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Evaluating the Effectiveness of Regulatory Stormwater Monitoring Protocols on Groundwater Quality in Urbanized Karst Regions

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EVALUATING THE EFFECTIVENESS OF REGULATORY STORMWATER MONITORING PROTOCOLS ON GROUNDWATER QUALITY IN URBANIZED KARST REGIONS

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Non-point pollution from stormwater runoff is one of the greatest threats to water quality in the United States today, particularly in urban karst settings. In these settings, the use of karst features and injection wells for stormwater management results in virtually untreated water being directed into the karst aquifer. Currently, no policies exist specifically to provide water quality protections to karst environments. This study utilized a combination of karst stormwater quality data, along with survey data collected from MS4 Phase II communities, and an analysis of current federal, local, and state water quality regulations, to assess the need for karst-specific water quality regulations. Water quality data indicate that significant levels of contamination are mobilized during storm events, and often are directed into the karst system via Class V injection wells.

Survey data collected from MS4 stakeholders in the karst regions of Kentucky indicate stakeholders are generally unable to explain local karst regulations or the steps taken to develop them. This confusion comes in part from insufficient progress on evaluation criteria available for the MS4 Minimum Control Measures (MCMs). Karst waters are often placed into the legal “gray zone” due in part to differences in definitions of key terms in state and federal regulations. This study recommends the development of regulations specific to karst waters at the state and federal levels through either the adaptation of existing or creation of new policies, which place an emphasis on the

integration of water quality monitoring and karst education.

Chapter 1: Stormwater Contamination in Karst

Introduction

The greatest source of potential contamination to water resources in the United States today comes from stormwater runoff (EPA, 2012). Stormwater runoff becomes contaminated as precipitation falls and moves across impervious surfaces, picking up oils, surfactants, pesticides, hydrocarbons, sediments, debris, and other pollutants, which are then directed toward collection areas or filtration structures. Generally, the stormwater runoff ends its journey when it is discharged to nearby surface streams. This represents a generalization of the typical stormwater process in most areas; however, some areas, specifically urbanized karst settings, face many unique challenges when 81dealing with stormwater runoff, and most regulatory policies in the U.S. do not recognize or address the water quality issues in karst environments.

The deficiencies and irregularities in stormwater policy at all levels have not gone unnoticed. Calls for policy reform, stormwater management research, and public education programs are prolific and are gaining a more prominent place on the national stage due largely in part to the rising awareness of the cost for updating water infrastructure and the realization that immediate action is required. In Kentucky, experts estimate that, during the next 20 years, over eight billion dollars will need to be invested in wastewater and stormwater infrastructure maintenance and upgrades in order to keep pace with increasing demand for water service and, of this amount, an estimated $312 million will need to be invested solely for the elimination of combined sewer systems currently operated by 17 Kentucky communities (ASCE, 2011). The scope and breadth of regulatory concerns requiring attention make the implementation of overarching federal regulations regarding stormwater quality difficult, but the lack of resources, especially funding, available for state and local governments also makes the development of focused regulations and policies challenging (Christian-Smith et al., 2011). The idea that a change in the policy making and implementation process is needed before progress can be made is not a new one. In Bowling Green, Kentucky, one of the most studied karst groundwater systems in the country, broader challenges were first identified by Daugherty (1976), before Crawford (1989) proposed recommendations to build stormwater and groundwater policy based on a watershed approach. This emerged as part of an effort to deal with flooding and water quality problems associated with the increasing urban footprint of the city over the underlying karst system.

The watershed-based system promotes a holistic approach to water resource management, evaluating changes to the watershed over time, and quantifying the relationships between the inputs and outputs of the system as a whole. The process involves identifying local stakeholders, or those who have a vested interest in the water resources of their area, and engaging them in characterizing existing problems, identifying and prioritizing the problems, defining objectives and protection/remediation strategies, and implementing selected actions or policies as necessary (Division of Water, 2010). A key focus of recent policy reform publications is the decentralization of water management responsibilities and the increase in local stakeholder participation with the goal of involving non-governmental professionals and water specialists to oversee policy creation and implementation (Christian-Smith et al., 2011). The creation of these stakeholder groups at both the state and local level are already occurring in Kentucky in the form of the Watershed Planning group in the Division of Water, which works to streamline and improve the existing resource management framework by providing ongoing opportunities for stakeholder groups and individuals who have an interest in managing natural resources. The Municipal Separate Storm Sewer System (MS4) requirements for the formation of a Stormwater Advisory Committee represent steps in the direction of a watershed-based management strategy. However, the lack of funding mechanisms or substantial report requirements for the committee mean that many of them, while not technically disbanded, are no longer functioning to their intended extent.

In 2003, the U.S. Environmental Protection Agency (EPA), under the Clean Water Act (CWA) and the National Pollutant Discharge Elimination System (NPDES) enacted what are known as the MS4 Phase II requirements. These requirements are different from any previous stormwater regulations in that, rather than setting numerical effluent limits for stormwater discharge, they provide narrative guidance under six Minimum Control Measures (MCMs): 1) Public Education and Outreach, 2) Public Participation/Involvement, 3) Illicit Discharge Detection and Elimination, 4) Construction Site Runoff Control, 5) Post Construction Runoff Control, and 6) Pollution Prevention/Good Housekeeping. This design was utilized in an attempt to alleviate some of the financial and personnel burdens that compliance testing for numerical limits place on the Phase II municipalities (White and Boswell, 2007). The Phase II regulations require that stormwater discharges do not degrade receiving water bodies beyond state or federal water quality standards for their specified use. The problem with this approach is that many areas lack set water-quality standards for the receiving water bodies, other than the CWA standards for drinking water even though the standard may not always be appropriate for the water body in question. Although the narrative effluent guidelines set by the MS4 Phase II regulations do not provide strict guidelines for water quality parameters, further guidance can be obtained from the water quality standards for drinking and surface water set by the CWA and Safe Drinking Water Act (SDWA). These regulatory policies are ineffective when the water body being impacted by stormwater runoff is not classified as a surface water system, such as many of those found in the subsurface of karst landscapes. Because of the explicit connections between surface water and groundwater in karst areas, it is vitally import that local, state, and federal policies and regulations regarding subsurface waters provide clear guidance on their designation, use, and protection.

The City of Bowling Green (CoBG), Kentucky, is situated on a karst landscape, typified by a lack of surface streams, numerous sinkholes, caves, and thin soils. The same geological traits that allow for the formation of karst landscapes also make them inherently susceptible to contamination that is difficult to remediate (Kemmerly, 1981). The lack of surface streams in the Bowling Green area, combined with the thin soils, makes the cave systems in the area natural candidates for stormwater runoff control through the use of injection wells and natural karst features (such as sinkholes), which direct water into underground streams and aquifer systems. As surface water, and any contaminants that are carried along with it, flows into the karst system, the contaminants are generally dispersed within the aquifer (Fleury, 2009). The fate of the contaminants is dependent on flow, and generally these are either transported through the system or, in some cases, may be detained in the conduits, to be flushed out during high flow events (Field, 1992). For many cities in karst regions, the relatively shallow depth to bedrock combined with thin soils makes the installation of storm sewer systems complicated and expensive, leaving the local karst systems as the most viable option for stormwater control. Surface water supplies are often limited in these areas, and the interconnected nature of the karst terrain makes the groundwater supply susceptible to contamination (Reeder and Crawford, 1989). Even though stormwater pollution poses a serious threat to groundwater quality, the characteristics that make it problematic also make it quite difficult to regulate.

Throughout its history, the CoBG has utilized the Lost River Cave system to dispose of everything from sewage to stormwater (Mace, 1921) but, while the practice of injecting raw sewage into the caves and underground rivers has stopped, the City still makes use of an estimated 1,400 Class V stormwater injection wells to deal with stormwater runoff issues, particularly flooding (Slattery, 2012). The EPA defines Class V injection wells as drainage wells that are any bored, drilled, or driven shaft or dug hole deeper than its widest surface dimension, or an improved sinkhole or a subsurface fluid distribution system (an infiltration system with piping to enhance infiltration capabilities) (UIC, 2007). Class V injection wells fall under the “regulated by rule” constraints (UIC, 2007), meaning that stormwater injection wells can be viewed as a ‘system’ so, as long as they are transporting only non-hazardous stormwater runoff, no formal monitoring plan is required.

Currently, the only regulatory requirements in place concerning the siting and use of injection wells require only depth and locational data to be recorded; no water quality testing or monitoring are required unless the well impacts a potential underground source of drinking water. Since the CoBG withdraws its drinking water from the Barren River, a surface water body, the karst aquifer is not considered a source of drinking water. Under the SDWA, however, it is possible that the karst aquifer under the CoBG, if shown to have below 10,000 mg/L of total dissolved solids (TDS), could be considered a potential source of drinking water as a replacement or supplement to the current source, thereby requiring it to be held to the same compliance standards as surface drinking water sources. Previous work on subsurface drainage and water quality in the 1980s concluded that stormwater posed little to no threat to subsurface water quality in Bowling Green (Crawford et al., 1987). In the subsequent 30 years, however, the population of Bowling Green has almost doubled, the city has grown by almost 25 square kilometers, and land use in the CoBG area has shifted from mainly agricultural to urban, including an increase in impervious surface cover and stormwater runoff potential.

This research aims to use the CoBG as a case study to determine if current theories on water quality monitoring in karst are viable when the karst system is being utilized as a stormwater drainage system, and if the CoBG is capturing relevant information with its current monitoring program. A second aim of this study is to determine if federal and state regulations, developed under the CWA and SDWA, along with state and local policies, effectively provide for monitoring and regulation for subsurface streams that show a direct hydrologic connection to surface water bodies.

Literature Review

Stormwater Regulations

The U.S. federal government has enacted many laws in an attempt to protect the country's water quality, starting with the Rivers and Harbors Act of 1886, which focused on improving navigable waters by restricting waste discharges. More recently, the Clean Water Act (1972) is regarded as the cornerstone of surface water quality policy in the U.S. While the CWA regulates and protects surface water quality, the SDWA does the same for drinking water supplies, and specifically covers groundwater, while the CWA specifically excludes groundwater. Both Acts set numerical standards for water quality, both consist of legally enforceable laws and statutes, and both directly have an impact on the regulation of stormwater. The regulation of karst waters is not well defined in either Act and the applicability of regulatory actions varies from state to state depending on factors such as the legal definition of groundwater and the protections afforded to water bodies under CWA, through designation as ‘Waters of the U.S.’ or, in Kentucky, under ‘Waters of the Commonwealth.’

Safe Drinking Water Act

The SDWA was originally enacted in 1974, and then heavily amended in 1986 and 1996, to assure safe drinking supplies for humans, establish standards and treatment requirements for public water supplies, control the underground injection of wastes, finance infrastructure projects, and protect sources of drinking water (Tiemann, 2011). The coverage provided by the SDWA extends to all current and future sources of drinking water, both above and below ground. The use of the SDWA to provide protection to karst aquifers is difficult to implement on a national scale due to region-specific complexities that are exhibited by karst areas. Some, but by no means all, of the variables that must be considered include local climate and precipitation patterns, the extent of urbanization, and the development and implementation of stormwater management. Best Management Practices (BMPs), and the maturity of the karst system, all must be accounted for when implementing protection programs.

Clean Water Act

The CWA traces its beginnings back to the 1948 Federal Water Pollution Control Act. This authorized the Surgeon General of the Public Health Service, with the cooperation of other federal and local entities, to develop plans to reduce or eliminate pollution from interstate waters, and to improve the sanitary conditions of surface and underground waters. The original wording of the Act also authorized the Federal Works Administrator to assist states and interstate agencies in constructing sewage treatment plants (EPA, 2013). The Federal Water Pollution Act underwent significant reorganization in 1972, emerging as what is now known as the Clean Water Act. The main function of the CWA is the protection of U.S. surface waters. This is accomplished by the implementation of various pollution control programs, the most notable of which, and the one that most directly relates to karst stormwater issues, is the National Pollutant Discharge Elimination System (NPDES, 2009), which allows the EPA to regulate discharges from point sources. Point sources are discrete conveyances, such as pipes or man-made ditches. Non-point-source discharges generally include agricultural runoff, or conglomerated runoff from a large area with varying landuses, as well as stormwater runoff from impervious areas. Non-point source pollution is difficult to regulate and remediate because of its diffuse nature; many sources, which often do not share a geographic proximity, can be contributors to the same pollution source (Naidu, 2006). Individual homes that are connected to a municipal system, use a septic system, or do not have a surface discharge, do not need an NPDES permit; however, industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters (NPDES, 2009). In karst regions, non-point source pollution is hard to delineate, since the surface and subsurface are interconnected, and it is often impossible to distinguish between these and other point source pollutants; therefore, it is important to understand these events within the geographical context of specific types of landscapes.

Karst Environments

Karst areas are described as areas with caves, sinkholes, underground streams and other features formed by the slow dissolution, rather than mechanical eroding, of bedrock (Veni et al., 2001). The role that karst plays in the groundwater supply of the U.S. is significant, with over 20 percent of the country categorized as karst landscape and nearly 40 percent of the nation's population relying on karst aquifers for water supplies (Ford and Williams, 2007). As the demand for potable water increases, not just in the U.S. but also worldwide, additional efforts must be made to understand and protect our groundwater sources, as the inherent difficulties that come with studying karst regions make it all the more important for continuous research and investigation in these areas.

Major karst areas are identified in 20 states (Veni et al., 2001), and these unique geologic environments present their own environmental challenges. Development of land in karst regions is problematic due to the unstable nature of the ground and the elevated probability of flooding attributed to sinkhole floodplains (Zhou, 2007). Since stormwater runoff has the potential to contain a wide variety of contaminants at varying degrees of concentration, its behavior in karst regions needs to be understood to the fullest extent possible. Karst areas are susceptible to a greater range of environmental impact problems than any other terrain, with major problems occurring when underground storage tanks or residential septic tanks leak, thus allowing pollutants to enter and collect in subsurface voids (Ford and Williams, 2007).

In non-karst aquifers, a degree of natural filtration can occur as stormwater runoff moves through the surface soils. The filtration capabilities of any aquifer are functions of the natural, physical, and chemical reactions that return polluted subsurface water to its original condition (Golwer, 1983). The behavior of pollutants in groundwater systems differs according to the types of pollutants, the physical and chemical characteristics of each contaminant, and the matrix through which they are traveling. During transport by groundwater, reactions between the contaminants and the matrix through which they are moving can cause chemical precipitation and/or adsorption that can result in the removal of the contaminants from the groundwater (Pronk et al., 2009)

The natural filtration of pollutants in karst aquifers is limited because: (1) of a significant lack of available surface area for adsorption, ion exchange, or colonization by microorganisms; (2) rapid infiltration of water and contaminants restricts the availability of highly volatile chemicals to evaporate; (3) typically thin soil cover and the relatively large secondary voids allow for rapid transport of contaminants; (4) turbulent flow regimes associated with the high flow rates enhances contaminant transport; and (5) a lack of sufficient time for time-dependent elimination mechanisms (bioremediation) to act on contaminants because of the rapid flow-through (Ford and Williams 2007; Ozyurt 2008). Human-made stormwater management features, such as injection wells, which take stormwater directly from the surface runoff areas and channel it into the porous karst surface, exacerbate this process.

Stormwater

Stormwater runoff is generated when precipitation from rain and snowmelt events flows over land or impervious surfaces immediately following these events and does not percolate into the ground (Livingston and McCarron, 1991). As the runoff flows over the land or impervious surfaces (paved streets, parking lots, and building rooftops), it accumulates debris, chemicals, sediment, or other pollutants that can adversely affect water quality if the runoff is discharged untreated (EPA, 2012). With the implementation of the CWA in 1972, it became illegal to discharge any pollutant from a point source into navigable waters unless a permit was obtained though the National Pollutant Discharge Elimination System (NPDES). The CWA significantly reduced the volume of contamination entering U.S. waters by regulating point sources, which are defined as discrete conveyances such as pipes or human-made ditches.

Although the CWA is successful at identifying and regulating point source discharges, surface water in the U.S. still does not meet the original (and daunting) goal of being 100 percent fishable and swimmable. It is impossible for every mile of every waterbody in the U.S. to be assessed, and the EPA (2012) estimates that 40 percent of all U.S. water bodies have actually been assessed. Of this 40 percent, roughly half are considered to be “impaired,” meaning that the waterbody does not meet the criteria for one or more of its designated uses. The success of the CWA at controlling pollution from point source discharges is not mirrored in the non-point-source (NPS) pollution programs; NPS pollution is now recognized as the leading source of water pollution in the United States (Lee et al., 2007). Because stormwater runoff comes into contact with a wide variety of potential contamination sources, the potential exists for a multitude of contaminants to be represented in any sample collected. Stormwater contamination can generally be divided into the following six categories: (1) water soluble compounds, both organic and inorganic; (2) slightly soluble organic compounds, light, non-aqueous phase liquids less dense than water (LNAPLS); (3) slightly soluble organic compounds, dense, non-aqueous phase liquids more dense than water (DNAPLS); (4) pathogens; (5) metals; and (6) trash (Vesper et al., 2001). Depending upon the land use in a given area, the runoff may also contain heavy metals and other industrial pollutants (NPDES, 2009).

Various contaminants can become part of stormwater runoff in many different ways. For instance, heavy metals can attach to sediment particles and be moved during rain events, oil and grease (O&G) from automobiles can be mobilized from roadways to storm drains, and fecal coliform bacteria from animal waste can move in much the same way (Mahler et al., 2000; Kambesis, 2007). These materials, when collected by stormwater runoff and deposited in streams, can create high pollutant loadings of sediment, which clog waterways, smother bottom-dwelling aquatic organisms, and increase turbidity. In addition to increased turbidity, it has been shown that *E. coli* and other pathogens readily sorb onto suspended sediments, which facilitate not only rapid transport but also provide a surface that can extend the life of the organism by up to seven days (Jeng et al., 2005). Additional impacts include an increase in oxygen-demanding substrates, which consume oxygen in the water and can lead to loss of aquatic life, in nutrients (nitrogen, phosphorous), which cause unwanted and uncontrolled growth of algae and aquatic weeds, in heavy metals (lead, cadmium, chromium, copper, zinc), which can disrupt the reproduction of fish and shellfish and accumulate in fish tissues, in petroleum hydrocarbons (O&G), which are toxic to many organisms, and in coliform bacteria, which can contaminate lakes and waterways and negatively impact both aquatic life and human health (Livingston and McCarron, 1991). Water soluble compounds (nitrates, cyanides, carboxylic acids, phenols) move with the water, but rather than forming a plume that spreads from the source, as in non-karst regions, in karst groundwater systems the contaminant forms linear stringers that migrate down the conduit system towards the discharge point (Livingston and McCarron, 1991).

The diffusion concepts that are used to explain the traditional three dimensional plumes visualized in contemporary groundwater modeling are not valid for karst settings. Instead, the model must be replaced with the concept of one dimensional flow along conduits interconnected in various ways (Vesper et al., 2001). Light non-aqueous phase liquids, LNAPL (petroleum hydrocarbons), float on the water surface, migrating slowly down gradient, where they generally pool in slow-moving water sections behind obstructions. In contrast to LNAPL contaminants, dense non-aqueous phase liquids, referred to as DNAPL, sink to the bottom of the conduit, where they typically mix and combine with sediment deposits. Pathogens (viruses, bacteria, parasites) move freely though karst water systems due to the lack of natural filtration associated with karst terrains. Metals associated with stormwater contamination generally precipitate as hydroxides and carbonates in most karst aquifers due to the near pH-neutral, carbonate-rich water that typifies karst systems. Metal transport generally occurs only during a flow of a sufficient velocity to mobilize sediment particles, as the precipitated metals generally adsorb onto small clays (Vesper et al., 2001).

The design and implementation of stormwater monitoring programs in karst areas present a variety of unique challenges. Generally, the highest concentrations of contaminants are recorded soon after the start of precipitation in what is known as the first flush. Though several definitions exist as to where in the runoff the first flush actually belongs, most studies place it in the first 10-30% of the total runoff volume (Stenstrom and Kayhanian, 2005). First flush events are observed more in small catchments than in large catchments (Bertrand-Krajewski et al., 1998), but the hypothesis is that this is due to the extended transport times and elevated mixing levels associated with larger catchment basins. Areas with extended dry seasons can also experience what is known as a seasonal first flush, which occurs during the first substantial rain of the season. During this event, contaminants that accumulated on impervious surfaces are washed away together, creating a large contaminant slug that is much more concentrated than what is generally associated with first flush events.

First flush events, however, are not always a straightforward concept. Although contaminant concentrations are higher in the early stages of runoff, a calculation of mass emission over the length of the storm shows that the increasing volume in the middle of runoff events can actually move more contamination than the highly concentrated First Flush event (Stenstrom and Kayhanian, 2005). A major hindrance in karst monitoring is that access to cave streams can be limited, making total event monitoring impractical or, in some cases, impossible. The limited sampling site access, in conjuncture with the rapid movement of water and contaminants, in some cases at speeds ranging from 10-500 m/h (Quinlan, 1990), makes accurate sampling of karst aquifers difficult. Large repositories of data exist to assist stormwater managers with designing and implementing sampling and monitoring plans in non-karst areas, but karst-specific resources are few and far between. The variability of karst systems from region to region makes the development of a standardized system for monitoring karst systems difficult, and the practice of taking systems designed by larger municipalities and scaling them down for smaller areas is generally not advisable, as site-specific data, such as precipitation patterns, flooding elevations, karst extent and maturity, karst water residence time, and land use, must be factored into each program.

Dealing with stormwater is a major concern for most urbanized and suburban areas, regardless of karstification. Stormwater infrastructure (in the form of storm sewer systems) is expensive to install and maintain and the prospect of such expenses can make undertaking such projects hard to achieve in smaller communities. Alternate methods of stormwater disposal, such as drilling injection wells, are much less expensive, take up almost no space, and take the stormwater out of sight of the community. In the karst region of Warren County, which encompasses the CoBG, and in other karst regions with major subsurface streams, the majority of stormwater flows into the karst aquifer with little to no treatment. This is not to say that the municipalities and their permit holders are simply letting the water go untreated; in most cases, the amount of treatment possible is dictated by the historical land use and planning in the area. Bowling Green requires stormwater flooding and treatment BMPs to be implemented in each new development, but it is difficult to retrofit older developments with the necessary treatment and management infrastructure (Slattery, 2012).

Stormwater Control in Karst Environments

Stormwater control and disposal pose problems regardless of location, but stormwater management in karst environments, such as Bowling Green, presents a difficult obstacle. As aforementioned, karst terrain is defined as an area formed of carbonate rocks, where subsurface drainage is based on solutionally enlarged openings in the bedrock (Crawford, 1989). Warren County and Bowling Green, Kentucky, in particular, contain two separate karst settings, the boundaries of which are determined by the bedrock type. Cesin and Crawford (2005) described these two types of karst terrains in relationship to sinkhole floodplains. Most of the CoBG is underlain by the Ste. Genevieve limestone, which is characterized by large, shallow sinkhole basins with large catchment areas for stormwater drainage. This presents major problems with flooding in the CoBG due to the large drainage areas for each sinkhole and the slow rate at which water is drained from them. The outer edges of the CoBG are underlain by the St. Louis limestone formation, which is characterized by numerous deep sinkholes with much smaller catchment areas. The well-defined sinkholes, along with the smaller catchment areas, make this area much less prone to flooding than the areas atop the Ste. Genevieve formation. Because of the obvious sinkholes and the clearly visible floodplains on the St. Louis formation, people generally refrain from constructing buildings in these flood-prone areas. The opposite is true in Bowling Green, however, since the large drainage areas and shallow basins of the Ste. Genevieve formation make the delineation of floodplains difficult, so many buildings and roads are constructed well within, and sometimes on top of, sinkhole flood zones.

By 1976, the flooding problem in the COBG presented such a large problem that actions were taken by the city to develop a Stormwater Management Plan (Daugherty, 1976). This plan requires that any time there is a land-use change within the CoBG, an engineering consulting firm must prepare a stormwater management plan that delimits the floodplain elevation in each sinkhole that would result from a 100-year probability, three-hour storm event (City of Bowling Green, 2011). In Bowling Green, this is equivalent to 10.2 cm of precipitation falling in three hours (Cesin and Crawford, 2005). Crawford's (1989) research concluded that a re-evaluation of the CoBG stormwater monitoring plan was necessary. The study concluded that the CoBG would benefit from the adaptation of a complete watershed approach when dealing with stormwater management. The complete watershed model uses technical field methods, including dye traces and microgravity to refine delineations of basins and sub basins in the area to improve the understanding of subsurface hydrology. The use of a watershed approach to designing stormwater systems is gaining popularity, but is still hindered by the cost of the initial background data collection. To evaluate a watershed as a system correctly, enormous amounts of background data are needed. Flow rates and paths of major streams and conduits must be mapped, and these must be observed during multiple flow conditions. In addition to the flow-path data gathered using geophysical techniques, it is also necessary to collect information on the regional water table to better understand seasonal and annual fluctuations. This can be difficult in karst areas, since the traditional methods of tracking water-table movement through the use of piezometers and monitoring wells do not work well in karst areas because of the presence of water-filled conduits that do not represent the true water table (Quinlan, 1990).

The influence of injection wells is mentioned several times in studies by Crawford (1989), Quinlan (1990), and Cesin and Crawford (2005), but none of them present a concentrated approach to assessing the potential input of these wells to the karst hydrology of the CoBG. These wells allow stormwater to pass through the soil unfiltered, enter subsurface streams, and ultimately emerge into the Barren River. Any approach to stormwater management in Bowling Green or any urbanized karst area must take the impact of features like injection wells into consideration if a true understanding of the dynamics of the local karst system is to be achieved.

Stormwater Drainage Wells

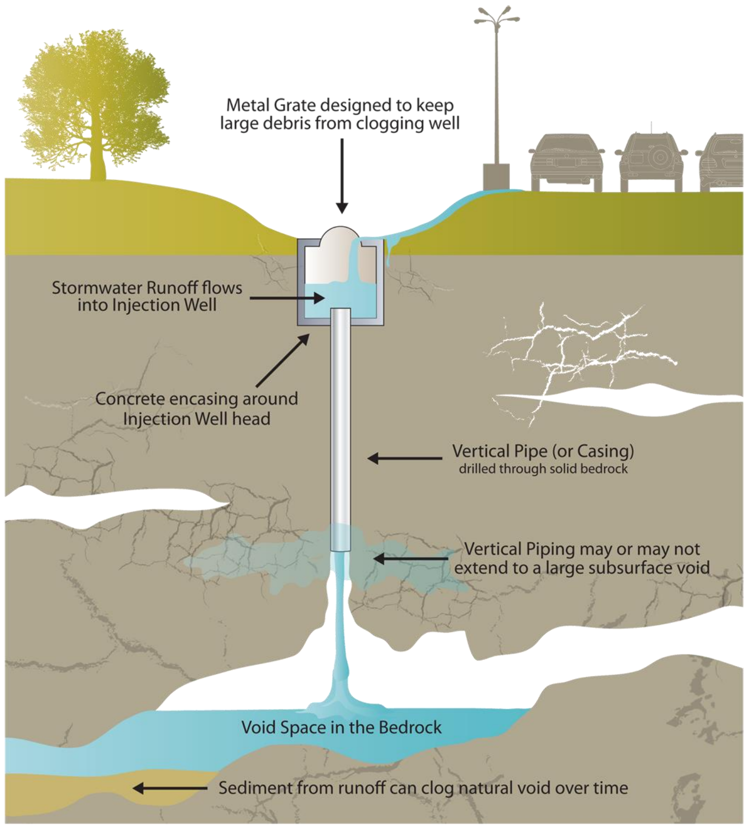
In karst areas, the lack of surface streams, combined with shallow depths to bedrock, make conventional storm sewer and drainage systems both physically and financially impossible for many areas. Typically, subsurface injection, either through the use of sinkholes as drainage basins, or through direct injection via wells, is the most efficient, or in some cases the only, way to dispose of stormwater runoff. Multiple areas in Kentucky, including Louisville, Lexington and Danville, use injection wells for stormwater drainage. This practice is also prevalent in parts of Florida, Washington, and Tennessee.

In Bowling Green, the most common type of stormwater drainage feature is an injection well, also referred to as a "dry well." These wells are regulated by the Underground Injection Control (UIC) division of the EPA through the Region 4 field office in Atlanta and are categorized as Class V drainage wells. Most of the well classification system developed by the EPA pertains to the oil, gas, and hazardous waste industries; there are more than 20 subtypes of these wells that all deal with the injection of non-hazardous waste. The EPA (1999) has estimated that there are more than 650,000 Class V wells nationwide, but it is believed that this number does not represent the true number of wells since minimal reporting regulations and the estimates of wells put in place before documentation became mandatory all point towards the actual number being much higher. The numbers may also vary because of the broad definitions for these wells; generally, a drainage feature can be classified as an injection well if the total depth is more than double the total width (UIC, 2007). Class V wells are of concern to human and environmental health, because they are most often used in karst areas where the potential exists to release contaminants into underground drinking water supplies. The EPA mandates minimum requirements for all Class V wells: they must be inventoried, they must not endanger sources of underground drinking water, and they must be properly closed when no longer in use. As long as well owners and operators comply with these three requirements, no permit is needed to operate the wells. These regulations are more focused on the industrial and human waste wells covered under the Class V regulations, with little attention given to stormwater runoff (EPA, 2001).

For these wells to operate to their maximum potential, it is imperative that they are installed based on the results of hydrological testing (Crawford et al., 1987) and not just drilled where ponded water is observed. The aforementioned estimated 1,400 injection wells in Bowling Green is an approximation, because no complete formal survey of the wells or compilation of records has been done since 1987; however, the CoBG is in the process of creating a GIS database of all stormwater drainage features in compliance with Phase II regulations. This represents a major gap in the CoBG’s body of knowledge when it comes to dealing with stormwater. Karst drainage and flow maps have been produced (Crawford, 1989; Cesin and Crawford, 2005), but these maps mainly deal with water movement as it pertains to sinkhole openings and traceable subsurface streams. Little to no information is available that details the movements of stormwater through the solution channels into which most injection wells are drilled.

Although numerous cave passages are present under the CoBG, it is rare that an injection well will come into contact with an actual cave passage (Crawford, 1989), but rather likely will intersect small solutionally-enlarged fractures, which may lead into assumed cave passages. These small channels will not exhibit the same flow characteristics observed in larger channels and, depending on local topography, could move in many directions. A GIS model of karst water flow and drainage features (Cesin and Crawford, 2005; Ross, 2009) provides an excellent platform for the study of the impact of injection wells on stormwater movement in the karst terrain of Bowling Green. The model developed by Ross (2009) focuses on identifying potential contaminant hotspots through the use of Resource Conservation and Recovery Act (RCRA) registration data. Potential flow paths for these areas are estimated by identifying nearby injection points and matching them to generalized flow patterns, as depicted in Figure 1-1. The identification of injection points by GPS coordinates is possible because, by law, the driller of any injection well in Kentucky must record and submit location data to the local city upon the completion of any wells (UIC, 2007), and these data can be layered over the existing map to present a generalized idea of wells in each drainage basin. Because of the volume of wells installed each year, it is difficult to keep the database up to date with injection well locations. The CoBG is currently in the process of bringing the information in this database up to date.

Figure 1-1. Idealized depiction of a stormwater drainage well in a karst setting.



Note: The void space in the diagram is not typical of conditions encountered in karst, generally the voids intersected are small; most water movement is through small solutionally enlarged channels leading away from the voids. Source: Graphic designed by Jonathan Oglesby.

The need for these data was proven during a 1999 EPA injection well study in which injection well census forms were sent to each state with the results being used to form an accurate prediction of the number of active Class V wells. The final report states that there are 71,515 registered Class V wells in the U.S., but it is unlikely that this estimate reflects the true number. The estimation model developed during this survey puts the number closer to 300,000, with even that believed to be low (EPA, 1999). This model relied on data about soil and bedrock conditions, karst potential, meteorological data, and level of urbanization. The calculation also relied on reported data about the number of wells in surrounding states or areas with similar geological conditions. Many states (Kentucky included) simply did not have the requested data or did not respond to the request for information. It is believed that these non-reporting states can skew the prediction data towards the low end of what may be the actual range. As mentioned before, it is crucial for Bowling Green, and Kentucky in general, to get a firm grasp on the number of operating Class V wells in the state, since without this information it is impossible to predict stormwater movement and volume accurately in the karst areas that make up much of the state.

Municipal Separate Storm Sewer Systems

Two phases of the NPDES deal directly with stormwater and are known as the Municipal Separate Storm Sewer System (MS4) Phase I and Phase II rules. An MS4 system is defined according to 40 CFR 122.26(b) (8) (EPA, 2003) as a:

> *.. conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains): (1) Owned or operated by a State, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to State law)...including special districts under State law such as a sewer district, flood control district or drainage district, or similar entity, or an Indian tribe or an authorized Indian tribal organization, or a designated and approved management agency under section 208 of the Clean Water Act that discharges into the waters of the United States." (2) "Designed or used for collecting or conveying storm water (3) Which is not a combined sewer; and (4) Which is not part of a Publicly Owned Treatment Works (POTW) as defined by 40 CFR 122.2.*

Phase I MS4 rules require medium and large cities with populations over 100,000 to obtain NPDES permits for stormwater discharges, while Phase II MS4 rules require regulated small MS4s in urbanized areas, as well as small MS4s outside the urbanized areas that are designated by the permitting authority, to obtain NPDES permit coverage for their stormwater discharges (NPDES, 2009). Phase II communities are those with a population of less than 100,000. A main difference between the two phases is how stormwater quality is regulated. Phase I communities are subject to numerical water quality limits, and must monitor several categories of industrial sites for compliance. Phase II communities show compliance by presenting an annual report to the appropriate permitting body, generally to a state department for states who have petitioned for and received primacy from the EPA, showing active compliance with the six minimum control measures set out in the Phase II regulations. Many karst regions, including the CoBG, are MS4 Phase II communities, and thus are the focal point of this study.

Monitoring Programs

Stormwater monitoring programs for Phase II communities are designed around the concept of attaining the Maximum Extent Practicable (MEP) reductions in stormwater contaminant loads using both structural and non-structural BMPs developed in conjuncture with the six MCM's required by NPDES regulations. The MEP, as defined by the Kentucky Pollutant Discharge Elimination System (KPDES, 2010:5), commonly referred to as KYG20, is "the control standard for discharges from the MS4 established by 40 CRF 122.34," which requires that, at a minimum, MS4 operators develop, implement, and enforce a stormwater management program with the purpose of reducing the discharge of pollutants from the MS4 to the MEP to satisfy water quality requirements established by the CWA.

The six minimum control measures that form the backbone of MS4 Phase II regulations are: Public Education and Outreach, Public Participation/Involvement, Illicit Discharge Detection and Elimination, Construction Site Runoff Control, Post

Construction Runoff Control and Pollution Prevention/Good Housekeeping (EPA, 2012). A review of the Final Ruling for Phase II shows that the EPA has purposely avoided setting a definition for MEP to provide MS4 operators with flexibility in creating location-specific pollutant reduction programs. It is suggested that the development of the program and of the conceptual MEP take into consideration the receiving waters, MS4 size, climate, local geology and hydrology, the capacity to maintain the program, and the ability to finance the program. The problem with this line of planning is that there are no checks on efficiency for the Best Management Practices (BMPs) and management plans that are supposed to be minimizing pollution loads. Developments can still meet MEP pollutant-removal guidelines by installing retention basins or other treatment devices, but still remove the water without treatment effectively by installing an injection well in the treatment train. The lack of a clear and concise definition of MEP for stormwater contamination reduction leads to the existence of numerous interpretations of the term. Numerous studies identify the need for a firm definition of MEP, or call for its removal from the federal regulations (Bloom, 2002), but documentation on individual determinations of MEP is less readily available.

The CoBG, lacking any specific state or federal water quality standards aside from the standards set by the CWA, determined that Total Suspended Solids (TSS), a measure of sediment suspended in water, would be the contaminant of concern around which the MEP determination would be made. MEP development should gather data from a variety of sources, ranging from the international BMP database to case studies performed locally. Important resources in determining MEP are local TMDLs, which pinpoint pollutants of concern for local water bodies. For areas without fully developed

TMDLs, it is still possible to obtain data from state agencies about potential contaminants of concern in local waterways. Without TMDLs against which to set water quality benchmarks, the CoBG determined that the average annual sediment removal efficiency for structural stormwater BMPs was 80% of the total load. Therefore, the CoBG determined that MEP was achieved when chosen BMPs are met, either individually or as part of a treatment train, at the 80% TSS removal standard. Monitoring programs in karst and non-karst settings are difficult to compare, not only because of the inherent differences between the two terrain types, but also because of the variation that occurs between karst areas. Variations in the degrees of karstification, including the hydrology, lithology, and type of karst features in each area, alter flow patterns and transport time for contaminants, in addition to presenting drainage and flooding challenges. The lack of karst specific regulations, or the requirements for locally developed regulations specific to karst, is a limitation of the NPDES Phase II program. The sheer number of variables inherent with karst aquifers warrants that monitoring programs for these areas should be examined more in-depth both in scope and in implementation. Thus, the proposed study addresses integrating the effectiveness of stormwater monitoring in urban karst environments within the existing policy guidelines.

The issue of stormwater regulation is multilayered and complex with various branches of local, state, and federal government having input in the development, implementation, and enforcement of the myriad regulations. Kentucky admisinsters its own permit program, known as the Kentucky Pollutant Discharge Elimination Program, or KPDES, through which Kentucky can grant, modify, monitor, or revoke permits to discharge. For Kentucky to admisister its own discharge program, its standards must be at least equal to the protections provided by the federal regulations. The NPDES (2009) system regulates discharges to U.S. waters, and is defined in 40 CFR 230.3(s) as meaning:

1. All waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;
2. All interstate waters including interstate wetlands;
3. All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation or destruction of which could affect interstate or foreign commerce including any such waters:
   (i) Which are or could be used by interstate or foreign travelers for recreational or other purposes; or
   (ii)(From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or
   (iii) Which are used or could be used for industrial purposes by industries in interstate commerce;
4. All impoundments of waters otherwise defined as waters of the United States under this definition;
5. Tributaries of waters identified in paragraphs (s)(1) through (4) of this section;
6. The territorial sea;
7. Wetlands adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs(s) (1) through (6) of this section; waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA (other than cooling ponds as defined in 40 CFR 423.11(m) which also meet the criteria of this definition) are not waters of the United States.

U.S. waters do not include prior converted cropland. Notwithstanding the determination of an area’s status as prior converted cropland by any other federal agency, for the purposes of the Clean Water Act, the final authority regarding the Clean Water Act’s jurisdiction remains with the EPA.

In a recent webinar through the EPA Water Quality Standards Academy (EPA, 2014), the EPA clarified the meaning of U.S. waters, reinforcing its position that groundwater is not included in this coverage. Because the majority of stormwater in karst regions finds its way into groundwater systems, it is important to understand how groundwater is regulated in the state. The KPDES system regulates surface water discharges just as the NPDES system does, but the language in the KPDES permit differs slightly. The KPDES program issues permits that allow small MS4 systems to discharge into Commonwealth waters, which has a different definition than U.S. waters. Commonwealth waters are defined by KRS 224.01-010(33) to include any and all rivers, streams, creeks, lakes, ponds, impounding reservoirs, springs, wells, marshes, and all other bodies of surface or underground water, natural or artificial, situated wholly or partly within or bordering upon the Commonwealth of Kentucky or its jurisdiction. The inclusion of wells, springs, and underground waters in the definition of Waters of the Commonwealth is of particular interest to this study, since the inclusion of these terms, in theory, should bring stormwater discharges into karst systems under the regulation of the MS4 program. This problem has not gone unrealized, but the task of education and implementation is daunting and slow to progress. Educational resources, such as those provided by the Kentucky Geological Society (KGS), Western Kentucky University (WKU), The University of Kentucky (UK), Kentucky Division of Water (KDOW), the Kentucky Transportation Cabinet (KYTC), and others, serve to augment local MS4 public education and outreach programs and serve as a reminder that, on a larger scale, progress is being made. To continue moving forward with protection efforts, it is important that decisions made regarding karst water policy are based on sound science of the physical, chemical, and human elements involved in the decision-making process. Karst settings have significant spatial variability in terms of size, extent, and composition, and differing land-use practices and degrees of urbanization make it impossible to apply successfully a one-size-fits-all regulatory approach to karst policy decisions.

Chapter 2: Stormwater Monitoring Effectiveness in Karst Areas

Introduction

The authority to regulate stormwater discharges in the U.S. belongs to the federal government in the form of the National Pollutant Discharge Elimination System (NPDES). The NPDES was implemented to assist in the Clean Water Act's goal of "restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters" (Clean Water Act, 1972:1). The initial focus of the Act was on the permitting and removal of point-source discharges from municipal and industrial sources; however, point-source discharges were identified as only part of the problem. For the program to be successful, non-point source pollution must be addressed as well.

In areas of karst geology, groundwater sources are often interconnected with surface streams and the tracking of pollutants can be complex. There exists a need to better evaluate how non-point pollutant sources impact water quality and how this is regulated by existing policies. Stormwater, in particular, is of concern in areas with karst aquifers, since current policies only provide general guidelines on monitoring and evaluating these pollutant sources.

Stormwater program regulators and managers nationwide face an array of challenges with respect to the control of water quality and quantity, particularly in urbanized karst regions. Karst terrains are formed from the dissolution of soluble bedrock material and are typified by caves, sinkholes, springs, sinking streams, and a lack of surface streams (Dicken, 1935; Quinlan and Rowe, 1977). Nearly 20 percent of the land surface in the U.S. is classified as karst, and karst aquifers provide close to 40 percent of the groundwater used for drinking purposes in the U.S. (Ford and Williams, 2007).

The 1987 Water Quality Act (WQA) expanded the scope of the NPDES to include stormwater discharges from a large selection of industrial, commercial, and municipal sources. Beginning in 1990, Phase I of the program required Municipal Separate Storm Sewer Systems (MS4s) located in areas with a population greater than 100,000 to obtain NPDES permit coverage. The Phase I regulations addressed stormwater discharges from 81.7 million people in 136 urbanized areas, and required NPDES permit coverage from industries in 11 categories (NPDES, 2009).

Phase II of the program, proposed in 1998 by the Environmental Protection Agency (EPA), was an expansion of the Phase I program designed to regulate discharges from MS4s in urban areas. Two classes of stormwater dischargers are automatically covered under the Phase II rule: operators of small MS4s (any MS4 not already covered by Phase I) located in "urbanized areas" as defined by the Census Bureau, and operators of small construction activities that disturb equal to or greater than one and less than five acres (2 hectares) of land. The state permitting authority, or the EPA, may designate additional dischargers, such as small MS4s located outside of urbanized areas, construction activities disturbing less than one acre (0.4 hectares), and other dischargers where the EPA or permitting authority determine the need for stormwater controls (EPA, 2005). Phase II is intended to protect existing water quality and reduce the impacts of stormwater runoff pollution through the use of narrative controls, rather than the numerical effluent limitations imposed on Phase I communities, but these guidelines are vague and provide only a secondary measure of control on possible pollution causes. These narrative controls come in the form of six minimum control measures (MCMs), which are: Public Education and Outreach, Public Participation/Involvement, Illicit

Discharge Detection and Elimination, Construction Site Runoff Control, Post-Construction Site Runoff Control, and Pollution Prevention/Good Housekeeping. Progress and accomplishments achieved toward meeting the MCMs are reported annually to the permitting authority, which in many cases is the state where the MS4 resides. While the report includes measurable standards for the performance of the MCMs, it does not specifically require MS4s to monitor the chemical composition or pollutant load of their stormwater discharges, or that they conduct quantitative data collection on the performance of their various BMPs.

Karst makes up nearly 50% of the land surface in Kentucky (Paylor and Currens, 2002). Much of Kentucky's karst region is urbanized, and while many cities in Kentucky have a long history of human/karst interactions, few have interactions on the scale seen in the CoBG. The karst landscape of Bowling Green has drawn the attention of researchers for nearly 100 years, with an article published in *Popular Mechanics* (Mace, 1921) describing the karst landscape and its use as a "natural" sewer system. Residents of Bowling Green could hire well drillers to install wells on their property and have their waste piped directly from the house into the cave systems, where, according to "expert chemists" cited in the article, the wonderfully efficient natural system would dispose of the waste. In reality, this waste was generally being transported directly to the Barren River, which borders the CoBG to the north. Most karst regions are typified by a lack of surface streams, and Bowling Green is no different. As the CoBG grew, so did its drainage requirements and problems. These problem were exacerbated by thin soil cover and shallow bedrock depths in the area (USDA-NRCS, 2004), meaning that Bowling Green could not drain stormwater runoff to surface streams and that it was generally cost prohibitive to blast passages for storm sewers out of the bedrock. Instead, the CoBG has used the karst system to deal with stormwater since its inception. Currently, Bowling Green has close to 1,400 Class V injection wells that are used to move stormwater from the surface to the subsurface rapidly in order to alleviate flooding concerns throughout the urban area (Slattery, 2012). Class V injection wells, also referred to as “injection wells” or “dry wells,” are defined by the EPA Underground Injection Control Program (UIC, 2007:2) as “any bored, drilled, or driven shaft whose depth is greater than the largest surface dimension; or a dug hole whose depth is greater than the largest surface dimension; or an improved sinkhole; or a subsurface fluid distribution system.” The Class V wells installed in the CoBG deal with urban runoff as well as commercial and industrial runoff. The runoff is directed to subsurface conduit systems, where it eventually makes its way to the Barren River. The direct connection to the subsurface provided by the injection wells means that stormwater runoff receives little to no filtration or pre-treatment, allowing contaminants to flow unobstructed through the subsurface and into the Barren River, the source of drinking water for Bowling Green’s residents.

Stormwater research in Bowling Green has received almost continuous attention since the early 1970s. This is, in part, due to the presence of Western Kentucky University, the willingness of the CoBG government to partner with research groups and, most importantly, because the City is faced with flooding issues during most large storm events, as shown in (Figure 1-2), where cars are seen trapped in flood water in the Fairview Shopping Center.

Figure 1-2. Injection well flooding, Fairview Plaza Shopping Center, CoBG, 2005.

Source: From KEEP (2002).

Stormwater-related flooding in karst areas is a well-documented phenomenon (Matheney, 1983; Groves, 1987; Crawford, 1989; Zhou, 2007). Prior to the implementation of the NPDES Phase II program, Bowling Green utilized zoning and construction ordinances designed to minimize damages from flooding associated with storm events. Because of the high cost associated with installing storm-sewer systems throughout the CoBG, alternative options were evaluated and put in place. The most common options for large-scale treatment and flooding mitigation are detention and retention basins or ponds, as described by Matheney (1983). It is generally realized that the expansion of urbanized areas places additional strain on karst systems (Matheney, 1983), and that the use of traditional karst drainage devices, such as dry wells, without proper pretreatment, could cause undesirable changes in the drainage patterns and capabilities of the hydrologic system. Stormwater treatment train design in karst areas requires special attention, as localized flooding is not always the biggest threat to infrastructure and homes. Crawford (1989) documented the flooding of upstream areas and hypothesized that it was caused by the blockage of downstream passages. Storm debris and sedimentation play a large role in the blockage of cave passages and drainage systems, making proper stormwater quantity and quality control vital in karst areas. Bowling Green adopted a series of planning and zoning regulations to ease the strain placed on the karst system during storm events, such as setbacks from sinkholes and the designation of sinkhole flooding zones (City of Bowling Green, 2011).

As described previously, the soils in Bowling Green are ill suited for infiltration purposes, and the high clay content makes their permeability too low to be of any use in the natural movement of water through the soil column so, in most cases, injection wells are added to the treatment train to move the water quickly from the surface to the subsurface (Zhou, 2007). In 2002, a stormwater advisory committee (SWAC) was formed to investigate the status of functionality of the current stormwater regulations and to provide an assessment of how best to bring them up to date with the needs of the growing city. The major take away point from the SWAC was the need to develop a rigorous protection program for areas utilizing Class V injection wells, since they represented the greatest potential for contaminant transport of all BMPs used by the CoBG. It was left undecided at the time if monitoring and sampling should be required of certain areas based on their pollution potential, or if baseline data collected from larger cities could be applied to Bowling Green with satisfactory results. Many municipalities are hesitant to engage in stormwater monitoring and sampling programs because of the financial and personnel burden these activities can place on city budgets and resources. Storm sampling can be time and resource intensive and, depending on the analytical parameters to be monitored, the analytical costs can mount quickly. Bowling Green has conducted quarterly monitoring since 2005 at nine sites throughout drainage basins in and around the CoBG limits to build a database of baseline water quality information. With the addition of storm sampling information, these data could be used to gauge the overall effectiveness of the CoBG's stormwater quality program, while providing the building blocks for karst water monitoring programs in other MS4 cities in karst areas. This research uses the CoBG as a case study to determine if current theories on water quality monitoring in karst areas are viable when the karst system is being utilized as a stormwater drainage system, and if the CoBG is capturing relevant information with its current monitoring program. A second aim is to determine if federal and state regulations, developed under guidelines set by the CWA and SDWA, along with state and local policies, effectively provide for monitoring and regulation for subsurface streams that show direct hydrologic connection to surface water bodies.

Study Area

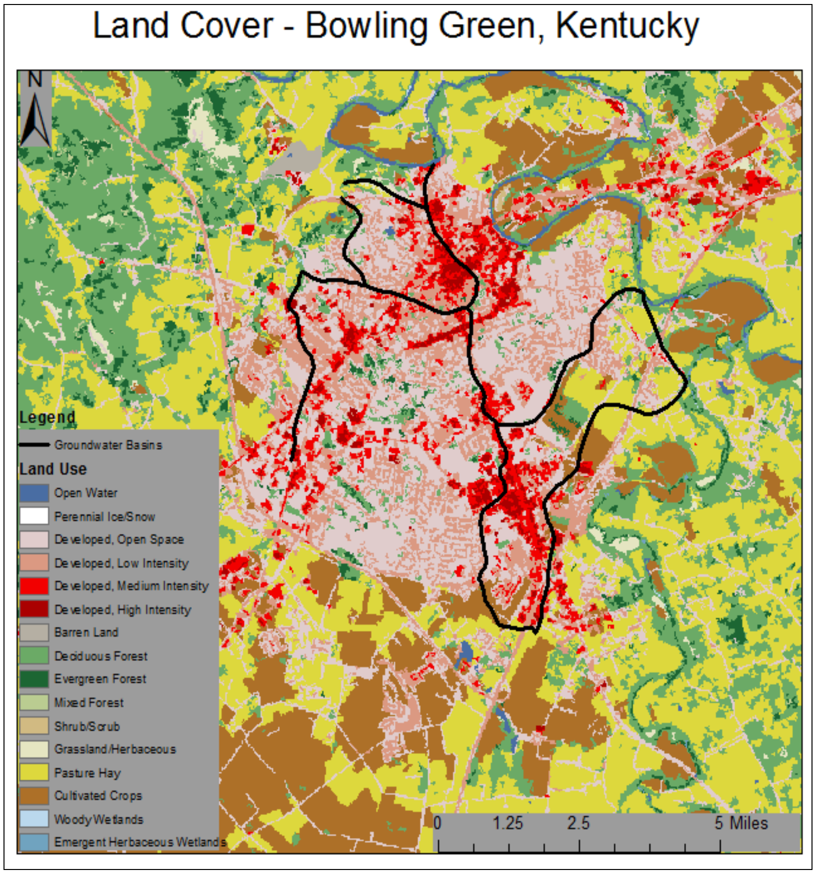
Local Setting

Bowling Green, Kentucky, encompasses 36 square miles (92.2 square kilometers) and has an average elevation of about 493 feet (150 meters) above sea level (Reeder and Crawford, 1989). Data from the 2012 census indicate the population of Bowling Green was 60,600. The city has a temperate climate with seasonal variations in temperature and precipitation. Average annual precipitation is 51.59 inches (131.06 cm), with 50% of the precipitation occurring between December and May, and the average temperature is

13.9°C (NOAA, 2013). The CoBG sits atop an iconic and extensive karst landscape, and is built over the Lost River Cave system, which includes Lost River, a combination of several subsurface streams that converge south of the city and flow north to resurgence at the Lost River Rise. The Lost River then flows as a surface stream for one mile (1.6 kilometers) until it joins the Barren River (Groves, 1987). The headwaters of the Lost River are located roughly 12 miles (19 kilometers) south of Bowling Green, near the town of Woodburn, where several surface streams sink into the Ste. Genevieve limestone, converging as they move northward towards Bowling Green. The first major resurgence of the Lost River occurs at the Lost River Blue Hole, where it flows approximately 400 feet (122 meters) as a surface stream before sinking into Lost River Cave (Groves, 1987; Reeder and Crawford, 1989). The river continues a northward progression until the final resurgence occurs at Lost River Rise, where it flows as a surface stream, joining Jennings Creek and finally discharging into the Barren River.

Land use in the CoBG trends from industrial and commercial to residential in a south to north fashion. The southern end of the city contains the Bowling Green industrial park along with a small, but growing, residential section. Moving north, the land use becomes a mix of residential and heavy commercial development, with the age of the residential developments increasing as you move closer towards the downtown area. The central and northern portions of the city are a mix of older residential developments and an increasing commercial presence.

Figure 2-1. Land Use and Cover in Bowling Green and Warren County.



Source: Created by the author from data provided by the Kentucky Geological Survey (2012) and the Natural Resources Conservation Services (USDA-NRCS, 2004).

Geology

The CoBG is built entirely upon the St. Louis, Ste. Genevieve, and Girkin limestone formations. It is the largest U.S. city to be built entirely over a cave system (Crawford, 1985). The lowermost layer, the St. Louis limestone, is described by Reeder and Crawford (1989) as finely to coarsely crystalline, gray to dark gray on fresh and weathered surfaces, and thick to massively bedded near the St. Louis/Ste. Genevieve boundary. The Corydon “Ball” Chert is present in the upper portion of the St. Louis formation and serves as a marker bed between the St. Louis and Ste. Genevieve boundary. The Ste. Genevieve formation is described by Shaw (1963) as fine to medium crystalline, gray to white limestone that darkens slightly with weathering. The entirety of Bowling Green lies within the Pennyroyal Sinkhole Plain, which is representative of karst topography perched on erosion-resistant chert, in this case the Lost River Chert bed, which extends from southern Indiana possibly as far south as the Highland Rim of Tennessee (Ryan and Meiman, 1996).

Methodology

Water quality (grab) samples were collected between March 28, 2013, and April 10, 2014, on a biweekly basis from three sites determined to be representative of karst outputs of three drainage basins in Bowling Green, Kentucky. Discharge calculations were conducted at Lost River Rise and New Spring when possible during the study period using methods described in Turnipseed and Sauer (2010). Staff gauges were installed at both sites to facilitate the development of discharge rating curves. As traditional stream gauging methods were not appropriate at the Petty well site, an attempt was made to establish a discharge rating curve using a Hobo U20 pressure transducer and Hobo U24 specific conductance (SpC)/temperature logger to measure the passage of salt slugs injected during storm events. Along with bi-weekly sample collection, samples were taken during six qualifying storm events over the course of the monitoring program at sites that were determined to be inputs for the basins receiving bi-weekly monitoring. Qualifying storm events are defined by the NPDES (2009) as those that deposit 0.1 inches (0.254 cm) or greater of precipitation and are preceded by a 72-hour dry period. All samples were analyzed for the following parameters at the Western Kentucky University (WKU) WATERS Lab and the Advanced Materials Institute (AMI).

Table 2-1. Water quality parameters monitored throughout the study.

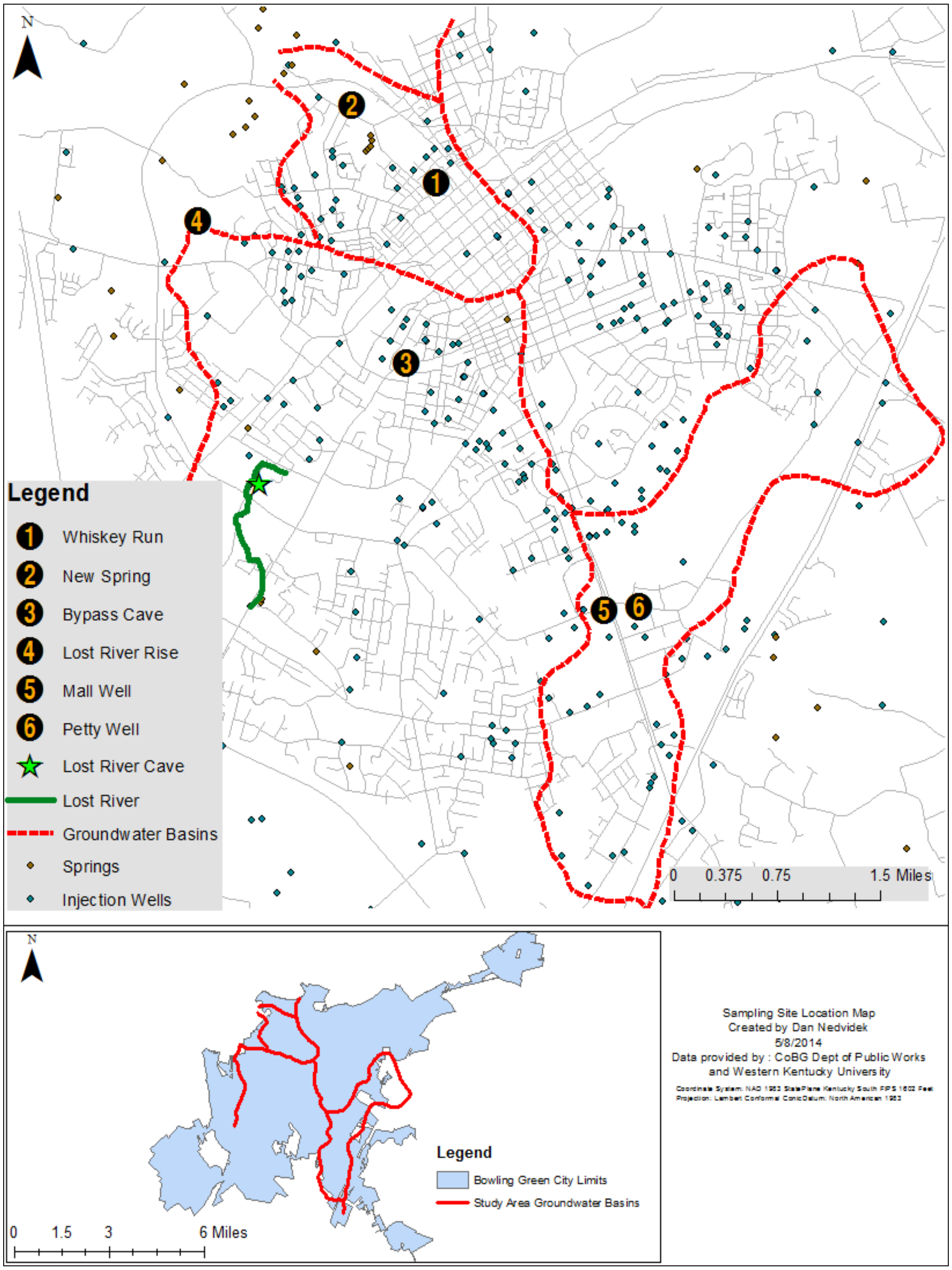
Analytical Parameters	
Total Suspended Solids (TSS)	Magnesium (Mg)
Biochemical Oxygen Demand (BOD	Manganese (Mn)
Total Coliform (TC)	Sodium (Na)
E. coli (EC)	Nickel (Ni)
Chemical Oxygen Demand (COD)	Lead (Pb)
Oil and Grease (O&G)	Antimony (Sb)
Silver (Ag)	Selenium (Sl)
Aluminum (Al)	Titanium (Ti)
Arsenic (As)	Vanadium (V)
Barium (Ba)	Zinc (Zn)
Beryllium (Be)	Fluoride
Calcium (Ca)	Chloride
Cadmium (Cd)	Nitrate
Chromium (Cr)	Nitrite
Copper (Cu)	Sulfate
Iron (Fe)	Bromide
Potassium (K)	Phosphate

Annual precipitation data collected at a 10-minute resolution were obtained from the Kentucky Mesonet monitoring site located on the WKU Agriculture Farm, while supplemental precipitation data were collected from a Texas Electronics TR-525M tipping bucket located on the roof of the Environmental Science and Technology building (EST) located on the main WKU campus. The supplemental gauge was added to provide additional data on assumptions made about regional scale differences in precipitation patterns. Water chemistry data were collected at 10-minute intervals from Lost River Rise using a YSI Exo II water quality sonde equipped to measure pH, specific conductance (SpC), temperature, turbidity, and absolute pressure. Data from the sonde were collected both manually and wirelessly through the use of a NexSens iSIC 3100 cellular telemetry system. Results from quarterly monitoring performed by the CoBG and from bi-weekly and storm samples collected during this study were analyzed using SigmaPlot and XLStat to determine the differences reported between the two sample frequencies, and to perform a cost/benefit analysis on the quarterly and bi-weekly results.

Site Selection

Six sites were used for data collection during the course of this study (Figure 2-2); three were selected because they represented outputs for the karst system in a particular drainage basin, and three because they represented the corresponding inputs for those basins. The current quarterly monitoring sites used by the CoBG were selected using recommendations made by Quinlan (1990) and Bakalowicz (2005), who made suggestions for site selection and monitoring frequency in karst areas. Groundwater basin delineation in Bowling Green has been an ongoing process for nearly 40 years; for this study, highly detailed maps produced by Crawford (1985) utilizing dye trace and potentiometric surface data were used for basin selection. Primary land use in each basin also played a part in site selection, as each site has a different land use that accounts for the majority of its surface area. Sites with varying land use were selected to provide data on where contaminants were coming from in the CoBG, and if any land use in particular could be tied to a specific contaminant or set of contaminants. Han et al. (2006) calculated metals concentrations from industrial, freeway, commercial, residential, and open space sites from stormwater samples to determine the source of metals in stormwater and to determine which land use contributes the most pollutant. Other studies have used similar approaches to show contamination contributions as a function of land use, but generally on a much larger scale and not in a karst setting (Pitt et al., 2004). The

Figure 2-2. Monitoring Location Site Map.



Note: Red boundaries show the approximate extent of local groundwater basins.
Source: Created by the author.

karst features located within each land-use category in Bowling Green play an important role in the movement of contamination, as described by Kambesis (2007), Vesper et al. (2001), and Ross (2009).

Lost River Rise (LRR)

Lost River Rise (LRR) represents the principal output for the Lost River basin, which is roughly 85 square miles (145 square kilometers) of agricultural and residential lands (Crawford, 1985). LRR has been the site of water quality and quantity monitoring sporadically since the late 1970s; rating curve development, dye traces, and water quality studies provided us with a strong foundation of historical background data on water quality and storm response at the site. In addition to the historical monitoring conducted by WKU over the years, this site has also been monitored on a quarterly basis by the CoBG since 2005, which provides the chance to compare recent trends in contaminant levels to bi-weekly trends.

Bypass Cave (BC)

Bypass Cave is the input site associated with LRR; it receives drainage from 189 acres (76.5 hectares) of mixed-use residential and commercial development. The site has been a place of interest for WKU and CoBG for a number of years (All et al., 2009), first as a cave to be explored and mapped and later as a major stormwater drainage feature. Dye traces (Crawford, 1985; 1989) have linked this site to the Lost River system. Because of the volume of water received at this site, it was improved with a stormwater quality unit designed to remove fats, oils, and grease (FOG), sediments, and any other pollutants, such as metals and pathogens, that adhere to the sediments.

New Spring (NS)

New Spring is the output for roughly 360 acres (145.7 hectares) of mainly residential drainage, including most of the WKU campus and large tracts of rental housing. The drainage is collected in Limestone Lake, an abandoned limestone quarry located roughly one mile (1.5 kilometers) from the spring. At the head of Limestone Lake is a large stormwater retention basin that is being modified as a low impact development subdivision by the local Habitat for Humanity chapter. New Spring was selected because it drains a mainly residential area, with older tracts of housing that may still be connected to septic systems. No documented evidence was found indicating it ever received concentrated monitoring attention.

Whiskey Run (WR)

The site chosen to represent the input for New Spring is dubbed "Whiskey Run," and takes its name from a small spring and associated stream that runs beneath downtown Bowling Green. Samples were collected from a curb inlet located in downtown Bowling Green located near the corner of 10^{th} and State streets. This site was used by Crawford (1989) as a dye injection location, which proved to be a direct connection to Limestone Lake and, therefore, New Spring.

Petty Well (PW)

Petty Well is the third output site used in this study. It has been used for quarterly monitoring samples collection by the CoBG since 2005 and was used for sample collection, cave radiolocation, and dye trace studies by WKU in the 1970s and 1980s. Petty Well intersects a cave stream that drains directly to the Barren River through Harris Spring. This stream receives drainage from a large commercial area, including the

Bowling Green/Warren County Regional Airport, and the Greenwood Mall complex. Several Class V wells in the area intersect the cave stream and move large quantities of water through it very quickly. Harris Spring was the initial monitoring choice for this basin, but was deemed unsuitable due to the potential for backflow from the river to overwhelm the discharge of the spring during high river-flow periods. This site is of interest to a number of entities outside WKU, as Harris Spring discharges to the Barren River less than one mile (1.5 kilometers) from the CoBG drinking water intake.

Greenwood Mall (Mall)

The input site associated with the Petty Well site is located in the parking lot of the Greenwood Mall, in the lowest corner of the parking lot that feeds into the final drainage basin for the site. Sample collection occurs at a curb inlet that receives runoff from a roughly 15.5 acre (6.3 hectares) parking lot, while the end drainage feature receives runoff from a total of nearly 19 acres (7.7 hectares) of impervious surface. This site was selected because it provides a clear example of contamination associated with parking-lot runoff and allows for rough estimation of the filtration and buffering capabilities of the retention basin associated with the site.

Sample Collection

Output Sample Collection

Output site sample collection was conducted on a bi-weekly basin from March 28, 2013, to April 10, 2014, for a series of parameters deemed essential to stormwater monitoring and general water quality. Samples were collected following the procedures set forth in the USGS Interagency Field Manual for the Collection of Water Quality Data

(USGS, 2000). Samples for each site were collected in a one-liter, wide-mouth glass jar preserved with HCL, a 500 mL plastic container with no preservative, an Idexx bacteria sample collection container, a 50 mL plastic vial preserved with H_2SO_4, a 50mL plastic vial preserved with HCL, and a 50 mL plastic vial with no preservative. After collection, samples were immediately placed in an ice-filled cooler and transported to the WATERS lab for analysis. During each sample collection event, basic geochemical data were collected using an YSI 556 multi-parameter water quality probe with a 10-second refresh rate over approximately five minutes. Averages for each parameter were taken for each site to reduce the influence of probe warm up and equilibration. The probe received dissolved oxygen, SpC, and three-point pH calibrations before each sampling event, and probe readings were monitored for drift using manufacturer provided limits. The probe was placed in the stream to be sampled slightly downstream from the sample location and allowed to equilibrate for five minutes before readings were taken. Measurements of pH, temperature, SpC, and dissolved oxygen concentrations were taken during each sample collection event. Sample collection at New Spring also included the collection of discharge data through the use of a wading rod and flow meter or using a salt slug dilution discharge reading, both coupled with a staff gauge reading. The discharge rating curve at LRR has been established for many years and was verified and updated at the beginning of this study; only staff gauge readings were taken for this site. Discharge measurements at the Petty Well site required slightly different equipment than used at the other sites, because access to the stream at the bottom of the well is very limited. To address this site limitation, it was decided to attempt the creation of a discharge rating curve using a Hobo brand pressure transducer coupled with a Hobo brand SpC logger to record water height and SpC readings. During storm events, salt slugs were injected into a nearby Class V well with mixed results. A more in-depth discussion of this method follows later.

Input Sample Collection

Input sample collection was attempted for 10 storm events during the course of the study, but due to various complications complete sample data are only available for seven storms. It was decided early on in the study that attempting to collect samples manually during the first 30 minutes of each storm would be nearly impossible, so Nalgene first-flush sample collectors were utilized at each site. The sample collection devices attach to the top of standard 1L plastic and glass sample containers and are equipped with a ball valve to ensure that water after the first flush does not contaminate the sample. Each site was equipped with one first-flush sample collector attached to a 1L plastic sample container and one first-flush sample collector attached to a 1L glass sample container. First-flush samples were collected within the first 30 minutes of each qualifying storm (Stenstrom and Kayhanian, 2005) and follow-up samples were collected between one and two hours after the first flush. Follow-up sample collection was dependent on storm duration and intensity; therefore, the timing of the secondary sample collection varied throughout the study. Immediately after collection, samples were placed in an ice-filled cooler and transported to the WKU WATERS Lab. The nature of the first-flush sample collectors is such that the plastic sample collection containers cannot be properly preserved for each parameter. Samples were split into separate containers and properly preserved upon delivery to the WATERS Lab.

Sample analysis

Sample analyses for general water-quality parameters (TSS, BOD, COD, O&G, and coliform) were conducted at the WATERS Lab. Cation/anion and metals analyses were conducted at the AMI. A complete list of methods is provided in Table 2-2.

Table 2-2. Analytical methods for monitoring parameters.

Analytical Parameters	**Analytical Method**	**Analytical Parameters**	**Analytical Method**
Total Suspended Solids(TSS)	*SM 2540 D Rev.20th ED 1998*	Magnesium (Mg)	EPA 200.7
Biochemical Oxygen Demand(BOD)	SM 5210 B Rev.20th ED 1998	Manganese(Mn)	EPA 200.7
Total Coliform (TC)	A. SM 9223 B. Enzyme Substrate Coliform Test	Sodium(Na)	EPA 200.7
E. coli (EC)	A. SM 9223 B. Enzyme Substrate Coliform Test	Nickel (Ni)	EPA 200.7
Chemical Oxygen Demand (COD)	Colilert-18 IDEXX Method (MPN/100mL or P/A	Lead (Pb)	EPA 200.7
O&G	SM 5520 B Rev.20th ED 1998	Antimony (Sb)	EPA 200.7
Silver (Ag)	EPA 200.7	Selenium (Sl)	EPA 200.7
Aluminum (Al)	EPA 200.7	Titanium (Ti)	EPA 200.7
Arsenic (As)	EPA 200.7	Vanadium (V)	EPA 200.7
Barium (Ba)	EPA 200.7	Zinc (Zn)	EPA 200.7
Beryllium (Be)	EPA 200.7	Fluoride	SM 4110 B Rev.20th ED 1998
Calcium (Ca)	EPA 200.7	Chloride	SM 4110 B Rev.20th ED 1998
Cadmium (Cd)	EPA 200.7	Nitrate	SM 4110 B Rev.20th ED 1998
Chromium (Cr)	EPA 200.7	Nitrite	SM 4110 B Rev.20th ED 1998
Copper (Cu)	EPA 200.7	Sulfate	SM 4110 B Rev.20th ED 1998
Iron (Fe)	EPA 200.7	Bromide	SM 4110 B Rev.20th ED 1998
Potassium (K)	EPA 200.7	Phosphate	SM 4110 B Rev.20th ED 1998

Cation analysis was performed using a Varian Inductively Couple Plasma Optical Emission Spectrometer (ICP-OES) at the WKU Advanced Materials Institute (AMI), while anion analysis was performed using a Dionex Ion Chromatograph. Cation samples were preserved with HCL and passed through a 0.45 micron filter before analysis. If samples were not ran the day of collection, they were kept in a refrigerated storage area until analysis could be completed. Acceptable sample hold time for metals and cation analysis once properly preserved is 28 days. Anion samples were passed through a 0.45 micron filter prior to analysis but received no preservation other than storage in a refrigerated area. Anion samples were analyzed within 24 hours of sample collection. All samples collected were analyzed within the hold times specified in the methods in use by the WATERS Lab.

Data Analysis

Analytical data and field or lab geochemical readings were stored in site-specific notebooks within SigmaPlot and combined into a master sheet at the end of each month. Data for each parameter, as well as for precipitation history and staff gauge readings, were stored in separate columns within each notebook. Time series plots generated within SigmaPlot provided initial observations on general trends in water quality at each site over the course of the study, as well as historical trends observed from the quarterly monitoring data provided by the CoBG. The time series plots were used to draw conclusions regarding the concentration and movement of contaminants through the karst system during normal flow conditions as well as during elevated storm flow conditions. For each output monitoring location, time series plots were created for selected pollutants that typically are of greatest interest to municipal stormwater managers, as they are commonly constituents included in TMDL monitoring programs and industrial stormwater monitoring permits. Nitrate (ppm), BOD (ppm), TSS (ppm), *E. coli* (MPN/100mL), COD (ppm), and O&G (ppm) levels were examined in greater detail than other parameters due to their frequent inclusion as contributing factors to water body impairment in 303(d) reports for the area and because of their historically elevated concentrations (Crawford, 1985). LRR was equipped with an EXO II sonde capable of recording geochemical parameters and pressure at 10-minute intervals and was installed on August 22, 2013, for continuous use into the future. In order to obtain estimates of flow volume, a simple stage-discharge relationship, or rating curve, was developed for the site using a third order polynomial regression to correlate observed staff gauge height to EXO II pressure readings, and another third order polynomial regression to correlate staff gauge height (stage) to discharge. A simple rating curve fits in this circumstance by making the assumption that discharge (Q) is a function of observed water level (h) or $Q=f(h)$. It is not always safe to assume that Q is a direct function of h because of slope change over time, the addition or removal of structural controls, and changes in vegetation, which can serve to alter discharge at the measurement point. For the purpose of this study, discharge measurements were made without corrections regarding controls to flow. Discharge measurements were taken using methods described by Turnipseed and Sauer (2010), in conjunction with a Marsh-McBirney Model 2000 Flo-Mate flow meter, by dividing the stream into equal segments stretching bank to bank and measuring the depth and velocity of each segment. The area of each segment was calculated and multiplied by the velocity to produce discharge, reported in cubic feet per second (cfs) and cubic meters per second (cms), and the summation of all segments gives the total discharge for the stream at the monitoring point. Fluctuations in contamination concentrations for both storm and baseflow samples were compiled into chemographs, with precipitation data from both monitoring locations overlaid. Data for LRR also include a hydrograph for the applicable monitoring period. These data are used to examine the variations in contaminant concentrations under a variety precipitation and seasonal conditions. Storm and baseflow contaminant-level parameters were subjected to the Mann-Kendall test for trend occurrence, the results of which allow us to provide predictions on local trends in water quality at a bi-weekly resolution and compare them to trends observed from the CoBG quarterly monitoring data dating from 2005. General descriptive statistics were also used to provide a clear picture on the role the karst system plays in transporting and storing contaminants. When combined, these data were used to report on the overall health of the three groundwater basins in Bowling Green and can be used in the future as justification for sampling frequency and site location selections in stormwater monitoring plans both in Bowling Green and similar urban karst areas.

Results and Discussion

Data collected during this study reflect the need for high frequency monitoring of stormwater runoff in karst areas. The levels of variability seen between baseflow, FF, and follow up stormwater samples indicate that water quality is not clearly elucidated from the current quarterly monitoring done by the CoBG. Despite the city's efforts going above and beyond what most MS4 communities sample in karst areas, a clear picture of water quality cannot be formed without a much more robust dataset. This increase in monitoring frequency is especially important in urban karst areas where the use of the karst system, through both natural and human-made inputs, introduces contamination instantly into the aquifer with minimal pretreatment. A monitoring program with an increased sampling frequency, which includes storm sampling, is needed to generate sufficient data for the characterization of a karst system's water quality (Ryan and Meiman, 1996). For a monitoring program to remain a financially viable undertaking for many MS4 Phase II communities, the contaminants of concern must be kept to a reasonable number and should reflect contaminants that may reasonably be expected given the surroundings and possible pollutant sources. The contaminants analyzed also reflect the varied nature of land use in the study area. The list of water quality parameters measured represents contaminants associated with industrial, commercial, residential, and agricultural landuse (Cesin and Crawford, 2005; Lee et al., 2007). Because no firm federal or state numerical limits exist on MS4 Phase II stormwater discharges, all results are compared to either standards found in industrial stormwater permits or surface water standards.

Stormwater Quality

Without the addition of stormwater monitoring, karst water quality monitoring programs are likely missing vital information. Results from this study show that significant levels of contamination are being introduced to the karst system during storm events through the injection wells and sinkholes commonly used for stormwater management in urban karst areas. Stormwater samples were collected at three sites over the course of seven storms; one sample was collected during the first flush of the storm, and a subsequent sample was collected within four hours of the first flush sample. Table 2-3 provides a basic descriptive analysis of contaminant levels at each site for the duration of the study. In almost every instance, the first flush concentrations were greater than that of the subsequent samples, and indicate that contaminants are entering the karst system. Each of the monitoring locations represents a direct input to the karst system meaning that the results provided here are representative of the actual contamination input to the system.

Table 2-3. Descriptive statistics for storm event sampling for first flush and subsequent samples.

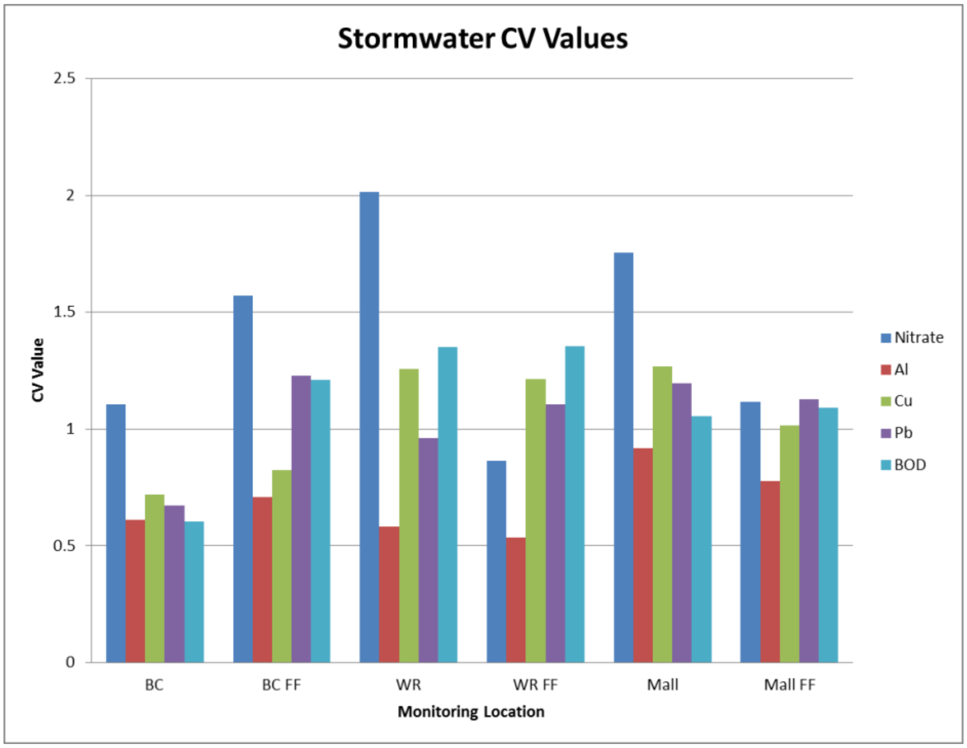
Storm Sample Descriptive Statistics									
		Monitoring Locations						Regulatory Limits	
		BC	BC FF	WR	WR FF	Mall	Mall FF	MCL	NSDWR
TSS	Mean	60.17143	79.18571	31.05714	103.7857	18.25	77		
	Min	7.2	28	4.2	11.5	11	10.5		
	Max	168	245	94	192	26	119.6		
BOD	Mean	10.04	32.45143	12.12	33.59857	4.448571	24.38571		
	Min	5.5	2.18	2.65	10.5	1.79	7.92		
	Max	23.5	116	48.6	136	15	84		
E. coli	Mean	8137.671	8557.314	24.41429	473.3571	31.42857	33.81429	0	
	Min	84	144	0	5	0	0		
	Max	24196	24196	100	2014	120	122		
COD	Mean	53.57143	125.1429	53.57143	142	23.85714	86.42857		
	Min	18	99	20	94	9	43		
	Max	88	154	83	189	41	144		
O&G	Mean	14.84857	18.30286	36.01429	60.13	34.11571	18.48143		
	Min	3	2.98	3.41	32	13.21	4.21		
	Max	24.35	43.88	123.8	135.01	56.6	32.66		
Nitrate	Mean	34.915	63.29143	15.47029	43.56157	21.2715	19.36433	10	
	Min	0.687	3.351	1.254	3.917	2.12	3.033		
	Max	110.45	301.148	91.836	94.568	104.56	65.487		
Al	Mean	0.21047	0.146258	0.19139	0.276995	0.139298	0.198975		0.2
	Min	0.035599	0.007968	0.03317	0.072336	0.005987	0.025796		
	Max	0.465874	0.270622	0.359874	0.46778	0.308351	0.4321		
Cu	Mean	0.030543	0.049383	0.122636	0.158607	0.0809	0.093122	1.3	
	Min	0.005484	0.01484	0.001327	0.011743	8.73E-06	0.014896		
	Max	0.062873	0.11056	0.36254	0.447533	0.258137	0.258137		
Pb	Mean	0.143702	0.102591	0.117143	0.100686	0.086261	0.083398	0.015	
	Min	0.007107	0.003221	0.002264	0.003223	1.23E-07	0.000857		
	Max	0.2181	0.32158	0.23598	0.236791	0.222221	0.222221		

Note: Results below laboratory reportable MDLs were omitted from these calculations. Concentrations are compared to Maximum Contaminant Level (MCL) and National Secondary Drinking Water Regulations (NSDWR).

Because there are no numerical discharge limits associated with MS4 Phase II stormwater discharges, the results from the stormwater sampling are compared to federal MCLs and SMCLs to illustrate the level of contamination entering the system. Statewide numerical limits do not exist for BOD, TSS, COD, O&G, and Al, but narrative guidance in the Kentucky administrative regulations state that surface waters shall not be aesthetically or otherwise degraded by these or other substances (KAR, 2014). While there are no mandated limits for O&G and TSS concentrations in stormwater runoff, in 2012, the Kentucky DOW proposed limits of 15 mg/l daily maximum and a monthly average of 10 mg/l for O&G, and a daily maximum of 60mg/l and a monthly average of 30 mg/l for TSS for stormwater discharges associated with industrial activity. Although these standards were not adopted for use by the DOW, they do provide a baseline with which to compare our results. O&G mean concentrations for the duration of the study were above 10 mg/l at all sampling locations, and above 15 mg/l at all but one location. Mean TSS concentrations were above 30mg/l at all but one site and above 60 mg/l at four of the six monitoring locations.

Nitrate concentrations at all sampling locations for both first-flush and follow-up samples are above MCLs, as are Pb and *E. coli* concentrations. In addition to surpassing drinking water levels, *E. coli* concentrations are above the limit for primary contact recreation waters in Kentucky at BC, which was selected as an input site because of its tie to the LRR. Connections between land use and contaminant concentration can be seen in the data: BC, which receives runoff from mixed residential and commercial areas, has the highest mean concentrations of nitrate and *E. coli*, which can reasonably be attributed to the presence of residential septic systems and the application of lawn-care chemicals in the area. It is also worth noting that the mean concentrations of Pb are highest at this site as well, which may be attributed to the close proximity of US-31W, a heavily traveled road near the sampling location (Sansalone and Buchberger, 1997; Brown and Peake, 2006). Elevated concentrations of O&G and Cu at the Mall and WR sites can reasonably be attributed to the predominantly industrial and commercial land use surrounding them. When viewed as individual sources it is entirely possible that the volume of water moving through these inputs is too small to affect the overall water quality in the karst system noticeably, but it must be remembered that these inputs represent a miniscule fraction of the inputs in the study area. Bowling Green has an estimated 1,400 injection wells to deal with stormwater runoff. Although each injection site is different, it can reasonably be assumed that the collective quantity of contamination being introduced to the karst system through stormwater runoff is much greater than what is captured by quarterly monitoring, and likely higher than even what is captured here in this study. In addition to assumed basin-wide fluctuations in contaminant concentration, the data from this study also highlight the variability of contaminant levels throughout the study period.

Figure 2-3. Stormwater CV Values.



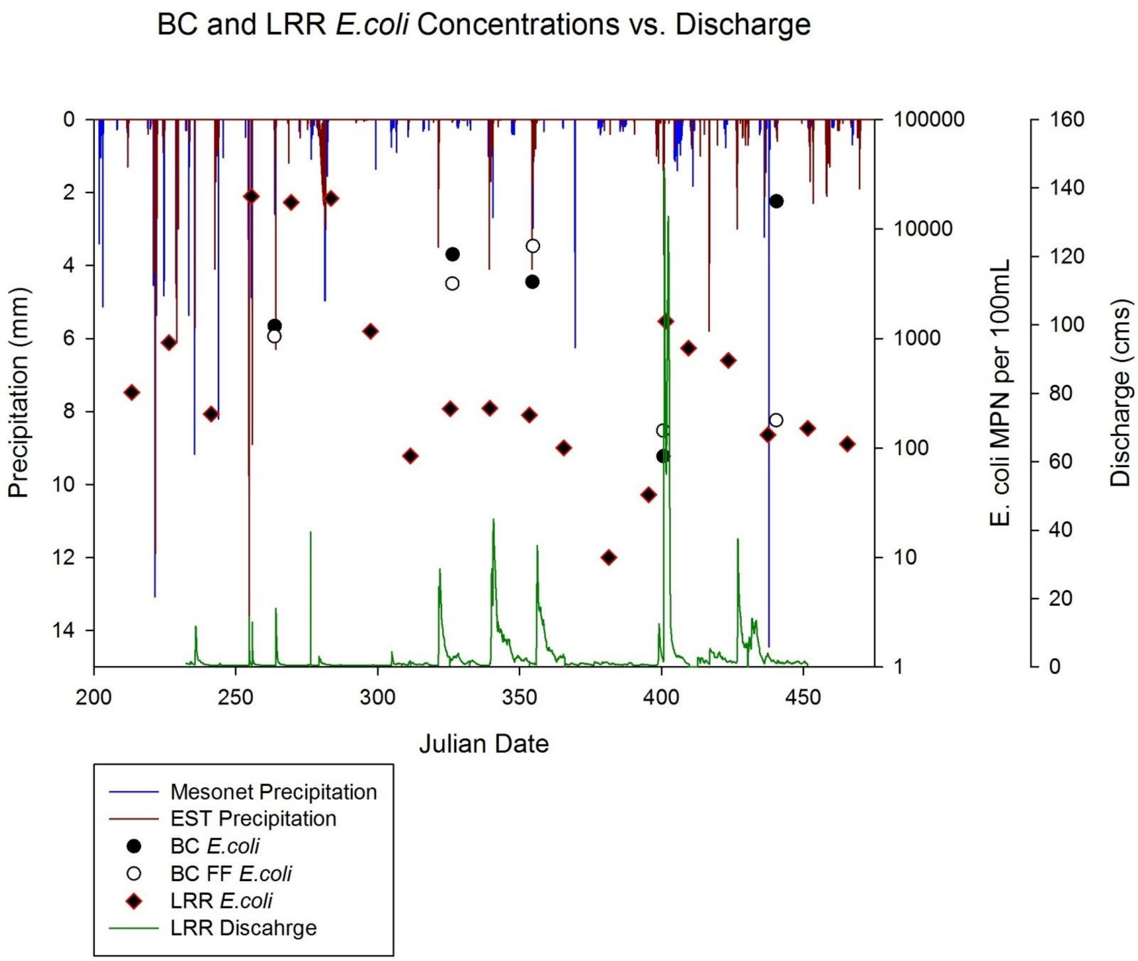
Note: Values are used as an indicator of variability in contaminant concentrations over the course of the study. Source: Created by the author.

A comparison of CV values was used to determine the variations from mean contaminant concentrations at each stormwater site (Figure 2-3). Relatively high (CV) values indicate high levels of variability in the data, which indicate fluctuating levels of contamination. The higher CV values do not necessarily represent higher levels of contamination but, rather, they point out fluctuations in contaminant concentrations over the course of this study. This information can be used to determine the effectiveness of sampling techniques and the appropriateness of sampling sites. Of the parameters monitored, nitrate CV values were the highest at the majority of monitoring locations, with little correlation existing between variability in first-flush samples and subsequent samples. The BC site is the only location to show CV values for nitrate that are higher during the first flush than during subsequent sampling: BC first-flush samples had a CV value of 1.57, and 1.11 for the subsequent samples. Without knowing the data behind the CV values, these numbers mean little; the BC first flush and BC CV values represent a difference in nearly 30 ppm. The mean nitrate concentration for the first flush at BC is 63.29 ppm, while the subsequent sample mean is 34.91 ppm. The results are even more pronounced at WR, where the CV values for nitrate concentrations at the first flush and subsequent sampling are 0.86 and 2.02, respectively, and the nitrate concentrations are 43.52 ppm and 15.47 ppm. While a larger storm sample dataset may reduce certain CV values, these values still provide a strong indicator of the variations in contaminant concentration moving through the karst system during storms. For Bowling Green, this means that quarterly monitoring at the current surface-water locations does not prove sufficient to capture contaminant pulses associated with storm events. For urban karst settings beyond the CoBG, these data serve as evidence of the potential for contamination that stormwater poses to karst aquifers.

Precipitation Data

Precipitation data collected during this study show that the duration and intensity of the storm event, as well as differences in the distribution of precipitation across the study site, impact the concentrations of contaminants measured at both the input and output sites. Data for LRR are presented below to show the correlation between precipitation and sample concentration (Figure 2-4). These data also illustrate the lag time in discharge response to precipitation at the site. Although every karst system will behave differently, these data underline the point that variations in response time mean that samples collected from multiple systems simultaneously, or nearly so, will not necessarily be identically influenced by a storm event.

Figure 2.4. E. coli Concentration Response to Storm Influence at LRR



Source: Created by the author.

Figure 2-4 shows *E. coli* concentration response to storm influence at the LRR compared to concentrations at BC both during the first flush and in the follow up samples. Storm-driven influence is clearly seen in the LRR samples, as is the difference between first flush and secondary samples. Two clear examples of storm influence on *E. coli* levels are seen between Julian date 310-366 and 380-423 (Figure 2-4). Between

Julian date 310 and 366, *E. coli* levels at LRR increased from 85 MPN to 228 MPN in an arc that brackets three storms and the resultant increases in discharge. During the same period, storm samples collected from BC on Julian date 325 and 354 produced *E. coli* concentrations of above 3,000 and 6,000 MPN for the first flush and subsequent samples, which are ten and twenty times greater, respectively, than the bi-weekly samples for the study period. When plotted in Figure 2-4, the *E. coli* levels define the rising and falling of the set of storms as a group, but do not distinguish concentrations attributed to individual storms. Samples collected between Julian date 381 and 423 better describe the response to a single storm event. The *E. coli* count from the pre-storm sample at LRR is 10 MPN; however, the concentration was measured at 35 MPN on Julian date 395. Storm samples collected from BC had MPN counts of 85 and 144 for first flush and follow up samples while the MPN count from the bi-weekly sample collected at LRR on Julian date 401 was 1528 MPN. These results serve to reinforce the importance of sample collection time in the determination of true storm response at the LRR and other outputs. The variety of storm responses recorded throughout this study illustrates a major challenge in karst stormwater monitoring. The complex interplay between storm input and contaminant concentrations, as exhibited in Figure 2-4, shows that sample collection time and frequency can have major impacts on calculated water quality levels.

Figure 2-4 also serves to illustrate one of the major problems with samples in karst terrains. Discharge response to precipitation is not immediate at this site, and the time period for the return to baseflow varies greatly as well. The elevated storm sample pollutant concentrations, along with the variations in response to precipitation at the LRR make the point that sample collection time can have a large impact on how water quality is perceived and must be timed correctly in order to minimize the erroneous influence. It should also be noted that precipitation data collected from the two sites utilized during the study often differ greatly from each another, a phenomenon that can cause errors in precipitation response model construction and make the appropriate sample collection time difficult to determine. Spatial variations in precipitation on a small scale are well documented (Faurès et al., 1995; Jensen and Pedersen, 2005), and are influenced by factors such as degree of urbanization, land use in the surrounding areas, and annual precipitation amounts. Data compiled during this study confirm previous work detailing the need for multiple precipitation monitoring stations within small basins. In this case, despite being less than four miles (6.4 kilometer) apart, a two-inch (five centimeter) difference in total precipitation over the course of the study was recorded.

Baseline Water Quality

The purpose of this study is not to prove that stormwater runoff is moving contamination into the karst system, but to determine if the current karst monitoring practices are effective in capturing data necessary to quantify this input. Using the CoBG as a case study, this was done by comparing contaminant concentrations during baseflow conditions to those during storm conditions and observing the variations. During this study, baseline water quality values were determined from bi-weekly sample collection and analyzed as shown in Table 2-4.

Table 2-4. Statistical analysis of monitoring locations for the study duration.

New Spring									
	TSS	BOD	E. coli	COD	O&G	Nitrate	Al	Cu	Pb
Max	79	5.23	4611	11	8.6	45.02	0.32	0.26	0.205
Low	1.1	1.22	30	1	1.1	4.28	0.008	0.0028	0.0022
Mean	9.05	2.51	957.66	4.94	3.06	12.9	0.076	0.04	0.04
Std. Dev	15.56656	0.952496	1334.675	2.751742	1.902607	7.277653	0.078034	0.07085	0.067627
CV	1.720062	0.379481	1.393683	0.557033	0.621767	0.564159	1.026764	1.771248	1.690683
Lost River Rise									
	TSS	BOD	E. coli	COD	O&G	Nitrate	Al	Cu	Pb
Max	160	6.54	19863	8	6.8	54.21	0.619	0.259	0.2223
Low	0.5	1.03	10	1	1	10.26	0.0201	0.0022	0.001
Mean	15.07	2.77	2258.38	2.42	2.47	24.37	0.1859	0.0353	0.0384
Std. Dev	29.69621	1.365315	5353.778	1.573166	1.216408	10.63546	0.194917	0.065824	0.065582
CV	1.970551	0.492894	2.370628	0.650069	0.492473	0.436416	1.048503	1.864703	1.707865
Petty Well									
	TSS	BOD	E. coli	COD	O&G	Nitrate	Al	Cu	Pb
Max	480	9.04	9804	62	16.5	51.386	0.903	0.381	0.215
Low	4	1.12	0	3	1.9	6.68	0.012	0.0056	0.0039
Mean	109.51	3.076	1085.9	13.788	5.317	14.92	0.244	0.1012	0.0467
Std. Dev	132.8374	1.672447	2439.482	11.8954	3.273516	10.74556	0.219709	0.117441	0.071633
CV	1.213016	0.543708	2.246507	0.862735	0.61567	0.720211	0.900445	1.160482	1.533893

Note: All concentrations, with the exception of E. coli (MPN), are reported in ppm.

Mean baseflow concentrations, calculated in Table 2-4 for each output site, were derived from bi-weekly sampling data collected for the duration of the study. PW results indicate the highest single and mean concentrations for all contaminants, with the exception of mean nitrate and maximum lead levels, which were the highest at LRR. The higher concentrations, indicating a more contaminated waterway, can be attributed to the surrounding land-use types in the basin. The large impervious areas associated with the Greenwood Mall complex combined with the high-density housing and restaurants subject this site to runoff that has potential to be substantially different from runoff observed at other monitoring locations. Although PW did not have the highest instantaneous values for all metals in the analytical suite, the majority of results were significantly higher than the values reported form the other bi-weekly sites. This is to be expected, again, because of the land use in the surrounding area. Apart from being located along the most heavily traveled road in the CoBG, the primary drainage from the mall complex parking lot flows directly into the conduit system associated with the PW (Cesin and Crawford, 2005). Lee et al. (2007) have shown that proximity to parking lots will have an elevating influence on the concentrations of O&G, metals, and COD in receiving waters, and this site is no exception.

To better understand the data, it is necessary to examine the bi-weekly monitoring results at various frequencies to discover if this annual overview provides sufficient data to determine overall water system health. Variability always exists in water quality data, and the influences of any given karst system being monitored will change throughout the seasons and over the years as the system matures. To determine the true baseflow conditions that are necessary to establish the actual impact of stormwater input, it is necessary to remove as much of the variability from the data as possible. Table 2-4 shows distinct changes in *E. coli* concentrations at the LRR that coincide with storm events and increased discharge. To remove this influence, it is necessary to quantify the response of the output to storm events. Over the course of this study, the length of response to storm input at the LRR ranged from three to fourteen days, with the average time for a return to baseflow roughly six days. Two methods for the removal of influencing factors were tested during this study: LRR bi-weekly *E. coli* data were filtered to remove all values greater than ten percent of the mean value in an attempt to reconcile the data for storm possible sample collection error or laboratory cross contamination, and the full dataset was also filtered to remove all sample data collected within the six day average response window to remove storm influences. The mean *E. coli* concentration for the study was

2258.4 MPN; with values greater than ten percent of the mean removed the value was reduced to 410.64 MPN, and when the full data set was filtered for storm events the mean value was 269.6 MPN. This has major implications for stormwater monitoring programs in karst, as the data demonstrate the ease with which samples collected under assumed baseflow conditions can actually still be elevated in response to storm events.

While storm influences are seen in non-karst monitoring conditions, as well as in karst settings, recent work in the Lost River basin by Lawhon (2014) sheds light on the intricacies of storm response in karst basins through chemical storm pulse tracking. Lawhon's (2014) data show the influence of multiple input sources on storm response in the Lost River basin and highlights the complexity of karst system responses to storms. A baseline concentration number must be approximated to serve as a building block for the monitoring program, but must be established without the influences on concentrations exerted by contaminants mobilized by storms. The cost of stormwater monitoring on a municipal level can be high but, without first establishing a baseline for comparison, the knowledge provided by the storm samples does not outweigh the cost of collection.

Monitoring Program Review

The CoBG has been collecting water quality data on a quarterly basis since 2007, with a focus on monitoring the quality of water at major outputs and karst features in the area, but it is not designed to account for the influence of stormwater on overall water quality. The results of the stormwater data analysis show that significant amounts of contamination are being mobilized by storm events and making their way into the karst system, but has the current quarterly monitoring program been catching these pulses? By comparing mean concentrations for both quarterly and bi-weekly monitoring, a major program flaw is brought to light: quarterly monitoring fails to capture the pulses of contamination associated with stormwater inputs effectively, thereby providing inaccurate data and interpretations about water quality and trends in contaminant concentration under the existing goals of the current MS4 regulations. Table 2-5 compares mean, standard deviation, and CV values at the LRR when filtered for three monitoring frequencies. To better understand the differences between monitoring frequencies, the full bi-weekly dataset was filtered to show results at bi-weekly, monthly, and quarterly sampling frequencies. The majority of contaminants at the LRR exhibits a decreasing mean concentration and CV as monitoring frequency drops. Mean *E. coli* concentrations drop from 2258.38 to 1969.99 and 694.03 as sampling frequency decreases from bi-weekly to quarterly, while O&G mean concentrations increase from 2.47 to 2.93 to 3.3 ppm, while following the same frequency progression. The elevated mean and CV values seen during bi-weekly monitoring, and shown in Table 2-5, indicate the need for changes to be made to the monitoring program in the CoBG and considered during the development of any stormwater monitoring plan in a karst area, to ensure that the best data are being captured to address any concerns from stormwater pollution.

Table 2-5. Statistical analysis of contaminant concentrations at LRR when filtered for multiple sampling frequencies.

TSS		BOD		*E. coli*		COD		O&G		Nitrate	
Bi-Weekly		**Bi-Weekly**		**Bi-Weekly**		**Bi-Weekly**		**Bi-Weekly**		**Bi-Weekly**	
Mean	15.06964	Mean	2.772188	Mean	2258.379	Mean	2.423077	Mean	2.46875	Mean	24.40794
SD	29.69621	SD	1.365315	SD	5353.778	SD	1.573166	SD	1.216408	SD	11.00551
CV	1.970598	CV	0.492505	CV	2.370629	CV	0.649243	CV	0.492722	CV	0.450899
Monthly		**Monthly**		**Monthly**		**Monthly**		**Monthly**		**Monthly**	
Mean	7.934615	Mean	2.8375	Mean	1969.985	Mean	2.4	Mean	2.930769	Mean	21.33938
SD	9.216444	SD	1.212801	SD	5183.934	SD	1.019804	SD	1.406788	SD	5.166681
CV	1.161549	CV	0.427419	CV	2.631459	CV	0.424918	CV	0.480006	CV	0.24212
Quarterly		**Quarterly**		**Quarterly**		**Quarterly**		**Quarterly**		**Quarterly**	
Mean	9.558333	Mean	2.721667	Mean	694.0333	Mean	3	Mean	3.3	Mean	23.1028
SD	12.57936	SD	1.545417	SD	546.0852	SD	1	SD	1.807392	SD	3.313863
CV	1.316062	CV	0.56782	CV	0.786828	CV	0.333333	CV	0.547695	CV	0.14344

The monitoring program in Bowling Green is unique in that it fulfills no specific regulatory requirement, but uses the collected data to provide a general overview of water quality and stormwater program effectiveness to the city government. Because current NPDES regulations do not require quantitative water-quality monitoring, it is difficult to establish a monitoring program that will meet the anticipated needs of future program requirements, but the CoBG is advanced in having already established baseline monitoring, which will aid in the future development of any required monitoring.

While MS4 Phase II stormwater monitoring programs could feasibly be tied into TMDL monitoring and the development of waste load allocations (WLAs), current program design should focus on efficient data collection, which, as demonstrated by this study, include background collection at a frequency greater than quarterly combined with stormwater monitoring at selected locations. The comparison presented in Table 2-5 corroborates data from Ryan and Meiman (1996), who found that, in order to completely characterize pollutant loading during storms, an event sampling at a bi-hourly rate is needed before, during, and after the storm event to capture the entire contaminant pulse reliably. Because sampling on this scale represents both a monetary and personnel burden that many MS4 Phase II communities cannot bear, the challenge becomes one of finding a balance between data cost versus data value. The data collected by the CoBG have no hard "value" to the general public because of the voluntary nature of collection; however, the collection has continued because city officials realize that at some point in the future these data will become useful at a broad scale and possibly will be required for continuing permit compliance, while also providing baseline data for establishing future monitoring programs if the requirement is mandated by new policy.

Conclusions

By utilizing relatively high-resolution water quality monitoring and combining this with stormwater sample collection, this study aimed to address the following questions:

1) Is the current CoBG monitoring program effective at capturing karst water quality data?

High levels of variability were observed in contaminant concentrations during background and stormwater quality monitoring at a bi-weekly frequency that were not observed in quarterly monitoring results. This indicates that the results being produced by the current program do not capture adequately changes in water quality that are associated with the local karst system. These results bolster work done by Ryan and Meiman (1996), Vesper et al. (2001), and others who demonstrated that the myriad factors affecting karst flow make low resolution monitoring programs ineffective.

2) Do current monitoring methods capture storm related changes in water quality?

Although complete storm responses were only quantified at one site, the information gained points to the need for relatively high frequency monitoring of storm events to completely quantify contaminant input and discharge response. The stormwater monitoring data show significant pulses of contamination being introduced to the karst system through Class V injection wells, with the contaminant concentrations varying greatly over the course of each storm event. Quarterly monitoring at the current locations may serve to show a slight rise in storm related contamination, but fails to show the true impact of stormwater input.

3) How can karst monitoring programs provide time and cost efficient data with practical value?

The development and implementation of watershed-based monitoring programs is not a new idea and data collected during this study reinforce its applicability. For many MS4 Phase II communities, the costs associated with high resolution monitoring at multiple locations would be prohibitive but, by selecting individual basins, targeting major outputs, and screening for likely contamination hotspots, the costs of the program can be reduced to a more reasonable level. Ultimately, the cost of the program is dictated by the determined need for the data being collected. The addition of a supplemental storm sampling regime could provide vital data on contaminant transport and storage in the karst aquifer, and could also allow municipalities to tailor their MS4 programs to address areas where elevated contaminant levels are detected.

The tremendous amount of data that must be collected to quantify contaminant transport in urban karst areas properly can seem daunting, especially because of the lack of governmental requirements behind these initiatives. The voluntary monitoring program in the CoBG serves as an excellent example of a building block for the development of urban karst-specific monitoring protocols. Each monitoring program will have to balance the need for data with the cost of obtaining it. More than likely, it might not be necessary for each program to collect bi-hourly water quality data during every storm for a year. Rather, through building a strong background knowledge of the study site and carefully describing background conditions and storm responses as described in this study, the collection and analysis of data become more manageable. It is anticipated that this study could serve as a starting point for future work in urban karst stormwater monitoring. The challenges faced in these settings are complex and understudied, and require additional knowledge and data to overcome. The general complexities of karst systems are greatly enhanced by human-made inputs and require special attention to understand and predict.

The Lost River Basin in Bowling Green is one of the most studied karst systems in the U.S., but the understanding of it is constantly evolving. Future work in the Bowling Green area includes the development of multiple real-time geochemical monitoring stations at significant karst outputs sites, as well as the continuation of background water quality and stormwater monitoring by the CoBG in cooperation with Western Kentucky University. This study can be used by the Public Works Department in Bowling Green and the Warren County Stormwater Division as a guide to improving existing monitoring plans and data collection, and by the karst community in general as a source of information and ideas for the development of specific plans.

Chapter 3: Karst Stormwater Policy Analysis

Introduction

Natural resource management and source water protection issues are at the forefront of national media discussions on an ever-increasing basis as more and more demands are being made on the nation's water resources. The protection of these resources is vital in ensuring that an adequate supply of water is available for residential, commercial, and agricultural uses. Surface waters receive protection from degradation from the Clean Water Act (CWA) and groundwater protection primarily stems from the Safe Drinking Water Act (SDWA), but where do karst groundwater systems fit into these regulations? Groundwater is specifically excluded from the CWA protections and, unless a karst aquifer system is being used as a source of drinking water, the SDWA has little to offer in terms of actionable regulations. The progress achieved by the National Pollutant Discharge Elimination System (NPDES) and CWA in regulating and reducing point source discharges means that these discharges are no longer the greatest threat to water quality in the U.S. (EPA, 2012); that distinction now belongs to non-point-source pollution, with the greatest contributors being agricultural and stormwater runoff.

Karst groundwater systems are particularly vulnerable to contamination from both point source and non-point source pollution due to the high degree of interconnectedness they share between surface and subsurface systems (Vesper and White, 2003), along with high flow rates, which are generally comparable to those of surface streams (Ryan and Meiman, 1996). This high level of connectivity provides for the direct recharge of karst systems by surface water, particularly stormwater runoff in urban areas, and eliminates natural filtration processes present in non-karst systems. Although karst contamination issues have received much attention, the complexities and variations that exist in each karst system make the development and implementation of karst specific groundwater regulations difficult.

Kentucky is known worldwide for karst systems such as Mammoth Cave, but it is less widely known that nearly 50% of the land surface in Kentucky overlies geology that is favorable for karst development. Urban areas built over karst terrains in Kentucky are a common occurrence and the systems under and surrounding these areas are widely studied. The karst systems under and around Bowling Green, Kentucky, have undergone intensive dye tracing, geophysical mapping, cave exploration, and water quality monitoring in an ongoing effort to better understand the interaction between urbanization and the karst system. Recent studies investigated the movement of contaminants associated with stormwater and land use through the karst system in Bowling Green (Lawhon, 2014; Nedvidek et al., in preparation), but few have investigated the potential implications that changes in municipal stormwater discharge regulations could have on karst water quality and protection.

This study represents efforts to better understand the protections afforded to karst systems under Kentucky law and the Municipal Separate Storm Sewer System (MS4) Phase II program, and the potential political and social implications of adapting karst-specific water quality regulations both at a local and state level. Three datasets were used to accomplish this: a comparative review of past and present stormwater regulations from Bowling Green and the surrounding areas, results from a survey of those involved with stormwater management from both private and government sectors about their depth of local karst knowledge and regulations, and data collected from a stormwater contaminant transport study conducted in Bowling Green concurrently with this study. By combining this information and using the City of Bowling Green (CoBG) as a case study, this research aimed to answer the following questions:

- Do local regulations effectively support the protection requirements of the MS4 Phase II program and state water quality protection programs?
- How do karst waters fit into the framework of water quality protection policies in local, state (Kentucky), and federal contexts?

The results of this study are intended to aid city and county government planners and state officials in the formation of karst-specific stormwater policies that provide protection for threatened water resources.

Stormwater Policy Review

The history of stormwater policy development in the U.S. is long and complex, but this study focuses primarily on the 1999 implementation of the MS4 Phase II program. This program was developed to regulate stormwater discharges in order to assure that water bodies receiving discharges continued to meet their designated use criteria. An MS4 is defined as "a publicly owned conveyance or system of conveyances (i.e., ditches, curbs, catch basins, underground pipes, etc.) that is designed or used for collecting or conveying stormwater and that discharges to surface waters of the state" (EPA, 2003:1). This program complemented the Phase I program, which required medium and large cities with populations greater than 100,000 residents to obtain NPDES permit coverage for their stormwater discharges. Phase II of the program requires that any small MS4 with a population greater than 10,000 and not covered under the Phase I program obtains NPDES permit coverage for stormwater discharges. Unlike the Phase I program, which placed numerical limitations on contaminants contained in stormwater discharges, the Phase II program relies on narrative guidelines for pollution control. The six guidelines outlined in the Phase II final rule - Public Education and Outreach, Public Involvement and Participation, Illicit Discharge Detection and Elimination, Construction Site Stormwater Runoff Control, Post Construction Stormwater Management in New Development and Redevelopment, and Pollution Prevention/Good Housekeeping (EPA, 1999) - are known as Minimum Control Measures (MCMs). Rather than focus specifically on “end of pipe” solutions, these guidelines established basic requirements for the development of engineering and administrative controls with the intent of reducing the financial burden on small municipalities and developers that comes along with compliance monitoring for numerical effluent limits.

Kentucky petitioned the EPA for, and received primacy over, its MS4 program, and administers Phase II programs under a blanket general permit, known as KYG20, which is revised and re-issued on a five-year cycle. To ensure compliance with KYG20, the state MS4 coordinator requires that every permitted authority submit an annual report that details efforts of continuing compliance with the six MCMs. A second major component required for permit compliance is the development of a Stormwater Quality Management Plan (SWQMP) that provides guidelines for municipal compliance with the six MCMs and details specific pollution prevention and reduction techniques and practices (KDOW, 2010). This document is also where the permit specific definition of what is arguably one of the most debated terms in stormwater permits. The Maximum Extent Practicable (MEP) remains undefined by the EPA in an effort to allow maximum flexibility in setting requirements that would best reflect local political and social expectations, as well as provide the most reasonable protections based on local geology and hydrology (McCulley, 2002). This means that every permit holder is responsible for developing treatment standards that represent the greatest efficiency and protection reasonably expected given local conditions. In Bowling Green, Kentucky, it was decided that the MEP requirement would be fulfilled by the installation of Best Management Practices (BMPs) that reduced the total suspended solid (TSS) load of runoff by 80% for stormwater in the City.

Karst Policy

The management and protection of karst water resources does not fit neatly into either the CWA or SDWA, and the CWA specifically excludes protection of groundwater, while the SDWA only relates to water used for human consumption. The problem exists because in all karst areas, especially in urbanized settings, groundwater systems receive significant input from stormwater runoff via sinkholes, swallets, cave entrances, and drilled or dug injection wells. These direct inputs from the surface mingle with the waters of the karst system and are eventually discharged to the surface at springs or seeps, where they eventually join with surface water bodies. There are several factors to be met before karst waters would fall under the jurisdiction of either of the federal acts, and a Kentucky statute further adds to the confusion.

Clean Water Act

The original intent of the CWA was to restore U.S. waters to fishable and swimmable quality by 1983 and to eliminate all discharges to water bodies completely by 1985 through the use of anti-degradation limitations that would require waters to, at minimum, remain suitable for their current designated use. Progress towards the as-of-yet unattained goals of the CWA is made through the implementation of the NPDES program, which regulates the addition of pollutants to any U.S. water bodies. The definition and application of the title “Waters of the United States” has major implications for karst water-quality regulations and is discussed in detail later. Designated uses are assigned by each state and include warm and cold water aquatic habitat, drinking water supply, and primary/secondary contact recreation, among others. Groundwater, including karst flows, does not fall under these protective regulations, however, because it is not included in the current interpretations of U.S. waters. In some instances, courts have ruled for CWA protection of groundwater when it can be proven that the water flows in distinct underground channels, but that protection is lost if the same underground water is directly recharged by precipitation or artificial recharge by injection. Karst waters fall under all three of these categories, and federal law provides no clear answer.

Safe Drinking Water Act

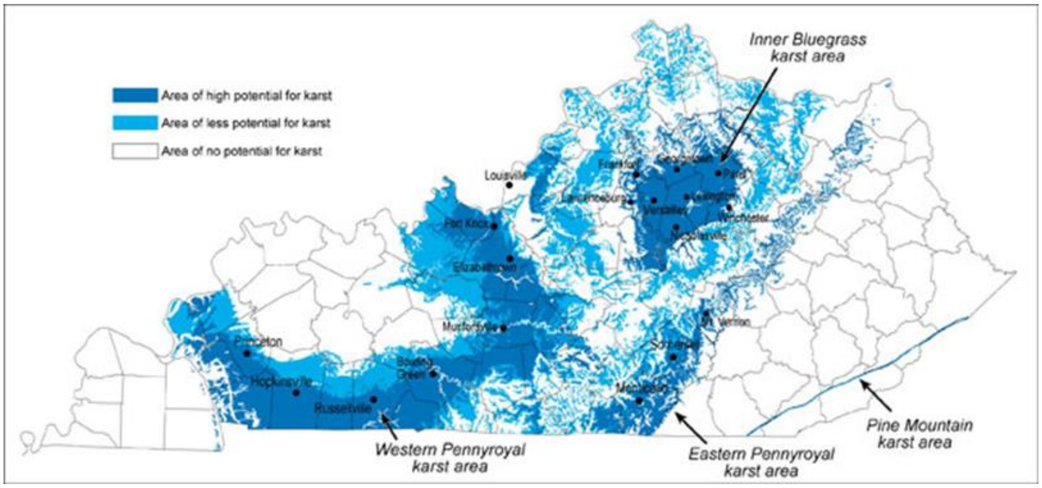
The SDWA provides groundwater protection through the establishment of national drinking water standards, but only for sources of municipal drinking water. Non-drinking water sources are not subject to these regulations. The standards set by the SDWA fall into two categories: National Primary Drinking Water Regulations and National Secondary Drinking Water Regulations. National Primary Drinking Water Standards protect human health against known health hazards, including any known physical, chemical, biological or radiological substances (SDWA). The levels of these contaminants are controlled by Maximum Contaminant Levels (MCLs), which may not be exceeded for water to be used for human consumption. National Secondary Drinking

Water Standards protect public welfare through the regulation of aesthetic contaminants commonly found in water, such as color and odor, which may make water unpleasant to consume, but do not pose known health risks. In Bowling Green, where the karst system is not directly used as a source of drinking water, the Underground Injection Control (UIC) branch of the SDWA, which regulates the injection of waste liquids into the subsurface, is most relevant to this study. Wells dealing with hazardous waste are strictly regulated, but stormwater injection through Class V wells is virtually unregulated, and the study area for this research utilizes nearly 1,400 Class V wells for stormwater management purposes.

Study Area

While the focus on policy analysis encompasses the U.S., survey data were collected from MS4 entities throughout the karst regions of Kentucky. Karst occurrence in Kentucky is most prominent in five physiographical regions as described by Paylor and Currens (2002) and depicted in Figure 3-1. The five regions are: The Inner Bluegrass, Outer Bluegrass, Eastern Pennyroyal, Western Pennyroyal and Pine Mountain.

Figure 3-1. Kentucky Karst Potential map



Note: Areas with potential for karst development in Kentucky: Darker blue shading represents higher potential for karst, while light blue shading represents lower karst potential. Source: From Paylor and Currens (2002).

Due to the predominantly rural nature of the Pine Mountain karst area and the lack of survey responses, the region was not included in the results. Bowling Green, Kentucky, was used as a case study for the development and progression of karst stormwater regulations in MS4 Phase II communities throughout Kentucky. The CoBG encompasses 92.2 square kilometers (36 square miles) and has an average elevation of about 150 meters (493 feet) above sea level (Reeder and Crawford, 1989). Census data indicate that the population of Bowling Green is 60,600 (U.S. Census, 2014). Bowling Green has a temperate climate with seasonal variations in temperature and precipitation. Average annual precipitation is 51.6 inches (131.06 cm), with 50% of the precipitation occurring between the months of December and May and the average temperature is 57° F (13.9° C). The city sits atop the Lost River Cave system, which houses Lost River, a combination of several subsurface streams that converge south of the city and flow north to resurgence at the Lost River Rise. The Lost River then flows as a surface stream for about one mile (1.6 kilometers) until it joins the Barren River (Crawford et al., 1987).

Methodology

An abbreviated policy review was undertaken with respect to existing federal, state, and local stormwater, groundwater and water quality regulations. Compilations of data from two sources were used in this study. Examples of land development and planning regulations and policies from Bowling Green were collected and reviewed to determine the evolution of karst specific regulations pertaining to stormwater and water quality. Data were collected from the CoBG Public Works Department, the Bowling Green/Warren County Planning Department, the Bowling Green Area Development District, Western Kentucky University, and the Bowling Green/Warren County Stormwater Advisory Committee. These documents were used to trace the formation and progression of karst-specific drainage and stormwater regulations and the BMPs used to control both water quality and quantity problems in Bowling Green. The review and summarization of these documents served as the basis for the formation of questions to be used in the survey, as well as the foundation for the analysis of stormwater policy evolution in Kentucky, with a focus on Bowling Green.

Survey data were collected from MS4 entities throughout the karst regions of Kentucky to gain a better understanding of how state policies are perceived and implemented, and to determine the attitudes towards, and knowledge of, individual karst systems. Due to the narrow target audience selected for this survey, a non-probability based census-style survey was designed using Qualtrics, an internet-based survey generation and analysis software program. The initial targets for the survey were those involved at the local government level with stormwater, public works employees, and city engineering staff, stormwater staff, MS4 coordinators, and anyone else who might have insight into local stormwater issues. The participant pool was limited to those working in the areas identified as having the potential for karst development. When possible, email invitations to participate in the survey were sent directly to city employees; however, in some cases, especially with the smaller municipalities, individual email addresses or contact information were not available. In these cases, email links to the survey were either sent to the generic city information email accounts or was submitted through web-based "Contact Us" forms. The final list of city employee contact information (n=28) was small enough to warrant widening the survey scope in terms of potential respondents. The scope was widened to include state Division of Water employees, non-profit environmental organizations, and environmental consulting firms to increase the number of participants who would potentially be involved with stormwater management.

E-mails were sent to potential survey participants (n = 292) on January 9, 2014, with reminder emails going out once per week until the survey closed on January 23, 2014. When emails were returned because of bad contact information or if there was no electronic form of contact available, hard copies of the survey were mailed out with pre-stamped, pre-addressed return envelopes (n = 23). The survey consisted of 39 questions designed to gauge the knowledge of the participant of local karst systems and how they interact with stormwater. The survey also was used to gather opinions from those working with stormwater on monitoring, protection, and urban development in karst areas. Logic design was used to ensure that participants did not answer questions that did not pertain to them; in the electronic version, questions would be shown or hidden depending on the answer to the pervious question. Hard-copy surveys were modified to include instruction for completing or ignoring certain questions based on answers to previous questions. Summary statistical methods were used to analyze survey population responses for scaled (i.e. Likert) questions when applicable. Open-ended and short-answer responses were summarized and grouped according to opinions expressed in the responses. Survey responses were compared to determine the attitudes and thoughts of those involved with the MS4 program, and to determine the importance they placed on the use and protection of their local karst systems. Results taken from a water quality study conducted in Bowling Green were used to assess the validity of several survey questions. The study of karst stormwater quality (Nedvidek et al., in preparation) served as a baseline from which the validity of responses to questions pertaining to karst water quality protection was assessed. Although the survey response was low, the limited data set does reveal trends from those surveys collected.

Survey Results

The initial survey questions served to establish baseline karst knowledge levels of respondents, as well as their awareness of the interplay that occurs between surface and groundwater in karst areas. Participants were given the chance to provide their own definition of karst, to rank their knowledge of their local karst system, and were asked to identify and explain their opinions on karst regulations. Of the total (n=41 of 327 distributed surveys), 48 percent of respondents chose to define or describe karst landscapes, each to a different degree of detail. Most mentioned in some way sinking streams, springs, caves, and sinkholes, while others chose to describe their level of knowledge in a more roundabout fashion. Respondents were then asked to rank their knowledge of the local karst terrain on a scale from 1 to 5, with 5 being the most knowledgeable.

Table 3-1. Self-evaluated karst knowledge of survey participants

#	Answer	Response	%
1	1	1	5%
2	2	2	9%
3	3	12	55%
4	4	5	22%
5	5	2	9%
	Total	22	100%

Note: The question asked: On a scale of 1-5, with 5 being the most knowledgeable, how would you rank your knowledge of your local karst terrain?

Table 3-1 presents the self-evaluated karst knowledge of survey participants. Of the total surveyed, 86% of respondents indicated they believe their karst knowledge is average or above average. Respondents were then presented with a series of general statements regarding karst protection and asked to rank their agreement or disagreement with each statement. Of the total, 48% of respondents ranked each statement and, of those, nine percent indicated that there is a clear distinction between ground and surface water in karst areas and one percent indicated that groundwater protection in karst faced no unique challenges. In Table 3-2, mean values over 2.5 are interpreted as general respondent agreement to the presented statement, while mean values under 2.5 indicate disagreement on the part of the respondents. Agreement values were generally high for each statement with values for question 6 scoring the closest to indicating group disagreement. Of the respondents, 27% either strongly agreed or agreed that karst aquifers should be required to meet surface water-body standards, while 18% strongly disagreed or disagreed with the statement. Overall, the trend of the mean values indicates that the respondents as a group agree, among other things, that surface water recharge of karst aquifers can be instantaneous, and that stormwater runoff is a major contributor to karst water pollution.

Table 3-2. Survey participant opinions on karst water policy issues.

Statistic	The distinction between surface and groundwater is not as clear in karst as in non-karst regions	Karst regions face unique challenges in groundwater protection	Surface water recharge of karst aquifers can be instantaneous	Special attention should be paid to groundwater protection in karst regions	Stormwater runoff is a major contributor of contaminants in urbanized karst areas	Karst aquifers should be required to meet surface water body standards
Min Value	1	2	3	3	3	1
Max Value	5	5	5	5	5	5
Mean	3.95	4.33	3.86	4.33	4.29	3.24
Variance	0.95	0.63	0.73	0.53	0.51	1.19
Standard Deviation	0.97	0.8	0.85	0.73	0.72	1.09
Total Responses	22	22	22	22	22	22

Following this line of questioning, participants were asked to evaluate another set of statements focused on current and potential karst water regulations. The group opinion was against the implementation of numeric discharge limits for MS4 Phase II communities in karst, citing a lack of resources, both technical and financial, and an assumed community backlash from the implementation of new regulations. Mean response values indicated that the group agrees that current regulations provide adequate protection for karst environments, while also agreeing that the government should work towards developing karst-specific groundwater monitoring regulations. Further exploring the development of water quality regulations, survey participants were asked to explain how their pollutant of concern in MEP development was decided, and how their removal rate was calculated. Although this topic is an essential part of each MS4 Phase II permit, the 24% response rate, along with several incorrect responses, indicates a lack of understanding of the topic.

Table 3-3. Survey participant knowledge of MEP development.

In the nineties, a fuel station was found to have tanks that had been leaking for several years. The EPA came in to check out the problem. Sampling wells were placed in several locations and some remediation was involved and testing is still being done on this project.
TSS, nutrients
Your question implies that I am in a position to make these regualtory decisions - I am not in that position
Bacteria, sediment, nutrients
onsite waste disposal
Bacteria. Dont know the MEP
a) Automotive fueling facilities; b) Automotive maintenance and repair facilities; c) Restaurants wit h grease collection and disposal ; and , d) Other land uses as determined to have a high potential of pollutant discharge i nto the MS4 as determined by the County Engineer .
We have pollutants of concern for surface water. Since we have a karst landscape, I am going to apply those pollutants of concern to karst as well. Pollutants of concern: sediment, nutrients, fecal coliform/e-coli. A tmdl is being developed for Strodes Creek, one of two streams that receive stormwater runoff.
I am not a representative of a governmental agency and to my knowledge we do not have any lists other than 80% removal for erosion and sediment control.
We only regulate sediment at this point in time.

Table 3-3 illustrates that, while participants may score themselves as well versed in local karst knowledge, there is a difference between this and regulatory knowledge. This gap in knowledge illustrates one of the major challenges of policy development in karst settings. Many survey participants demonstrated a surficial knowledge of karst systems, but were unable to explain more complicated regulatory concepts clearly. Additional voluntary demographic information collected during the survey indicated that the lack of in-depth regulatory knowledge is not a good indicator of education levels in the survey group. Only 6% of survey participants indicated a high school diploma/GED as their highest level of education completed, 56% had obtained Bachelor's degrees in science/engineering fields, 33% indicated having obtained Master's degrees, mostly in civil engineering, and 6% indicated a Ph.D. as their highest educational achievement. Table 3-4 shows concentration subjects for higher education degrees as reported by the survey group.

Table 3-4. Education levels of survey participants.

Bachelors Degree (Major/Minor)	Masters Degree (Concentration)	PhD.D (Concentration)
Geology/Earth Sciences	Water Resources Engineering	
3 years college biology/forestry	geography	
Civil Engineering	education	
Civil Engineering	Masters of Civil Engineer	
Civil Engineering Technology	MSCE	
Civil Engineering Technology - WKU		
Plant Science		
Natural Resources Conservation Management		
Bachelor of Science, Civil Engineering		

The disparity that exists between the education levels of survey participants and the low levels of comprehension concerning regulatory matters points to a problem within the community education components of the MS4 program. Therefore, it is prudent to examine the existing polices at the national, state, and local levels to determine if adequate protection exists for karst groundwater given the potential lack of mitigation provided by the MS4 educational policy in place to help with this aspect of regulation. The CoBG provides an ideal case study for local karst stormwater policy effectiveness, given its long history in dealing with these issues.

Policy Review

Status Quo Policy

Currently there are no karst-specific policies regarding water quality at either the state or federal level. The Clean Water Act and the Safe Drinking Water Act have the capacity to provide protective regulations for karst water quality, but for various reasons fail to do so. The CWA excludes groundwater from its regulation, a position recently reinforced by the EPA during the unveiling of the clarification of the “Waters of the United States” rule (EPA, 2014). Challenges to the exclusion of groundwater from CWA regulations have met with mixed results. Courts generally do not extend CWA protections to non-tributary groundwater systems, which are those that do not discharge to surface water systems. However, courts have been split on affording CWA protections to tributary groundwater, with those ruling in favor of CWA protection take the view that it may be impossible to protect the quality of surface waters systems if they are being recharged by polluted groundwater (McClellan v. Weinberger, 1988; ACORN v. TAP, 2011). The SDWA specifically includes groundwater in its regulations, but only if that water is a current or potential underground source of drinking water. Waters can be considered potential underground drinking water sources if they have less than 10,000 mg/L of total dissolved solids (EPA, 2012). Mechanisms exist, such as the creation of wellhead protection programs, and the designation of sole source aquifers, the most notable example of which are the protection and research programs developed around the Edwards Aquifer in Texas. What is not addressed, however, is the fact that karst streams generally support the base flow of surface streams in the area (KGS, 2012). This would seem to indicate that, in karst areas, even when surface systems are identified as primary drinking water sources, karst systems still play a role in supplying drinking water.

In Kentucky, where karst can be considered both groundwater and surface water, karst water-quality issues are most frequently identified and monitored at springs, but the system as a whole is rarely monitored. The majority of karst-specific regulations that do exist are created at the city and county government level, generally through ordinances concerning construction and land use. These ordinances work toward filling water-quality requirements set forth by the MS4 Phase II program, which stresses the use of non-numerical discharge limitations and the development of both structural and non-structural BMPs. However, the driving mechanism of policy formation is not usually due to karst specific groundwater concerns or to mitigate impact on the karst hydrological system.

State Level Policy

Water quality policy at the state level in Kentucky does not include karst specific protections or requirements. Some state agencies, such as the Kentucky Transportation Cabinet (KTC) have developed karst specific stormwater BMPs, but these regulations are not binding on other groups at any level. The closest that state government comes to including karst waters in quality policies is the inclusion of major impaired springs in the 303(d) report on water quality made to the EPA every two years. Springs and the stream segments flowing from groundwater sources are given designated uses and included on the list when appropriate, but rarely are the underground systems leading to the springs included on the list. This fails to identify the source of the water and any possible contaminant source from which pollution of the entire water body may occur upstream.

Indirect protections are provided to karst systems through the implementation of the Kentucky Pollution Discharge Elimination System (KPDES) system, which requires the implementation of the six MCMs outlined in the NPDES program. This program relies primarily on education and BMP development; it does not require water quality monitoring, nor does it set numerical limits on allowable contaminant concentrations in municipal stormwater discharge. Permit holders are required to develop a locally based treatment standard for construction site BMPs, but are not required to implement runoff monitoring requirements.

Local Government Ordinances

Indirect regulatory mechanisms for karst water quality protection come from state and county government ordinances. Because there are no mandated karst requirements in stormwater or water quality regulations, it is up to local governments to protect water quality. The creation and implementation of these policies cannot, however, be performed in a vacuum. Local stakeholder involvement and participation in policy development is needed to ensure participation and engagement from the group to be regulated. It is important to give consideration to stakeholder and public education when dealing with the complex hydrological concepts found in karst areas, as many stakeholders are often unaware of the nature of karst aquifer processes (Fleury, 2009). Survey data indicate that a majority of participants rank their knowledge of local karst terrain as above average, but few were able to name local regulations or restrictions pertaining to karst. The complicated nature of karst flow is compounded by the extreme variability seen in subsurface conditions within a relatively small area. Research by Nedvidek et al. (in preparation) and Lawhon (2014) demonstrate the variability in stormwater contaminant transport in karst and prove that one-size-fits-all management plans have a low probability of capturing data that are relevant to the local karst system.

Many karst regulations in place in Bowling Green, Kentucky, were initiated as actions taken to prevent property damage associated with flooding. Water quality regulations grew from the flooding concerns as emerging research demonstrated the potential for contaminant transport associated with stormwater (Matheney, 1983; Crawford et al., 1987). While the high visibility and tangible effects of flooding in karst areas keep that issue fresh in the mind of the general public, less attention is paid to issues of water quality, especially when the contamination is of a relatively low level and continues for decades. Contamination linked to non-point-source pollution has been documented in the karst system below Bowling Green both directly and indirectly for nearly 100 years. A 1921 *Popular Mechanics* article detailed the magnificent natural "sewer system" upon which Bowling Green was built (Mace, 1921). Special attention in this article was given to the use of the cave system as a sanitary sewer, which would function to remove naturally all contaminants added to it. More recently, a study by Nedvidek et al. (in preparation) determined that, despite MS4 regulation and a proactive, unrequired stormwater quality monitoring program, stormwater runoff being directed into the karst system in Bowling Green exceeded SDWA National Drinking Water Standards for several contaminants (Table 2-3). Although these data clearly demonstrate discernable levels of contamination moving through the karst system, without the proper monitoring and reporting protocols this information will not reach the broad audience necessary for change to be enacted.

Analysis of Status Quo Policy

The benefits of water quality regulations are easily recognizable when the water system in question is directly used as a drinking water supply, since regular monitoring and control are required. But when the primary use of the water body in question is not for human consumption, the costs associated with protection become more difficult to justify. In a 1997 report, the EPA estimated the costs of private and public point source pollution control under CWA regulations were $14 billion and $34 billion, respectively, the majority of which was expected to come from state budgets (EPA, 2014). A 2005 study of Phase II MS4 communities in California found that the average cost per household of stormwater management and control in relation to MS4 permit conditions ranged from $18 to $61 per household, depending on the scope of the applicable stormwater program (Currier et al., 2005). Because these numbers represent Phase II communities, the costs of sample collection, analysis, and monitoring equipment are not included. The Phase II final permit eliminated discharge quality monitoring that was required of Phase I communities in an effort to reduce the financial burdens the regulation would place on the smaller Phase II communities. Before the cost of additional monitoring could be justified, a value or benefit must be assigned to the data that the monitoring would provide. Monitoring water quality in urban karst settings is an expensive and time consuming process, and one that requires specialized equipment and knowledge.

The best way to justify the additional expense of monitoring water quality arguably would be to highlight the interconnected nature of the karst and surface water systems, and demonstrate the connection between karst flows and drinking water system recharge. Survey data indicated that, currently, few stakeholders in Kentucky could easily make this connection, much less with viable policy regulations. This is a policy implementation challenge, since the current MS4 Phase II regulations primarily require education and outreach as the mechanism by which stormwater quality is mitigated. Current policies assume that public education efforts and the conveyance of the complexity of karst groundwater systems are effective, which has been shown not to be the case (North, 2011). However, there are no set criteria under which these actions must be undertaken, nor is there a stringent reporting mechanism for evaluating these activities and measuring their effectiveness at mitigating groundwater pollution problems. Furthermore, even if the educational activities where measureable in their effectiveness at eliciting behavioral change, which is the main goal of any policy enacted, there is no quantifiable mechanism by which any collection of stormwater or groundwater quality data is required by the current regulations, thus eliminating the ability to measure the effectiveness of educational efforts through these means as well (Cave et al., 2006).

Karst Stormwater Policy Recommendations

In order to allow for the development of local regulations, it may be most beneficial from a cost and enforcement perspective to develop policy using municipal government-based ordinances as the primary protection for karst waters. This ensures that local knowledge is utilized and prevents the alienation of local industry that could occur if more stringent regulations were developed and enforced.

By identifying the complexities involved with successfully creating and implementing a federal-level, karst water-quality standard, time and money are saved by federal and state government agencies by allowing local governments to develop their own treatment policies if desired. By allowing individual or groups of MS4 Phase II communities to apply for permits under the KPDES program, the decision to include or ignore the need for karst water quality measures is left up to the local governments. This allows for the creation of locally targeted programs that can best make use of local karst knowledge. The absence of direct pressure from the state government may also make the identification and recruitment of local stakeholders easier, as they may be more inclined to work with local rather than state governments.

There are several disadvantages to staying with the current policies in terms of water quality protection in karst. By never truly placing karst waters into a regulatory category, such as surface or groundwater, the state misses an opportunity to provide a legal basis for the development of water quality standards. By not defining the place of karst waters in the state regulatory scheme, it is impossible to formulate meaningful regulations. Kentucky includes language that could indicate the inclusion of karst systems in the definition of groundwater and surface water in the Commonwealth. "Waters of the Commonwealth" is a catch-all term that sets legal boundaries for waters over which Kentucky can claim regulatory control. In terms of karst areas, it identifies these as "wells, springs, and all other bodies of surface or underground waters, natural or artificial…," while the state definition of groundwater (KAR, 2014:12) is:

> .. the subsurface water occurring in the zone of saturation beneath the water table

> and perched water zones below the B soil horizon including water circulating through fractures, bedding planes, or solution conduits (401 KAR 5:037(12).

Surface water is defined in 401 KAR (2014:160) 5:002 as including:

> .. anything having well defined banks and beds including…any subterranean waters flowing in well-defined channels and having demonstrable hydrologic connection with the surface.

It would seem that, with the use of these terms, the state of Kentucky is acknowledging the need for the development of karst specific regulations, but fails to provide the specialized guidance needed to move forward. In contrast, Florida has established groundwater categories, much like the designated-use categories established for surface water standards under the CWA (FAC, 2009). The state of Florida makes these categories necessary by excluding underground or karst waters from the definition of surface waters. Until Kentucky clearly defines the status of karst groundwater, little progress can be made towards the implementation of protective regulations in these areas.

Regulation of Karst Water Quality under the Clean Water Act

The integration of karst groundwater into the CWA would provide the basis for a nationwide comprehensive policy regarding subterranean water quality, through standardized definitions of groundwater and karst water that would clarify the confusion resulting from the multiple definitions that exist. As mentioned previously, the inclusion of groundwater within the CWA has traditionally hinged on the connectedness of the groundwater to surface water systems, although this is far from a firm rule. While it is generally agreed upon that non-tributary groundwater does not meet the requirement of "traditionally navigable" required by the CWA, much of the confusion regarding the inclusion of tributary groundwater stems from the Supreme Court decision in Rapanos v. United States (2006), in which two tests for determining CWA jurisdiction were presented. The tests introduced with the Rapanos ruling both used slightly different language, creating confusion over which test would be acceptable. Justice Scalia requires courts to determine if the water body in question contains a “relatively permanent flow” and, if so, does the water possesses “a continuous surface connection to a navigable water of the United States” (Rapanos v. United States, 2006: 2). The test put forth by Justice Kennedy requires that courts determine that the waters share a “significant nexus” with jurisdictional waters to fall under the CWA (Rapanos v. United States, 2006). In June 2013, the environmental group *Save the Wild UP* filed a notice of intent to sue the U.S. EPA alleging that it was negligent in not requiring an NPDES permit for a mine whose drainage makes its way into seeps and wetlands and eventually into the Salmon Trout River. The implications for karst groundwater areas are obvious; much of past and present karst research focuses on delimiting the extent of karst systems using various tracer methods, many times with the intent of determining points of interaction with nearby surface water systems.

Federal and State Level Karst Policy

If the conditions of either test proposed by the Supreme Court in response to Rapanos v. United States (2006) are met, the waters of karst systems fall under the jurisdiction of the CWA. In this respect, the role of the federal government is to define the jurisdiction of the CWA and to provide the technical guidance and funding required by the states for successful program development and implementation. The incorporation of karst waters into CWA regulations acknowledges that it may be impossible to protect the quality of surface waters systems if they are being recharged by polluted groundwater (McClellan v. Weinberger, 1988; ACORN v. TAP, 2011). This opens the door for karst-specific protections under the CWA, as it has long been accepted that karst waters directly recharge nearby surface water systems and are directly recharged by surface runoff and injection (Crawford, 1989; Zhou, 2007). However, like many federal policies, including the NPDES and others, state or local policies often require more stringent regulations, or different enforcement mechanisms, as all karst areas are not created equally, and each presents its own unique challenges in terms of stormwater runoff, flooding, and groundwater pollution.

While the federal government provides the legal justification for the creation of water quality regulations, the burden of design and implementation of these programs falls to the individual states. The ability to include karst systems in both TMDL programs and state-run subsidies of the NPDES program allows contamination to be investigated and controlled from both point and non-point sources, while providing the legal backing for enforcement that has been lacking to this point. The implementation of a watershed management plan, based on the *Handbook for Developing Watershed Plans to Restore and Protect our Watersheds* (EPA, 2005), is necessary to regulate point and non-point-source pollution under the umbrella of the CWA. The Kentucky Pollutant Elimination System (KPDES) is the state-administered version of the federal NPDES program. The KPDES program follows the letter and intent of the NPDES program, but misses its chance to promote karst-protective regulations in applicable areas. As it is built on the framework of the NPDES program, the KPDES requirements for MS4 Phase II communities focus heavily on education and community involvement and participation, rather than relying on numeric discharge limitations to protect water quality. This reliance on education as a preventative BMP makes the assumption that those in charge of providing the education are knowledgeable enough about the local karst system to communicate the necessary messages effectively and elicit behavioral change in response to the policy, along with enforcement when appropriate.

Regulation by Permit

The inclusion of karst waters in the CWA point-source-pollution program necessitates the development of a new NPDES permitting framework that would apply to both municipal and private discharge points. This new framework would be formed around the theory of water quality management on a watershed scale to ensure that a cohesive monitoring plan and vision for future achievements is maintained (EPA, 1999). The development of a watershed-based management plan requires that the area be well defined in a hydrological, geological, and geographical sense, which is a task made even more difficult in karst areas, yet is of high importance in being able to enforce policy. Defining boundaries of local watersheds in karst serves a two-fold purpose: 1) it allows for the investigation and documentation underground flow routes and systems, and 2) it allows the plan managers to collect detailed data on all possible stressors, or inputs, to the karst system. These inputs, in this case focused on NPDES permit holders, can have a major impact on karst water quality, especially in areas where improved karst features or Class V injection wells are used to deal with stormwater runoff. In areas where a high density of karst injection points exists, the option for blanket permitting of injection wells and karst features could be incorporated into the management plan.

Results from studies by Ryan and Meiman (1996) and Nedvidek et al. (in preparation) demonstrate the high temporal and spatial variability shown by stormwaterborn contaminants, and also serve to provide verification of the introduction of contaminant loads above drinking water and designated use standards into local surface water systems via karst input. The observed high temporal variations in water quality indicate that a high monitoring frequency is needed to calculate contaminant loads accurately (Nedvidek et al., in preparation), the requirement of which would prove unobtainable by many permit holders. The issuance of a blanket permit for a designated area does not release permit holders from monitoring requirements, but rather it allows for combined monitoring efforts at confirmed output areas for the karst system. The primary mechanism for controlling pollution input to U.S. waters is the effluent limitations that come with each NPDES permit; these limits are designed to prevent the degradation of quality in the receiving water body. To simplify the question of designated use and water quality standards in karst systems, unless it can be proven that the receiving karst stream can be granted its own use category, the karst system shall be assigned the same designated use as held by the CWA regulated water body to which the majority of its flow discharges.

Analysis of Karst Regulation under the Clean Water Act

There are several disadvantages to including karst waters in CWA regulations, stemming from problems with community education and the technical aspects involved with karst water quality monitoring. Survey data presented in this study show that many of those involved with the operation of MS4 permits do not have a full understanding of the policies that form the foundation of the MS4 program. Additional evidence showing the lack of education and its impacts on CWA regulations can be found in a 2013 report by the Government Accountability Office (GAO), which details the shortcomings of the

TMDL program and CWA in general, and outlines recommended changes to bring the programs back on track (Allerhand et al., 2012). The lack of stakeholder education and involvement described by these studies represents a problem for the implementation of a watershed management plan. This type of plan relies heavily on the involvement of stakeholders in the public and private sectors, as well as support from the general public, in order to succeed (EPA, 2013).

Another potential problem lies in the cost of enforcement associated with CWA regulations. In a 1997 report, the EPA estimated the costs of private and public point source pollution control under CWA regulations were $14 billion and $34 billion, respectively, the majority of which is expected to come from state budgets (EPA, 2014). While the initial cost of monitoring additional discharge points in karst areas could be controlled by the issuance of a blanket permit, these savings would soon be offset by the resources required to locate, map, and describe each input point. The technical and legal difficulties arising from assigning responsibility for elevated pollution levels would also be an additional major financial drain. To collect accurate, defensible water-quality data, the monitoring program associated with the permit would need to follow recommendations provided in Nedvidek et al. (in preparation) regarding monitoring frequency and location. The results presented in Nedvidek et al. (in preparation) show that high-frequency monitoring of water quality, paired with storm-event monitoring, is needed to assess water quality accurately in urban karst settings. High frequency monitoring programs are expensive and difficult to maintain, as dedicated personnel and equipment would need to be retained to ensure permit compliance was met. By adopting a blanket permit policy for discharge into karst waters and monitoring at select output sites, it becomes difficult to determine the appropriate responsible party when contamination occurs above expected levels.

Policy Recommendation

Any policy that expects to provide meaningful protections to karst waters will need to combine elements from each of the policies listed above, as well as incorporating specific regulatory items from each state implementing the policy. The contribution of urban stormwater runoff to karst water contamination is well documented and demonstrates the need for a permitting process aimed at controlling discharges into karst systems, much in the way the NPDES controls discharges into surface waters. Current differences in federal and state policies concerning the legal definitions of karst water and groundwater results in confusion among municipal governments, which leads to a lack of comprehension of current policy and its shortcomings (Fleury, 2009; North, 2011; Nedvidek et al., in preparation). The importance of effective stormwater policy in karst terrains is vital to protecting water quality, both for the local area and for downstream users affected by upstream karst inputs. As described in Nedvidek et al. (in preparation), the unique aspects of karst systems make them vulnerable to contamination, especially in urban areas where stormwater runoff, and the contaminants carried with it, is frequently injected directly into the karst system with minimal, if any, pretreatment. While public education and outreach represent a significant condition of current MS4 Phase II permits, little data are available on the effectiveness of such programs, making the evaluation of progress in municipal permits complicated (Taylor et al., 2007).

The justification for a karst policy focused on stormwater-driven pollution can be found in recent studies performed in Bowling Green, Kentucky, that have examined the movement of stormwater and its associated contaminants through the karst system upon which the city is built. These studies document the extreme variability seen in contaminant concentrations at a variety of monitoring frequencies ranging from bi-weekly to quarterly and assess this base flow water quality with samples taken during storm events. The results show that significant levels of contamination, some above National Primary Drinking Water Standards, are being transported directly into the karst system via Class V wells (Lawhon, 2014; Nedvidek et al., in preparation).

Future policies should address the needs for enhanced educational programs that include benchmarks against which program efficiency can be monitored, along with the need for well-developed monitoring programs that provide accurate information on karst water quality. The policy should follow the general framework of CWA and SDWA policies couched within the watershed-based management plan outlined by the EPA. The policy also should focus on broad defining regulations promulgated by the EPA, in which legal definitions for karst systems and water quality standards are presented, followed by guidelines for the implementation of a watershed based management plan. Just as with CWA and SDWA regulations, the implementation and development of specific karst management plans would be left to state and municipal governments, with technical and financial assistance available at a federal level for research and development of monitoring plans. This requirement would encourage the involvement of stakeholders and local and state levels, ensuring that concerns for local water quality are adequately addressed.

Conclusions

This research used data collected from a karst knowledge survey of MS4 Phase II communities in Kentucky and a review of current karst/water policies in Kentucky and the United States, combined with high-frequency water quality monitoring data, to assess the need for karst-specific water protection policies. Survey data were collected to assess the knowledge of those associated with MS4 Phase II programs located in karst regions of Kentucky about local karst systems, current water quality and stormwater policy, structural and non-structural BMP implementation, and opinions on topics related to karst-specific water quality policies and regulations. Federal, state, and local water quality regulations were reviewed and assessed to determine their applicability to karst water quality, and to inform the design of recommendations for future policy development. Survey data indicated that, while many participants claimed to have an above average knowledge of local karst systems, few were able to explain details related to the development or implementation of local karst ordinances. The majority of survey participants agreed that karst-specific water quality regulations were needed, but that the cost of data collection and implementation outweighed the need for regulation.

A review of existing water quality policy served to identify areas of confusion regarding karst waters. There exist differing legal definitions of karst and groundwater between the Clean Water Act, the Safe Drinking Water Act, and state regulations. These differing, and often contradictory, definitions create a fractured and incomplete regulatory platform that lacks the cohesiveness needed to form comprehensive karst policies at the state or federal levels.

This study has implications not only for the formation and implementation of policy at a local level, but also presents arguments for amending federal regulations to reflect more accurately the need for a better understanding of karst systems and the contamination threats they face. The inclusion of karst waters in the tributary groundwater considerations of the CWA would provide the backing necessary to enact change at the state and local level, where change can be best effected.

Chapter 4: Conclusions

Through the combination of high-resolution water quality monitoring, analysis of federal, state, and local water policy, and a survey of MS4 stakeholders in the karst regions of Kentucky, this study set out to determine the effectiveness of accepted monitoring protocols at identifying stormwater pollution in karst, determine the impact of urban stormwater runoff on karst water quality, and define the need for development of karst-specific water quality policies. Data were collected over a year for stormwater analysis, and the CoBG, Kentucky, was used as a case study site for evaluating local karst policies within the broader state and federal context.

High levels of spatial and temporal variation were observed in water quality samples collected from the karst system under both wet and dry weather conditions in the CoBG. All monitoring locations showed distinct responses in contaminant concentration to storm events, with elevated levels of select contaminants persisting for an average of six days after the event. The differing response to storm influence noted across the study area indicated the need for the development of storm monitoring programs tailored to each output. Certain contaminants appeared to follow seasonal patterns, but stronger ties were observed between land use and contaminant concentration. Nitrate and pathogen concentrations were highest in outputs dominated by agricultural land use, while concentrations of metals, including lead and copper, were highest at monitoring locations associated with commercial and industrial activity. Output monitoring frequency was found to have major impacts on reported contaminant concentrations. The high temporal variability of contaminate concentrations in relation to storm events means that data are easily influenced by sample collection time, indicating the need for storm event-based monitoring programs over traditional quarterly programs.

A review of federal, state, and local water policies and regulations revealed that karst waters exist in a legal "gray area" when it comes to water quality standards and regulation. The differences in legal definitions of groundwater, combined with the failure to define karst systems specifically at a federal level, resulted in different treatments of groundwater and karst systems at all levels of government. In particular, the use of MS4 Phase II enforcement for municipalities like Bowling Green provides only educational steps toward mitigating stormwater pollution and, even when advanced, proactive monitoring programs are utilized without proper scientific context, these, too, are ineffective at depicting accurately the stormwater pollution profile of runoff entering the groundwater system.

Analysis of the stormwater survey data revealed that, while generally well educated as a group, few participants demonstrated more than a surficial knowledge of their local karst system. The majority of survey participants agreed that karst-specific water quality and stormwater regulations are needed, but indicated that the development and implementation costs of these regulations would be higher than the value of the protection offered. Although many survey participants indicated that they understood the nature of connectivity between surface and karst systems, it does not appear that this knowledge translates into a willingness to act or invest in future policy changes. These data show that even in areas with prominent karst systems, many people do not understand the full extent of the surface/karst interaction. Future work in this area is needed to assess further the education and opinion not only of those involved in the MS4 decision making process, but also of the general public in karst areas.

The development of this knowledge, along with continued karst stormwater monitoring, can allow Bowling Green to serve as a template from which other karst communities can model water quality and educational programs. The results indicate that adequate policies can be formed for karst water protection either through the amendment of current policies, or from the formation of new, karst-centric policies. While the overarching policy guidance should come at the federal level, policies, if possible, should be made at the state level and left flexible enough to account for the variations that occur between karst systems. These policies should include a strong focus on water quality monitoring and the development of benchmark data against which program efficiency and progress can be measured. Enhancements to the six MCMs outlined by the MS4 Phase II program can be made to enhance the value of educational components by the dissemination of water-quality monitoring results to the public. The CoBG is in the process of taking the first step in this direction and, by the time of publication, the city, in conjunction with Western Kentucky University, will have 10-minute-frequency water quality data collected from Lost River Rise available for viewing on a public website. This first-hand display of information allows the connection to be made between stormwater runoff and karst response and contaminant transport. This helps to show the interconnections that exist between surface and groundwater in karst areas, and viewers will be able to watch near real-time responses in SpC, temperature, pH, TDS, and discharge as storm events move through the area. Current policies fail to place sufficient emphasis not only on the value of education, but also on stormwater program evaluation and monitoring. Because karst aquifers supply a significant amount of drinking water to communities in the U.S., it is important that this connection be made for the true value of these policies to be realized, and for their development, implementation, and enforcement to occur.

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Appendix: Survey Results

My Report

Last Modified: 04/13/2014

1. The purpose of this study is to collect data on the implementation and development of water quality policy in karst areas, with a focus on stormwater issues. This data will be collected anonymously and will be used in part for the completion of a masters thesis. You should only take part in this study if you want to volunteer. Refusal to participate in this study will have no effect on any future services you may be entitled to from the University or the Bowling Green Public Works Department. Anyone who agrees to participate in this study is free to withdraw at any time with no penalty. There are no known risks associated with this survey, and there are no benefits or compensation offered for participation. By selecting "I Agree" below you are confirming that you agree with the terms listed above and are choosing to participate in this survey.

#	Answer		Response	%
1	I agree		40	98%
2	I disagree		1	2%
	Total		41	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.02
Variance	0.02
Standard Deviation	0.16
Total Responses	41

2. In your own words, please define or describe a karst landscape. If you are uncertain of how to define or describe these landscapes, write "skip" in the box below.
Text Response
Karst landscapes occur in areas underlain by bedrock that has a water-soluble matrix (predominantly limestone). Over very long periods of time (from the human aspect) cracks, joints, and highly soluable matrixes are enlarged by surface water (above the groundwater table) and groundwater flow. As a result, underground channels, conduits, and caves are formed and continuously enlarged and extended. Subsequently, these underground voids enlarge to the point that they can nolonger support the weight of the overburden sitting on the roof and the roof collapses forming sinkholes and blueholes. In well developed karst areas there is a lack of surface streams; however, where streams exist they are connected to groundwater sources via seeps, springs, streambed exfiltration (the stream intercepts the groundwater table).
There are several areas in Logan County with caves and underground water waterways that effect the land use. The areas in and around Russellville are of particular interest to us as we try to control flooding and some karst areas help while in other areas it is a curse. We have dye trace some of these areas to find and describe the path ways with some success.
A region characterized by underlying limestone geology that has experienced severe weathering creating large interconnected conduits capable of transporting water at similar rates observed for surface water channels.
A landscape that has a lot of sinkholes and caves.
caves and conduits leading to caves with connection to groundwater
Karst topography describes an underground "system of streams". It is formed by the erosion of bedrock, and moves/changes on a frequent basis.
Karst landscapes in Ky are areas of Limestone bedrock generally gently rolling hills to fairly level areas. Evergreens will be cedar trees that grow in limestone soils. Also areas will have a few to multiple sinkholes. Areas in the inner bluegrass can have large acreage that is a basin with no outflowing water drainage but all going down the swallet of a sink. Small springs may also appear and disappear down a sink. Caves are also a feature of karst areas.
land with underground rock conduits in which water is conveyed.
SKIP
limestone geology, areas where bedrock has dissolved creating sinkholes, streams may sink and rise thru these areas
limestone under dirt. Usually has sinkholes, caves or swallets
Karst refers to areas drained mostly by underground streams.
A karst landscape involves the underground movement of water through a limestone substrate.
Karst topography consists of depressions where water can collect without any outlet. In a limestone substrate area this is an indication of a potential sinkhole created by karst

topography.
Skip
An area underlaid with limestone. The limestone has cracks and fissures that lead to sinkholes, caves and vertical pits.
Karst landscapes are areas with limestone that create significant pathways for water (and anything carried by water) to travel from one place to the next.
Limestone area around with shallow clayey topsoil cover.
A karst landscape is one that is comprised of limestone that can be eroded away by subsurface water channels that can collapse creating sinkholes.
Skip
A karst landscape is one in which water drains into the ground, whether it is direct or indirect, by draining into a creek or stream that eventually goes underground.

Statistic	Value
Total Responses	21

3. On a scale of 1-5, with 5 being the most knowledgeable, how would you rank your knowledge of your local karst terrain?

#	Answer		Response	%
1	1		1	5%
2	2		2	9%
3	3		12	55%
4	4		5	22%
5	5		2	9%
	Total		22	100%

Statistic	Value
Min Value	1
Max Value	5
Mean	3.19
Variance	0.86
Standard Deviation	0.93
Total Responses	21

4. Please indicate the level to which you agree or disagree with the following statements								
#	Question	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Total Responses	Mean
1	The distinction between surface and groundwater is not as clear in karst as in non-karst regions	1	1	1	14	5	21	3.95
2	Karst regions face unique challenges in groundwater protection	0	1	1	10	10	21	4.33
3	Surface water recharge of karst aquifers can be instantaneous	0	0	9	7	6	21	3.86
4	Special attention should be paid to groundwater protection in karst regions	0	0	3	9	10	21	4.33
5	Stormwater runoff is a major contributor of contaminants in urbanized karst areas	0	0	3	10	9	21	4.29
6	Karst aquifers should be required to meet surface	1	3	11	2	4	21	3.24

	water body standards							

Statistic	The distinction between surface and groundwater is not as clear in karst as in non-karst regions	Karst regions face unique challenges in groundwater protection	Surface water recharge of karst aquifers can be instantaneous	Special attention should be paid to groundwater protection in karst regions	Stormwater runoff is a major contributor of contaminants in urbanized karst areas	Karst aquifers should be required to meet surface water body standards
Min Value	1	2	3	3	3	1
Max Value	5	5	5	5	5	5
Mean	3.95	4.33	3.86	4.33	4.29	3.24
Variance	0.95	0.63	0.73	0.53	0.51	1.19
Standard Deviation	0.97	0.80	0.85	0.73	0.72	1.09
Total Responses	22	22	22	22	22	22

5. Please rank how heavily you depend on the karst system of your region to deal with stormwater runoff, with 5 representing the greatest amount of dependence.

#	Answer		Response	%
1	1		4	18%
2	2		6	27%
3	3		2	9%
4	4		6	27%
5	5		4	18%
	Total		22	100%

Statistic	Value
Min Value	1
Max Value	5
Mean	3.76
Variance	3.09
Standard Deviation	1.76
Total Responses	21

6. Please describe how your region utilizes the karst system for stormwater runoff management

Text Response
All managed stormwater is directed to either detention basins and drained through injection wells into the subsurface karst features (thus into groundwater).
We try to utilize karst areas to some extent most cases but it is easier to gather storm-water runoff to the town creek which then takes the water to Mud River. We have two areas that take a lot of water to underground karst streams, however they sometimes can not take the water fast enough for the amount of water that falls.
Extremely limited since most of my work is conducted in Fayette County and the surrounding area.
Practicacly every area within our urban service area is dependent upon a sink or cave to carry stormwater to the lowest areas and creeks.
I'm aware of numerous commerical and industrial (and likely residential) properties that direct surface by design to the subsurface (e.g., drywell)
Northern Kentucky has little to no karst.
Do not deal with storm water. Work with farming and onsite sewage systems.
surface water has no option but to be discharged into karst systems in many cases. Treatment for quality and quantity may occur prior to discharge, but discharge into karst is unavoidable.
Injection wells are constructed to discharge the runoff.
i don't know
My region depends heavily on local sinks to rid the strormwater.
That's a good question. We generally don't think about how we use the karst system for our stormwater runoff. Our stormwater obviously comes from urbanized areas. The water is channelized to catch basins and sent directly to our creeks. So, we don't think of using the karst system to manage our stormwater. However, as sinks and cracks develop in the stream bed, our karst sytem is utilized. However, I've not given much thought to how our stormwater affects the water quality underground.
In our region, Central Kentucky, we typically try to avoid using the karst system for stormwater management except where it is the only option. We feel that using karst is an unknown and the conditions could change which would impact our development negatively.
Development in karst areas at times use sinkholes as their stormwater outlets. We have regulations related to pretreatment of the runoff before entering the sinkhole. We do highly recommend against using sinkholes in stomrwater runoff planning but at times there is no other place for the water to go.
Karst sinkholes are pretty rare here but when available, we will discharge stormwater runoff into them versus going to a nearby waterway
little to no dependence.
A large percentage of the urban storm water passes thru subsurface channels before daylighting in to streams. On site stormwater controls are required but the karst system is affected.

Warren County has few surface streams - the only way to handle runoff is utilization of underground resources.
Large areas of central Kentucky drain into karst formations, but other than managing the rate of runoff there is no other runoff management, i.e., water quality. Lexington has developed a series of non-building zones that reduce the development potential for destruction of karst features.

Statistic	Value
Total Responses	19

7. Please choose your answer based on your level of agreement with the following statement, with 1 representing strongly disagree and 5 being strongly agree. Consideration of karst features plays a significant role in final decisions when evaluating the following:

#	Question	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Total Responses	Mean
1	Subdivision planning	0	3	2	10	7	22	3.95
2	Commercial development	0	3	2	9	8	22	4.00
3	Septic system installation	0	2	4	6	10	22	4.09
4	Stormwater control	0	3	3	7	9	22	4.00

Statistic	Subdivision planning	Commercial development	Septic system installation	Stormwater control
Min Value	2	2	2	2
Max Value	5	5	5	5
Mean	3.95	4.00	4.09	4.00
Variance	1.00	1.05	1.04	1.14
Standard Deviation	1.00	1.02	1.02	1.07
Total Responses	22	22	22	22

8. Specific to your region, please select all of the following for which you have implemented karst-specific regulations/ordinances and list the relevant policy documents.

#	Answer		Response	%
1	Commercial/Residential Zoning		8	62%
2	Home construction		0	0%
3	Septic systems		4	31%
4	Drinking water well use		1	8%
	Total		13	100%

Commercial/Residential Zoning	Home construction	Septic systems	Drinking water well use
unknown (non-regulatory capacity)		Under Health Department Regulations	
subdv. regs.,geotec requierments. retention basins for developments		Design , locate, inspect, onsite systems.. Also repairs and straight pipes	
Subdivision Regulations			
Land Development Code and MSD Design Manual			
Through City - County Planning Commission			
Lexington-Fayette Urban County Subdivison and Zoning regulations			

Statistic	Value
Min Value	1
Max Value	4
Mean	1.85
Variance	1.31
Standard Deviation	1.14
Total Responses	13

9. Do you impose restrictions on the use of the karst drainage system for areas of new development?

#	Answer		Response	%
1	Yes		7	37%
2	No		12	63%
	Total		19	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.63
Variance	0.25
Standard Deviation	0.50
Total Responses	19

10. Please list the restrictions and include the name of the document containing these ordinances.

Text Response
Unknown
Chapter 10 of the MSD Design manual outlines restrictions related to stormwater runoff to karst areas. Erosion prevention and Sediment control ordinance identifies karst areas as those areas to be protected during construction.
Storm water design manual illicit Discharge

Statistic	Value
Total Responses	3

11. Has a pollutant of concern been identified for your region?

#	Answer		Response	%
1	Yes		10	59%
2	No		7	41%
	Total		17	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.41
Variance	0.26
Standard Deviation	0.51
Total Responses	17

12. Please list your pollutant(s) of concern and indicator pollutants and Maximum Extent Practicable removal rate.

Text Response
In the nineties, a fuel station was found to have tanks that had been leaking for several years. The EPA came in to check out the problem. Sampling wells were placed in several locations and some remediation was involved and testing is still being done on this project.
TSS, nutrients
Your question implies that I am in a position to make these regualtory decisions - I am not in that position
Bacteria, sediment, nutrients
onsite waste disposal
Bacteria. Dont know the MEP
a) Automotive fueling facilities; b) Automotive maintenance and repair facilities; c) Restaurants wit h grease collection and disposal ; and , d) Other land uses as determined to have a high potential of pollutant discharge i nto the MS4 as determined by the County Engineer .
We have pollutants of concern for surface water. Since we have a karst landscape, I am going to apply those pollutants of concern to karst as well. Pollutants of concern: sediment, nutrients, fecal coliform/e-coli. A tmdl is being developed for Strodes Creek, one of two streams that receive stormwater runoff.
I am not a representative of a governmental agency and to my knowledge we do not have any lists other than 80% removal for erosion and sediment control.
We only regulate sediment at this point in time.

Statistic	Value
Total Responses	10

13. How were the pollutant(s) of concern and maximum Extent Practicable removal rate decided?

Text Response
Much of the polluted earth was removed and hauled to a special site. The work was quite extensive but it was decided that there was no danger as long as the product was not found in the test wells.
Not involved in decision making process.
Based on 303(d) list
skip
There is a TMDL for one of the streams in the county
conform to the design criteria of a BMP developed based on all applicable City/County/State/Federal ordinances and guidelines established by Warren County Fiscal Court Division for Stormwater Management policy and procedure.
N/A
We decided on 80% removal rate based on EPA regulations.

Statistic	Value
Total Responses	8

14. If possible, please include a link to the document containing your stormwater quality management plan.

Text Response
LFUCG
http://www.sd1.org/ProjectsandPrograms/PhaseIIStormWaterRegulations.aspx
skip
http://www.warrencountygov.com/sites/default/files/SWQMP2010FINAL.pdf
Not posted on the web. Available electronically upon request. scecil@winchesterky.com
N/A

Statistic	Value
Total Responses	6

15. Which of these systems do you use to control stormwater runoff? (Select all that apply)

#	Answer		Response	%
1	Injection Well (Class V drainage well)		5	33%
2	Storm Sewer (including collection systems that drain collected water to the karst system)		13	87%
3	Dry detention basin		11	73%
4	Wet detention basin		11	73%
5	Wetland		5	33%
6	Other (please explain)		6	40%

Other (please explain)
At least 70% of our stormwater goes into the Creek then to Mud River
Retention basins
I do not design or require these - in my line of work I have only seen these used by others
Site specific designs would be considered IF they met State and Federal regulations.
Infiltration trenches, rain gardens, bio-swales
surface water to creeks then to river system.

Statistic	Value
Min Value	1
Max Value	6
Total Responses	15

16. Please answer the following questions carefully.

#	Question	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Total Responses	Mean
1	Current state stormwater regulations provide adequate protection for karst environments	0	4	10	4	0	18	3.00
2	The state government should develop karst specific groundwater monitoring regulations	1	1	7	7	2	18	3.44
3	Numerical discharge limits should be included in MS4 permits for karst areas	2	4	7	4	1	18	2.89
4	You possess sufficient information to create and implement an efficient and effective water quality monitoring program if it were to be required by the state.	4	5	5	4	0	18	2.50

Statistic	Current state stormwater regulations provide adequate protection for karst environments	The state government should develop karst specific groundwater monitoring regulations	Numerical discharge limits should be included in MS4 permits for karst areas	You possess sufficient information to create and implement an efficient and effective water quality monitoring program if it were to be required by the state.
Min Value	2	1	1	1
Max Value	4	5	5	4
Mean	3.00	3.44	2.89	2.50
Variance	0.47	0.97	1.16	1.21
Standard Deviation	0.69	0.98	1.08	1.10
Total Responses	18	18	18	18

17. Please explain if numerical discharge limits should or should not be included in stormwater permits in karst areas. Please provide your reasoning.

Text Response
No, because In order to accurately evaluate the results, you would need to know the entire network of subsurface flow channels and when they are active. That is overwhelming enough, but to be able to understand the significance of the numbers obtained you would also need to be able to quantify the flow/conduit. This is not possible. Without knowing that, how could you effectively choose what remedy to apply and where to apply it? Hence all the monitoring costs are wasted, plus all of the subsurface investigation costs.
Probably should, but would likely be met with significant backlash from local agencies due to prohibitive cost, prevalent budget shortfalls and technical monitoring demands.
I dont think there should be accountability for stormwater discharge limits until there is a total revamping of a stormwater system in acommunity. There needs to be a time frame and revenew source for reworking stormwater systems in communities and incentives other than threats from the state or federal governments.
this could have wide ranging impacts on businesses; rather than creating a set of regualtions specific to karst perhaps you coould use the existing surface water regs to address groundwater quaily IF the permit holder intentionally uses karst conduits to receive surface
skip
I have no problem with limits being placed on discharge, just be mindful of the cost/benefit of any regulation. Society is rapidily reaching the point where we have so many regulations that no one can keep up with all of them. If numerical discharge limits are going to be required, they should not be any different than those required for surface runoff discharge.

Statistic	Value
Total Responses	6

18. Please indicate the level of importance you would assign to each of the following topics if they were proposed to be included in your MS4 permit

#	Question	Low Importance	Medium Importance	High Importance	Total Responses	Mean
1	Karst water quality monitoring	4	9	3	16	1.94
2	Karst Best Management Practices research	4	7	6	17	2.12
3	Karst water quality monitoring program development	4	9	4	17	2.00

Statistic	Karst water quality monitoring	Karst Best Management Practices research	Karst water quality monitoring program development
Min Value	1	1	1
Max Value	3	3	3
Mean	1.94	2.12	2.00
Variance	0.46	0.61	0.50
Standard Deviation	0.68	0.78	0.71
Total Responses	16	17	17

19. Is groundwater used as a drinking water source in your area?

#	Answer		Response	%
1	Yes		4	24%
2	No		13	76%
	Total		17	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.76
Variance	0.19
Standard Deviation	0.44
Total Responses	17

20. What percentage of households in your area would you estimate use groundwater as a drinking water source?

#	Answer		Response	%
1	0-5		3	75%
2	5-10		1	25%
3	10-50		0	0%
4	50 or greater		0	0%
	Total		4	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.25
Variance	0.25
Standard Deviation	0.50
Total Responses	4

21. Do you believe the groundwater in your area could be a potential source of drinking water in the future?

#	Answer		Response	%
1	Yes		2	15%
2	No (please explain)		11	85%
	Total		13	100%

No (please explain)
We have a regional water source that takes good care of our needs and prefer everyone to use this water.
Local demand for Fayette Co. far too high.
Ohio River is primary source
The river has more than adequate capacity
Barren River is the current source and not likely to change.
insufficient quantity
KAW just built at new pipeline
For the near future, we have a steady source of drinking water from the KY River and a reservoir.
Our water comes from the Kentucky River and I assume ground water ends up there.
Surface water lakes (impoundments) are already subject to groundwater influence

Statistic	Value
Min Value	1
Max Value	2
Mean	1.85
Variance	0.14
Standard Deviation	0.38
Total Responses	13

22. Do you or any other non-state government entity in your area monitor stormwater runoff quality?

#	Answer		Response	%
1	Yes		6	32%
2	No		13	68%
	Total		19	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.68
Variance	0.23
Standard Deviation	0.48
Total Responses	19

23. Please describe any monitoring efforts that you are aware of

Text Response
Those associated with Indidual KPDES Industrial Permits.
Work closely with Watershed Watch
Water quality Consortium is performing testing int he streams

Statistic	Value
Total Responses	3

24. Do you or any other non-state government entity in your area monitor karst water quality?

#	Answer		Response	%
1	Yes		3	18%
2	No		14	82%
	Total		17	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.82
Variance	0.15
Standard Deviation	0.39
Total Responses	17

25. Please describe any monitoring efforts that you are aware of.

Text Response
Watershed Watch groups in each of the 8 major drainage basins monitor limited water quality parameters on pre-set dates (not intentionally related to storm events)
Mammoth Cave National Park monitors this area.

Statistic	Value
Total Responses	2

26. Do you keep a GIS (or any other form) inventory of karst features in your region?

#	Answer		Response	%
1	Yes		7	37%
2	No		12	63%
	Total		19	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.63
Variance	0.25
Standard Deviation	0.50
Total Responses	19

27. Please select all features that are included in your database. Please list any other relevant features in your database that are not listed.

#	Answer		Response	%
1	sinkholes		5	71%
2	springs		5	71%
3	cave entrances		3	43%
4	cave streams		2	29%
5	cave passages		0	0%
6	injection wells		2	29%
7	drinking water wells		3	43%
8	other wells (list)		0	0%
9	None		1	14%

other wells (list)

Statistic	Value
Min Value	1
Max Value	9
Total Responses	7

28. How long has the database been in place?

#	Answer		Response	%
1	0-1 years		1	13%
2	1-3 years		3	38%
3	3-5 years		2	25%
4	5+ years		2	25%
	Total		8	100%

Statistic	Value
Min Value	1
Max Value	4
Mean	2.63
Variance	1.13
Standard Deviation	1.06
Total Responses	8

29. Are any waterways in your jurisdiction 303(d) listed?

#	Answer		Response	%
1	Yes		7	54%
2	No		6	46%
	Total		13	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.46
Variance	0.27
Standard Deviation	0.52
Total Responses	13

30. Please provide a generalized list of waterways and pollutants of concern. Note it is not necessary that you provide each segment of each listed water body, an overview will be sufficient.

Text Response
Claylick Creek (4.1 to 5.3) - nutrient/eutrophication biological indicators; sedimentation/siltation
I believe Town Branch, North Elkhorn and Cane Run
Most creeks/waterways within NKY are listed on the 303(d) list. Primary pollutants for each include sediment, bacteria and nutrients.
all are warm water habitat and pollutants of concern include: Nutrients Bacteria Sedimentation
Strodes Creek Sediment Fecal Coliform/E-coli Nutrients

Statistic	Value
Total Responses	5

31. Please list your age

Text Response
66
63
38
55
40+
27
62
46
59
63
57
36
39
64
41
56
40
40

Statistic	Value
Total Responses	18

32. What is your gender?

#	Answer		Response	%
1	Male		14	78%
2	Female		4	22%
3	Other		0	0%
	Total		18	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.22
Variance	0.18
Standard Deviation	0.43
Total Responses	18

33. Please list your job title and years of relevant experience

Text Response
KDOW Basin Coordinator - 13 years
I have many jobs one of which is the Floodplain Coordinator, Building Inspector, Zoning Administrator.
Storm Water Engineer, 8 years
assistant public works director 12 years
Environmental Compliance Manager, 5 years
Registered Sanitarian Public Health for 38 yrs
Consultant for 21 years
Stormwater Agency Manager ` 10 Years
public health environmentalist
Project Engineer 35 years
i am the Executive Director of a nonprofit organization. We do a lot with education about water quality issues, including Karst, but many of the questions did not apply to me.
Project Coordinator-14 years
Quality Control Manager/Project Manager for a major mulit-national engineering firm, 35 years' experience in private land development
Development Team Leader with 18 years of experience
City Engineer (13) Civil Engineer

Statistic	Value
Total Responses	15

34. What is your highest level of education completed?

#	Answer		Response	%
1	High school Diploma/GED		1	6%
2	Bachelors Degree (Major/Minor)		10	56%
3	Masters Degree (Concentration)		6	33%
4	PhD.D (Concentration)		1	6%
	Total		18	100%

Bachelors Degree (Major/Minor)	Masters Degree (Concentration)	PhD.D (Concentration)
Geology/Earth Sciences	Water Resources Engineering	
3 years college biology/forestry	geography	
Civil Engineering	education	
Civil Engineering	Masters of Civil Engineer	
Civil Engineering Technology	MSCE	
Civil Engineering Technology - WKU		
Plant Science		
Natural Resources Conservation Management		
Bachelor of Science, Civil Engineering		

Statistic	Value
Min Value	1
Max Value	4
Mean	2.39
Variance	0.49
Standard Deviation	0.70
Total Responses	18

35. Please select any professional certifications that you currently hold

#	Answer		Response	%
1	PE		6	46%
2	PG		0	0%
3	CPSWQ		0	0%
4	CESPC		0	0%
5	CHMM		1	8%
6	CEP		0	0%
7	REP		0	0%
9	Other		3	23%
10	None		4	31%

Other
EIT
land surveyer

Statistic	Value
Min Value	1
Max Value	10
Total Responses	13

36. If you could add questions to this survey what would they be?

Text Response
How would you rate the current level of awareness of karst issues to elected officials and the community? What are you or others in you community doing to educate the citizens about how they affect water quality?
1. do you work for a governmental agency or a private consulting firm 2. are you involved in developing storm water regulations for your community
Add location and do you work for a state, local agency or on the private side

Statistic	Value
Total Responses	3

37. Please list the contact information for anyone you feel would be interested in taking this survey

Text Response

Statistic	Value
Total Responses	0

38. May we contact you for additional information?

#	Answer		Response	%
1	Yes		14	78%
2	No		4	22%
	Total		18	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.22
Variance	0.18
Standard Deviation	0.43
Total Responses	18