A Maintenance System for Stormwater Infrastructure

A tool was developed to help manage maintenance operations for stormwater drainage infrastructure located along two Alabama highways.

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Physical features of stormwater management infrastructure (pipes, culverts, open channels, inlets, outlets, manholes, and junction boxes) are generally designed to have operational lives of several decades. Lacking an effective operation and/or maintenance program, stormwater infrastructure can become overgrown by vegetation, partially or fully clogged by sediments and debris, or become ineffective due to a decrease in structural integrity.

Possession of comprehensive knowledge of stormwater infrastructure features and their conditions in an easily accessible database, and having the ability to project the data geographically, could greatly enhance the efficiency of stormwater infrastructure maintenance. Current maintenance procedures rely on reactionary measures after problems have been identified, usually by citizens. A stormwater infrastructure inventory allows for the identification and repair of features that are performing in an inadequate manner before they become a problem. A history of maintenance performed is also beneficial so more timely maintenance visits can be scheduled for critical locations. These capabilities can help shift maintenance from its current reactive state to a proactive state.

A detailed infrastructure inventory of feature attributes can also contribute to future design and runoff modeling projects. Exact dimensions and locations of existing stormwater infrastructure, combined with land use and topographical information, can help determine features that can accommodate future development and features that will have to be adjusted or replaced.

Project Description

The University Transportation Center for Alabama (UTCA), headquartered at The University of Alabama in Tuscaloosa, AL, sponsored the development of a computer-based tool intended to help manage maintenance operations of stormwater infrastructure located along two highways, one federal and one state, in Tuscaloosa County, AL. Because of the limited extent of the database as assembled using UTCA funding, this effort should be considered a demonstration project. However, the basis of such a system has been firmly established, and the system as presently developed may be expanded to serve additional transportation routes and corridors. The system consists of 1) a graphical user interface, and 2) a relational database for storage of data related to individual stormwater drainage features. The database of feature locations and attributes has been established via field surveys using GPS. The inventory of stormwater features established in this project is stored in a GIS.

The proposal and completion of this project was greatly influenced and enhanced by a search for and examination of similar studies for management of stormwater infrastructure. Projects accomplished in Greensboro, NC; Minneapolis-St. Paul, MN; and Hillsborough County, FL made significant contributions that helped us.

Greensboro began developing a stormwater infrastructure inventory in 1997. This inventory, in conjunction with a GIS, is used to determine the current and possible future effects that development, organizational procedures, and transmission networks have on stormwater infrastructure and waterways within a watershed. The mission development sequence and innovative field procedures were prominent aspects of this project.

A team of consultants chosen by Greensboro compiled the inventory and developed the database. The first step in the process was to design the database to ensure that relevant data were collected and use of the information was maximized. The database was populated by efficiently collecting stormwater feature locations and their associated attributes in the field. Data collection activities were initialized on a pilot scale basis before expanding to entire watersheds. Finally, the data were integrated into a GIS.

Cutting edge data collection equipment and software enabled proficient assembly of the stormwater inventory in Greensboro. Durable hand-held computers with pen-enabled screens were used to inventory features in the field. The computers were equipped with software customized for the collection of stormwater infrastructure data. The devices increased efficiency and practically eliminated hard copy data collection.

Hillsborough County developed a stormwater infrastructure inventory to conform to governmental regulations. Meeting NPDES and GASB 34 requirements as well as FEMA National Flood Insurance Program (NFIP) Community Rating System (CRS) Credits for

Stormwater Management and Drainage System Maintenance, was a daunting task. Further complicating matters, the inventory had to be completed under imminent deadlines while maintaining economic feasibility.

To overcome these constraints, the county enlisted the help of the Florida Center for Community Design and Research located at the University of South Florida (USF). Three teams were formed with each consisting of one member from the county and one member from USF. For the first six months of data collection, the USF team members recorded feature locations using GPS devices and the county team members recorded feature attribute data. After six months, the county team members were trained in GPS technology and the entire data collection procedure was turned over to them.

To process and manage the data for the first year, Hillsborough County used geography students from USF. In addition, the county hired a GIS specialist to be trained by the students regarding project specifics. At the end of the first year, the county had a stormwater infrastructure inventory and maintenance system that was completely operable without any outside support.

Minneapolis-St. Paul region consists of seven counties in Minnesota that realized early the benefits a GIS has to offer. Several entities within the Minneapolis-St. Paul area have been developing and working with a GIS since the early 1980s. Over time, their MetroGIS has come to encompass the seven counties entirely and has provided a plethora of data concerning a vast number of topics. To fulfill these goals, the policy board of MetroGIS developed a Web page, providing easier data submission, the ability to adjust data as they change over time, and access to data from any computer at any time.

Database Design

The benefits provided by a stormwater infrastructure maintenance system are strongly linked to the types and attributes of the data collected and archived. Therefore, it is crucial to understand and define stormwater features and their associated attributes that are relevant to the tasks facing the end user. A vision of both current and future data applications helps focus the design and population of a useful database. Such understanding and vision should also reduce or eliminate the collection of data with limited uses.

The database should be scrutinized and evaluated during its development. Additions and deletions to the features and/or attributes collected are inevitable. Realizing when and what type of a change should be implemented at any point will reduce the amount of time and money spent collecting either useless or additional data.

The features and attributes chosen for this project's database were determined initially based on suggestions from the projected end user of the stormwater maintenance system, the Alabama Department of Transportation (ALDOT). Upon the completion of a pilot study conducted on the University of Alabama campus, ALDOT officials were again consulted and the database was revised to the version used for the remainder of the project.

An objective in selecting features for a project of this type is to identify all structure types that are involved in stormwater collection and conveyance along highways. After researching similar projects and consulting ALDOT, it was determined that seven structure types were sufficient to describe most or all stormwater features.

1. Pipe or Culvert—a hollow conduit, usually with a circular or rectangular cross section, extending under a road or embankment that is used to convey stormwater
2. Paved Open Channel—an open-top watercourse that has been lined using a man-made material such as concrete or asphalt
3. Street Inlet—a drainage opening along a roadway to capture surface flow and convey it to a subsurface conveyance system
4. Junction Box—a structure where subsurface conduits join or intersect to accommodate access for maintenance; and changes in flow direction, pipe diameter, and/or elevation
5. Manhole—the same as a junction box, but generally constructed of precast materials and cylindrical in shape
6. Culvert Inlet—the entrance to a culvert
7. Culvert Outlet—the outlet of a culvert

For purposes of graphical display in the GIS, five of these seven feature types (street inlet, junction box, manhole, culvert inlet, and culvert outlet) are represented as a point with one (x,y) coordinate describing the location. The remaining two features (pipe or culvert and paved open channel) are represented as a line with both starting and ending (x,y) coordinates.

Each of the seven types of features has associated with it unique characteristics, or attributes, that describe its physical properties. Feature attributes chosen for use in this project reflect mainly the needs of maintenance personnel, but also reflect some of the needs of design personnel as the developed system may be expanded in the future to support their activities.

The attributes used for this project are either general and apply to all features, or they are feature-specific. The general attributes, applicable to all seven feature types, are as follows:

- Maintenance department—party or organization responsible for maintaining a feature
- Road number—numeric designation of the highway where a feature is located
- Mile post—numeric designation, observed from mile markers, of where a feature is located (estimated to the nearest 0.1 mile)
- Condition—ability of a feature to perform as designed; response limited to good, fair, or poor
- Comments—additional information deemed helpful to the maintenance process
- Coordinates—geographic location; listed as latitude and longitude or northing and easting
- Riprap—refers to the presence of large angular boulders used for erosion control; response limited to yes or no

The remaining attributes are feature-specific and are listed below by feature type:

1. Pipe or Culvert
   - Width—horizontal dimension (span) of inside of conduit
   - Length—distance from the inlet to the outlet
   - Rise—vertical dimension (rise) of inside of conduit
   - Object Above—objects on the land surface above the pipe or culvert; response limited to curb, sidewalk, both, or other.
2. Paved Open Channel
   - Material—the material used to pave the channel; response limited to concrete or asphalt
   - Width—the dimension across the channel at its widest point
   - Length—distance from the point where stormwater enters the channel to the point where it exits
   - Depth—maximum possible depth of water in the paved portion of the channel
   - Near Side Slope—slope of the channel side closest to the highway, expressed as a horizontal:vertical ratio
   - Far Side Slope—slope of the channel side farthest from the highway, expressed as a horizontal:vertical ratio
3. Street Inlet
   - Width—shortest dimension across the inlet opening
   - Length—longest dimension across the inlet opening
   - Material—the material used to construct the inlet; response limited to concrete or steel
   - Type—refers to the type of street inlet; response limited to concrete inlet, steel grate inlet, or other
4. Junction Box
   - Width 1—longest horizontal dimension of the junction box
   - Width 2—shortest horizontal dimension of the junction box
   - Surrounding Material—land surface material located around the outer edges of the junction box access cover; response limited to concrete, asphalt, soil, or other
5. Manhole
   - Inside Diameter—horizontal diameter of the inside of the manhole
   - Material—the material used to construct the manhole; response limited to steel or other
6. Culvert Inlet
   - Width—horizontal dimension from one side to the other
   - Height—vertical dimension from top to bottom
   - Headwall—refers to the presence of a headwall structure at the inlet; response limited to yes or no
   - Depth of Cover—height of backfill material above culvert barrel(s)
   - Surface Type—material on the land surface above the culvert; response limited to asphalt, concrete, soil, or other
   - Type—refers to the type of culvert inlet; response limited to cast-in-place concrete, paved slope, or other
   - Right Wingwall Length—longest dimension of the right wingwall
   - Left Wingwall Length—longest dimension of the left wingwall
   - Right Wingwall Angle—angle of the right wingwall, measured in a horizontal plane from the axis of the culvert barrel
   - Left Wingwall Angle—angle of the left wingwall, measured in a horizontal plane from the axis of the culvert barrel
   - Skew Angle—angle the headwall makes with culvert barrel, measured in a horizontal plane from a line perpendicular to the axis of the culvert barrel
7. Culvert Outlet
   - Attributes for the culvert inlet and culvert outlet are the same

The stormwater system features and their associated spatial data (i.e., coordinates) are stored in shape files within the GIS. For graphical display, they are overlaid on a base map as a point, line, or polygon. Associated with each shape file is a relational database where the attributes are stored. Information storage within a relational database permits the GIS user to make logical associations of mutual-attribute data and creation of additional data tables that can be used for data analysis. Structuring of the organization of the database is referred to as normalization and is directed by the following rules: 1) tables should have unique names, 2) columns within a table should have unique names, 3) a row must have a primary key, 4) there should be no redundant data in the database, 5) there should be no repeating attributes in a row, 6) a field should not contain coded data, and 7) rows should contain attributes specific only to the entire primary key.

Normalization of a relational database is what enables the advanced query functions of a GIS to perform. The application of database normalization rules guarantees that the management system has maximum flexibility and can deal with specific requests for information.

The tools used to establish the linkages between how data are stored, retrieved, manipulated, and graphically displayed are collectively referred to as the interface and are the pinnacle of what makes the stormwater maintenance system unique and useful. The capabilities provided by these tools allow the system user to perform numerous analyses in a short time frame. Another advantage is the ability to analyze the data visually. Studying the projected data often reveals relationships that might otherwise remain unnoticed. The interface consists of an ArcView 3.2a GIS (www.esri.com), which stores, manipulates, and displays both a digitized base map and overlain stormwater features and attributes.

A base map is the background image or framework upon which the stormwater infrastructure data are superimposed. Base maps used in a GIS can be of several types, including aerial photographs and digitized paper maps. Base maps derived from aerial photographs display a great amount of detail on land use and land cover, but can make it difficult or even impossible to distinguish survey or political boundaries such as county or state lines. Digitized paper maps may show little information on land cover and land use, but can clearly depict both natural and man-made boundaries. Whatever type of base map is used, its coordinate system must either be consistent with that used by the GPS data collection tools, or provisions must be made for conversion from one coordinate system to another.

The primary coordinate systems used in collection of GPS data are the latitude/longitude system and the state plane system. The latitude/longitude system is global and uses the equator and the prime meridian as reference points. The state plane coordinate system is exclusive to North America and uses local reference systems that are tied to a national datum. The coordinates in the state plane system are recorded in units of feet, which enable the physical measurement of distances between features on the base map. Conversion between the two systems is possible, but increases the possibility of errors when projecting the data.

A base map may be equipped with layers of information that can be turned on or off depending on the use of data as it pertains to a project. Examples of the types of information that may be included and displayed as are: points—cities, landmarks, airports, miscellaneous; lines—roads, rivers, streams, railroads; and polygons—lakes, parks, county lines, city limits.

The base map employed for this project is a digitized map of Tuscaloosa County in State Plane NAD83 Alabama west coordinates. The layers (map features) used for this project consist of roadways, rivers and streams, and county lines. The map was purchased from American Digital Cartography, Inc. (www.adci.com), for $1,050.

A key element of developing a stormwater infrastructure maintenance system is collection of accurate and representative field data for population of the database. The maintenance system can be no better than the data upon which it relies. Each feature must be physically located in the field to enable recording of its attributes as well as its geographical location. In practice, some features are easily located while others may be partially or fully covered by brush or debris, or buried by soil.

The area designated for data collection in this project was divided into two segments. The first segment consists of the length of Alabama State Highway 69 from its intersection with U.S. Highway 82 northerly to the Tuscaloosa County line. The second segment consists of U.S. Highway 43 extending northerly from its intersection with U.S. Highway 82 to the Tuscaloosa County line. The total study area extended over about 55 roadway miles of varying terrain in Tuscaloosa County. For data collection activities, both highways were divided into incremental segments ranging from one to three miles long, depending upon the density of features and difficulty in traversing the terrain. It was not uncommon, however, for data from several segments to be collected in a single day. With the exception of the most northerly eight miles of each highway, the two highways were traveled entirely by foot. The northern segments near the Tuscaloosa County Line were traveled by vehicle due to the sparse population of stormwater infrastructure features and the relative ease of identifying their locations. For safety reasons, highway crossings by field personnel were limited by collecting features and attributes along one side of the highway at a time. This method resulted in a total distance walked of over 78 miles.

Data collection was not continuous from one day to the next, and occurred on both weekends and weekdays over the course of about four months. Each field trip for data collection occurred during daylight and lasted from one to eight hours depending upon weather conditions, traffic intensity, and data collector fatigue. The entire project required 30 days in the field to inventory the storm water infrastructure, with additional time for quality assurance and quality control.

Populating the database for the stormwater infrastructure maintenance system was the most time consuming aspect of the project. Two separate GPS units with different technological capabilities, the Trimble GeoExplorer 3C (www.trimble.com) and Garmin GPS 12 MAP (www.garmin.com), were chosen for data collection to demonstrate the versatility of the system. Each unit had distinctive processes for device configuration, field data collection, data processing, and quality assurance/quality control. Data for 1,307 stormwater infrastructure features were collected over 55 miles of highway.

The stormwater maintenance system developed in this project can accommodate data collected by any GPS unit. This allows the users of the system, or others developing similar systems, to examine the array of commercially available GPS units and select one appropriate for their needs based on accuracy, cost, and training required for field data collection personnel.

The management system developed in this project can record maintenance histories for individual stormwater features. This could, for example, include the dates and types of maintenance performed on a feature. A history of maintenance performed draws attention to those features that have functioned inadequately in the past and may require more frequently scheduled monitoring. It may also shed light on infrastructure problems or inadequacies where frequent maintenance has been required in the past. The maintenance history should also prevent the repetitive application of ineffective maintenance procedures through its indications of the types and frequencies of maintenance that have been performed on a feature in the past.

In addition, the stormwater management system contains information that can be used in a variety of other areas such as planning and design. If it were to be linked to other hydrologic prediction and design tools, projections could be made regarding the effects of land development on stormwater infrastructure. Analyses could also be made to determine if existing structures can handle the increase in stormwater volume due to development. Using and sharing databases and information on various projects has the potential to enhance existing relationships between disciplines, thereby improving management. GE

Dr. Durrans and Dr. Graettinger, respectively, are Professor and Associate Professor of Civil and Environmental Engineering at The University of Alabama. At the time this project was completed, Mr. Tucker and Ms. Supriyasilp were graduate research assistants. Mr. Tucker is currently a staff engineer with Burke-Kleinpeter in Birmingham, AL. Dr. Supriyasilp is now an Assistant Professor at Chiang Mai University, Thailand.