Investigation into Sinkhole & Depression Flooding Oak Grove, Kentucky

By
Kentucky Division of Water
Groundwater Branch
Rob Blair and John Shuttleworth

Prepared for the
U.S. Army Corps of Engineers
And
The City of Oak Grove

December 18, 2002

OAK GROVE, KENTUCKY
SINKHOLE & DEPRESSION FLOODING

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Executive Summary

The city of Oak Grove, Kentucky has experienced flooding for several decades. These problems result from intermittent lakes forming in large sinkhole depressions. This intermittent flooding is a particular problem for Oak Grove because of local development pressure; specifically the need for housing relative to Fort Campbell and other local growth.

The Oak Grove area is nearly entirely drained to the West Fork of the Red River by subsurface conduits developed in the underlying limestones; there are no significant surface overflows to this waterway. The subsurface (karst) drainage system in the Oak Grove area has a finite drainage capacity. However, during periods of excess precipitation the drainage network can become overwhelmed. During and following such events, excess water is stored in sinkholes and depressions on the land surface, creating a karst flood plain. Homes and buildings constructed in the karst flood plain are subject to intermittent, temporary inundation by floodwaters. Injection wells designed to expedite the floodwater to the subsurface have proven ineffective in alleviation of the flooding problem during high precipitation events and may even exasperate the problem.

There is no cost-effective engineering solution to alleviate this problem. The Division of Water recommends that Oak Grove delineate a "no build zone" based on historical data and flood projection maps, created by the US Army Corps of Engineers (USACE). This local "no build zone" could be set aside for use as 'green-space', wildlife sanctuary or recreation area but should not include structures sensitive to intermittent flooding, such as housing and most businesses.

Oak Grove, Kentucky
Sinkhole & Depression Flooding

Introduction

The area within and surrounding the city of Oak Grove, Kentucky has had a long history of flooding which was most dramatically illustrated during March of 1997 when abnormal amounts of rainfall resulted in the significant flooding of several area houses. Unless a solution to the problem is addressed, sinkhole and depression flooding will continue to cause problems for residents of Oak Grove and will frustrate and impede developers as housing needs in this community increases. This report is a effort to assist the community of Oak Grove by providing technical assistance and in-kind matching funds on a joint endeavor between the U.S. Army Corps of Engineers, Oak Grove, and the Kentucky Division of Water to identify the problem of Oak Grove's sinkhole flooding. The Kentucky Division of Water has surveyed the area and has met with Oak Grove and Corps officials and as a result herein offers a cause to Oak Grove's flooding problem and recommends not a solution to the flooding but an approach to managing growth.

Regional Geology (Physiography)

Oak Grove, located in Christian County, Kentucky, lies within the Mississippian Plateau Physiographic Region of the state. The Mississippian Plateau is characterized by relatively thick, clay soils overlying soluble, carbonate (limestone) rocks of Mississippian age (approximately 320 to 345 million years old). Oak Grove is specifically situated within the low-relief sinkhole plain, also known as the Pennyroyal (or Pennyrile) Plain, south of the Dripping Springs Escarpment (a.k.a. Chester Cuesta) (Walker, 1956). The sinkhole plain in the Oak Grove area is locally a level upland, with the river valleys forming the lowland and drainage patterns typical of karst terrane.

Karst terrane is a distinct type of topography prevalent throughout the Mississippian Plateau region and is associated with a particular type of hydrology and topography. Karst Terrane is dominated by the presence of nonporous soluble rocks, such as limestone, dolomite or gypsum located at or near the surface. In karst terrane the traditional idea of a water table typically does not apply because of the relatively nonporous character of the soluble rocks and hydrologic confinement. Typically an aquifer is thought of as a rock formation or a group of formations that is saturated and sufficiently permeable over a wide geographic region to transmit quantities of water to wells and springs. However in karst terrane groundwater movement is "channelized". Movement is predominately through underground channels or conduits (pipes) formed by dissolution of carbonate rocks under the influence of turbulent groundwater with relatively anisotropic flow. Aquifer characteristics such as specific capacity, specific retention, and specific yield are much harder to predict and fluctuate more than in "typical" aquifers. Well-developed karst terrane typically contains naturally occurring closed topographic depressions or sinkholes, sinking streams, caves, large springs, and conduit flow of groundwater.

Karst drainage networks typically range in magnitude from shallow epikarst systems that drain a few acres to large well-developed systems where interconnecting conduits can be up to 20 miles or more in length and drain groundwater basins containing thousands of acres. The world's largest known karst drainage network, the Mammoth Cave system, is located in Edmonson County, Kentucky. The Mammoth Cave system is a large mature system that has several hundred miles of interconnected conduits and caverns developed in a multi-level system. The development of the karst terrane in the Oak Grove area falls somewhere between these extreme examples. Dye trace studies have been performed on Hunter Spring, the base-level spring for the basin in which Oak Grove is located. Based on these tracer tests the approximate drainage basin for Hunter Spring has been delineated and it has been estimated that Hunter Spring drains a basin that is approximately 5.4 square miles.

Recharge in a karst system, in the form of precipitation and snowmelt, moves into the subsurface through various avenues. If the precipitation is a gradual, steady influx then the majority of the moisture will slowly percolate through soil macropores and eventually reach a zone of vertical fractures in the bedrock known as the epikarst. The epikarst zone is where moisture is stored and slowly released into the lower part of the drainage network by seepage and/or percolation. This storage capacity can result in springs flowing long after a precipitation event. Water may locally discharged from shallow, perched springs (if perching layers are locally present). From the epikarst system, the moisture flows through vertical fractures, pipes, or along nearly horizontal bedding planes until it reaches a major conduit (or cave) network. (See Figure 1 below).

These conduits normally have a dendritic pattern, with minor tributaries converging into a main trunk conduit (See figure 2 below). Similar to surface streams, these channels gradually down-cut within the bedrock, effectively lowering the elevation of the water level. As the channel is incised deeper into the aquifer, some of the upper conduits will be abandoned. However, during extremely high water conditions higher level abandoned conduits may function as overflow routes for excess water flowing to adjacent karst basins or conduit systems. Depending on the geology of the area these conduit networks may be measured in as little as yards or may extend for miles. It is common for rain and snow melt events to exceed the soil's and/or epikarst's ability to absorb significant amounts of the precipitation. In these cases and where the development of surface drainage features are minimal, combined with area sinkholes that do not have open drains or have immature conduit's, the excess water will be temporarily stored in sinkholes or surface depressions.

Where water pools in depressions and sinks without open drains, water will gradually percolate through the soil into the subsurface drainage network recharging the fracture network, eventually draining into a lower-lying conduit network. This natural infiltration through plants and soils will tend to attenuate contaminates by dispersion, adsorption, leaching, or biological degradation. Quantity, quality, and times frames of this percolation will depend upon biology and soil characteristics. For example sandy soils will allow water to migrate downwardly at a relatively fast rate, while soils containing large quantities of clay will inhabit or prevent vertical movement.

Sinkholes themselves can also have a direct hydraulic connection to the conduit network, acting like "funnels" draining the surface. However, these conduits can be overwhelmed causing water to impound should the influx of precipitation exceed the conduits capacity to transport water. Direct flow into sinkhole conduits typically results in little or no natural filtration occurring before precipitation enters the aquifer. Any contaminates encountered and transported with flow will be directly introduced into the groundwater system. This would result in a significant detrimental effect to groundwater quality should contaminates be of sufficient quantity and toxicity. Likewise, over-land runoff can reach sinkholes, swallets and sinking creeks, collecting sediment and debris along the way, which may result in groundwater turbidity and/or introduction pathogens.

Eventually, the conduit or cave network will discharge at the surface in the form of a spring. Spring morphology varies from site to site depending on the geologic setting. A minor type of spring is termed a 'seep', where water infiltrates through the rock or soil and is discharged as a trickle or film of water and is usually observed only during wet weather. "Gravity springs" discharge water from a point above base level (local stream level), sometimes creating spectacular waterfalls and cascades. Many springs discharge from the base of a bluff, flowing through mounds of talus, ranging in size from sand to boulders. "Bluehole springs" discharge from near vertical fractures or conduits where the water has enough hydrostatic pressure within a confined aquifer (known as "head") behind it to overcome gravity and force it upward toward the surface. Blueholes are generally observed as pools, sometimes with turbulent 'boils' forming on the surface. Water level may rise and fall based upon the local water table. "Overflow springs" are discharge points that are only active during high water conditions. They may be storm-related or seasonal in duration. "Estavelles" are a unique overflow spring that function during low flow as a swallet (sink) or recharge point for an aquifer. Following periods of excessive precipitation, intermittent lakes can also form in depressions, due to the inundation of shallow karst systems which overflow and store water in the depression. Some springs drain large enough areas with enough storage capacity in the soil and epikarst to be the headwaters of a surface stream and maintain base flow during times of little or no precipitation. Smaller springs also function as tributaries to surface streams.

The following diagrams are offered to illustrate karst drainage.

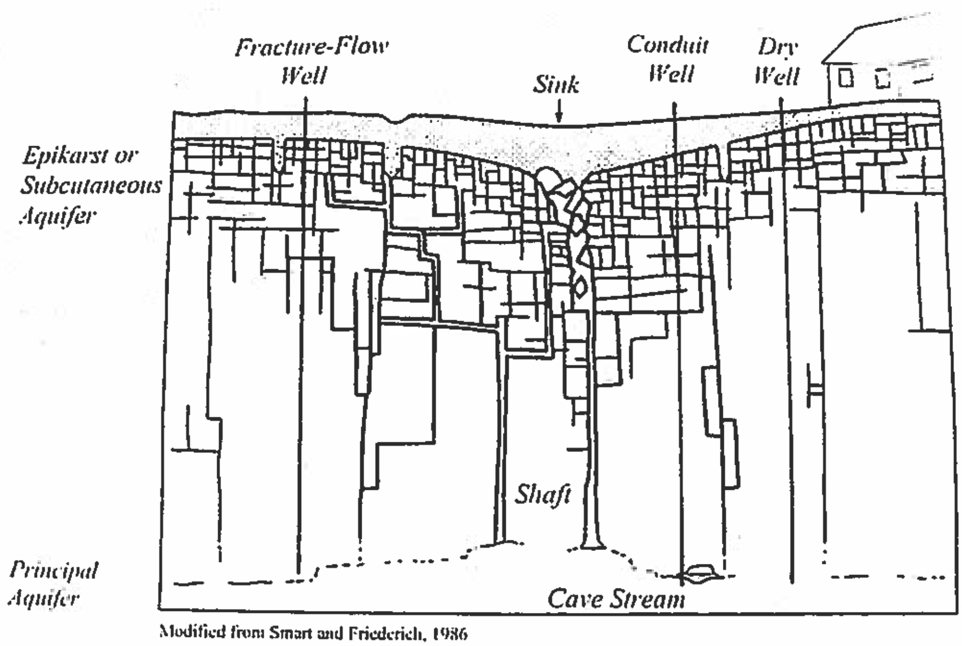

FIGURE 1. Conceptual diagram showing a shallow epikarst aquifer in fractured and weathered limestone, containing relatively low groundwater storage potential. Fractures and conduits (secondary porosity) indicate water-bearing zones within the bedrock. Most of the long-term storage of groundwater occurs within the epikarst and gradually seeps and percolates downward to the larger conduit network, draining the principal or regional karst aquifer. Vertical lines represent three types of bored water wells in a karst aquifer. The fracture-flow well collects minor amounts of water from the epikarst and deeper fractures. It is the most common type of water well in a karst terrane and it's recharge area is generally within a 1000 ft radius of the well. The conduit well has intercepted a significant water-bearing conduit. The recharge area is the sub-basin of the cave stream plus the locally intercepted epikarst drainage. Dry wells fail to intercept significant volumes of fracture flow or conduit drainage.

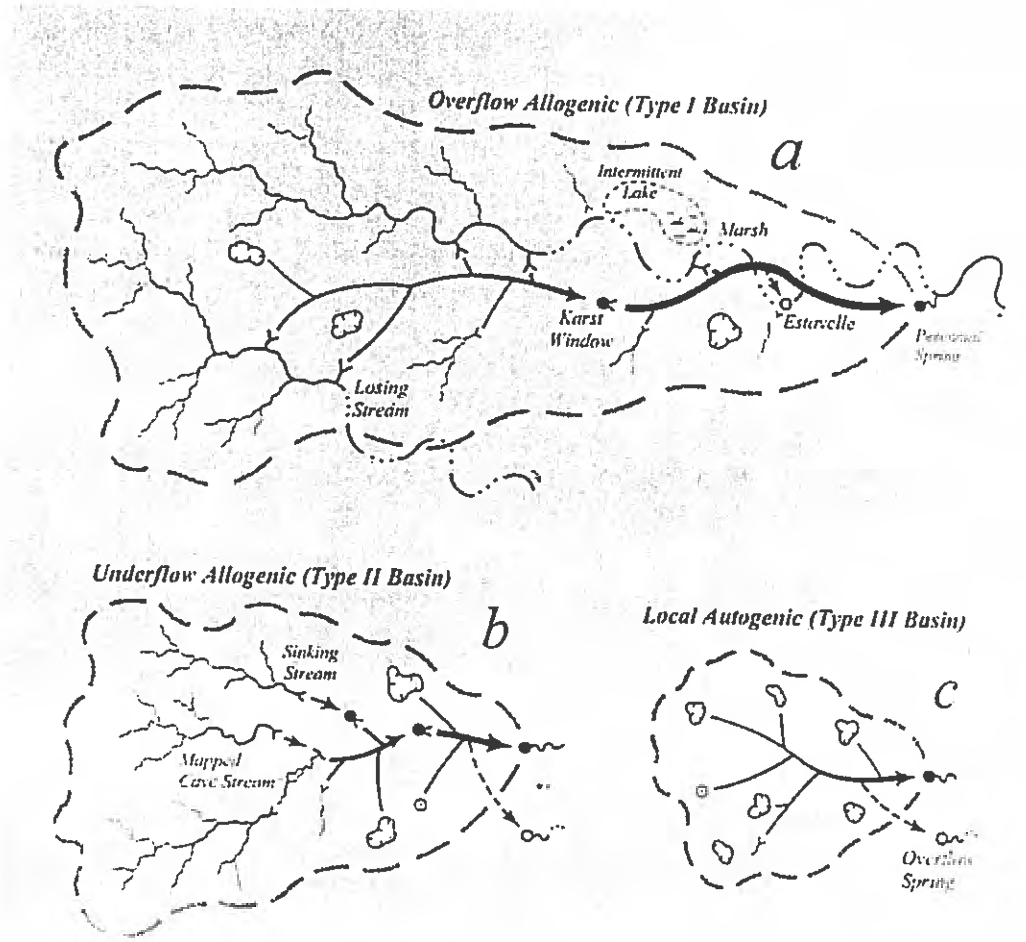

FIGURE 2. Major types of karst drainage basins. Overflow Allogenic (Type I) basins contain losing streams which maintain surface overflow channels across the groundwater basin (a). An example is Big Spring watershed, Missouri's largest karst drainage basin. Underflow Allogenic (Type II) basins evolve when sinking stream valleys become blind and cease erosion of overflow channels across the basin (b). An example is Gorin Mill Spring watershed, Kentucky's largest karst drainage basin. Local Autogenic (Type III) basins lack sinking streams and are primarily recharged by infiltration through the land-surface and sinkhole drainage (c). An example is Waterworks Spring watershed, near Bowling Green, Kentucky.

Local Geology

The geology of the Oak Grove area is comprised mainly of two limestone units of Mississippian age, separated by a chert bed. The uppermost unit is the Ste. Genevieve Limestone. This limestone is described on the USGS 7.5' Geologic Quadrangle as light gray and medium to coarse grained with some clastics. Some beds in the upper-strata are oölitic. While thin, dolomitic beds occur in this unit, it is most commonly a thick-bedded limestone. Light-to-dark gray chert nodules are common throughout the limestone. Bryzoa and brachiopod fossils are abundant in this unit. The soil overlying this limestone is thick, reddish-brown clay. Soil thickness is variable, with an average of 30 feet. The soil contains very little chert, compared to the underlying Ste. Genevieve (Klemic, 1966). The Ste. Genevieve Limestone has numerous, well-developed sinkholes that serve to intercept surface drainage and direct it to the subsurface. Except for local epikarst springs there is little evidence for a well-developed karst aquifer within this unit. Instead, this limestone body acts as storage for groundwater that is released into the lower, St. Louis Limestone.

The St. Louis Limestone is medium gray to dark gray, fine to medium grained, and occurs as thin and thick beds in the upper portion. Some beds are dolomitic, argillaceous, fossiliferous and clastic. Clastics are mainly chert nodules, 4 to 10 inches in diameter and are bluish-gray to white. Interlayered coarse and fine-grained beds occur in the lower portion of the unit. Fossils present in this limestone include colonial corals and bryzoans (Klemic, 1966). The most developed karst aquifers in the Oak Grove area occur in this limestone unit, as evidenced by Hunter Spring and others. Dye-tracer tests (discussed in depth later in this paper) have shown that Hunter Spring is the principal drainage for a large portion of the area in and around Oak Grove. The area drained by Hunter Spring is approximately 5.4 square miles and is delineated on the following map (Figure 3):

Hunter Spring Basin and Karst Floodplain Interactions at Oak Grove, Kentucky

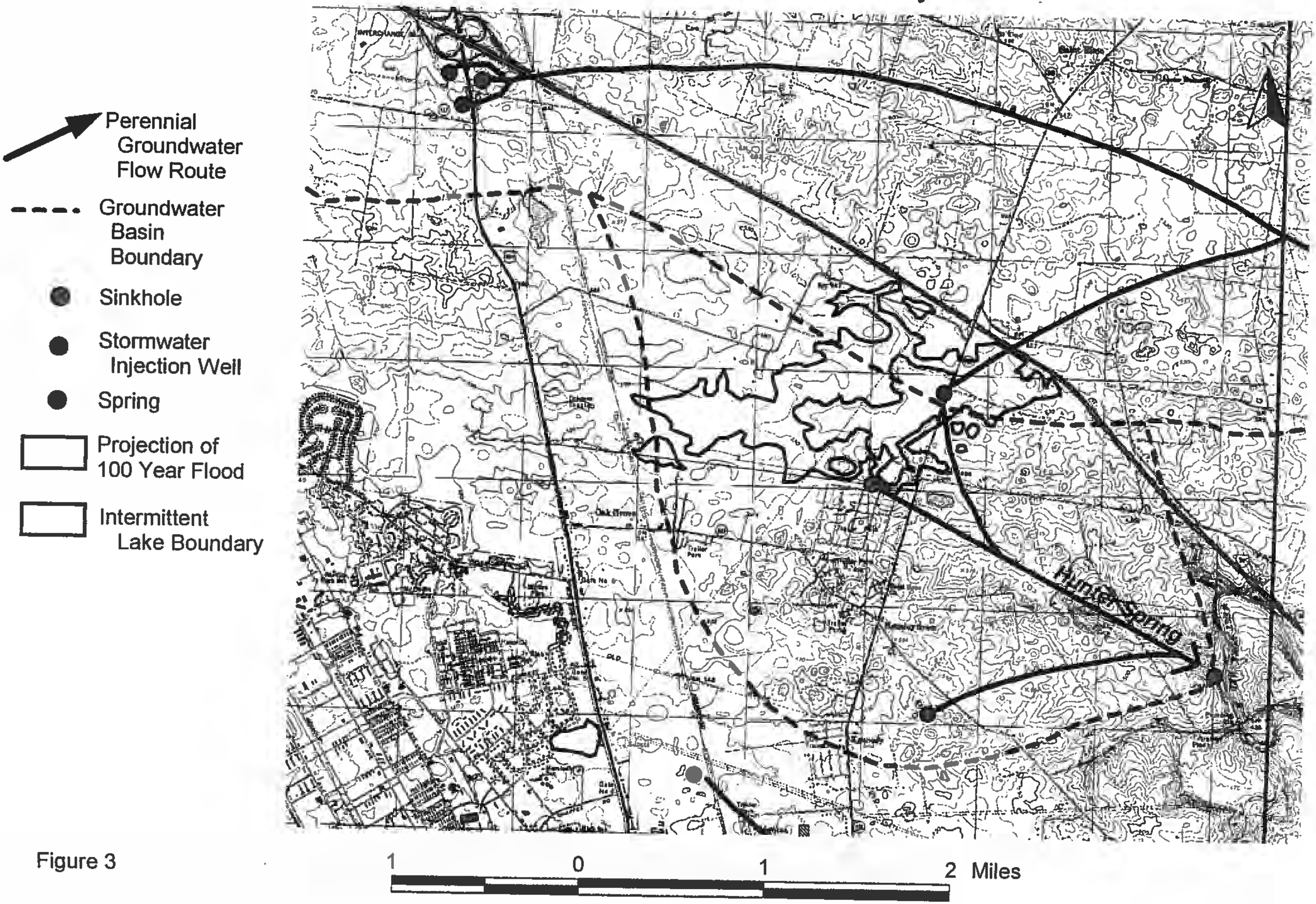

Figure 3

Groundwater

Ewers Water Consultants Inc. (EWC) of Richmond, Kentucky performed dye-tracer tests in the Oak Grove area during the winter of 1998 - 1999 to confirm groundwater flow paths and subcutaneous basin delineation. Using this information the drainage basin for Hunter Spring was estimated to be 5.4 square miles. [Map Attachment (1) and the "Dye Trace Study Work Plan Stormwater Injection Sites, Oak Grove, Kentucky" illustrate Karst interactions and groundwater fate (Ewers, 1998)].

Groundwater Quality

Dye-tracer tests by Ewers Water Consultants have confirmed that Hunter Spring primarily drains the flood prone area in question. Sample results from the Kentucky Division of Water taken between October 1995 and August 2000 show that the water quality at Hunter Spring has been highly variable. Conductivity values range from 272 Micromhos (UU/C) to 494 UU/C with an average of 414.3 UU/C (Figure 4). Nitrate concentrations vary between 3.21 mg/L and 24.5 mg/L with an average of 10.24 mg/L (Figure 5). Total Dissolved Solids (TDS) range from 184 mg/L to 386 mg/L with an average value of 256.1 mg/L (Figure 6). These parameters are summarized in Table 1 below. Groundwater samples were taken at the mouth of Hunter Spring, prior to any treatment. The sample results are compared to Drinking Water Standard Maximum Contaminant Levels (MCL). As noted above, the average Nitrate concentration at the spring is 10.24 mg/L, slightly higher than the MCL of 10 mg/L.

	Minimum Value	Maximum Value	Median Value	Mean
Conductivity	272 UU/C	494 UU/C	419 UU/C	414.3 UU/C
TDS	184 mg/L	386 mg/L	246 mg/L	256 mg/L
Nitrate	3.48 mg/L	24.5 mg/L	5.15 mg/L	10.24 mg/L

Table 1.

Sharp increases in TDS and conductivity give further evidence for the aquifer's inability to attenuate contaminants. Increased soil erosion during heavy precipitation events leads to an increase in Total Suspended Solids (TSS), conductivity and the overall turbidity of waters within the aquifer. The variability in water quality is due to the karst aquifer's lack of filtration capability. Sources of other contaminants that can be introduced into the aquifer with these turbid waters might include, but are not limited to land application of fertilizers, pesticides and herbicides, failing septic systems, leaking sewer systems and urban/suburban runoff. During times of flooding, water quality problems (turbidity in particular) are exacerbated by attempts to alleviate floodwaters with injection wells. Unpredictable changes in water quality are indicative of an aquifer that cannot be regulated or easily stabilized. This is most profoundly demonstrated by the aquifer's tendency to inundate the karst flood plain during periods of excessively high precipitation.

Appendix *A* gives concentrations of selected parameters over the above mentioned time frame. The graphs included serve to further illustrate the variability of water quality at the spring. Figure 7 illustrates the observed discharge at Hunter Spring.

Base flow for the spring is estimated to be 1.1 cubic feet per second (cfs), with a peak capacity of approximately 15 cfs. Appendix *A* also contains a table of these observations.

Climate

Oak Grove is in a humid climate region. Based on approximately 100 years of record, the area receives an average of 50.79 inches of precipitation each year. The most precipitation for one year was 71.97 inches in 1979 and the least was 28.47 inches in 1963. During the flood of March 1997 Oak Grove received approximately 9 inches of rain in a 24-hour period. The weather station at Hopkinsville (nearest station) received 7.06 inches in that same time frame. According to data collected by the Kentucky Climate Center at Western Kentucky University this precipitation event was the largest one day total for the region in recorded history (please refer to Figures 4 & 5). This event was also considered the 50-year flood for the Oak Grove area (Huff and Angel, 1992). This means that there is a distinct probability that a precipitation event of this magnitude will occur every 50-years. However, the "50-year" flood may occur twice in the same decade or may not recur for another 100 years. Any flood control measure calculations should be based on the water level reached during this precipitation event.

Karst development can be attributed, in part, to high amounts of moisture present in humid climate regions. While many factors contribute to karst development, water is the driving force behind rock dissolution. Dissolution of the country rock forms the cavities, conduits and caves that are typical of karst terranes.

DATE	RAINFALL AMOUNTS (in inches) FOR HOPKINSVILLLE, KY	RAINFALL AMOUNTS (in inches) FOR HERNDON, KY
2/26/1997	0.09	0.47
2/27/1997	0.53	0.80
2/28/1997	0.00	0.00
3/1/1997	2.89	3.12
3/2/1997	7.06	5.43
3/3/1997	0.90	0.91
3/4/1997	0.02	0.00
Totals	11.49 inches	10.73 inches

Figure 4. Rainfall amounts for the Cities of Hopkinsville and Herndon, Kentucky. As reported by the Kentucky Climate Center.

Climate Data from Hopkinsville Weather Station 153994

	Mean	High	Year	Low	Year	1-Day Max	Date
January	3.81	21.86	1937	0.61	1943	5.33	01/08/1920
February	4.25	13.77	1989	0.31	1947	4.75	02/14/1949
March	5.25	16.43	1997	0.86	1918	7.06	03/02/1997
April	4.69	13.19	1912	0.70	1915	6.30	04/02/1912
May	4.81	11.60	1983	0.59	1951	4.00	05/26/1905
June	3.53	12.88	1928	0.46	1952	4.22	06/28/1960
July	4.35	8.07	1959	0.26	1902	4.13	07/26/1933
August	3.43	10.89	1923	0.12	1900	2.93	08/17/1949
September	3.45	10.19	1979	0.00	1997	5.38	09/14/1979
October	3.19	10.47	1919	0.00	1908	5.60	10/06/1900
November	4.90	13.66	1957	0.71	1954	6.18	11/24/1900
December	5.13	14.59	1978	0.53	1976	4.75	12/15/1902
	Mean	High	Year	Low	Year	1-Day Max	Date
Annual	50.79	71.97	1979	28.47	1963	7.06	03/02/1997
Winter	13.19	27.86	1937	4.27	1963	5.33	01/08/1920
Spring	14.75	26.82	1983	4.90	1941	7.06	03/02/1997
Summer	11.31	22.63	1923	4.84	1913	4.22	06/28/1960
Fall	11.54	21.91	1979	2.75	1963	6.18	11/24/2000

Figure 5. Historical Climatic Data for Hopkinsville Weather Station, precipitation measurements in inches. As reported by the Kentucky Climate Center.

Topography and Surface Drainage

The U.S. Geological Survey topographical 7.5' Quadrangle map indicates that the City of Oak Grove is located at an elevation of approximately 550 feet above mean sea level with the maximum relief of approximately 180 feet. Numerous sinkholes and depressions, some densely packed, dot the landscape, which is typically characteristic of a sinkhole plain.

The West Fork of Red River is the closest major surface channel and is located approximately three miles to the east of Oak Grove. The West Fork meanders in a general north-to-south direction and gains flow from springs discharging along its banks including Hunter Spring. There are no overland drainage channels that connect the flood prone area to the West Fork of Red River; all drainage routes are located in the karst drainage system. Water collects in sinkholes and depressions on the land adjacent to the river during excessively wet periods. This water gradually moves overland, down gradient, toward the river, until it is allowed to infiltrate into the subsurface drainage network. It eventually reemerges via a spring before finally entering the West Fork.

Cause of Flooding

The flooding of the Oak Grove area occurs due to the current natural state of the karst system underlying the Oak Grove area. The shallow nature of the karst aquifer, which may be immature or locally constricted, results in its inability to adequately drain the area during times of unusually heavy or prolonged precipitation.

Precipitation reaches the earth and percolates through the soil or runs off, depending on the severity of the precipitation event. If precipitation is heavy enough to cause run off, the excess water is stored in sinkholes until it is allowed to percolate into the subsurface. In the subsurface, water is stored in available porosity until it is released and carried away via a conduit network to a spring(s). However, during excessively wet periods, such as a 50 or 100-year precipitation event, the karst aquifer becomes inundated; the drainage capacity of the aquifer is insufficient to quickly transport the water away. Intermittent lakes form in the sinkholes and low-lying areas, flooding the area and causing property damage (Ray, 2001). This water can take significant time to recede. For example, in 1997 the floodwater that developed in March did not drain completely until July.

The previously described flooding was recently witnessed during a site visit to Oak Grove on October 15, 2001, immediately following 4 days of continuous rain resulting in nearly 7 inches of rainfall. Mild flooding was observed and while no property was threatened, it was evident that the aquifer had reached its drainage capacity. On the same day Hunter Spring, which drains most of the area, was observed to be flowing at an estimated 15 cubic feet per second, its estimated peak capacity. Calculations based on the spring's maximum discharge indicate that it would take approximately 92 days to drain the intermittent lake following a 9.5 inch rain event in a 72-hour period. This calculation assumes that the epikarst is saturated and that there is no further input after the initial rain event. Calculations are available in Appendix *C*.

The capacity of the spring is controlled by the degree of development within the karst aquifer. Karst aquifer development is defined by the occurrence and connectivity of porosity within the soluble, country rock. Development is dependent upon the physical and chemical characteristics of the country rock and the environmental conditions of the region. The soluble nature of the rock is the key chemical characteristic in karst development. Carbonate rocks, such as limestone and dolostone, are more soluble than sandstone or shale and are prone to dissolution. Environmental conditions, or climate, also play a role. Humid climates are more conducive to karst development because there is more moisture interacting with the country rock.

The amount of topographic relief is a key physical characteristic because it helps to create the hydraulic head, which drives the system. The rock's proximity to the surface is another contributing factor to karst development. Soluble rock at or near the earth's surface is more susceptible to environmental conditions. Porosity and permeability are both important factors in karst development. Primary porosity, or the amount of void space within the rock, allows absorption of water. Permeability describes the degree to which pore spaces are connected. As karst development occurs the permeability is increased. This increase is due to fractures in the rock (secondary porosity) and dissolution of the rock as water flows through fractures and along bedding planes (tertiary porosity). Finally, the amount of time that has elapsed since lithification of the original sediments also contributes to development. A karst aquifer takes tens of thousand of years to develop. Therefore, solely relying on this karst system to eliminate future flooding is unrealistic. A supplemental way to handle excess water must be found if flooding is to be controlled.

In an attempt to alleviate the flooding problem injection wells have been installed and retention pits constructed. However, the effectiveness of the current injection wells is in question for three reasons:

(1) The injection wells were installed by local land owners/developers. According to Oak Grove officials little or no on site investigation was conducted prior to their construction. No determination was made as to where these injection wells should be located in order to best facilitate drainage. In order to be most effective, injection well should be drilled in a location and deep enough as to intersect relatively mature conduits. Limited site inspection indicates that at least some of these wells do not directly intersect the karst system and in one case only penetrates the soil profile. These injection wells may actually enhance flooding during a large precipitation event. In such cases, the injection wells act as man-made shaft connections giving flood waters another avenue to reach the surface.

(2) Secondly, the location and construction specifications of the wells do not appear to maximize their effectiveness. One injection well in particular is located at an elevation where some homes will be flooded long before the well starts accepting water. In another instance, one well's opening extends in excess of 11 feet above grade. This well is located in a lowland area and may take on water before local structures are

inundated. However, if the opening to the well was lowered, the well could possibly start draining off water long before the storage capacity of the depression is reached.

(3) Thirdly, regardless of how many injection wells are constructed or how good their communication with the karst system, the system will only drain significant precipitation events over a longer period of time. The karst system has finite capacity to transport water. As previously stated, the karst system which underlies Oak Grove may be a relatively immature or locally constricted. Hunter Spring was observed in October 2001 flowing at maximum capacity of 15 cubic feet per second after a significant rain. However, this rain event was smaller than the rainfall event that led to the 1997 flood. In conclusion, the injection wells, if properly constructed, may provide expedited drainage during normal flow events.

Recommendations

Water will continue to pool on the surface in and around the Oak Grove area during large or prolonged rainfall events. The Oak Grove area does not contain any major natural overland channels and the underlying karst system does not have the capacity to drain off excess rainfall in a timely manner to prevent pooling of water on the surface.

In order to alleviate flooding, the City of Oak Grove has constructed a retention pond at the Shadow Ridge Subdivision on the border of Kentucky and Tennessee at N36° 38' 30.48" and W87° 25' 9.54". Local surface drainage is channeled to the retention pond via a ditch network were it can be safely stored until a storm water injection well can drain the pond. To date this seems to be working in protecting the area immediately around the retention pond. However, erosion problems beneath the ditch network and along the fringes of the retention pond were observed. This is evidenced by gullies on the banks of the retention pond and soil removed from beneath the concrete lined ditches. This could cause problems in the future and should be controlled by the placement of a substantial vegetative cover, concrete, and rip-rap. Whether this retention pond will be adequate is questionable as it is yet to be tested during a rainfall event equal to the one experienced in 1997.

Even if this retention pond has sufficient storage and drainage capacity to contain precipitation event equal to those experienced in 1997, the impoundment will only protect a limited area. Many such ponds would need to be constructed involving hundreds of acres and requiring thousands of cubic yards of material to be excavated to adequately protect all Oak Grove. The amount of acreage involved, the amount of material needed to be excavated, and the constant maintenance required does not appear to be practical or an economical solution for Oak Grove.

Injection wells have been constructed in the retention pond and various locations within and around Oak Grove in an attempt to facilitate surface drainage by providing a direct path for surface water to enter the underlying karst system. However, it appears that no attempt was made to insure that these wells intercept a substantial conduit. Even if these injection wells directly intersected a major conduit, these injection wells do not appear to be a viable solution. The underlying karst system reaches it carrying capacity long before flooding to existing structures becomes a problem. Locally, it is possible that an injection well could cause increased flooding instead of relieving it as intended. An injection well that intersects a conduit that has reached its maximum carrying capacity and with sufficient head could cause artesian conditions, forcing water upward through the injection well to the surface instead of allowing it to draining.

In addition to the two attempts discussed above, it appears that Oak Grove has only three remaining remotely possible solutions to control flooding. These are either the construction of manmade drainage ways, either above or below ground which will carry the precipitation to the West Fork of the Red River; the construction of retaining dykes with subsequent pumping stations; or to exclude flood prone areas from flood sensitive development.

The creation of manmade drainage ways is well beyond the resources of the Oak Grove community. The necessary land acquisition and right of ways, the actual construction of drainage ways, and their maintenance and upkeep would tax the community of Oak Grove far beyond its means. State and federal assistance may be obtained but even with unlimited resources the project would take years to complete.

The possibility of constructing retaining dykes around endangered structures with subsequent pump stations has also been considered. This system would have limitations similar to retention ponds and would also be cost prohibitive and the threat of soil erosion breaching or undermining the integrity of the dyke would be constantly present. Also, the cost of maintenance on the retaining walls and the pump stations would be substantial in both labor and materials putting an enormous strain on limited resources.

The focus of the discussion now turns to the most viable, economical, and simplest solution to Oak Grove's flooding problem, the creation on "No Build Zones". These No Build Zones appear to be the most practical and realistic solution to Oak Grove's flooding problem and should reflect the included flood projection maps from the U.S. Army Corps of Engineers (USACE). Using the USACE flood projection maps the karst flood plain can be delineated and this area should be excluded from future flood sensitive development such as houses, schools, and businesses. However, this land could still be productive and useful. It could be used for the creation of more flood tolerant development such as parks, fair grounds, wildlife sanctuaries, and athletic fields. This would probably necessitate Oak Grove to acquire land outside of the karst flood plain in order to meet its growth needs. However, the creation of No Build Zones would pay off to the community in the long run. Not only would it help prevent large scale economic loss during flood events and have a positive effect on land values, but would also provide areas that would enhance the quality of life at Oak Grove.

It should be noted that according to the Kentucky Climate Center the March 1997 precipitation event was considered a 50-year storm event. It would be prudent to plan, at a minimum, for a 100-year storm event and preferably beyond that. The end result being the creation of the largest possible buffer zone between human habitation and flood prone areas.

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Appendices

Appendix A: Water Quality Charts

Appendix B: Climatic Data from the Kentucky Climate Center

Appendix C: Drainage Calculations

Appendix A

Water Quality Charts

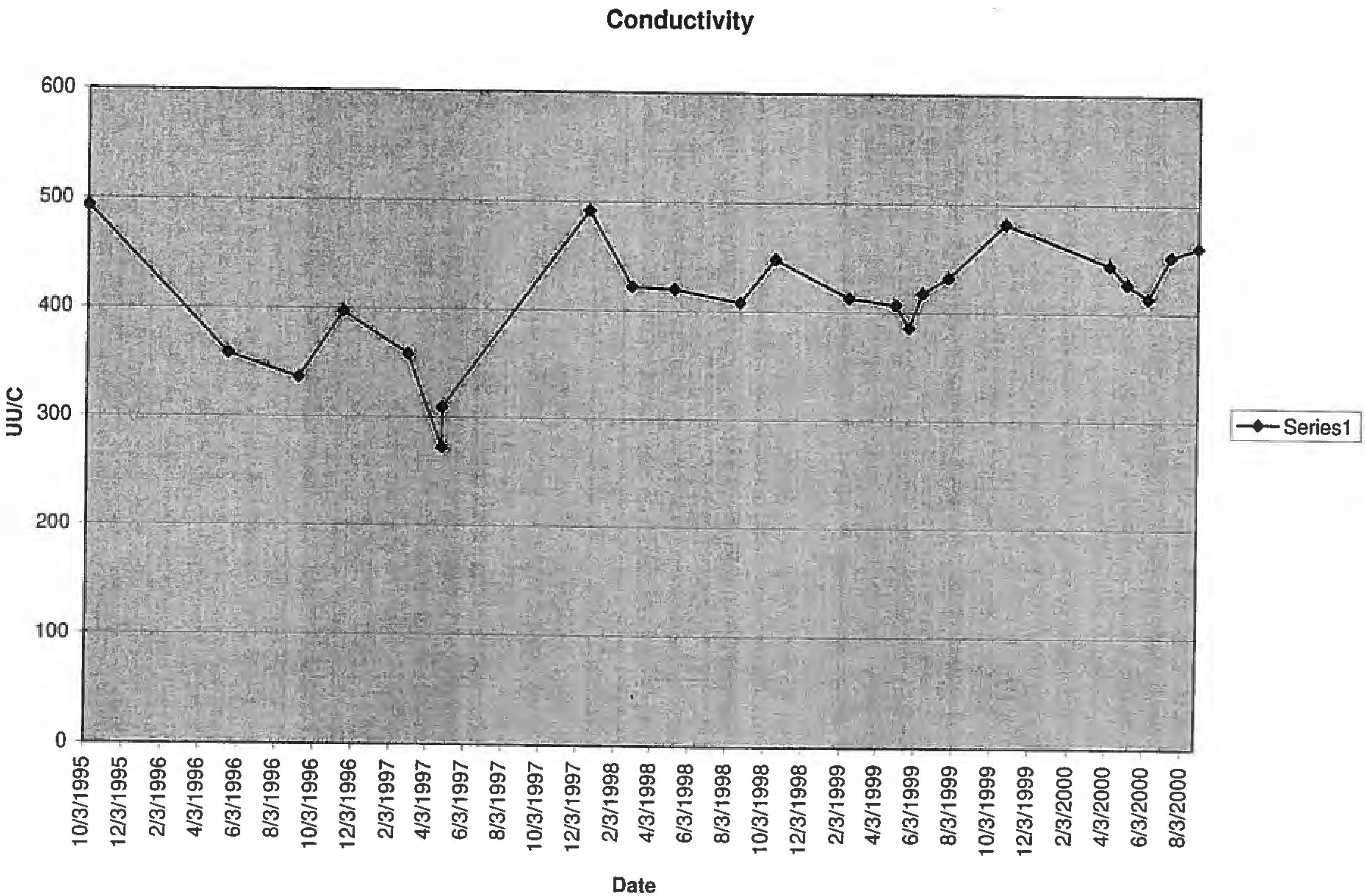
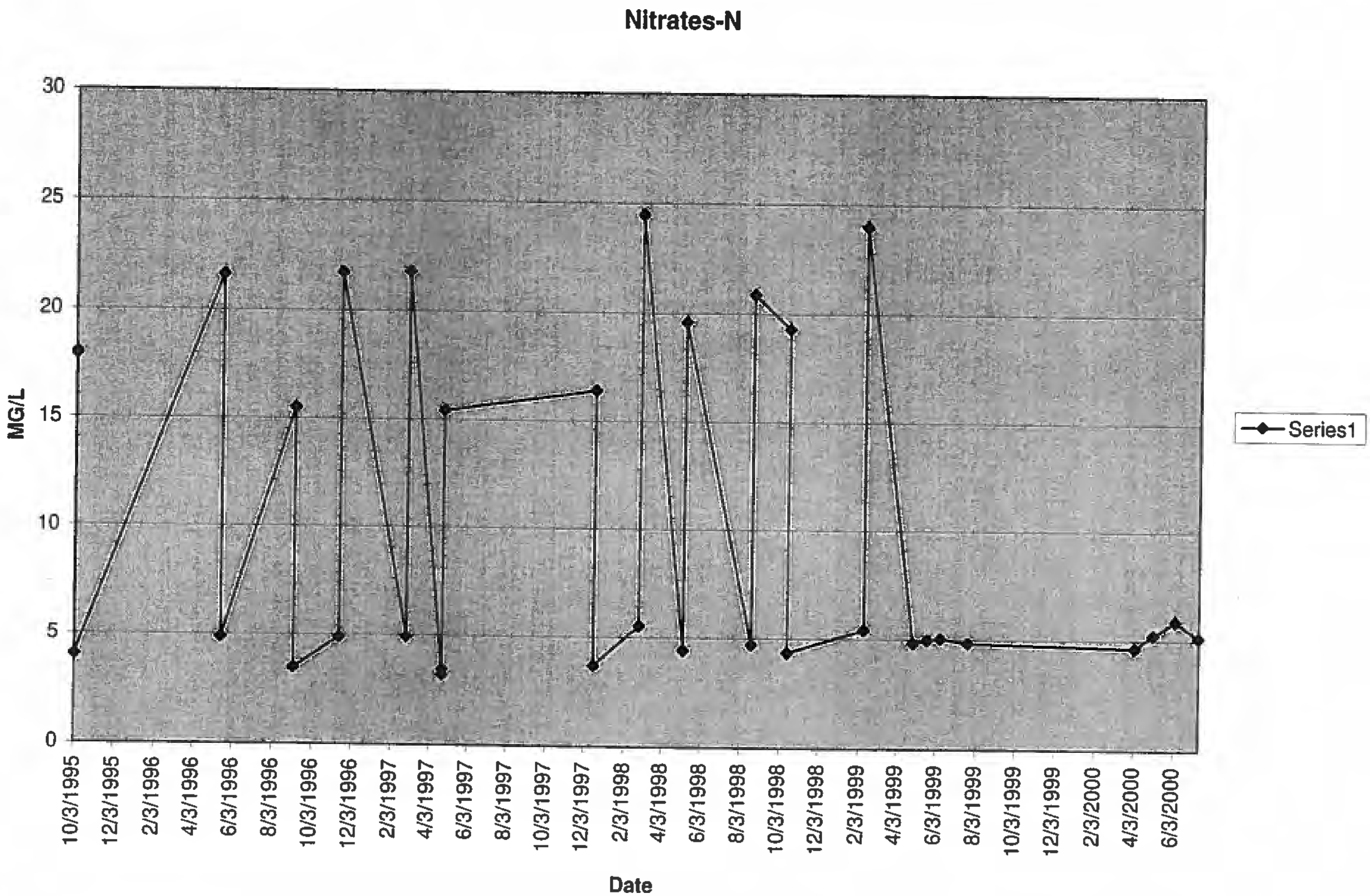
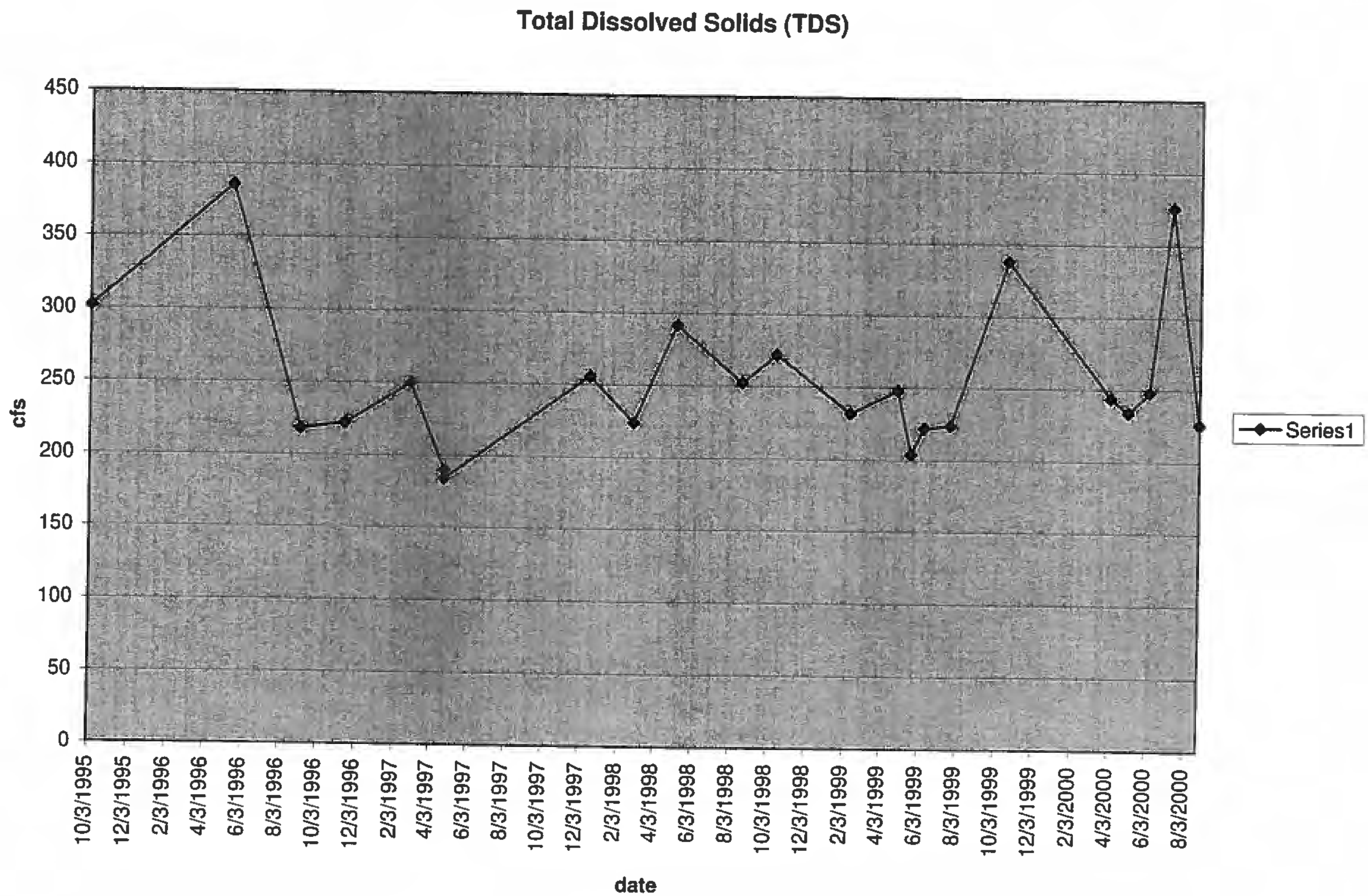

Conductivity
600
500
400
300
200
100
0
UU/C
Series1
10/3/1995
12/3/1995
2/3/1996
4/3/1996
6/3/1996
8/3/1996
10/3/1996
12/3/1996
2/3/1997
4/3/1997
6/3/1997
8/3/1997
10/3/1997
12/3/1997
2/3/1998
4/3/1998
6/3/1998
8/3/1998
10/3/1998
12/3/1998
2/3/1999
4/3/1999
6/3/1999
8/3/1999
10/3/1999
12/3/1999
2/3/2000
4/3/2000
6/3/2000
8/3/2000
Date

Figure 6



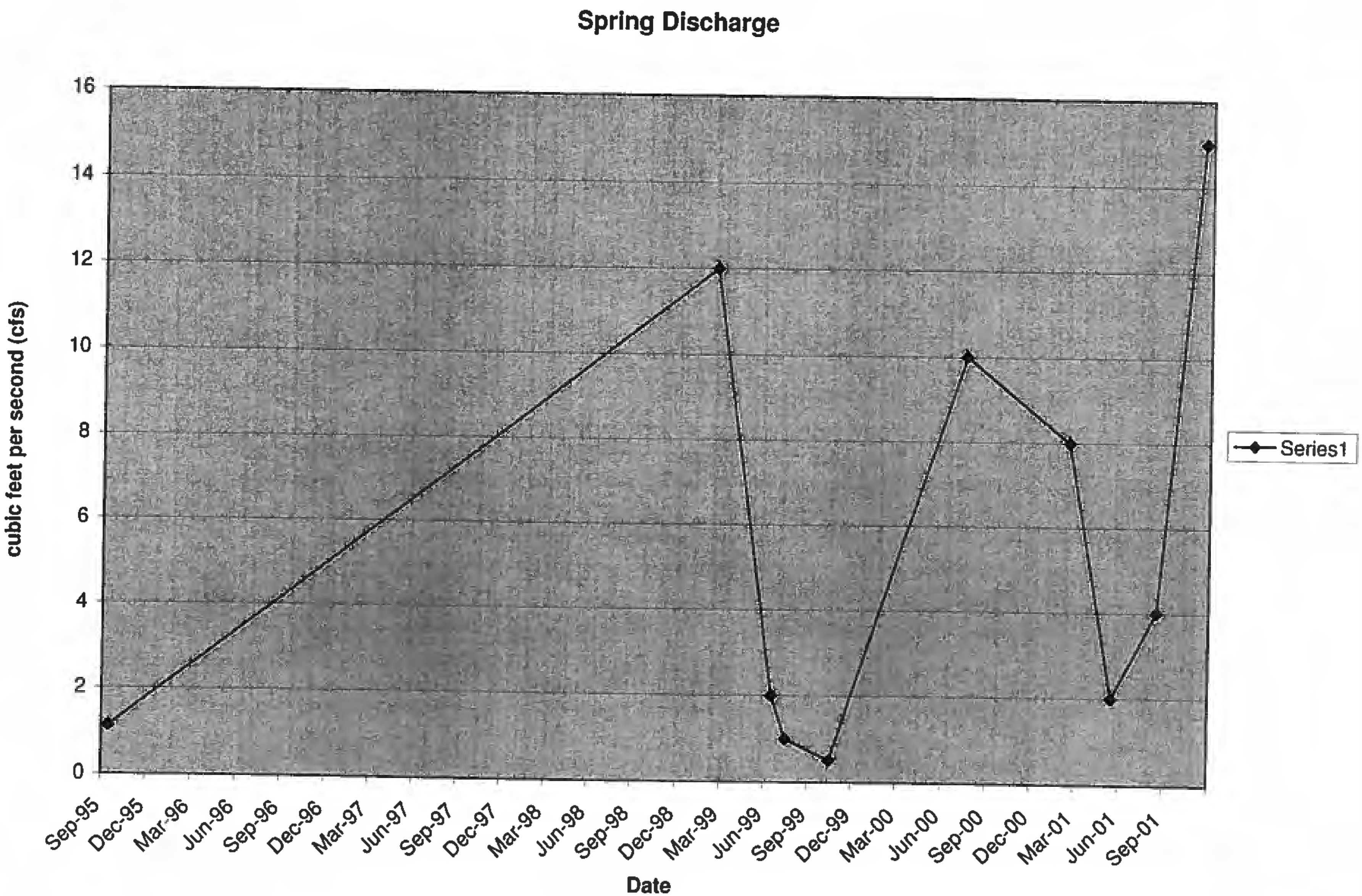
Nitrates-N
30
25
20
15
10
5
0
MG/L
10/3/1995
12/3/1995
2/3/1996
4/3/1996
6/3/1996
8/3/1996
10/3/1996
12/3/1996
2/3/1997
4/3/1997
6/3/1997
8/3/1997
10/3/1997
12/3/1997
2/3/1998
4/3/1998
6/3/1998
8/3/1998
10/3/1998
12/3/1998
2/3/1999
4/3/1999
6/3/1999
8/3/1999
10/3/1999
12/3/1999
2/3/2000
4/3/2000
6/3/2000
Date
Series1

Figure 7



Total Dissolved Solids (TDS)
450
400
350
300
250
200
150
100
50
0
cfs
10/3/1995
12/3/1995
2/3/1996
4/3/1996
6/3/1996
8/3/1996
10/3/1996
12/3/1996
2/3/1997
4/3/1997
6/3/1997
8/3/1997
10/3/1997
12/3/1997
2/3/1998
4/3/1998
6/3/1998
8/3/1998
10/3/1998
12/3/1998
2/3/1999
4/3/1999
6/3/1999
8/3/1999
10/3/1999
12/3/1999
2/3/2000
4/3/2000
6/3/2000
8/3/2000
date
Series1

Figure 8



Spring Discharge
cubic feet per second (cfs)
16
14
12
10
8
6
4
2
0
Sep-95
Dec-95
Mar-96
Jun-96
Sep-96
Dec-96
Mar-97
Jun-97
Sep-97
Dec-97
Mar-98
Jun-98
Sep-98
Dec-98
Mar-99
Jun-99
Sep-99
Dec-99
Mar-00
Jun-00
Sep-00
Dec-00
Mar-01
Jun-01
Sep-01
Date
Series1

Figure 9

CAS_NAME	SAMPLE_DATE	RESULT_VALUE	RESULT_UNIT_OF_MEASURE	LAB_NAME
Conductivity	03-Oct-95	493	UU/C	KGS Lab
Conductivity	03-Oct-95	494	UU/C	KGS Lab
Conductivity	15-May-96	358	UU/C	KGS Lab
Conductivity	04-Sep-96	336	UU/C	KGS Lab
Conductivity	13-Nov-96	397	UU/C	KGS Lab
Conductivity	26-Feb-97	358	UU/C	KGS Lab
Conductivity	23-Apr-97	272	ÆMHO	DES Lab
Conductivity	23-Apr-97	309	UU/C	KGS Lab
Conductivity	16-Dec-97	492	UU/C	KGS Lab
Conductivity	25-Feb-98	422	UU/C	KGS Lab
Conductivity	05-May-98	420	UU/C	KGS Lab
Conductivity	19-Aug-98	408	UU/C	KGS Lab
Conductivity	14-Oct-98	448	UU/C	KGS Lab
Conductivity	10-Feb-99	413	UU/C	KGS Lab
Conductivity	27-Apr-99	407	ÆMHO	DES Lab
Conductivity	19-May-99	386	ÆMHO	DES Lab
Conductivity	09-Jun-99	418	ÆMHO	DES Lab
Conductivity	21-Jul-99	432	ÆMHO	DES Lab
Conductivity	20-Oct-99	482	UU/C	KGS Lab
Conductivity	04-Apr-00	444	ÆMHO	DES Lab
Conductivity	02-May-00	427	ÆMHO	DES Lab
Conductivity	05-Jun-00	414	ÆMHO	DES Lab
Conductivity	11-Jul-00	452	ÆMHO	DES Lab
Conductivity	24-Aug-00	461	UU/C	KGS Lab
Average Value		**414.2916667**		
Median Value		**419**		

CAS_NAME	SAMPLE_DATE	RESULT_VALUE	RESULT_UNIT_OF_MEASURE	LAB_NAME
Nitrate	03-Oct-95	18	MG/L	KGS Lab
Nitrate	03-Oct-95	4.05	MG/L	KGS Lab
Nitrate	03-Oct-95	17.9	MG/L	KGS Lab
Nitrate	03-Oct-95	4.07	MG/L	KGS Lab
Nitrate	15-May-96	21.6	MG/L	KGS Lab
Nitrate	15-May-96	4.88	MG/L	KGS Lab
Nitrate	04-Sep-96	15.5	MG/L	KGS Lab
Nitrate	04-Sep-96	3.5	MG/L	KGS Lab
Nitrate	13-Nov-96	4.9	MG/L	KGS Lab
Nitrate	13-Nov-96	21.7	MG/L	KGS Lab
Nitrate	26-Feb-97	4.93	MG/L	KGS Lab
Nitrate	26-Feb-97	21.8	MG/L	KGS Lab
Nitrate	23-Apr-97	3.21	MG/L	DES Lab
Nitrate	23-Apr-97	3.48	MG/L	KGS Lab
Nitrate	23-Apr-97	15.4	MG/L	KGS Lab
Nitrate	16-Dec-97	16.4	MG/L	KGS Lab
Nitrate	16-Dec-97	3.71	MG/L	KGS Lab

Nitrate	25-Feb-98	5.54	MG/L	KGS Lab
Nitrate	25-Feb-98	24.5	MG/L	KGS Lab
Nitrate	05-May-98	4.43	MG/L	KGS Lab
Nitrate	05-May-98	19.6	MG/L	KGS Lab
Nitrate	19-Aug-98	4.72	MG/L	KGS Lab
Nitrate	19-Aug-98	20.9	MG/L	KGS Lab
Nitrate	14-Oct-98	19.3	MG/L	KGS Lab
Nitrate	14-Oct-98	4.36	MG/L	KGS Lab
Nitrate	10-Feb-99	5.42	MG/L	KGS Lab
Nitrate	10-Feb-99	24	MG/L	KGS Lab
Nitrate	27-Apr-99	4.83	MG/L	DES Lab
Nitrate	19-May-99	4.98	MG/L	DES Lab
Nitrate	09-Jun-99	5.05	MG/L	DES Lab
Nitrate	21-Jul-99	4.85	MG/L	DES Lab
Nitrate	04-Apr-00	4.66	MG/L	DES Lab
Nitrate	02-May-00	5.25	MG/L	DES Lab
Nitrate	05-Jun-00	5.9	MG/L	DES Lab
Nitrate	11-Jul-00	5.15	MG/L	DES Lab

Average Value **10.242**

Median Value **5.15**

CAS_NAME	SAMPLE_DATE	RESULT_VALUE	RESULT_UNIT_OF_MEASURE	LAB_NAME
Total Dissolved Solids	03-Oct-95	302	MG/L	KGS Lab
Total Dissolved Solids	03-Oct-95	302	MG/L	KGS Lab
Total Dissolved Solids	15-May-96	386	MG/L	KGS Lab
Total Dissolved Solids	04-Sep-96	218	MG/L	KGS Lab
Total Dissolved Solids	13-Nov-96	222	MG/L	KGS Lab
Total Dissolved Solids	26-Feb-97	250	MG/L	KGS Lab
Total Dissolved Solids	23-Apr-97	190	MG/L	DES Lab
Total Dissolved Solids	23-Apr-97	184	MG/L	KGS Lab
Total Dissolved Solids	16-Dec-97	256	MG/L	KGS Lab
Total Dissolved Solids	25-Feb-98	224	MG/L	KGS Lab
Total Dissolved Solids	05-May-98	292	MG/L	KGS Lab
Total Dissolved Solids	19-Aug-98	252	MG/L	KGS Lab

Total Dissolved Solids	14-Oct-98	272	MG/L	KGS Lab
Total Dissolved Solids	10-Feb-99	232	MG/L	KGS Lab
Total Dissolved Solids	27-Apr-99	248	MG/L	DES Lab
Total Dissolved Solids	19-May-99	204	MG/L	DES Lab
Total Dissolved Solids	09-Jun-99	222	MG/L	DES Lab
Total Dissolved Solids	21-Jul-99	224	MG/L	DES Lab
Total Dissolved Solids	20-Oct-99	338	MG/L	KGS Lab
Total Dissolved Solids	04-Apr-00	244	MG/L	DES Lab
Total Dissolved Solids	02-May-00	234	MG/L	DES Lab
Total Dissolved Solids	05-Jun-00	248	MG/L	DES Lab
Total Dissolved Solids	11-Jul-00	376	MG/L	DES Lab
Total Dissolved Solids	24-Aug-00	226	MG/L	KGS Lab

Average Value 256.0833333

Median Value 246

CAS_NAME	SAMPLE_DATE	RESULT_VALUE	RESULT_UNIT_OF_MEASURE	LAB_NAME
Total Suspended Solids	03-Oct-95	7	MG/L	KGS Lab
Total Suspended Solids	03-Oct-95	7	MG/L	KGS Lab
Total Suspended Solids	15-May-96	41	MG/L	KGS Lab
Total Suspended Solids	04-Sep-96	17	MG/L	KGS Lab
Total Suspended Solids	13-Nov-96	3	MG/L	KGS Lab
Total Suspended Solids	26-Feb-97	6	MG/L	KGS Lab

Total Suspended Solids	23-Apr-97	12	MG/L	DES Lab
Total Suspended Solids	23-Apr-97	17	MG/L	KGS Lab
Total Suspended Solids	16-Dec-97	5	MG/L	KGS Lab
Total Suspended Solids	25-Feb-98	9	MG/L	KGS Lab
Total Suspended Solids	05-May-98	9	MG/L	KGS Lab
Total Suspended Solids	19-Aug-98	7	MG/L	KGS Lab
Total Suspended Solids	14-Oct-98	4	MG/L	KGS Lab
Total Suspended Solids	10-Feb-99	23	MG/L	KGS Lab
Total Suspended Solids	27-Apr-99	14	MG/L	DES Lab
Total Suspended Solids	19-May-99	22	MG/L	DES Lab
Total Suspended Solids	09-Jun-99	18	MG/L	DES Lab
Total Suspended Solids	21-Jul-99	6	MG/L	DES Lab
Total Suspended Solids	20-Oct-99	11	MG/L	KGS Lab
Total Suspended Solids	04-Apr-00	16	MG/L	DES Lab
Total Suspended Solids	02-May-00	3	MG/L	DES Lab
Total Suspended Solids	05-Jun-00	25	MG/L	DES Lab

Total Suspended Solids	11-Jul-00	4	MG/L	DES Lab
Total Suspended Solids	24-Aug-00	11	MG/L	KGS Lab

Average Value **12.375**

Median Value **10**

CAS_NAME	SAMPLE_DATE	RESULT_VALUE	RESULT_UNIT_OF_MEASURE	LAB_NAME
Atrazine	03-Oct-95	0.3	UG/L	KGS Lab
Atrazine	15-May-96	5.46	UG/L	KGS Lab
Atrazine	04-Sep-96	1.01	UG/L	KGS Lab
Atrazine	13-Nov-96	0.3	UG/L	KGS Lab
Atrazine	26-Feb-97	0.3	UG/L	KGS Lab
Atrazine	23-Apr-97	0.3	UG/L	KGS Lab
Atrazine	23-Jul-97	0.000188	MG/L	DES Lab
Atrazine	16-Dec-97	0.000052	MG/L	DES Lab
Atrazine	05-May-98	0.000474	MG/L	DES Lab
Atrazine	19-Aug-98	0.000065	MG/L	DES Lab
Atrazine	27-Apr-99	0.000164	MG/L	DES Lab
Atrazine	19-May-99	0.00415	MG/L	DES Lab
Atrazine	09-Jun-99	0.0002	MG/L	DES Lab
Atrazine	21-Jul-99	0.00012	MG/L	DES Lab
Atrazine	20-Oct-99	0.00009	MG/L	DES Lab
Atrazine	04-Apr-00	0.00157	MG/L	DES Lab
Atrazine	02-May-00	0.00032	MG/L	DES Lab
Atrazine	05-Jun-00	0.0003	MG/L	DES Lab
Atrazine	11-Jul-00	0.00005	MG/L	DES Lab
Atrazine	22-Aug-00	0.00007	MG/L	DES Lab
Atrazine	13-Feb-01	0.00011	MG/L	DES Lab
Atrazine	29-May-01	0.00012	MG/L	DES Lab
Atrazine	28-Aug-01	0.000052	MG/L	DES Lab

CAS_NAME	SAMPLE_DATE	RESULT_VALUE	RESULT_UNIT_OF_MEASURE	LAB_NAME
Alachlor	03-Oct-95	0.02	UG/L	KGS Lab
Alachlor	15-May-96	0.02	UG/L	KGS Lab
Alachlor	04-Sep-96	0.06	UG/L	KGS Lab
Alachlor	04-Sep-96	0.04	UG/L	KGS Lab
Alachlor	13-Nov-96	0.02	UG/L	KGS Lab
Alachlor	13-Nov-96	0.09	UG/L	KGS Lab
Alachlor	26-Feb-97	0.02	UG/L	KGS Lab
Alachlor	26-Feb-97	0.06	UG/L	KGS Lab
Alachlor	23-Apr-97	0.00005	MG/L	DES Lab
Alachlor	23-Apr-97	0.06	UG/L	KGS Lab
Alachlor	23-Apr-97	0.02	UG/L	KGS Lab

Alachlor	23-Jul-97	0.00005	MG/L	DES Lab
Alachlor	16-Dec-97	0.00005	MG/L	DES Lab
Alachlor	05-May-98	0.00005	MG/L	DES Lab
Alachlor	19-Aug-98	0.00005	MG/L	DES Lab
Alachlor	27-Apr-99	0.00004	MG/L	DES Lab
Alachlor	19-May-99	0.00004	MG/L	DES Lab
Alachlor	09-Jun-99	0.00004	MG/L	DES Lab
Alachlor	21-Jul-99	0.00004	MG/L	DES Lab
Alachlor	20-Oct-99	0.00004	MG/L	DES Lab
Alachlor	04-Apr-00	0.00004	MG/L	DES Lab
Alachlor	02-May-00	0.00004	MG/L	DES Lab
Alachlor	05-Jun-00	0.00004	MG/L	DES Lab
Alachlor	11-Jul-00	0.00004	MG/L	DES Lab
Alachlor	22-Aug-00	0.00004	MG/L	DES Lab
Alachlor	13-Feb-01	0.00004	MG/L	DES Lab
Alachlor	29-May-01	0.00004	MG/L	DES Lab
Alachlor	28-Aug-01	0.00004	MG/L	DES Lab

CAS_NAME	SAMPLE_DATE	RESULT_VALUE	RESULT_UNIT_OF_MEASURE	LAB_NAME
Metolachlor	03-Oct-95	0.2	UG/L	KGS Lab
Metolachlor	03-Oct-95	0.2	UG/L	KGS Lab
Metolachlor	15-May-96	1.546	UG/L	KGS Lab
Metolachlor	04-Sep-96	0.11	UG/L	KGS Lab
Metolachlor	04-Sep-96	0.294	UG/L	KGS Lab
Metolachlor	13-Nov-96	0.2	UG/L	KGS Lab
Metolachlor	13-Nov-96	0.08	UG/L	KGS Lab
Metolachlor	26-Feb-97	0.2	UG/L	KGS Lab
Metolachlor	26-Feb-97	0.05	UG/L	KGS Lab
Metolachlor	23-Apr-97	0.00005	MG/L	DES Lab
Metolachlor	23-Apr-97	0.2	UG/L	KGS Lab
Metolachlor	23-Apr-97	0.05	UG/L	KGS Lab
Metolachlor	23-Jul-97	0.00005	MG/L	DES Lab
Metolachlor	16-Dec-97	0.00005	MG/L	DES Lab
Metolachlor	05-May-98	0.000191	MG/L	DES Lab
Metolachlor	19-Aug-98	0.000053	MG/L	DES Lab
Metolachlor	27-Apr-99	0.000033	MG/L	DES Lab
Metolachlor	19-May-99	0.00051	MG/L	DES Lab
Metolachlor	09-Jun-99	0.00009	MG/L	DES Lab
Metolachlor	21-Jul-99	0.00004	MG/L	DES Lab
Metolachlor	20-Oct-99	0.00004	MG/L	DES Lab
Metolachlor	04-Apr-00	0.00009	MG/L	DES Lab
Metolachlor	02-May-00	0.00011	MG/L	DES Lab
Metolachlor	05-Jun-00	0.00015	MG/L	DES Lab
Metolachlor	11-Jul-00	0.00004	MG/L	DES Lab
Metolachlor	22-Aug-00	0.00002	MG/L	DES Lab
Metolachlor	13-Feb-01	0.00004	MG/L	DES Lab
Metolachlor	29-May-01	0.00002	MG/L	DES Lab
Metolachlor	28-Aug-01	0.000049	MG/L	DES Lab

CAS_NAME	SAMPLE_DATE	RESULT_VALUE	RESULT_UNIT_OF_MEASURE	LAB_NAME
Simazine	03-Oct-95	0.3	UG/L	KGS Lab
Simazine	03-Oct-95	0.02	UG/L	KGS Lab
Simazine	03-Oct-95	0.3	UG/L	KGS Lab
Simazine	03-Oct-95	0.3	UG/L	KGS Lab
Simazine	03-Oct-95	0.3	UG/L	KGS Lab
Simazine	15-May-96	0.3	UG/L	KGS Lab
Simazine	15-May-96	0.3	UG/L	KGS Lab
Simazine	04-Sep-96	0.3	UG/L	KGS Lab
Simazine	04-Sep-96	0.3	UG/L	KGS Lab
Simazine	13-Nov-96	0.3	UG/L	KGS Lab
Simazine	13-Nov-96	0.3	UG/L	KGS Lab
Simazine	26-Feb-97	0.3	UG/L	KGS Lab
Simazine	26-Feb-97	0.3	UG/L	KGS Lab
Simazine	23-Apr-97	0.00005	MG/L	Division of Environmental Services
Simazine	23-Apr-97	0.3	UG/L	KGS Lab
Simazine	23-Apr-97	0.3	UG/L	KGS Lab
Simazine	23-Jul-97	0.00005	MG/L	DES Lab
Simazine	16-Dec-97	0.00005	MG/L	DES Lab
Simazine	05-May-98	0.00005	MG/L	DES Lab
Simazine	19-Aug-98	0.00005	MG/L	DES Lab
Simazine	27-Apr-99	0.00004	MG/L	DES Lab
Simazine	19-May-99	0.00004	MG/L	DES Lab
Simazine	09-Jun-99	0.00004	MG/L	DES Lab
Simazine	21-Jul-99	0.00004	MG/L	DES Lab
Simazine	20-Oct-99	0.00004	MG/L	DES Lab
Simazine	04-Apr-00	0.00004	MG/L	DES Lab
Simazine	02-May-00	0.00004	MG/L	DES Lab
Simazine	05-Jun-00	0.00004	MG/L	DES Lab
Simazine	11-Jul-00	0.00004	MG/L	DES Lab
Simazine	22-Aug-00	0.00004	MG/L	DES Lab
Simazine	13-Feb-01	0.00004	MG/L	DES Lab
Simazine	29-May-01	0.00004	MG/L	DES Lab
Simazine	28-Aug-01	0.00004	MG/L	DES Lab

CAS_NAME	SAMPLE_DATE	RESULT_VALUE	RESULT_UNIT_OF_MEASURE	LAB_NAME
Cyanazine	03-Oct-95	0.1	UG/L	KGS Lab
Cyanazine	03-Oct-95	0.1	UG/L	KGS Lab
Cyanazine	15-May-96	0.1	UG/L	KGS Lab
Cyanazine	04-Sep-96	0.1	UG\L	KGS Lab
Cyanazine	13-Nov-96	0.1	UG\L	KGS Lab
Cyanazine	26-Feb-97	0.1	UG/L	KGS Lab
Cyanazine	23-Apr-97	0.00005	MG/L	DES Lab
Cyanazine	23-Apr-97	0.1	UG/L	KGS Lab
Cyanazine	23-Jul-97	0.00005	MG/L	DES Lab

Cyanazine	16-Dec-97	0.00005	MG/L	DES Lab
Cyanazine	05-May-98	0.00005	MG/L	DES Lab
Cyanazine	19-Aug-98	0.00005	MG/L	DES Lab
Cyanazine	27-Apr-99	0.00004	MG/L	DES Lab
Cyanazine	19-May-99	0.00004	MG/L	DES Lab
Cyanazine	09-Jun-99	0.00004	MG/L	DES Lab
Cyanazine	21-Jul-99	0.00004	MG/L	DES Lab
Cyanazine	20-Oct-99	0.00004	MG/L	DES Lab
Cyanazine	04-Apr-00	0.00004	MG/L	DES Lab
Cyanazine	02-May-00	0.00004	MG/L	DES Lab
Cyanazine	05-Jun-00	0.00004	MG/L	DES Lab
Cyanazine	11-Jul-00	0.00004	MG/L	DES Lab
Cyanazine	22-Aug-00	0.00004	MG/L	DES Lab
Cyanazine	13-Feb-01	0.00004	MG/L	DES Lab
Cyanazine	29-May-01	0.00004	MG/L	DES Lab
Cyanazine	28-Aug-01	0.00004	MG/L	DES Lab

CAS_NAME	SAMPLE_DATE	RESULT_VALUE	RESULT_UNIT_OF_MEASURE	LAB_NAME
Benzene	04-Apr-00	0.0005	MG/L	DES Lab
BENZENE	04-Apr-00	0.0005	MG/L	DES Lab
BENZENE	02-May-00	0.0005	MG/L	DES Lab
Benzene	02-May-00	0.0005	MG/L	DES Lab
BENZENE	05-Jun-00	0.0005	MG/L	DES Lab
Benzene	05-Jun-00	0.0005	MG/L	DES Lab
BENZENE	11-Jul-00	0.0005	MG/L	DES Lab
Benzene	11-Jul-00	0.0005	MG/L	DES Lab
BENZENE	22-Aug-00	0.0005	MG/L	DES Lab
Benzene	22-Aug-00	0.0005	MG/L	DES Lab
Benzene	27-Sep-00	0.0005	MG/L	DES Lab
BENZENE	27-Sep-00	0.0005	MG/L	DES Lab
BENZENE	13-Feb-01	0.0005	MG/L	DES Lab
Benzene	13-Feb-01	0.0005	MG/L	DES Lab
Benzene	29-May-01	0.0005	MG/L	DES Lab
BENZENE	29-May-01	0.0005	MG/L	DES Lab

Hunter Spring Discharge Observations

Date	CFS	Observer
9/12/1995	1.12	Ray-measured
2/10/1999	12	Webb-est.
6/9/1999	2	Webb-est.
7/22/1999	1	Yarnell-est.
10/20/1999	0.5	Moody-est.
7/11/2000	10	Nicotera-est.
2/13/2001	8	Nicotera-est.
5/29/2001	2	Nicotera-est.
8/28/2001	4	Nicotera-est.
11/27/2001	15	Nicotera-est.

Appendix B

Climatic Data

Blair, Robert (NREPC, DEP)

From: KY Climate Center [KYClim@wku.edu]
Sent: Friday, August 03, 2001 10:39 AM
To: robert.blair@mail.state.ky.us
Subject: Hopkinsville Climate Summary

KENTUCKY CLIMATE CENTER
DEPARTMENT OF GEOGRAPHY AND GEOLOGY
WESTERN KENTUCKY UNIVERSITY

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*********************** PRECIPITATION SUMMARY ******************************
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Station: (153994) HOPKINSVILLE   Missing Data: 0%
NCDC Averages: 1961-1990 Extremes: 1896-2000 '=prior to 1900 +=after 1999

	Total Precipitation								Snow			#Days Precip		
	Mean	High--Yr		Low--Yr		1-Day Max		Mean	High--Yr		=>.01	=>.50	=>1.
Ja	3.81	21.86	37	0.61	43	5.33	08/1920	4.9	16.5	78	9.9	3.3	1.4
Fe	4.25	13.77	89	0.13	47	4.75	14/1949	4.0	15.2	79	8.9	2.7	0.9
Ma	5.25	16.43	97	0.86	18	7.06	02/1997	1.4	25.7	60	11.0	3.6	1.4
Ap	4.69	13.19	12	0.70	15	6.30	02/1912	0.1	1.5	83	10.3	3.0	1.2
Ma	4.81	11.60	83	0.59	51	4.00	26/1905	0.0	0.0	00	10.5	3.2	1.2
Jn	3.53	12.88	28	0.46	52	4.22	28/1960	0.0	0.0	00	9.4	2.8	1.1
Jl	4.35	8.07	59	0.26	02	4.13	26/1933	0.0	0.0	00	8.4	2.8	1.2
Au	3.43	10.89	23	0.12	00	2.93	17/1949	0.0	0.0	00	7.7	2.4	1.0
Se	3.45	10.19	79	0.00	'97	5.38	14/1979	0.0	0.0	00	7.4	2.2	0.8
Oc	3.19	10.47	19	0.00	08	5.60	06/1900	0.0	0.5	93	7.0	2.2	0.9
No	4.90	13.66	57	0.71	54	6.18	24/1900	0.4	5.0	66	8.5	3.0	1.2
De	5.13	14.59	78	0.53	76	4.75	15/1902	1.5	8.1	63	9.7	3.3	1.4
An	50.79	71.97	79	28.47	63	7.06	03/02/97	12.3	36.6	60	108.7	34.5	13.7
Wi	13.19	27.86	37	4.27	63	5.33	01/08/20	10.4	28.5	78	28.5	9.3	3.7
Sp	14.75	26.82	83	4.90	41	7.06	03/02/97	1.5	25.7	60	31.8	9.8	3.8
Su	11.31	22.63	23	4.84	13	4.22	06/28/60	0.0	0.0	00	25.5	8.0	3.3
Fa	11.54	21.91	79	2.75	63	6.18	11/24/00	0.4	5.0	66	22.9	7.4	2.9

Heavy Precipitation Events
Based on Daily Precipitation Totals
1896-2001

Precipitation Total (inches)	Average Days Per Year
> 1.0	13.2
> 2.0	2.7
> 3.0	0.7
> 4.0	0.2

Precipitation Recurrence Intervals
Kentucky, Western Climate Division

Rainfall(inches) for given recurrence interval

Duration	1-year	5-year	10-year	50-year	100-year
24-hr	3.10	4.66	5.39	7.19	8.09
12-hr	2.70	4.05	4.69	6.26	7.04
6-hr	2.32	3.49	4.04	5.39	6.07
3-hr	1.98	2.98	3.45	4.60	5.18
1-hr	1.46	2.19	2.53	3.38	3.80

Source: Rainfall Frequency Atlas of the Midwest
Floyd A. Huff and James R. Angel
Midwestern Regional Climate Center
Bulletin 71 (MCC Research Report 92-03), 1992

Dr. Stuart A. Foster
State Climatologist for Kentucky

Shuttleworth, John (NREPC, DEP)

From: KY Climate Center [kyclim@wku.edu]
Sent: Tuesday, October 29, 2002 1:10 PM
To: John.Shuttleworth@mail.state.ky.us
Subject: Re: Inquiry

KENTUCKY CLIMATE CENTER
DEPARTMENT OF GEOGRAPHY AND GEOLOGY
WESTERN KENTUCKY UNIVERSITY

STATION: HOPKINSVILLE, KY (Station ID: 153994)

Year	Mo	Dy	Precip-itation (in)	Obser-vation Time	Data Source
1997	02	24	0.00	AM	F
1997	02	25	0.00	AM	F
1997	02	26	0.09	AM	F
1997	02	27	0.53	AM	F
1997	02	28	0.00	AM	F
1997	03	01	2.89	AM	F
1997	03	02	7.06	AM	F
1997	03	03	0.90	AM	F
1997	03	04	0.02	AM	F
1997	03	05	0.70	AM	F
		Sum	12.19		
		Average			

M = missing, e = estimated, T = trace
P = preliminary data, F = final data from NCDC

Stuart A. Foster, Ph.D.
State Climatologist for Kentucky

Shuttleworth, John (NREPC, DEP)

From: KY Climate Center [KYClim@wku.edu]
Sent: Thursday, November 29, 2001 8:51 AM
To: John.Shuttleworth@mail.state.ky.us
Subject: Re:

KENTUCKY CLIMATE CENTER
DEPARTMENT OF GEOGRAPHY AND GEOLOGY
WESTERN KENTUCKY UNIVERSITY

STATION: HERNDON_3_SW, KY (Station ID: 153798)

Year	Mo	Dy	Precip-itation (in)
1997	02	21	0.81
1997	02	22	0.00
1997	02	23	0.00
1997	02	24	0.00
1997	02	25	0.00
1997	02	26	0.47
1997	02	27	0.80
1997	02	28	0.00
1997	03	01	3.12
1997	03	02	5.43
1997	03	03	0.91
1997	03	04	0.00
		Sum	11.54
		Average	

M = missing, e = estimated, T = trace
P = preliminary data, F = final data from NCDC

STATION: CLARKSVILLE_SEWAGE_PLT, TN (Station ID: 401790)

Precip-

Year	Mo	Dy	itation (in)
1997	02	21	0.15
1997	02	22	0.00
1997	02	23	0.00
1997	02	24	0.00
1997	02	25	0.00
1997	02	26	0.13
1997	02	27	0.50
1997	02	28	0.02
1997	03	01	4.94
1997	03	02	1.00
1997	03	03	0.59
1997	03	04	T
		Sum	7.33
		Average	

M = missing, e = estimated, T = trace
P = preliminary data, F = final data from NCDC

Dr. Stuart A. Foster
State Climatologist for Kentucky

John.Shuttleworth@mail.state.ky.us wrote:

> On 3/2/97 a 1 day precipitation of 7.06 inches was recorded at Hopkinsville,
> Ky. I would like to know the amount of precipitation recorded at the
> nearest station to Oak Grove, Ky. the 5 days proceeding this event. Your
> timely response would be greatly appreciated. Thanks,

Appendix C

Drainage Calculations

Official rainfall totals were not recorded at Oak Grove during March 1997. However, rainfall totals from the end of February through March 3rd of 1997 have been obtained from the Kentucky Climate Center for the communities of Hopkinsville and Herndon Kentucky. (Figure 6). Considering their relative location to Oak Grove and the prevailing weather patterns of Southwestern Kentucky, it is felt that the recorded rainfalls for these to towns can provide a reasonable estimate of the amount of rain that fell in the vicinity of Oak Grove March 1st through March 3rd, 1997.

Hopkinsville lies approximately 14 miles north and only slightly west of Oak Grove. Herndon lies 8.4 miles west of Oak Grove but is only 4.8 miles north of Oak Grove. Since weather patterns for this region of Kentucky is predominately west to east or southwest to northeast, the rainfall amounts of these two nearby communities are in all probability representative of precipitation experienced by Oak Grove.

During March 1st rough March 3rd of 1997 Hopkinsville received 10.85 inches of rainfall and Herndon received 9.46 inches. Based up these two numbers, a rainfall amount of 9.5 inches was projected to the Oak Grove area.

Estimated area drained by Hunter Spring: 5.4 square Miles

Maximum flow capacity of Hunter Spring: 15 CFS (Cubic Feet Per Second)

Rain fall event = 9.5 inches

Hunter Spring Drainage

$$\frac{15\,\text{ft}^3}{1\,\text{sec}} \cdot \frac{60\,\text{sec}}{1\,\text{min}} \cdot \frac{60\,\text{min}}{1\,\text{hr}} \cdot \frac{24\,\text{hr}}{1\,\text{day}} = 1.296 \times 10^6\,{}^{\text{ft}^3}\!/_{\text{day}}$$

Rainfall Event

$$\frac{9.5\,\text{in}}{1} \cdot \frac{5.4\,\text{mi}^2}{1} \cdot \frac{1\,\text{ft}}{12\,\text{in}} \cdot \frac{5280\,\text{ft}}{1\,\text{mi}} \cdot \frac{5280\,\text{ft}}{1\,\text{mi}} = 1.1918 \times 10^8\,\text{ft}^3$$

Number of Days to Drain

$$\frac{1\,\text{day}}{1.296 \times 10^6\,\text{ft}^3} \cdot \frac{1.1918 \times 10^8\,\text{ft}^3}{1} = 91.96\,\text{days or } 92\,\text{days}$$

Conclusion: Assuming that there was no additional precipitation between the 9.5 rainfall event and the time it would take Hunter Spring to drain such a event would take approximately 92 days. Any additional precipitation over the 92 day period would only increase the total time it would take Hunter Spring to drain the basin. Since the Oak Grove area was not subject to such a period of prolonged drought in 1997, this explains why standing water was still observed well into the summer.

It should also be noted that Herndon had received rainfall amounts of 1.27 inches and Hopkinsville .62 inches on February 26th and 27th. Therefore, the area around Oak Grove was already saturated and most likely already pooling water at some locations. This only compounded the flooding problem and extended the drainage time.

Appendix D

Key Terms

Key Terms

Allogenic-produced from an outside source, generated elsewhere.

Anisotropic- physical properties are not equal in all directions.

Aquifer- a water bearing rock or rock formation.

Argillaceous- containing clay minerals.

Autogenic- produced from an interior source.

Base flow- the normal amount of discharge for a given spring. Generally expressed in cubic feet per second (cfs).

Base-level spring- the main spring, attributed to a basin, which drains that basin.

Bluehole spring- a spring that is driven by hydrostatic pressure, forcing water up through a conduit or fracture. Generally observed as pools, some with turbulent boils.

Chert- flint rock

Clastic- a sedimentary rock consisting of rock fragments cemented together by a finer grained matrix.

Conduit- a naturally occurring passage through a rock or rock formation. A cave would be considered a large conduit.

Dendritic- having a pattern that resembles the branches of a tree. As with surface streams, tributaries(branches) converge with the main channel (trunk).

Diagenesis- the process of forming a consolidated rock formation from sediment.

Epikarst- the weathered zone of soluble bedrock where a perennial or seasonal groundwater zone tends to be perched. Typically 5-10 meters thick, the epikarst is recharged by precipitation and seepage from the overlying soil cover. The combined soil/weathered bedrock unit may store groundwater over seasonal time scales. Percolation and seepage from this zone is largely responsible for maintaining base flow in local springs and streams.

Estavelle- a karst feature that can function as a groundwater sink or overflow spring.

Gravity Spring- spring discharging horizontally from a point above base-level.

Hydraulic Head (or Head)- the pressure of a fluid upon a unit area due to the height at which the surface of the fluid stands above the point where the pressure is determined.

Karst- a type of terrane where soluble rocks are present at or near the land surface. Characterized by underground channels (or conduits) formed by dissolution of these rocks by groundwater with anisotropic flow.

Karst Window- a section of an underground channel exposed by roof collapse.

Macropores- soil pores that are large enough to be easily observed.

Morphology- the form and structure of land.

Oolitic- containing *oolites (a spherical or ellipsoidal body with concentric or radial structure).*

Overflow spring- a groundwater discharge point that is only active during times of excess water.

Perched aquifer- a water bearing zone above an impermeable bed, underlain by an unsaturated rock formation with sufficient permeability to transmit water.

Perching layer- the impermeable layer (or bed) that creates a perched aquifer. This may be clay, chert or some other impermeable rock.

Permeability- the degree to which porosity is connected.

Porosity- the amount of void space in a rock formation.

a)**Primary Porosity**- the amount of void space in a rock formation due to initial deposition and lithification.

b)**Secondary Porosity**- the amount of void space in a rock formation due to fracturing or natural weakness, such as bedding planes.

c)**Tertiary Porosity**- the amount of void space in a rock formation due to dissolution by moving water or other chemical reaction.

Sinkhole- a closed depression on the land surface that serves to transmit water to the subsurface.

Sinking spring- a spring that discharges to the land surface and then enters the subsurface drainage network.

Sinking (or losing) stream- a surface channel that contributes flow to the subsurface drainage network.

Swallet- a land surface feature that accepts surface water and transmits it to the subsurface drainage network.

Talus- a mound or pile of broken rock, generally at the base of a slope or bluff, ranging in size from sand to boulder.

*Some definitions provided by "Dictionary of Geological Terms", prepared by The American Geological Institute, 1976.

Acknowledgements

The authors would like to express thanks to all those involved with this investigation. Joseph A. Ray for guidance in preparation of this document, explanations of karst terranes and features and assistance in field observations. Tracy M. Burgess, III for aiding in map design and creation. Jo Blanset for assistance with data and statistical analysis. Keith Lampkin, City Planner for Oak Grove for assistance in field reconnaissance and flooding history. Finally, thanks to Peter Goodmann, Manager, Groundwater Branch, KYDOW, for assistance with document preparation and editing.