Mapping Storm Water Runoff Using GPS and GIS

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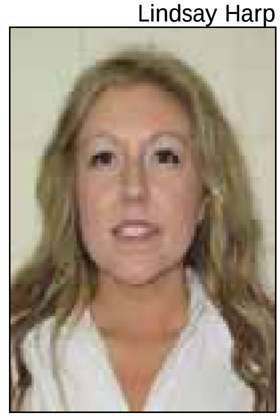
This document will show how both GPS technology and a GIS were used in tandem to map the area surrounding the culvert of an urban creek where two University of Kentucky students were swept away by floodwaters generated by heavy rainfall. Students at Bluegrass Community and Technical College mapped impermeable and permeable surfaces surrounding the creek and superimposed the data on a Digital Elevation Model of central Lexington to determine whether the surrounding urban topography played a critical role in spawning the fatal flood. The data created by this project was shared with Kentucky Water Watch and Friends of Wolf Run, a local community activist organization that has been instrumental in making recommendations to both the city of Lexington and the University of Kentucky to initiate modifications on the current urban drainage infrastructure.

An Urban Flash Flood Kills Two Young Women

During the early morning hours of Saturday, September 23, 2006, two young women, Lauren Fannin and Lindsay Harp, both aged 25, were swept away by raging floodwaters in the heart of downtown Lexington. Their bodies were found shortly after dawn more than ¾ of a mile downstream in the backyard of a quiet suburban neighborhood. The deaths of the two young women, one a University of Kentucky medical student, the other a recent graduate of the University of Kentucky, added to a community already recovering from the catastrophe of the fatal crash of a passenger jet a month earlier.

Lindsay Harp



Lauren Fannin

Several hours of steady rainfall began late Friday morning and by nightfall had dropped in excess of six inches of precipitation across central Kentucky. The rainfall was subsequently amplified by a series of powerful thunderstorms that began shortly after midnight. By 2:00AM Saturday much of the Bluegrass Region of central Kentucky had registered upwards of ten inches of rain.

A total of eight people across central Kentucky were killed in flash flood related incidents that evening, but it was the deaths of Lauren Fannin and Lindsay Harp that received the majority of the coverage. That their deaths had occurred in the center of the city, at an intersection that during the day ranks as amongst the busiest in the city, made them unique amongst the fatalities. The police had blocked the intersection to traffic shortly after 1:15AM due to the rising waters; the two young women, who were riding in a taxi, opted to wade across the flooded intersection to reach their apartment 100 yards beyond the intersection. One was swept into the raging current and pulled under, at which point the other, who, according to eyewitnesses, had successfully forded the flooded intersection, turned back to assist her companion and in the process was also dragged under. Police and eyewitnesses at the scene attempted unsuccessfully to rescue them. Their bodies would not be recovered until dawn and had floated more than ¾ of a mile downstream before being deposited in the backyard of a home in an adjacent subdivision.

Storm Water Runoff in Lexington

Urban flash flooding, though less common than its mountain counterpart, has increased nationwide in recent years, as the continuous process of increasing impermeable surfaces in urban and suburban communities forces water into increasingly more restrictive corridors. Urbanization has the potential to increase runoff by a fivefold factor over rural terrain[1], and coupled with the higher population density, can prove to be exceptionally fatal. The difference in many

[1] Baltimore County MD Emergency Preparedness – Flash Flooding (http://www.baltimorecountymd.gov/News/emergency_prep/floods.html

communities between a flash flood and drainage may hinge on whether a lone storm sewer is blocked by debris.

Lexington is no exception to this trend. The population of the city has increased from 200,000 in 1980 to more than 275,000 in 2005, fueled largely by spectacular suburban growth. The majority of this growth has occurred beyond the municipal city limits of Lexington, but a sizeable fraction has been initiated within the city as the last remaining green zones have been sold to developers for suburban residential and retail outlets. The latter of these has greatly increased the impermeable surfaces within the core of the city and has amplified the amount of storm water draining into the concrete culverts which attempt to funnel the water into the series of streams that traverse Fayette County.

Vaughn's Branch of Elm Fork Creek, (seen below at left), is a minor urban tributary that bisects several neighborhoods just south of the University of Kentucky campus. The branch is normally benign; on any given day one can leap across it with ease. It runs parallel to a walking path for several hundred yards next to the edge of the University of Kentucky campus before disappearing beneath Nicholasville Road and into a concrete sluice canal (seen below at right). The constrictive nature of this narrow entrance played a key role in dragging the two women into the subterranean water diversion canal.

Vaughn's Branch, Elm Fork Creek, October 1, 2006

Site of the fatal accident on September 23, 2006

The topography of central Lexington is remarkably hilly. The University of Kentucky is situated on terrain that is anywhere from seven to forty feet above the surrounding residential neighborhoods and adjacent commercial corridors. This is especially in evidence on the southern end of campus, dominated by Bluegrass Community & Technical College (known as BCTC for the remainder of the document) and Commonwealth Stadium, both of which are surrounded by extensive parking lots that serve the undergraduate student population when football games are not in progress. This area gives way to the 250 acre UK Arboretum and a series of graduate student apartment blocks that, save their parking lots, are surrounded by grassy meadows and a forested tract.

Residents of neighborhoods that lie adjacent to the south end of the University of Kentucky campus and its Arboretum have long had issue with the university when it comes to water drainage issues. Heavy rains inevitably cascade downhill into the surrounding residential neighborhoods where they can often form marshy pools that leave backyards saturated and basements infiltrated with storm water runoff. A hike along the main paved trail that runs through the UK Arboretum will often reveal backyards with several inches of standing water in the aftermath of a major rainfall event. The expansion of the southern end of campus and the concomitant increase in paved surfaces has amplified this problem in recent years. The situation is further confounded by the fact that the University of Kentucky, like many major university campuses located within mid-sized cities (ex. OSU in Columbus, UT in Knoxville), is often treated by the city as an independent fiefdom. The city of Lexington and the University of Kentucky, in short, have not been well coordinated in the management of their storm water runoff systems.

Data Collection and Methodology

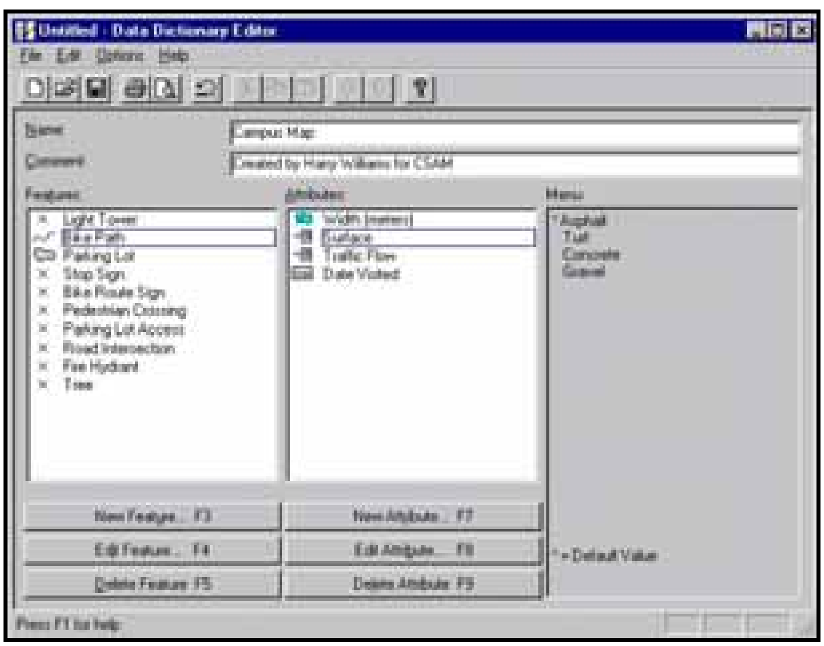
Students pursuing the Certificate in GIS Technology at BCTC take a three semester sequence of courses in both GIS and GPS applications (see Appendix

A). Students, depending upon their course of study, must also complete a six credit hour requirement in a related technical field, such as hydrology, civil engineering or computer science. A sizeable minority of the students enrolled in the Certificate in GIS Technology are also pursuing a two-year technical degree in Environmental Science Technology, in which students receive extensive exposure to basic hydrology and waste water management techniques.

The first course in the GIS Certificate sequence is Spatial Data Analysis and GPS Applications (GIS 110). Students, in addition to covering the essentials of remote sensing techniques and aerial image interpretation, are required to complete a series of projects using Trimble GeoXM GPS units and Pathfinder Office software. Students must be able to develop mastery with the Trimble GPS unit before they are eligible to enroll in the next course in the program, and data collected in the field during GIS 110 has been used by students in subsequent semesters as they learn to master the fundamentals of ESRI software in GIS 120 and GIS 210.

The terminal project the students were charged to complete during the Fall 2006 semester was an extensive survey of the southern end of the University of Kentucky campus. This also included the entirety of the BCTC campus, the Commonwealth Stadium complex and the College of Agricultural Engineering. A sizeable percentage of this area of coverage is comprised of impermeable surfaces, namely parking lots, the largest of which are a series of lots surrounding the football stadium that can accommodate 20,000 vehicles.

The first step in the completion of this project was to develop a **data dictionary**. A data dictionary is a very powerful tool that should always be developed before proceeding into the field to collect data. The data dictionary, using Pathfinder Office 3.10 (written as PFO 3.10 for the remainder of the document), enables the user of the GPS to develop feature classes and attributes for each feature class. The developers of the software, cognizant of the need for it to be compatible with ESRI products, require the user select a geometry for each feature class – point, line or polygon. The data dictionary is, essentially, the construction of multiple attribute tables that will be exported to a GIS as either individual shapefiles or as feature classes within a Microsoft Access geodatabase file. The creator of the data dictionary is, in essence, creating the fields in the attribute table, replete with domain values (if necessary). The collection of data in the field is the acquisition of records for each feature class, and the data collector is forced to enter values within the predetermined domain parameters. The following image is a generic example of a PFO Data Dictionary.



The students in GIS 110 at BCTC were assigned to teams to map a specific sector of the coverage area, but had to work as a class to create a single data dictionary in order to ensure the end product would have standardized feature classes. The data dictionary ended up containing the following fields:

Pathfinder Data Dictionary, UK Water Project 2006

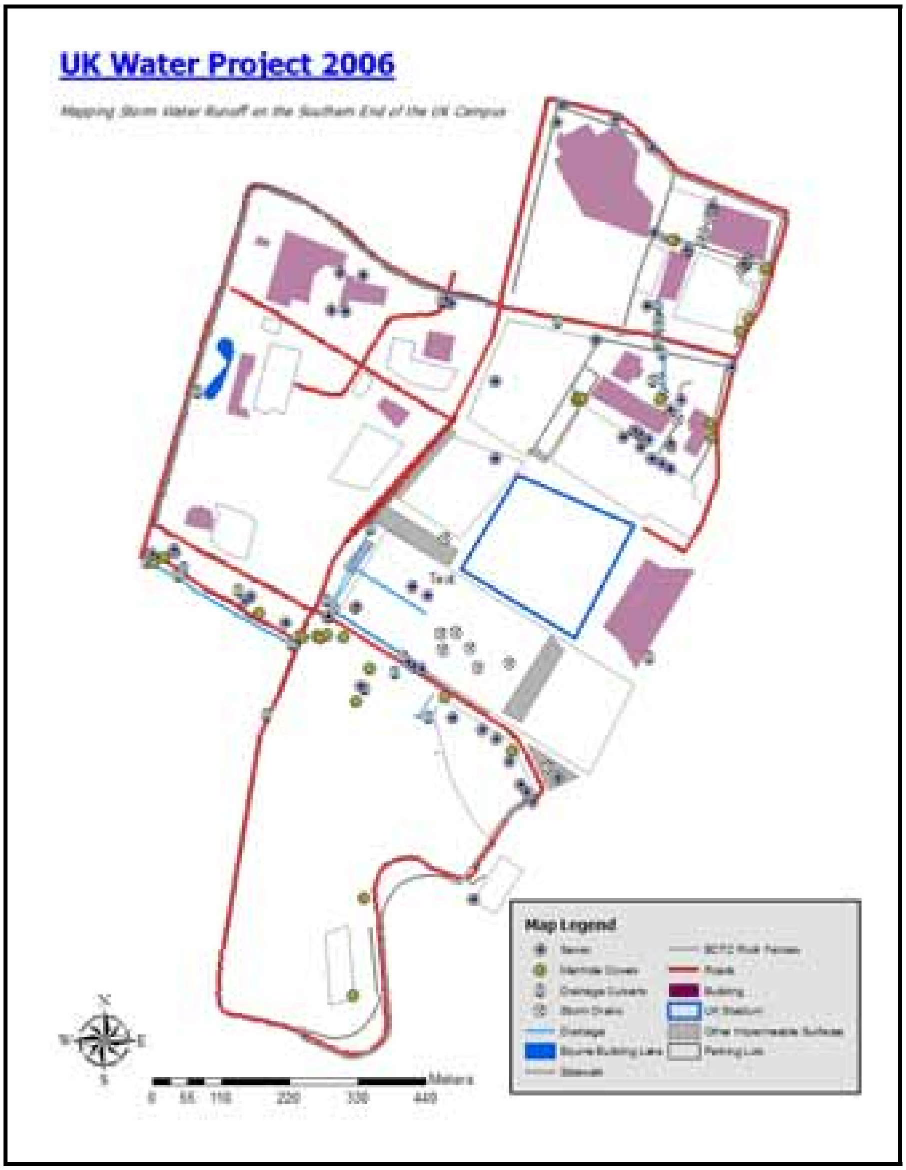
Feature Class	Shape	Attributes	Domains
Parking Lot	Polygon	None	No
Water	Polygon	None	No
Roads	Line	None	No
Walking Path	Line	Type	Yes
Drainage	Line	Type	Yes
Sidewalks	Line	None	No
Sewer	Point	Owner, Date, Time	Yes
Manhole	Point	Owner, Date, Time, Reference Code	Yes
Drainage Culvert	Line	Type, Width, Height	Yes
Football Stadium	Polygon	None	No
Buildings	Polygon	Name	No

PFO 3.10, prior to export to the GIS, allows the user to export additional fields to the attribute table that are exclusive to GPS terminology. These fields are auto-generated by the GPS and may include such attributes as PDOP, HDOP, VDOP, standard deviations from the norm and height above sea level. These fields can be instrumental in the data analysis phase of the report as they may contain potential outliers that can lead to inaccurate results.

The data collection phase of the project began Tuesday, October 31, 2006 and concluded Thursday, November 16, 2006. A total of five class sessions were utilized for the data collection. The size of the area of coverage and the level of accuracy needed for the project required that the class be broken into teams. GPS multi-path error was minimized by starting the data collection phase of the project at the end of October as the vast majority of the trees had already lost their foliage. Students were given strict guidelines to ensure accuracy by collecting a minimum of 30 position points for every point feature (ex. sewers, manholes). The large number of position points per each point feature ensured that the standard deviation from the norm would be lessened and would allow post-processing editors to eliminate potential outliers. The GPS units were calibrated to record point positions every 5 seconds when line and polygon features were being mapped to ensure that building and parking lot contours and curves in such objects as roads, streams and drainage culverts would be recorded as accurately as possible. The students recorded more than 18,400 GPS position points on 232 different point, line and polygon features during the two week data collection period.

The next phase of the project required the students to use PFO 3.10 to edit their uncorrected GPS point positions. The students manually went through the entirety of their recorded features to identify outliers. These often could be identified visually, in particular with line and polygon features, where the removal of a point with high multi-path error would result in a line or the side of a polygon to "snap" back into its appropriate position. Point features were manually edited by checking the standard deviation from the norm of their positions. A threshold tolerance of 2.0 meters was utilized, by which if the standard deviation exceeded that maximum, the student editing the point feature would then have to manually select position points to eliminate from the data set.

GPS data in PFO 3.10 is initially classified as uncorrected. Students, using the University of Kentucky Base Station at the UK Arboretum for reference, performed differential correction on their .ssf files. Differential correction enabled more than 99.65% of all points to be edited and repositioned down to sub-meter accuracy. The final task for which the students were responsible was to export their corrected PFO files as shapefiles so that they could be read by ESRI ArcGIS 9.2 Desktop. The following image shows the final product without an aerial imagery backdrop:



The author of this document proceeded to add an aerial image of the University of Kentucky and BCTC campus as a backdrop. The addition of the aerial photography demonstrated the high degree of accuracy the students achieved in their collection and recording of data. The following are selected images of the data superimposed on an aerial image of the UK and BCTC campuses.

South end of UK Campus and UK Arboretum

Site of the two fatalities marked with black ***X***

Analysis of the Data Using a Digital Elevation Model

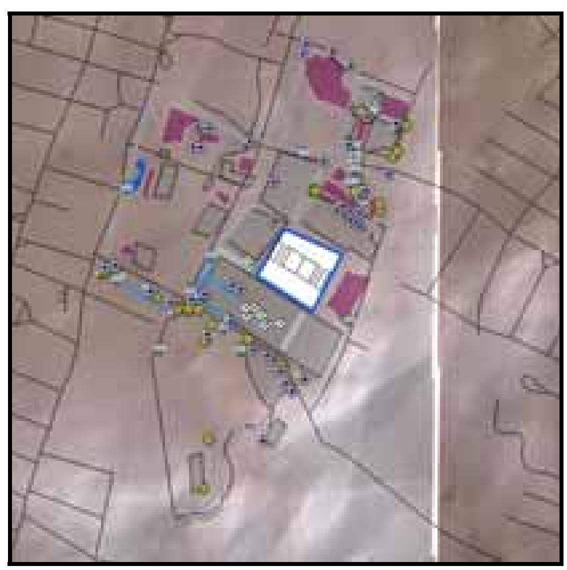
Students in the terminal course in the GIS Technology program (GIS 210) gain exposure to several advanced extensions, including Spatial Analyst and 3D Analyst. Using the services of the state GIS server, Http://kygeonet.net a DEM of the University of Kentucky campus and the surrounding environs was downloaded and the data generated from the GPS field sessions was then superimposed atop it. A hillshade effect was added for visual enhancement and then using 3D Analyst the DEM raster was converted into a Triangulated Irregular Network (TIN) file. The TIN is displayed below by elevation in thirty separate classes in panchromatic color with a 60% transparency filter atop the original DEM, which is monochromatic in color. A watershed layer for western Fayette County has been added for enhanced visual effect.

DEM with TIN and watershed layer, 1:100,000

The University of Kentucky and BCTC campuses are located in the lower right corner of this file. Note that this terrain contains the highest elevation within the DEM. The subsequent image, scaled to 1:12500, superimposes the GPS data collected in the field atop the DEM. A layer of Fayette County streets has been added for reference to this image. The white slash down the right side of the image is a slight gap of coverage between two different DEM raster files.

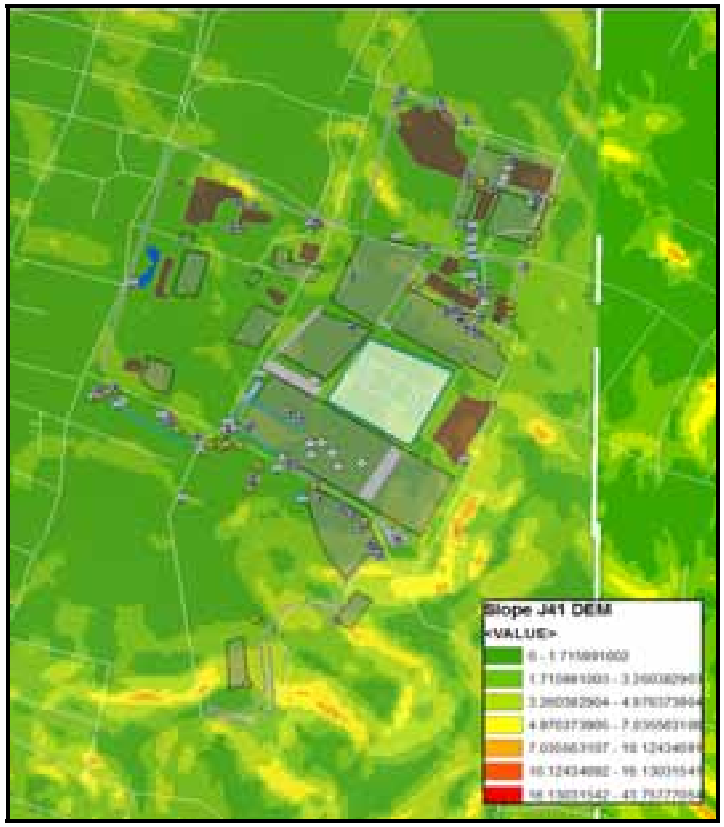
<u>Using 3D Analyst in the Analysis</u>

The analysis of the data was performed in two segments. The first step was to determine slope. Slope was determined by using tools located within the 3D Analyst toolbox and creating options to maximize the differences in percent gradients. The end product produced a raster image of slope, classified by percent gradient.



DEM of south UK and BCTC campuses, 1:12500

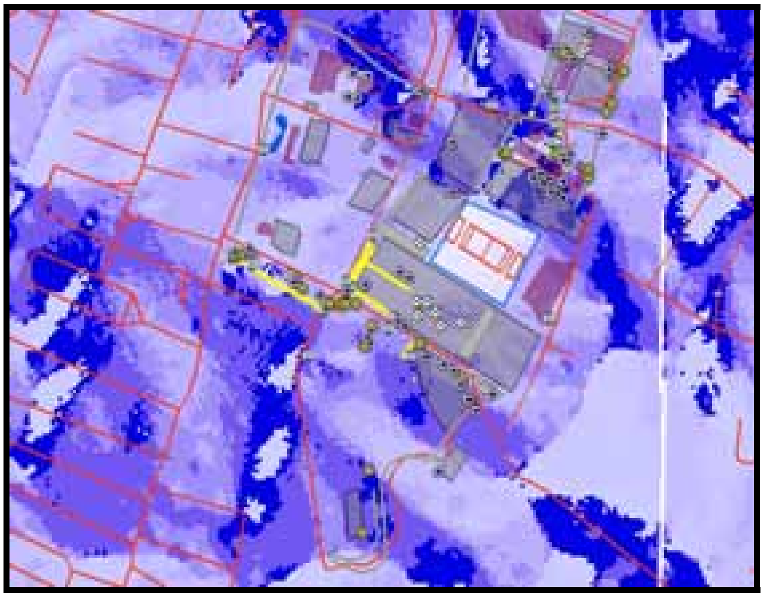
Green represents low slope percentages, red high percentages. The slope percentages on the south end of the University of Kentucky campus range from 0% to 43.75%. Note that the highest slope percentages are located to the southeast of the Commonwealth Stadium parking lot and within the UK Arboretum, also located southeast of the stadium. 3D Analyst was also utilized to build a feature class of contour lines from the TIN that could be superimposed atop various raster layers, including the DEM, for further visual enhancement of the final product.



Raster Image of Slope, 1:20,000

Using Spatial Analyst in the Analysis

Spatial Analyst was used for two primary purposes. The first purpose was to develop a series of additional raster layers based on the flow direction and flow accumulation of surface water. The second was to conduct a surface analysis of the slope of impermeable surfaces. Spatial Analyst enables the user to calculate water flow and accumulation given a DEM and a raster of the slope. The results of the analysis were quite dramatic. A raster image of the water flow clearly correlates to the topographic features of the land, with areas of significant gradient having a much higher flow variable (dark blue) than areas with flat topography (light blue). The following image is of the Flow Direction raster. The features mapped by students using the GPS are superimposed atop the raster layer. Streets have been highlighted in red and existing storm drainage culverts have been highlighted in yellow to contrast with the blue color ramp used with the raster image. The raster of flow direction



Flow Direction Raster of south UK and BCTC campuses

was processed to determine the degree of flow accumulation. This component of the analysis clearly showed that surface water on the south end of the University of Kentucky and BCTC campuses will accumulate in Vaughn's Branch of Elm Fork Creek. The following image is scaled at 1:5000 and includes the site where Lauren Fannin and Lindsay Harp were swept into the subterranean storm water canal. The site of the two fatalities has been circled in **black**. Areas in dark blue indicate a significant amount of water accumulation. It is not without surprise that the area with the highest water accumulation is the Vaughn Branch of the Elm Fork Creek.

Spatial Analyst was also used to determine what percent of the surface area on the south end of the University of Kentucky and BCTC campuses sits on impermeable surfaces. The phenomenon of urban flash flooding is one in which too often the culprit is not topographic but the degree of impermeability of the surface. Storm water cannot percolate into the ground in the same manner in which it can in a rural setting; therefore, the water cascades into constrictive passages until it reaches a permeable surface and/or a storm water diversion canal. The greater the amount of impermeable surfaces the greater the potential for amplification of a flash flood.

The analysis determined that 48% of the total surface area bounded by Cooper Drive, Nicholasville Road, Alumni Drive, the service drive that runs behind Commonwealth Stadium linking Cooper to Alumni (seen in the photo below, outlined in red) including the football overflow parking lot south of Alumni Drive, is comprised of impermeable surfaces. No impermeable surface rests on a slope greater than 7% anywhere within the area of study, but the largest two impermeable surfaces in the survey area, the main Commonwealth Stadium parking lot and the overflow lot to the south of Alumni Drive, are both contiguous to land with a slope that ranges between 7% and 10.3%.

GPS data collected by the students revealed that a total of eight storm drains are located within the main Commonwealth Stadium parking lot, and a ninth drain is located within the overflow parking lot south of Alumni Drive. An additional three storm drains are located in the parking to the west of Commonwealth Stadium, and a fourth at the intersection of University Drive and Alumni Drive. The research team did not have access to any storm drain data as to where the water was diverted beneath the ground; they did, however, map a total of eleven drainage culverts parallel to the Vaughn Branch of the Elm Fork Creek. Eight manhole access covers were also located in the general vicinity of these drainage culverts, indicating an extensive series of sewage and storm drainage lines located beneath the study area.

Conclusions Drawn from the Analysis

The conclusion generated by the study was that excessive rainfall which began on the afternoon of Friday, September 22, 2006 and continued unabated into the early morning hours of Saturday supersaturated the permeable ground surfaces, initiating a flow of water downhill into the vast area of largely impermeable surfaces that cover the south end of the University of Kentucky and BCTC campuses. This storm water was sucked into the storm drains that punctuate these impermeable surfaces and funneled into drainage culverts that empty into Vaughn's Branch, which would have already been swollen from excessive runoff that had fed into Elm Fork Creek during the course of the afternoon and evening. The constrictive entrance to the storm runoff channel that disappears beneath Nicholasville Road and the subdivisions to its immediate west caused Vaughn's Branch to overflow and ultimately spill over the major Nicholasville-Alumni traffic intersection; Lexington – Fayette County police indeed closed this intersection to traffic shortly after 12:30A.M. due to the rising waters. This narrow entrance also acted to pull the water at a much greater speed and force into the subterranean storm runoff canal, and was ultimately strong enough to pull two young women into its deadly vortex of floodwaters.

Community Usage of the Data

The data for this project was shared with faculty in the Environmental Science Technology degree program and will likely be incorporated into the curriculum in subsequent courses in hydrology and water management techniques. The data was also shared with two organizations that have a dedicated commitment to the preservation and appropriate management of the local watershed – Kentucky

Water Watch (http://www.state.ky.us/nrepc/water/wwhomepg.htm) and Friends of Wolf Run (http://kywater.net/WolfRun/). The latter is a local community activist organization, the former a statewide watchdog agency. Results of this study were given to these organizations in April 2007, and at the time of the publication of this document it has yet to be determined how this research will be incorporated into existing legislation and lobbying efforts to re-examine the storm water runoff system for the city of Lexington.

Credits:

The author wishes to extend his thanks to J. Aaron Morgan and his classmates enrolled in GIS 110 during the Fall 2006 academic term at Bluegrass Community & Technical College

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Maverick Cook
Tracy Cowart
Kyle Davenport
John Douglass
Matt Hubbard
Adam Moody
Barbara Ward

Appendix A – The Certificate in GIS Technology

Core Courses
CIT 105 – Introduction to Computing
GIS 110 – Spatial Data Analysis and Map Interpretation
GIS 120 – Introduction to Geographic Information Systems
GIS 210 – Advanced Geographic Information Systems

Eligible Course Pairings for GIS Technology Certificate

- Earth's Physical Environment (GEO 130) *and/or* Pollution, Natural Hazards and Environmental Management (GEO 210) *and/or* Introduction to Planning (GEO 285)
- Fundamentals of Hydrological Geology (EST 160) *and* Fundamentals of Solid Waste (EST 250)
- Visual Basic I (CIT 148) *and* Visual Basic II (CIT 248)
- Introduction to Computer-Aided Design (CAD 100) *and* Intermediate Computer-Aided Design (CAD 200)
- Computer Aided Drafting I (ACH 185) *and* Computer Aided Drafting II (ACH 285) *or* Computer 3-D Modeling (ACH 298)
- Introduction to Surveying (CE 211) *and* Intermediate Surveying (CET 220)

Students must also take a minimum of six (6) hours of General Education courses in order to receive a certificate in GIS Technology from Bluegrass Community & Technical College, unless otherwise noted on their academic transcript(s).