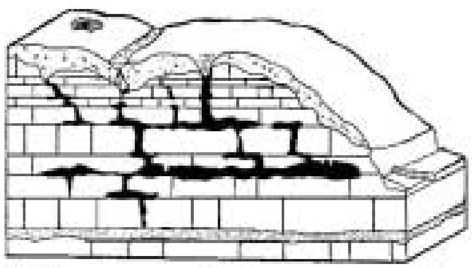
Despite the ability of karst groundwater to move rapidly through conduits and fractures, contaminants introduced into karst aquifers may persist for long periods of time. Investigations in groundwater tracing using dyes have shown that conduits are often intimately connected with fractures, bedding-plane partings, and less integrated bedrock pores. As a result, conduit water may permeate these adjacent bedrock features, which act as storage reservoirs during periods of high flow (Recker et al., 1988).

Physical properties of the contaminant may also affect contaminant transport. Light non-aqueous phase liquids (LNAPL's) for example, may move several kilometers per hour through conduits which are not totally flooded, while migration of heavier solids particles may be limited or stopped where a conduit becomes completely flooded. In highway runoff, LNAPL's in the form of oil and gasoline are present and metal contaminants are typically associated with solids particles. When a high intensity storm event occurs, an initial pulse of water can wash pollutants from the roadway surface and re-suspend the materials deposited deep within the underground caverns. Occurrences, such as these, have been noted in research conducted near Bowling Green, KY (Crawford, 1988).

Although very few studies have been directed toward assessing the impacts of highway runoff on groundwater in karst areas, there has been a report on the effectiveness of installing rock and peat filters to sinkholes receiving highway runoff. In a study by Keith and others (1995), preliminary findings indicated that peat filters were successful at removing approximately 80 percent of suspended particulate materials (measured as total suspended solids and selected total recoverable metals) and about 50 percent of dissolved copper and zinc. Rock filters were able to remove approximately 33 to 76 percent of the total suspended solids and 35 to 55 percent of the total recoverable metals. Rock filters required little maintenance and were very effective at removing contaminants typically associated with solids particles. In karst terrain, these filters were often used in conjunction with small upgradient detention basins, which were installed to capture spills of hazardous materials and to protect the filters.

The effects of highway runoff on groundwater quality depend on local hydrogeologic conditions, including sorption processes of the aquifer material and groundwater velocity. As a result of the near-surface immobilization of pollutants, highway runoff may pose a greater threat to soil than groundwater contamination in many areas. This occurs when particulate metals are filtered out at the soil surface, and dissolved metals are removed by adsorption onto soil particles during infiltration. Highway runoff in karst terrains however, where soil may be thin or nonexistent, may have a more significant impact on groundwater quality.

In regards to karst groundwater quality, it is difficult to generalize about the natural background characteristics in karst aquifers. Most studies have been conducted in aquifers, which have been impacted by one or more land-use activities. The impacts of stormwater runoff on groundwater quality are often complicated by other nearby contaminant sources (Hoos, 1990). Additionally, there is often a wide range of permeability, groundwater velocity, and groundwater resistance time among karst aquifers. Spatial and temporal water quality variations can be extreme in karst systems, as discovered in the studies by Werner (1991). Because of these factors, long-term site specific monitoring before, during, and after storm and meltwater events is necessary to fully determine the range and variability of background water quality characteristics in a karst aquifer. Several studies have suggested that highways are not major contributors of nonpoint source pollution in karst aquifers compared to other land uses (FHWA, 1997).



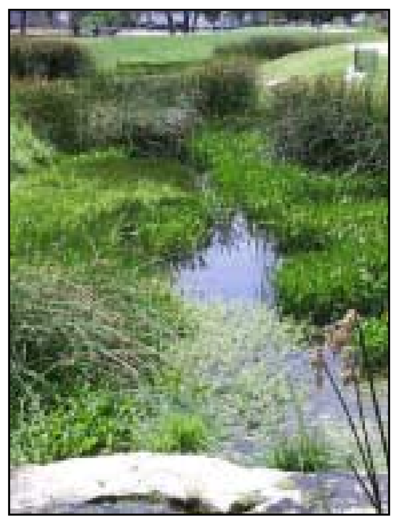
BEST MANAGEMENT PRACTICES

The Best Management practices, or BMPs typically used for controlling pollution from runoff water are categorized as either structural or non-structural practices. Often a combination of one or more practices is necessary to minimize the impacts of development on water quality. Non-structural BMPs are typically “source control” systems designed to minimize the accumulation of pollutants, and reduce their initial concentrations in stormwater runoff. Structural BMPs on the other hand, operate by trapping and detaining runoff water until unwanted pollutant constituents settle out or are filtered through the underlying soil.

Nonstructural practices may include street sweeping, fertilizer application controls, vegetated buffer areas, and land use planning, and are often used in conjunction with structural controls to create a more efficient treatment system. Reduction of pollutant runoff can be accomplished by the elimination of curbs or other barriers, traffic flow regulation, and minimizing the use of fertilizers and pesticides. Several studies have reported that the effectiveness of street sweeping for reducing pollutant loads in runoff is low. Sweeping is most effective at removing the larger particles; however pollutants are generally associated with smaller particles, which have a larger surface area. There is some indication that measurable improvement in metals and solids concentrations in runoff could be obtained with frequent (i.e., twice weekly) sweeping. Vegetative controls such as grassed swale and vegetated buffer strips are popular because of their low costs and minimum maintenance requirements. They have been shown to reduce the concentrations of metals, oil and grease, and suspended solids (Young, G.K., et al., 1996). Removal of nutrients is often less effective. Factors that reduce the effectiveness of swales include steep slopes and fine-grained soils.

Most structural BMPs used to treat highway runoff are found in the form of detention basins. They operate by trapping and detaining runoff until unwanted pollutant constituents settle out or are filtered through the underlying soil. Periodic maintenance is often required for the removal of these pollutants. Pollutant removal in structural BMPs is achieved by the gravitational settling of pollutant, infiltration of soluble nutrients through the soil profile, and to a lesser extent, biological and chemical stabilization of nutrients. One distinct advantage of structural BMPs is the minimum amount of land required on which to locate the structure and ensure optimum operation.

Some examples of the different types of detention basins used to treat highway runoff include dry detention, extended-dry detention, and wet ponds. Primarily a flood control device, dry detention basins are designed to remain dry between storm events. These structures are neither reliable nor effective in treating highway runoff because of the short detention times associated with these structures. Extended dry detention basins are designed to retain the runoff for 6 to 12 hours. As a result there is increased removal of particles and particle associated pollutants. Studies have shown however, that nutrient removal rates are low in extended-dry detention basins and sometimes even negative. An advantage of the dry and extended dry basins is that the construction costs are generally low however; the maintenance burden for these basins is usually higher.



The third type of detention basin, the “wet” pond has been found to be considerably more effective at mitigating pollution. A wet pond is the best choice for controlling highway runoff pollution when non-structural vegetative controls are not feasible. Some of the important factors affecting pollutant removal include pond depth, surface area, and shape. Although many pollutants in a wet pond settle to the bottom, concentrations do not typically come close to exceeding EPA’s criteria for hazardous waste designation. Some of the disadvantages of wet ponds are the considerably higher costs associated with design, permitting, and the purchase of land. Surrounding land use designation may also restrict their applicability.

In constructed wetlands, pollutant removal is achieved primarily through plant uptake, physical filtration, adsorption, gravitational settling, and microbial decomposition. They have the ability to assimilate large quantities of dissolved and suspended solids and exhibit a high nutrient demand. The high cost of wetlands is usually associated with their increased land requirements, which may be two to three times the space required for other control methods. Wetlands are difficult to establish in areas with high soil permeability or high evapotranspiration rates.

Infiltration trenches and basins are designed to contain a certain volume of highway runoff and treat it through a prepared porous media filter bed. Although not well documented, pollutant removal rates appear to be very high. These controls are highly dependent on specific site conditions, so they may not be applicable in many areas. Costs for infiltration structures are higher than for pond systems especially when based on volume of runoff treated, and maintenance appears to be a serious problem. Most infiltration basins have failed due to rapid clogging, usually within 5 years.

Sand filters treat stormwater runoff by percolating it through sand beds, after which, it is collected in drainage pipes and discharged downstream. Removal rates are high for suspended solids and trace metals, and moderate for biochemical oxygen demand, nutrients and fecal coliform. Incorporating peat into the filter material can increase sand filter performance. These filters are useful in areas with thin soils, soils with low infiltration rates, and areas of high evapotranspiration. Construction costs are very high and maintenance is required on a regular basis to prevent clogging of the sand bed with sediment.

Several structural additions have been used in conjunction with primary runoff controls to increase their performance. These additions include oil/grit chambers, sediment forebays, and granular activated carbon filters. Oil and grit chambers used to remove heavy particulates and adsorbed hydrocarbons are relatively ineffective due to their high maintenance requirements. Sediment forebays have been shown to be useful in reducing the sediment load to infiltration structures and sand filters. Granular activated carbon has been used to treat runoff before discharge to underground drainage wells, but it is very expensive.

Combining several of the structural control devices can also increase pollutant removal. Combinations may increase the ability to effectively filter suspended solids or may be useful in reducing the site limitations of a single control measure. The redundancy of expected pollutant removal efficiencies increases the overall reliability and performance of the system.

For highway runoff, most design references specify vegetated controls as their first choice because of their wide adaptability, low costs, and minimal maintenance requirements. When adequate soil depths are present in karst terrain, natural vegetated controls should always be considered. Wet ponds are recommended when site conditions are not conducive to vegetated controls and when there is limited land available for treatment. In karst areas, the location of any pond introduced as a BMP could be critical. Standing water in areas with thin top soils underlain by limestone may increase the potential of developing new sinkholes. Further research in this area is needed. Finally, infiltration practices, although offering excellent treatment potential, are the least desirable because of their high maintenance requirements.

SITE CHARACTERIZATION REPORT

BACKGROUND

Managing and protecting groundwater sources within karst areas are not simple tasks. In order to determine which best management practices are most applicable to a particular highway site, background studies which characterize the highway design features, operating conditions, maintenance practices, and drainage system are all needed. It is also necessary to understand the types of contaminants coming from highway runoff and their effects on the surrounding environment.

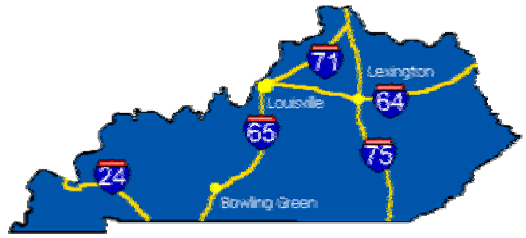
Since the initiation of this investigation, several highway design features at the research site have, or will soon be, modified to provide for the widening of Interstate highway I-65 to six lanes. These changes will greatly affect the drainage paths of the highway runoff as well as incorporate some additional mitigation measures to contain highway spills and slow the water runoff draining into the karst aquifer. In addition, the construction of a Heritage Welcome Center is under proposal to be built near the highway intersection. At the time of this writing, the center is expected to be built within the catchment area, thereby increasing the amount of runoff from impervious areas to the sinkhole under investigation.

SITE LOCATION

For this research investigation, runoff from Interstate highway I-65 draining into the Mammoth Cave karst aquifer was chosen to study. The site is located at the interchange of I-65 and KY 255 at exit 48 near Park City, Kentucky (Figure 1). This site

was recommended by personnel from the Mammoth Cave Park Service and selected for a number of reasons. Runoff from the northbound lanes of I-65 at this intersection drains directly down to concrete lined channels which carry the runoff into a sinkhole. The sinkhole is located approximately 100 yards southeast of I-65. Dye tracing studies previously performed for Mammoth Cave National Park have determined that water entering the sinkhole travels downstream through the Mammoth Caves karst aquifer and discharges into major springs along the south side of the Green River. This aquifer is home to at least nine federally endangered species, including Kentucky Cave Shrimp (*Palaemonias ganteri*) and eyeless cavefish (*Tryphlichthys subterraneus* and *Amblyopsis spelaea*), as well as numerous other sensitive species. Two species of bats also live within the vadose, or air-filled part of the aquifer. Lastly, the site was chosen for its practically in implementing and evaluating a variety of best management practices.

HIGHWAY DESIGN FEATURES



Interstate highway I-65 is a major north-south route, linking the Great Lakes to the Gulf Coast. In Kentucky, it passes by Bowling Green, Elizabethtown, and Louisville while offering intersections with all major east-west highways crossing this section of central and west-central Kentucky. The highway runs approximately 140 miles through Kentucky and is currently being widened to at least six-lanes throughout the state.

At the research site, there are presently four lanes of traffic paved with asphalt. The north and southbound lanes are separated by a grassed median approximately 25 yards wide that serves as a water collection system. Lane widths are 12 feet and highway shoulders extend approximately 10 feet on the right side and 2 feet on the median side. It is estimated that 26% of the impervious area contributing to runoff in the watershed comes from roadways.

HIGHWAY OPERATING CONDITIONS

Vehicle counts around Park City, Kentucky conducted in 1999 estimated the traffic flow to be 32,600 vehicles per day. Of those vehicles, approximately 45 to 50 percent are trucks. For this reason, there has been much concern about accidental spills from tanker trucks containing hazardous material. A toxic spill along I-65 or the CSX railroad in the recharge area of the Mammoth Cave karst aquifer could potentially have devastating consequences. As a result, emergency spill response plans were drawn up and maps were compiled between 1994 and 1995 that locate all of the sinkholes in the recharge area and other geologic features that could affect the movement of a spill. The maps cover a 12-miles stretch of I-65 between mile marker 42 and 54, a 5-mile stretch of the Cumberland Parkway, and the CSX railway that runs above the karst groundwater basin of Mammoth Cave National Park. The emergency response plan is a product of the Mammoth Cave Area International Biosphere Reserve and is used primarily by park officials and employees of the Kentucky Transportation Cabinet.

HIGHWAY MAINTENANCE PRACTICES

During the winter months, two types of highway maintenance practices are used to prevent and remove ice buildup along I-65. When weather reports indicate that there is a high likelihood for snow or ice conditions, anti-icing practices are put into effect. Anti-icing is the practice of preventing the formation or development of snow and ice by applying a chemical freezing-point depressant to the roadways. The chemical used on Kentucky highways is a brine solution of 2.3 pound of salt per gallon of water. It is believed that the application of anti-icing can increase traffic safety by preventing snow and ice accumulation and reduce the overall quantity of chemicals needed to remove snow and ice once it has fallen and bonded to the road surface. The second type of winter highway maintenance practice is de-icing, which occurs after the snow has fallen.

This practice includes the application of a calcium chloride spray and/or road salt granules to the road surface. Although calcium chloride is the preferred method, the cost of its application is at least five times greater than traditional road salt.

In the summer months, pesticide application is used along I-65 to prevent roadside vegetation from interfering with traffic flow. The impact of this application to aquatic life in the Mammoth Cave karst aquifer is not known, however, it is believed to be minimal.

DRAINAGE SYSTEM CHARACTERISTICS

Highway runoff from I-65 drains into either the center grassed median or the grass lined right-of-ways. Drainage pipes, located in the lowest elevation point of the center grassed median, carry runoff to various concrete-lined channels which drain the water away from the highway surface. At the intersection of I-65 and 255, the concrete lined ditches carry the highway runoff along both the north and south sides of KY 255 for approximately 50 yards (Appendix A- Photo Log). After which the runoff travels down through a rocky, bare soil path and into a sinkhole. The concrete-lined channels measure approximately 2 feet on the bottom with sides flaring up at 45 degree angles and also measuring approximately 2 feet as shown in Figure 2. The ditches on the south side of KY 255 are overgrown with vegetation which partially disrupts the flow path. The ditches on the north side of KY 255 are mostly free of vegetation however, in a few sections they pass under areas of overgrown trees limbs (Appendix A- Photo Log).

A third drainage route terminating at the sinkhole comes directly from parking lot runoff of the adjacent towing and service station. An 18" corrugated metal pipe carries the parking lot runoff underground to the edge of the pavement closest to the sinkhole, at which point the water pools, and drains down a steep rocky embankment to join the other paths before reaching the mouth of the sinkhole. This drainage route was found to contribute the greatest quantity of runoff to the sinkhole. Approximately 70-75% of the water observed came from this source, while the other two drainage routes, which both originate at the highway intersection, only contributed a combined flow quantity of approximately 25-30%. A much larger pulse of runoff was also observed to be coming from the parking lot runoff soon after a rain event began. This was to be expected since pavement has a much lower saturation threshold then natural vegetation and the travel distance from the parking lot ranged only from 5 – 25 yards. Lastly, runoff draining from the parking lot was cloudy grey in appearance and left residue on the vegetation along the drainage path.

During the widening phase of I-65, the construction plans include the removal of the concrete-lined channels on both sides of KY 255 with the replacement of natural vegetation. Earthen dams with porous rock cores are also proposed to be built in series along the runoff drainage routes. The dams have been designed to ideally slow the runoff in the event of a hazardous spill and allow enough time for the material to be pumped out by a hazardous response team before reaching the sinkhole. The design in effect will also be slowing the normal runoff velocity from the highway drainage routes and thereby provide both a settling out and filtration mechanism to improve water quality.

HYDROLOGIC CHARACTERISTICS

Hydrologic modeling was performed on the sinkhole catchment area to determine the amount of storage that would be needed to contain various peak flow amounts of a one-hour storm event for the frequency of 2, 5, and 10 years. The modeling was performed using the HEC-HMS software application. From topographic maps, the catchment area was estimated to be 0.0667 mi^2. From site investigations, the watershed cover was estimated to consist of roads making up 26%, parking lot in 2.3% of the area, grass area in 11.6%, and forest in 60% of the catchment area. From this data, the SCS composite curve number was computed to be 69.37. Peak conditions occurred at the simulated reservoir during the 10 year frequency event when 25% of the peak flow was being attenuated. From this data, it was determined that the amount of storage needed was 1.37 acre-feet. See Appendix B for details on the model assumptions used and methods employed.

MONITORING DATA ON WATER QUALITY

In order to establish a baseline of water quality data at the research site, runoff entering the sinkhole was monitored for a period of approximately three months from April to July of 2002. Runoff was collected from five separate monitoring locations as shown in Figure 3. The drainage paths are also noted in the figure. A summary of all laboratory results by site location can be found in Appendix C. A considerable number of samples were collected for sites E48N and E48S because of their proximity to the highway. It was believed that these monitoring locations would provide data on the greatest concentration strengths of pollutants before reductions occurred due to movement of the water through concrete lined ditches and vegetated swales. The runoff collected at site S255 was found to originate mainly from the adjacent parking lots of a gasoline and towing service station.

A number of different water quality parameters were chosen to be tested based on the most common contaminates found in highway runoff. For each sample that was collected from the research sites, the following analyses were performed: total suspended solids (TSS), total organic carbon (TOC), and total dissolved metals. A limited number of samples were also tested for total petroleum hydrocarbons (TPH). All laboratory tests were performed using EPA certified standard methods as described in the following sections.

TOTAL SUSPENDED SOLIDS (TSS)

EPA Method 2540 D was used to perform the total suspended solids analysis. Each sample was collected in an unpreserved 8 oz. plastic bottle and refrigerated to 4 degrees Celsius upon arrival at the laboratory. According to this method, a glass-fiber filter disk was first prepared through the successive rinsing of de-ionized water followed by the drying of the disk in an oven set at approximately 104 degrees Celsius. The disk was then weighed for its initial mass. Next, 50 mL of sample was passed through the disk under vacuum pressure leaving any solids particles greater than 1.5 μm on the disk. The disk was then placed in an oven set between 103 and 105 degrees Celsius for at least one hour. The final weight of the disk was next obtained. The determination of total suspended solids was computed as follows:

Total Suspended Solids (mg/L)

$$= \frac{(A - B)x1000}{samplevolume, mL}$$

where:

A = weight of filter + dried residue, mg.
B = weight of filter, mg.

TOTAL ORGANIC CARBON (TOC)

Samples collected for TOC measurement were contained in 8 oz. plastic bottles preserved with hydrochloric acid and refrigerated to 4 degree Celsius upon arrival at the laboratory. A Shimadzu Model TOC-5000A analyzer and Autosampler ASI-5000A were used to measure the amount of organic carbon found in the sample. The analyzer determined the TOC results by sparging the acidified sample with high purity air to eliminate inorganic carbon components prior to measuring the total carbon concentration. This method is also known as combustion/non-dispersive infrared gas analysis method. The standards used in this method were potassium acid phthalate solutions at concentrations of 1.0, 2.5, and 5.0 mg/L.

TOTAL PETROLEUM HYDROCARBONS (TPH)

EPA method 10050 was used to determine the qualitative TPH results as a factor of gasoline presence. Samples obtained for this analysis were collected in unpreserved 32 oz. amber glass jars and refrigerated to 4 degrees Celsius upon arrival at the laboratory. The method used is an immunoassay method that provides semi-quantitative results expressed as greater or less than the threshold values. To perform this analysis, a spectrophotometer measured the light absorbance level of the samples and calibrators after a color developing reaction was performed. Each TPH calibrator was formulated to represent a specific concentration of diesel fuel. The absorbance levels of the samples were then compared to the calibrator levels in order to determine the approximate concentration of gasoline found in the sample.

TOTAL DISSOLVED METALS

All samples collected for metals analysis were contained in 8 oz. plastic containers preserved with nitric acid. To begin the analysis procedure samples were filtered with 0.2 micron Nalgene Syringe Filters. All samples were digested and analyzed by ICP-OES following Methods 3030F and 3120B in the Standard Methods for the Examination of Water and Wastewater 20th ed. (1998) in the laboratory of Dr. David Atwood, Associate Chemistry Professor at the University of Kentucky.

ANALYSIS RESULTS

A summary of the average values obtained from laboratory analysis for each site along with those reported in literature are presented in Table 2. The results demonstrate the relatively low concentration of metals and organic pollutants coming from the highway runoff under evaluation in comparison to other highway runoff reported in literature. Only the water quality constituents thought to have the greatest impact on both human and aquatic life are shown in Table 2.

A complete listing of all laboratory analyses for each site can be found in Appendix C. Other metal concentrations of significance found in this study included levels of calcium and sodium which ranged from 0.13 to >100 mg/L and from 1.56 to 31.9 mg/L respectively. These metals are known to occur naturally in karst soils found in this region. The site with the highest concentration of suspended solids was S255, which is the site that receives runoff from the adjacent parking lots. The only two sites (E48N and E48S) where lead was detected were the ones located closest to the highway intersection. Samples taken at these sites also contained significantly greater amounts of sodium in comparison to the other two sites. The highest concentration of TOC was found at site N255 just north of KY 255 and across the street from the paved areas. Overall, very few notable trends were observed in the analysis data. This is most likely due to the highly complex nature of highway runoff sample collection.

SUMMARY AND CONCLUSIONS

The literature review presented in this report indicates that there have been many significant findings regarding the nature of highway runoff quality and its influencing factors. Research has found vehicles to be both a direct and indirect source of highway pollutants. Directly, they contribute to the runoff though vehicle exhaust, the wearing of automotive parts, and the leakage of automotive associated fluids. Indirectly, vehicles carry solids that are acquired from the atmosphere and later deposited on roadways, often during storms. Although storms are the primary removal mechanism of pollutants, neither storm duration nor antecedent dry period were found to significantly impact the amount of pollutants found in runoff. Intensity however, was found to impact the type and quantity of pollutants. Although it would seem that traffic volume would influence the accumulation of contaminants on a road surface, most studies have found no strong or definitive relationship between average daily traffic and pollutant levels. Instead, it is believed that higher traffic volumes generate greater vehicle disturbance of the pollutants often causing them to be found in the soils of right-of-ways instead of left on the highway surface.

It was reported that the greatest influencing factor on pollutant loads in highway runoff is surrounding land use and in particular atmospheric quality. This suggests that atmospheric fallout contributes more contaminants to the impervious surface of roadways than vehicles either directly or indirectly.

The way that pollutants interact with the environment also influences their effects. Pollutants such as heavy metals, oil and grease, TOC, and COD are often found attached to solids particles and can generally be significantly reduced through infiltration techniques. Higher concentrations of these pollutants however, are often associated with smaller size soil fractions. Nutrients have been found to occur more often in the dissolved rather than the particulate phase.

Karst aquifers have been found to be unique in a number of ways. Runoff on karst terrain enters the aquifer with little or no infiltration through sinkholes, springs, and underground streams. Karst groundwater typically travels at very high velocities, comparable to surface streams which can cause re-entrainment of cave sediments. Although karst groundwater is able to move rapidly through conduits and fractures, it may also permeate bedrock features which can act as storage reservoirs. When this occurs contaminants may become stagnant for long periods of time. As a result of these features, groundwater found in karst is often more susceptible to contamination. Also, sensitive ecosystems are often found in karst aquifers.

Studies previously conducted on karst aquifers have been highly site specific. Due to the nature of the rock characteristics and age of the caverns, natural background characteristics cannot be generalized to all karst regions. Preventing contaminants from entering the aquifers and preventing re-entrainment of sediments within the cave system are the only ways to ensure their protection. Studies have found that peat filters have had much success in removing suspended solids particulate materials as well as rock filters.

The recommended best management practices for highway runoff in any terrain are vegetative controls such as grassed swales and buffer strips. These have been found to have wide adaptability, low cost, and require minimum maintenance. When vegetative controls are not conducive to site conditions, wet ponds are recommended.

In addition to the literature review, a site characterization was performed to provide some background data on highway runoff entering the Mammoth Cave karst aquifer. The site chosen is known to enter the aquifer upstream of the national park and eventually discharge into the Green River. The estimated traffic flow at the site location has previously been estimated to be around 32,000 vehicles per day. The highway characteristics include a four lane road with center grassed median. The vegetated median is believed to serve a very beneficial role, by slowing the highway runoff and allowing it to infiltrate. The surrounding land characteristics include mostly agriculture and forest. A significant source of runoff entering the sinkhole comes from the parking lots of the gasoline and towing station located adjacent to the sinkhole. In a hydrologic analysis performed on the catchment area, it was estimated that 1.37 acre feet would be needed for the storing of the peak flow of a one-hour storm event.

From the water quality data obtained for this report, the analyses are very typical and the results fall well within the ranges of average values obtained in other highway runoff studies. There was no significant single source of contamination found and the overall concentration of metals and total organic carbon were determined to be at the lower ends of the average value ranges. Three main sources of runoff, two from highway and one from a parking lot were found to be feeding the sinkhole under investigation. It was observed that the parking lot runoff was a much larger contributor to the overall drainage amount than originally anticipated. Additional laboratory analyses for total petroleum hydrocarbons were performed on this source but did not yield any significant results. In regards to the drainage path that was used by the runoff originating on the highway, concrete lined drainage ditches were believed to inhibit the beneficial effects of water infiltration from natural vegetated drainage ways. The concrete lined channels were also thought to be the result of greater water quantities reaching the sinkhole with higher velocities. Finally, it is projected that the plans to widen the highway at the investigation site and remove the vegetated center grassed median will increase the amount of runoff leaving the highway and prevent many of the contaminants from being infiltrated before traveling along KY 255 to the sinkhole. However, with the removal of the concrete-lined ditches and the construction of earthen dams, the ultimate overall positive or negative effect has yet to be realized.

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TABLES

Table 1. Constituents of highway runoff, ranges of average values reported in literature
(As reported by Driscoll, et al., 1990)

Constituent	**Concentration** (mg/L)	**Load** (kg/ha/year)	**Load** (kg/ha/event)
Solids			
Total	437-1147		58.2
Dissolved	356	148	
Suspended	45-798	314-11,862	1.8-107.6
Volatile, dissolved	45-798		
Volatile, suspended	131	45-961	.89-28.4
Volatile, total	4.3-79	179 – 2518	10.5
Metals (totals)			
Zn	0.56 .929	.22-10.40	.004-.025
Cd	0.00-0.04	0.0072-0.037	.002
As	0.058		
Ni	0.053	0.07	
Cu	0.022-7.033	0.03-4.67	.0063
Fe	2.429-10.3	4.37-28.81	.56
Pb	0.073-1.78	.08-21.2	.008 -.22
Cr	0.00-0.04	.012-.10	.0031
Mg	1.062		
Hg, x 10^{-3}	3.22	.007	.0007
Nutrients			
Ammonia, total as N	0.07-0.22	1.03-4.6	
Nitrite, total as N	0.013-0.25		
Nitrate, total as N	0.306-1.4		
Nitrite + Nitrate	0.15-1.636	.8-8.0	.078
Organic, total as N	0.965-2.23		
TKN	0.335-55.0	1.66-31.95	.17
Nitrogen, total as N	4.1	9.80	.02-.32
Phosphorus, total as P	0.113-0.998	.6-8.23	
Miscellaneous			
Total Coliforms (orgs./100mL)	570-6200		
Fecal Coliforms (orgs./100 mL)	50-590		
Sodium		1.95	
Chloride		4.63-1344	
PH	7.1-7.2		
Total Organic Carbon	24-77	31.3-342.1	.88-2.35
Chemical Oxygen Demand	14.7-272	128-3868	2.90 66.9
Biological Oxygen Demand (5 day)	12.7-37	30.60-164	0.98
Polyaromatic Hydrocarbons (PAH)		0.005-.018	
Oil and Grease	2.7-27	4.85-767	0.09-0.16

Surrounding Land Use Considerations

Table 2. Average Values of Highway Runoff Constituents (All results are in mg/L)

	As Reported in Literature	E48N	E48S	S255	N255
Metals (mg/L)					
Zn	.056 - .929	0.338	0.344	0.183	0.258
Cd	ND - 0.04	ND	ND	ND	ND
As	0.058	ND	ND	ND	ND
Ni	0.053	ND	ND	ND	ND
Cu	.022-7.033	0.079	0.045	0.024	ND
Fe	2.429-10.3	0.842	1.050	0.364	0.083
Pb	0.73 -1.78	0.090	0.112	ND	ND
Cr	ND - 0.04	ND	ND	ND	ND
Mg	1.062	2.080	4.067	3.258	4.353
Others (mg/L)					
TSS	45-798	62	62	100	41
TOC	24-77	20	28	25	31
TPH (Gasoline)	2.7-27	< 2	< 2	2-5	< 2

ND = Detection was less than 0.01 mg/L

FIGURES

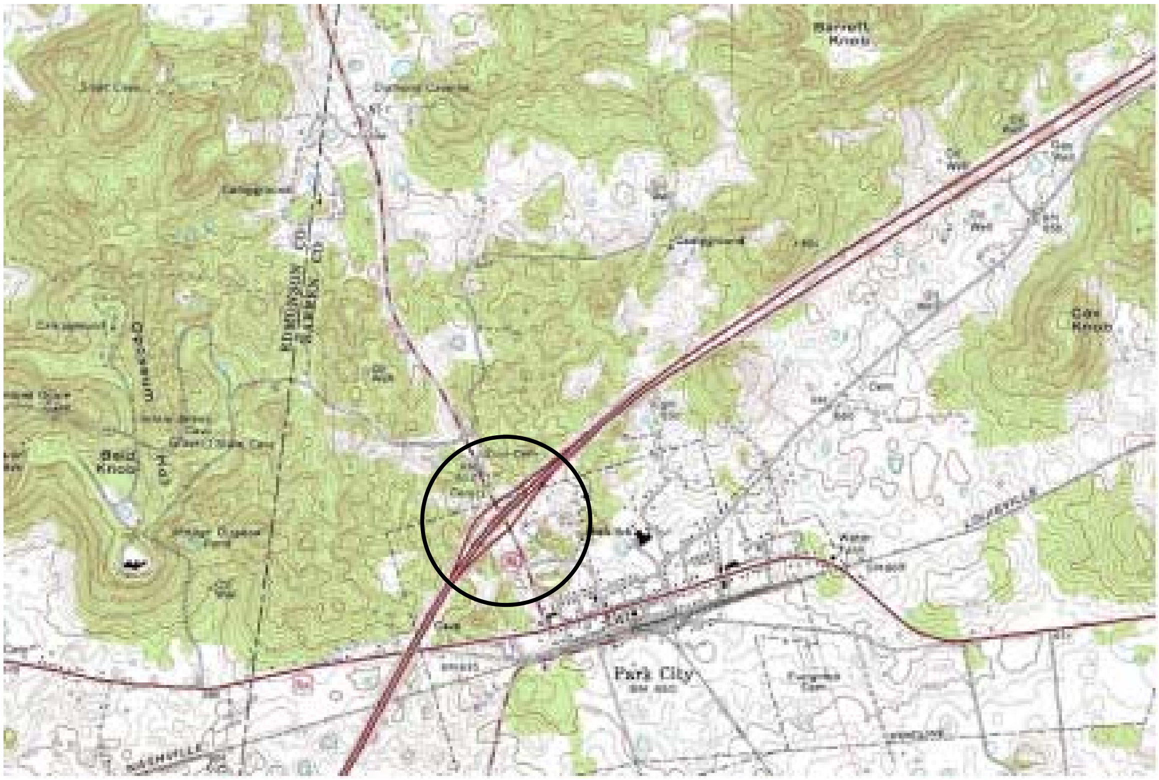


Figure 1. Site location map

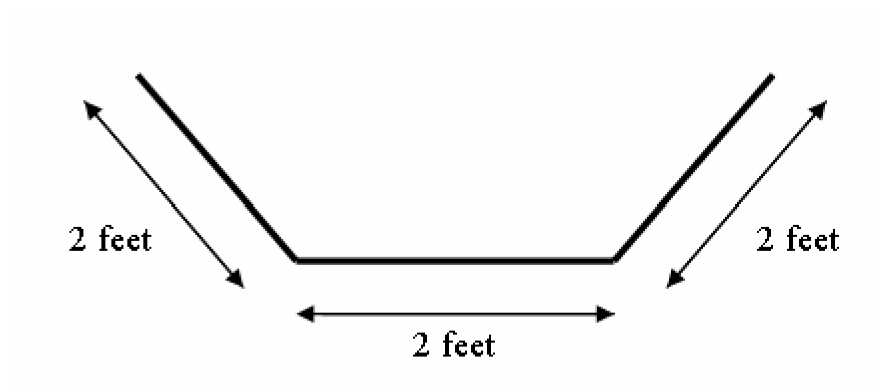


Figure 2. Concrete-lined channel dimensions

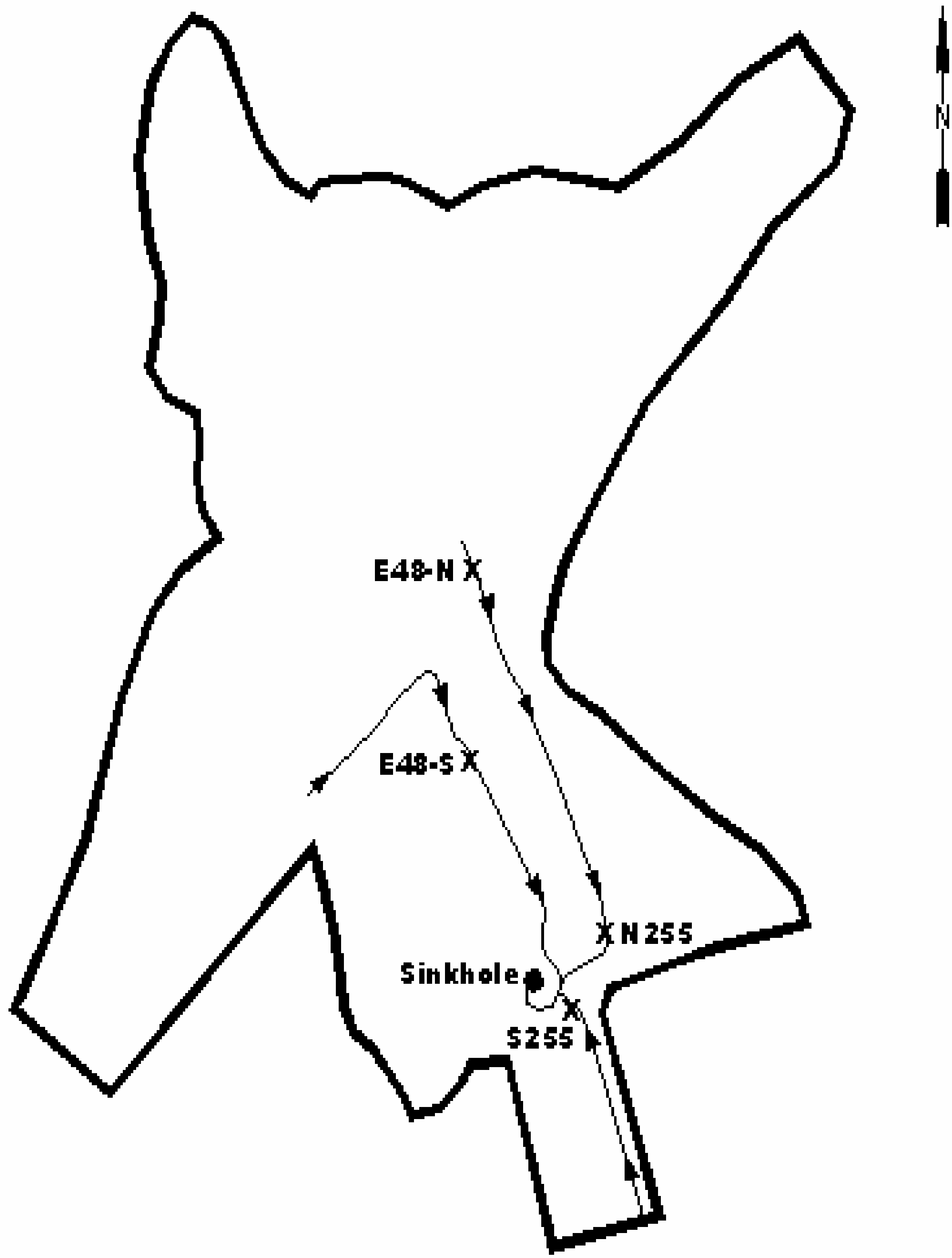


Figure 3. Sampling points and flow routes to sinkholes

APPENDICES

APPENDIX A – PHOTO LOG

Figure 4. Interstate I-65 looking north from exit 48.

Figure 5. I-65 looking south at exit ramp for Park City.

Figure 6. Looking east at KY 255 where the sinkhole is located from I-65 south.

Figure 7. Drainage grates in grassed highway median.

Figure 8. Drainage under I-65 to prevent highway flooding.

Figure 9. Drainage from northbound I-65 lanes (sampling point E48N).

Figure 10. Drainage under ramp to I-65 north.

Figure 11. Concrete lined channel from I-65 onto KY 255.

Figure 12. Concrete-lined channel carrying runoff north of KY 255.

Figure 13. Concrete lined channel carrying runoff into the sinkhole.

Figure 14. Cracks in the lined channel carrying runoff from I-65.

Figure 15. Lined channel covered with brush north of KY 255.

Figure 16. Sampling point N255 at end of concrete channel.

Figure 17. Concrete lined channel on south side of KY 255.

Figure 18. Drain across KY 255 feeding into the sinkhole.

Figure 19. Concrete lined channels on east of I-65.

Figure 20. Concrete channel feeding runoff from I-65 N onto north of KY 255.

Figure 21. Concrete lined channel on east of I-65 N.

Figure 22. Sampling point S255 where water pools from parking lot drainage.

Figure 23. Gasoline and towing station parking lot.

Figure 24. Runoff paths down to sinkhole.

Figure 25. Mouth of sinkhole.

Figure 26. At the mouth of the sinkhole.

Figure 27. With Mr. Joe Meiman of National Parks Service at the sinkhole.

APPENDIX B – HYDROLOGIC ANALYSIS RESULTS

DELINEATED CATCHMENT AREA

The catchment area calculated from topographic maps is 0.0667 mi^2. Delineated catchment is shown in Figure 1.

COMPOSITE SCS CURVE NUMBER CALCULATION

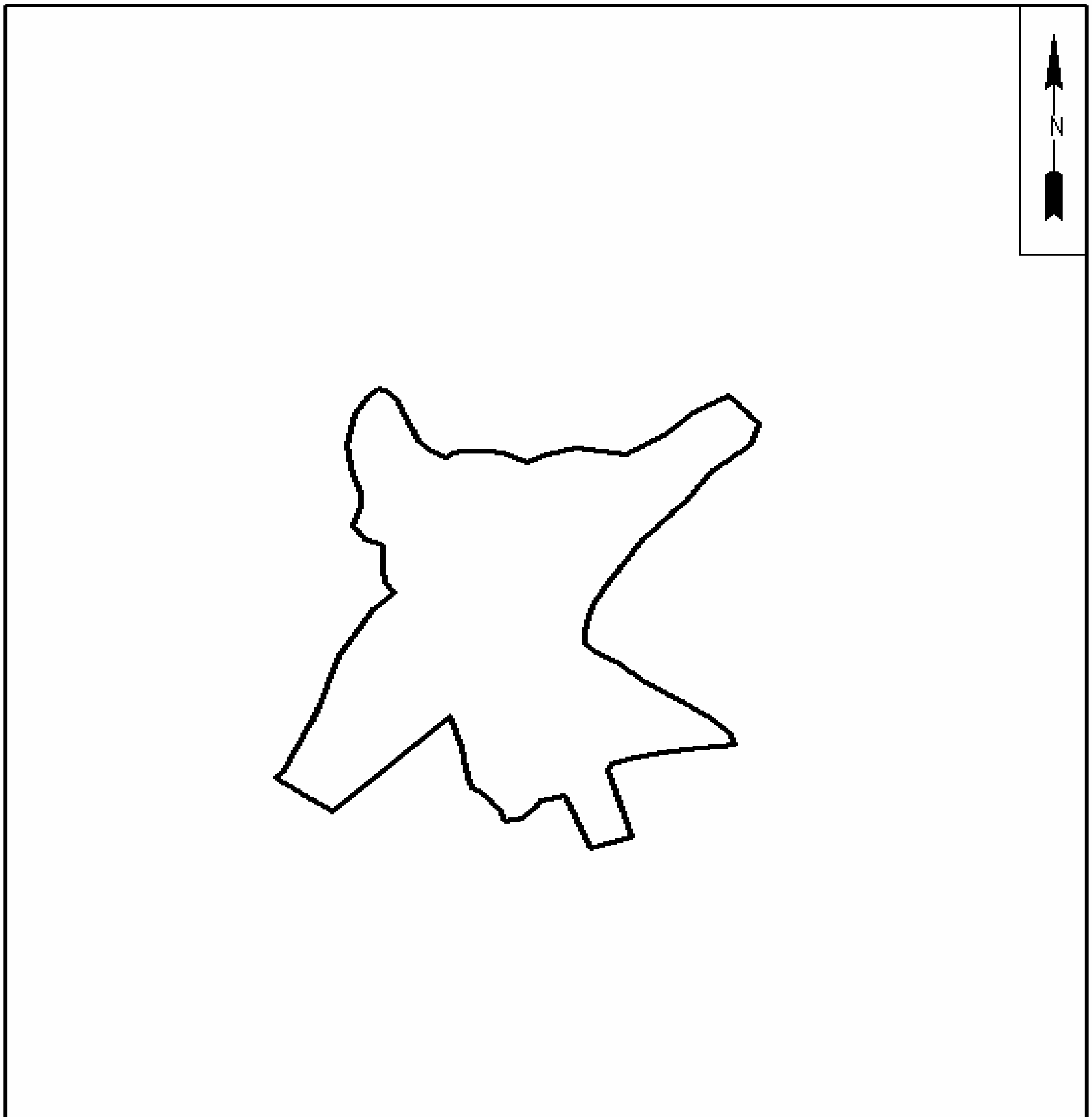
Table 3. Composite SCS Curve Number Calculation

Cover Description	Hydrologic Condition	Hydrologic Group	CN	% Area	CN * Area
Roads	--	B	98	26.16	2563.68
Parking Lot	--	B	98	2.32	227.36
Grass Area	--	B	58	11.63	674.54
Forest	Good	B	58	59.89	3471.88

Total = 6937.46

CN = 6937.46 / 100

CN = 69.37



Scale 1" = 1000'

Figure 1 - Delineated Watershed
Watershed area = 0.0667 square miles
Near Park City, Kentucky

B-2

CRITICAL STORM

One-hour rainfall events of 2, 5, and 10 year frequency were used to determine the critical storms for Edmonson County. The storm analysis was based on the SCS method for 24-hour rainfall distribution. See Table 2 on the following page for analysis results.

Table 4. One-hour rainfall hyetograph for Edmonson county

Time (minutes)	**Fraction**	**Rainfall Frequency**		
		10 year (2.1 in.)	**5 year (1.8 in.)**	**2 year (1.5 in.)**
0	0	0	0	0
3.75	0.02	0.042	0.036	0.03
7.5	0.04	0.084	0.072	0.06
11.25	0.06	0.126	0.108	0.09
15	0.08	0.168	0.144	0.12
18.75	0.1	0.21	0.18	0.15
22.5	0.103	0.2163	0.1854	0.1545
26.25	0.108	0.2268	0.1944	0.162
30	0.608	1.2768	1.0944	0.912
33.75	0.8	1.68	1.44	1.2
37.5	0.808	1.6968	1.4544	1.212
41.25	0.9	1.89	1.62	1.35
45	0.903	1.8963	1.6254	1.3545
48.75	0.905	1.9005	1.629	1.3575
52.5	0.907	1.9047	1.6326	1.3605
56.25	0.9085	1.90785	1.6353	1.36275
60	1	2.1	1.8	1.5

HYDROLOGICAL MODELING

Using HEC-HMS software, the catchment area for the conditions noted above was used to produce various outflow hydrographs. The models were all based on the following assumptions:

- SCS loss rate method
- SCS rainfall-runoff transform method with lag time of 10 minutes
- Initial loss is of 0.1 inches
- Impervious area = 0%.

In order to determine the amount of storage needed for each storm condition, a reservoir was introduced into the model. The storage required to attenuate the peak flow by 25%, 50%, and 75% were modeled. The storage data results for the various cases can be found in Table 2 on the following page. Figure 1 shows the hydrograph and storage characteristics needed for the overall peak flow which occurred during the 10-year event.

Table 5. Outflow from reservoir and storage required

S. No.	**Peak flow**		**Storage acre-ft**
	%	**cfs**	
10 year frequency			
1.1	100	72	--
1.2	75	54	0.5376
1.3	50	36	0.9056
1.4	25	18	1.3704
5 year frequency			
2.1	100	54	--
2.2	75	41	0.40507
2.3	50	27	0.68326
2.4	25	14	0.98806
2 year frequency			
3.1	100	38	--
3.2	75	29	0.26876
3.3	50	19	0.48454
3.4	25	10	0.70054

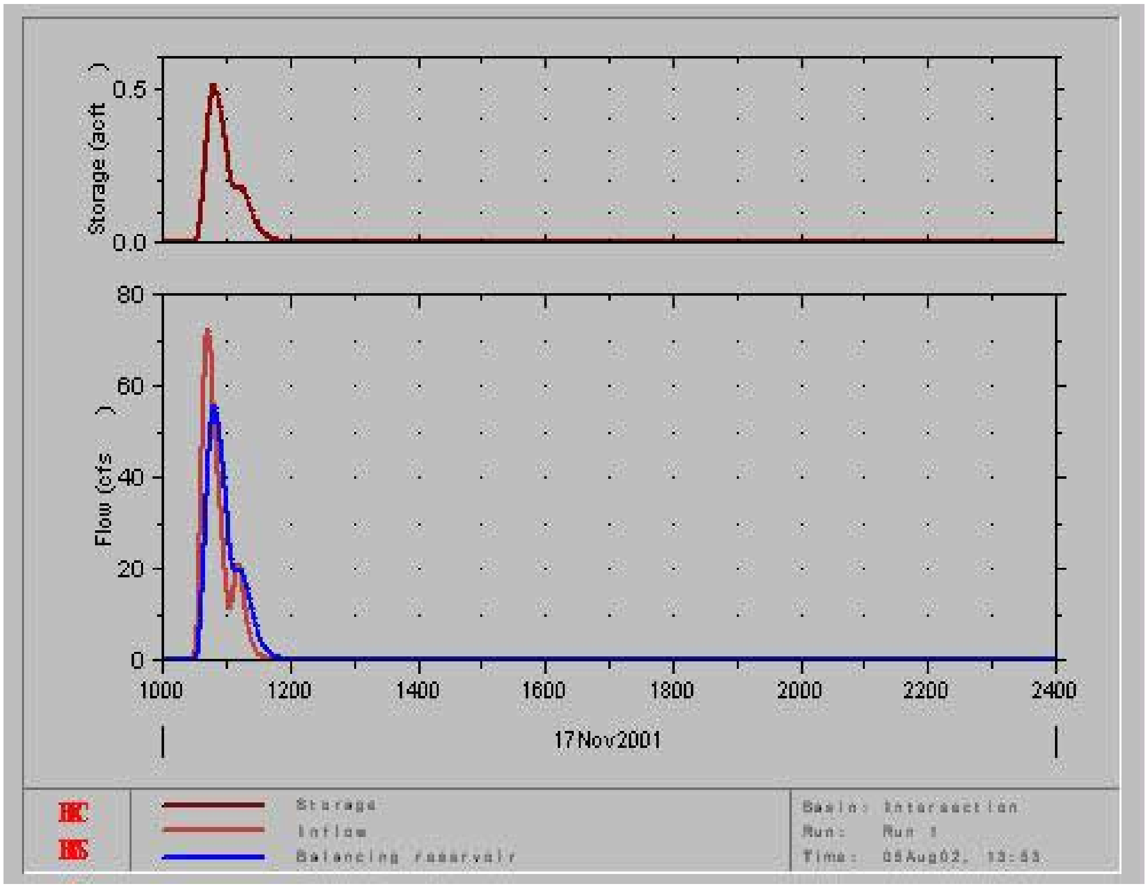


Figure 2 - Reservoir outflow and storage for 10-year event

APPENDIX C – WATER QUALITY ANALYSIS RESULTS

Table 6. Constituents of Highway Runoff, Ranges of Average Values Reported in Literature

	Concentration (mg/L)
Metals	
Zn	.056 - .929
Cd	ND - 0.04
As	0.058
Ni	0.053
Cu	.022-7.033
Fe	2.429-10.3
Pb	0.73 -1.78
Cr	ND - 0.04
Mg	1.062
Others	
TSS	45-798
TOC	24-77
Oil and Grease	2.7-27

Table 7. Constituents of Highway Runoff, Average Values (mg/L) found in this Study Near Intersection of I-65 and KY 255

	E48N	**E48S**	**S255**	**N255**
Metals				
Zn	0.338	0.344	0.183	0.258
Cd	ND	ND	ND	ND
As	ND	ND	ND	ND
Ni	ND	ND	ND	ND
Cu	0.079	0.045	0.024	ND
Fe	0.842	1.050	0.364	0.083
Pb	0.090	0.112	ND	ND
Cr	ND	ND	ND	ND
Mg	2.080	4.067	3.258	4.353
Others				
TSS	62	62	100	41
TOC	20	28	25	31
TPH (Gasoline)	< 2	< 2	2-5	< 2

Collection SITE Locations:

E48N - Runoff from exit 48, north of 255. Collected at spillway where northbound highway runoff drains.

E48S - Runoff from exit 48, south of 255. Collected from concrete lined channel just after passing under northbound exit ramp.

N255 - Runoff collected from the north side of 255 just before it travels under 255. Samples collected where concrete channel ends.

S255 - Runoff collected from parking lot runoff on the south side of 255 where pooling occurs before water travels down rock embankment toward sinkhole.

Table 8. Exit 48 North of 255 (All results are in mg/L)

Sample #	Sample #1	Sample #3	Sample #7	Sample #8	Sample #11	Sample #15	Sample #19	Averages
Collection	4/24/2002	5/13/2002	5/9/2002	5/17/2002	6/6/2002	6/13/2002	7/10/2002	
TOC Analysis Date	5/24/2002	5/24/2002	5/24/2002	5/24/2002	8/5/2002	8/5/2002	8/5/2002	
TOC Results	21.63	21.23	25.47	29.10	10.90	10.13	21.91	20
TSS Analysis Date	06/05/02	06/05/02	06/05/02	06/05/02	06/17/02	06/17/02	07/16/02	
TSS Results	238	16	4	78	12	12	76	62
TPH Analysis Date	8/21/2002	8/21/2002		8/21/2002	8/21/2002	8/21/2002		
TPH Results[1]	< 2	< 2		2-3	< 2	< 2		
Metals Analysis Date	5/13/2002	5/15/2002	5/15/2002	5/20/2002	6/10/2002	6/14/2002	7/11/2002	
Metals Results[2]								
Ag	<.01	<.01	<.01	<.02	<.01	<.01	<.01	ND
Al	1.390	1.460	0.079	0.996	0.444	0.321	0.570	0.751
As	<.01	<.01	<.01	<.02	<.01	<.01	<.01	ND
B	<.01	<.01	<.01		0.404	0.121	0.435	0.320
Ba	0.086	0.056	0.122	0.225	0.220	0.122	0.173	0.144
Be	<.01	<.01	<.01	<.02	0.000	<10	<10	ND
Ca	38.800	19.800	17.800	36.400	11.300	10.700	26.300	23.014
Cd	<.01	<.01	<.01	<.02	1.000	<.01	<.01	ND
Co	<.01	<.01	<.01	<.02	0.000	<.01	<.01	ND
Cr	<.01	<.01	<.01	<.02	<.01	<.01	<.01	ND
Cu	<.01	<.01	<.01	0.079	<.01	<.01	<.01	0.079
Fe	0.931	0.894	0.186	1.840	0.966	0.452	0.624	0.842
K	3.130	2.980	2.670	3.360	1.260	1.310	1.800	2.359

Table 8. Exit 48 North of 255 Continued..

Sample #	Sample #1	Sample #3	Sample #7	Sample #8	Sample #11	Sample #15	Sample #19	Averages
Mg	4.500	2.180	1.230	2.890	0.878	0.833	2.050	2.080
Mn	0.140	0.010	0.011	0.065	0.014	0.012	0.070	0.046
Mo	<.01	<.01	<.01	<.02	0.023	<.01	<.01	0.023
Na	20.400	15.500	21.400	11.000	3.420	2.170	6.530	11.489
Ni	<.01	<.01	<.01	<.02	<.01	<.01	<.01	ND
Pb	0.090	<.01	<.01	<.02	<.01	<.01	<.01	0.090
Sb	<.01	<.01	<.01	<.02	<.01	<.01	<.01	ND
Se	<.01	<.01	<.01	<.02	<.01	<.01	<.01	ND
Si	1.440	2.900	0.929	1.120	1.110	0.623	1.200	1.332
Ti	0.068	0.042	<10	<.02	0.024	<10	<10	0.045
Tl	<.01	<.01	<.01	<.02	<.01	<.01	<.01	ND
V	<.01	<.01	<.01	<.02	<.01	<.01	<.01	ND
Zn	0.292	0.062	0.222	0.965	0.207	0.128	0.487	0.338

[1]TPH analysis was a qualitative test for gasoline levels.
[2]For metals values listed as below the safe calibration range of <.01 mg/L, the recorded values fell near detection

Sample # 1 - Collected by J. Meiman on 4/24/02. First flush sample contained a lot of visible solids particles.
Sample # 3 - Collected by J. Webster on 5/13/02. Heavy Rains started around 3 a.m. Samples collected at 9:00 a.m.
Sample # 7 - Collected by J. Webster on 5/9/02. Light rain started around 8 a.m. Samples collected at 10:45 a.m.
Sample # 8 - Collected by J. Webster on 5/17/02. First flush samples collected at 10:15 a.m.
Sample # 11 - Collected by J. Webster on 6/6/02. Moderate rain started around 7 a.m. Collected samples at 11:00 a.m.
Sample # 15 - Collected by J. Webster on 6/13/02. Scattered showers throughout the morning. Collected samples around 10:30 a.m. at end of storm.
Sample # 19 - Collected by J. Webster on 7/10/02. Collected sample immediately after a 5 minute hard, summer rainfall around 11 a.m.

Table 9. Exit 48 South of 255 (All results are in mg/L)

	Sample #2	**Sample #4**	**Sample #9**	**Sample #12**	**Sample #16**	**Sample #20**	**Averages**
Collection	4/24/2002	5/13/2002	5/17/2002	6/6/2002	6/13/2002	7/10/2002	
TOC Analysis Date	5/24/2002	5/24/2002	5/24/2002	8/5/2002	8/5/2002	8/5/2002	
TOC Results	16.79	30.23	18.71	32.60	34.49	33.46	28
TSS Analysis Date	06/05/02	06/05/02	06/05/02	06/17/02	06/17/02	07/16/02	
TSS Results	312	16	38	4	2	2	62
TPH Analysis Date	8/21/2002	8/21/2002	8/21/2002				
TPH Results[1]	< 2	< 2	2-3				
Metals Analysis Date	5/13/2002	5/15/2002	5/20/2002	6/10/2002	6/14/2002	7/11/2002	
Metals Results[2]							
Ag	0.000	<.01	<.02	<.01	<.01	<.01	ND
Al	1.260	3.890	0.457	0.448	0.596	0.308	1.160
As	<.01	<.01	<.02	<.01	<.01	<.01	ND
B	<.01	<.01	<.02	0.374	0.726	0.417	0.506
Ba	0.339	0.033	<.02	0.088	0.054	0.059	0.115
Be	<.01	<.01	<.02	<.01	<.01	<.01	ND
Ca	53.900	26.300	12.500	29.900	29.500	37.000	31.517
Cd	<.01	<.01	<.02	<.01	<.01	<.01	ND
Co	<.01	<.01	<.02	<.01	<.01	<.01	ND
Cr	<.01	<.01	<.02	<.01	<.01	<.01	ND
Cu	0.045	<.01	<.02	<.01	<.01	<.01	0.045
Fe	2.350	2.330	0.075	0.230	0.264	<.01	1.050
K	2.400	6.750	4.180	13.800	7.880	7.560	7.095

Table 9. Exit 48 South of 255 Continued..

	Sample #2	Sample #4	Sample #9	Sample #12	Sample #16	Sample #20	Averages
Mg	6.230	3.760	2.320	3.900	3.890	4.300	4.067
Mn	0.222	0.023	0.023	0.019	0.011	0.017	0.052
Mo	<.01	<.01	<.02	0.010	<.01	<.01	0.010
Na	8.175	29.300	2.940	20.400	17.000	31.900	18.286
Ni	<.01	<.01	<.02	<.01	<.01	<.01	ND
Pb	0.112	<.01	<.02	<.01	<.01	<.01	0.112
Sb	<.01	<.01	<.02	<.01	<.01	<.01	ND
Se	<.01	<.01	<.02	<.01	<.01	<.01	ND
Si	0.774	7.730	1.180	2.480	2.420	6.010	3.432
Ti	0.008	0.108	<.02	<.01	<.01	<.01	0.058
Tl	<.01	<.01	<.02	<.01	<.01	<.01	ND
V	<.01	<.01	<.02	<.01	<.01	<.01	ND
Zn	0.654	0.035	<.02	<.01	<.01	<.01	0.344

[1]TPH analysis was a qualitative test for gasoline levels.
[2]For metals values listed as below the safe calibration range of <.01 mg/L, the recorded values fell near detection

Sample # 2 - Collected by J. Meiman on 4/24/02. First flush sample contained a lot of visible solids particles.
Sample # 4 - Collected by J. Webster on 5/13/02. Heavy Rains started around 3 a.m. Samples collected at 9:00 a.m.
Sample # 9 - Collected by J. Webster on 5/17/02. First flush samples collected at 10:15 a.m.
Sample # 12 - Collected by J. Webster on 6/6/02. Moderate rain started around 7 a.m. Collected samples at 11:00 a.m.
Sample # 16 - Collected by J. Webster on 6/13/02. Scattered showers throughout the morning. Collected samples around 10:30 a.m. at end of storm.
Sample # 20 - Collected by J. Webster on 7/10/02. Collected sample immediately after a 5 minute hard, summer rainfall around 11 a.m.

Table 10. S255 (All results are in mg/L)

	Sample #5	Sample #6	Sample #10	Sample #13	Sample #17	Sample #21	Averages
Collection	5/13/2002	5/9/2002	5/17/2002	6/6/2002	6/13/2002	7/10/2002	
TOC Analysis Date	5/24/2002	5/24/2002	5/24/2002	8/5/2002	8/5/2002	8/5/2002	
TOC Results	8.93	33.22	42.90	18.76	15.12	29.73	25
TSS Analysis Date	06/05/02	06/05/02	06/05/02	06/17/02	06/17/02	07/16/02	
TSS Results	24	50	350	110	34	32	100
TPH Analysis Date	8/21/2002	8/21/2002	8/21/2002	8/21/2002	8/21/2002		
TPH Results[1]	<2	2-5	5-10	<2	<2		
Metals Analysis Date	5/15/2002	5/15/2002	5/20/2002	6/10/2002	6/14/2002	7/11/2002	
Metals Results[2]							
Ag	<.01	<.01	<.02	<.01	<.01	<.01	ND
Al	0.058	0.124	0.962	0.826	0.304	0.304	0.430
As	<.01	<.01	<.02	<.01	<.01	<.01	ND
B	<.01	<.01		0.253	0.426	0.488	0.389
Ba	0.027	0.065	0.107	0.084	0.072	0.062	0.069
Be	<.01	<.01	<.02	<.01	<.01	<.01	ND
Ca	16.400	35.600	>100	34.600	27.100	29.500	28.640
Cd	<.01	<.01	<.02	<.01	<.01	<.01	ND
Co	<.01	<.01	<.02	<.01	<.01	<.01	ND
Cr	<.01	<.01	<.02	<.01	<.01	<.01	ND
Cu	<.01	<.01	0.024	<.01	<.01	<.01	0.024
Fe	0.075	0.121	0.772	0.719	0.131	<.01	0.364
K	0.571	2.800	3.090	1.040	1.080	5.220	2.300

Table 10. S255 Continued..

	Sample #5	Sample #6	Sample #10	Sample #13	Sample #17	Sample #21	Averages
Mg	0.955	2.340	7.260	2.920	1.870	4.200	3.258
Mn	0.011	0.022	0.073	0.029	0.016	0.015	0.028
Mo	<.01	<.01	<.02	<.01	<.01	<.01	ND
Na	0.893	11.100	4.830	1.250	1.560	16.100	5.956
Ni	<.01	<.01	<.02	<10	<.01	<.01	ND
Pb	<.01	<.01	<.02	<10	<.01	<.01	ND
Sb	<.01	<.01	<.02	<10	<.01	<.01	ND
Se	<.01	<.01	<.02	<10	<.01	<.01	ND
Si	<.01	<.01	0.128	1.180	0.438	3.310	1.264
Ti	<.01	<.01	<.02	0.043	<10	<10	0.043
Tl	<.01	<.01	<.02	<.01	<.01	<.01	ND
V	<.01	<.01	<.02	<.01	<.01	<.01	ND
Zn	0.061	0.120	0.432	0.118	<.01	<.01	0.183

[1]TPH analysis was a qualitative test for gasoline levels.
[2]For metals values listed as below the safe calibration range of <.01 mg/L, the recorded values fell near detection

Sample # 5 - Collected by J. Webster on 5/13/02. Heavy Rains started around 3 a.m. Samples collected at 9:00 a.m.
Sample # 6 - Collected by J. Webster on 5/9/02. Light rain started around 8 a.m. Samples collected at 10:45 a.m.
Sample # 10 - Collected by J. Webster on 5/17/02. First flush samples collected at 10:15 a.m.
Sample # 13 - Collected by J. Webster on 6/6/02. Moderate rain started around 7 a.m. Collected samples at 11:00 a.m.
Sample # 17 - Collected by J. Webster on 6/13/02. Scattered showers throughout the morning. Collected samples around 10:30 a.m. at end of storm.
Sample # 21 - Collected by J. Webster on 7/10/02. Collected sample immediately after a 5 minute hard, summer rainfall around 11 a.m.

Table 11. N255 (All results are in mg/L)

	Sample #14	**Sample #18**	**Sample #22**	**Averages**
Collection	6/6/2002	6/13/2002	7/10/2002	
TOC Analysis Date	8/5/2002	8/5/2002	8/5/2002	
TOC Results	25.26	28.81	39.08	31
TSS Analysis Date	06/17/02	06/17/02	07/16/02	
TSS Results	8	2	114	41
TPH Analysis Date			8/21/2002	
TPH Results[1]			<2	<2
Metals Analysis Date	6/10/2002	6/14/2002	7/11/2002	
Metals Results[2]				
Ag	<10	<10	<10	ND
Al	0.299	0.262	0.537	0.366
As	<.01	<.01	<.01	ND
B	0.283	0.441	0.522	0.415
Ba	0.025	0.046	0.058	0.043
Be	<.01	<.01	<.01	ND
Ca	12.6	29.4	56	32.667
Cd	<.01	<.01	<.01	ND
Co	<.01	<.01	<.01	ND
Cr	<.01	<.01	<.01	ND
Cu	<.01	<.01	<.01	ND
Fe	0.148	0.018	<.01	0.083
K	10.7	5.12	2.07	5.963
Mg	4.86	4.56	3.64	4.353
Mn	0.013	<.01	0.047	0.030
Mo	<.01	<.01	<.01	ND
Na	8.42	2.24	4.45	5.037
Ni	<.01	<.01	<.01	ND
Pb	<.01	<.01	<.01	ND
Sb	<.01	<.01	<.01	ND
Se	<.01	<.01	<.01	ND
Si	1.38	1.64	0.803	1.274
Ti	<.01	<.01	<.01	ND
Tl	<.01	<.01	<.01	ND
V	<.01	<.01	<.01	ND
Zn	<.01	<.01	0.258	0.258

[1]TPH analysis was a qualitative test for gasoline levels.
[2]For metals values listed as below the safe calibration range of <.01 mg/L, the recorded values fell near detection

Sample # 14 - Collected by J. Webster on 6/6/02. Moderate rain started around 7 a.m. Collected samples at 11:00 a.m.

Sample # 18 - Collected by J. Webster on 6/13/02. Scattered showers throughout the morning. Collected samples around 10:30 a.m. at end of storm.

Sample # 22 - Collected by J. Webster on 7/10/02. Collected sample immediately after a 5 minute hard, summer rainfall around 11 a.m.