A Maintenance System for Stormwater Infrastructure

By

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Prepared by

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This report describes the development of a computer-based tool intended to aid management of maintenance operations for stormwater drainage infrastructure located along two highways in Tuscaloosa County, Alabama. Because of the limited extent of the database as assembled using UTCA funding, this effort should be considered as a demonstration project. However, the basis of such a system has been firmly established, and the system may be expanded to serve additional transportation routes and corridors.

The system consists of a graphical user interface, and a relational database for storage of data related to individual stormwater drainage structures. The database of structure locations and their attributes has been established via field surveys using global positioning system (GPS) technology. A geographic information system (GIS) manages the stored database and enables not only graphical displays of structure locations, but also permits queries of the database to identify logical relationships among individual structures and their physical locations.

The 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 are capable of handling the increase in stormwater volume due to development. Using and sharing such databases and other information has the potential to enhance existing relationships between disciplines, thereby improving management.
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Executive Summary

This report describes the development of a computer-based tool intended to aid management of maintenance operations for stormwater drainage infrastructure located along two highways in Tuscaloosa County, Alabama. Because of the limited extent of the database as assembled using UTCA funding, this effort should be considered as a demonstration project. However, the basis of such a system has been firmly established, and the system may be expanded to serve additional transportation routes and corridors.

The system consists of a graphical user interface, and a relational database for storage of data related to individual stormwater drainage structures. The database of structure locations and their attributes has been established via field surveys using global positioning system (GPS) technology. A geographic information system (GIS) manages the stored database and enables not only graphical displays of structure locations, but also permits queries of the database to identify logical relationships among individual structures and their physical locations.

The management system has the capability of storing maintenance histories for individual stormwater structures. This could, for example, include the dates and types of maintenance performed. Recording the history of maintenance draws attention to those structures 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 in the past.

The management system also contains information that can be used in a variety of other areas such as planning and design. If 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 are capable of handling 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.
Section 1
Introduction

Background and Motivation

Physical features of stormwater management infrastructure (consisting of 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. These encumbrances can impede the intended use of a system and can lead to extensive maintenance requirements or even replacement (Dean et al. 2002).

The capital cost of stormwater management infrastructure is often a large fraction of the total cost of a new or improved highway. High expenses are also associated with recurring operation and maintenance procedures. Thus, stormwater management systems represent a considerable burden on always-limited fiscal resources. The development of powerful databases and tools that can be used by operation and maintenance personnel to more effectively manage their operations and activities has the potential to minimize inefficiencies that may exist in those operations, and to maximize the utility of the physical drainage systems.

Knowledge of the physical locations of the various features of stormwater infrastructure, and proper maintenance of existing infrastructure, are integral elements in the protection of both the structural elements and the users of the systems (e.g., the traveling public). Having knowledge of stormwater features and their conditions also can be useful in future engineering endeavors, such as planning highway improvements and modeling runoff events associated with observed rainfall events or with design storms.

Development of a tool to aid management of stormwater infrastructure maintenance activities may be based on an inventory of existing features and their associated attributes. In Alabama, the majority of existing records on stormwater infrastructure consist of paper reports or plans that provide a snapshot of the actual features in existence; such records may or may not be accurate (Public 2001). 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.

An ounce of prevention is worth a pound of cure. This old adage is attributed to an early American statesman and philosopher, Benjamin Franklin, and is applicable to 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 aid in shifting maintenance from its current reactive state to a proactive state (Robbins 1996).

A detailed infrastructure inventory of feature attributes can contribute to future design and runoff modeling projects. Exact dimensions and locations of existing stormwater infrastructure, combined with land use and topographical information, can assist in determination of features that can accommodate future development and features that will have to be adjusted or replaced. The ability to conduct these theoretical “what if?” scenarios over minute or vast areas of a watershed have the potential to save both taxpayer dollars and future man-hours in both maintenance and design.

**Project Description**

This report describes the development of a computer-based tool intended to aid management of maintenance operations of stormwater infrastructure located along two highways, one federal and one state, in Tuscaloosa County, Alabama. 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 a graphical user interface, and 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 global positioning system (GPS) technology.

The inventory of stormwater features established in this project is stored in a computerized database referred to as a geographic information system (GIS). The chief operation of the GIS system is the management of information. As with traditional database systems, the GIS system has the capability of storing data in a manner that is conducive to retrieval and analysis. What sets the GIS apart from traditional database systems is the ability to display spatial data, and an infinite flexibility in developing relationships among data by query and manipulation.

**Outline of Report**

Section 2 of this report summarizes research by others that influenced the proposal and completion of this project. Section 3 discusses the selection and evolution of stormwater features and attributes used in the population of the database. In Section 4, interface development is described. Field data collection using two alternative GPS devices is discussed in Section 5. Section 6 presents the results of the project. Finally, Section 7 offers conclusions drawn from this research and provides recommendations for both practical implementation of the maintenance system and for future work.
Section 2
Related Studies by Others

Case Studies

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, North Carolina; Minneapolis-St. Paul, Minnesota; and Hillsborough County, Florida made significant contributions that aided this project; those projects are summarized in the following subsections. These projects also introduced techniques and equipment that should be evaluated by those considering implementation of a maintenance system.

Greensboro, North Carolina

The City of Greensboro, North Carolina, 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 (Dewberry & Davis 2001). The mission development sequence and innovative field procedures were prominent aspects of this project.

A team of consultants chosen by the City of Greensboro embarked upon the task of compiling the inventory and developing 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 (Inouye 1998). Data collection activities were initialized on a pilot scale basis before expanding to entire watersheds. Finally, the data were integrated into a GIS where pertinent information may be displayed (Woolpert 2001).

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 (Dewberry & Davis 2000).

Hillsborough County, Florida

The decision to develop a stormwater infrastructure inventory in Hillsborough County was motivated by the necessity of conforming to governmental regulations. Meeting the requirements of the National Pollutant Discharge Elimination System (NPDES), Governmental Accounting Standards Board (GASB) Statement No. 34, and the Federal Emergency
Management Agency (FEMA) National Flood Insurance Program (NFIP) Community Rating System (CRS) Credits for Stormwater Management and Drainage System Maintenance proved to be a daunting task facing Hillsborough County. 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 (Landry and Oliver 2002).

**Minneapolis-St. Paul, Minnesota**

The 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 including:

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<th>Cultural</th>
<th>Demographic</th>
<th>Educational</th>
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<tr>
<td>Economic</td>
<td>Environmental</td>
<td>Natural Resources</td>
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<tr>
<td>Transportation</td>
<td>Utilities</td>
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<td>Public Works</td>
<td>Recreation</td>
<td>Imagery</td>
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<td>Political and Administrative</td>
<td>Emergency and Social Services</td>
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<td>Planning and Development</td>
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The policy board of MetroGIS rationalized that the data collected would be most effective if they were precise, up to date, and easily accessible by the individuals who utilize the information. These issues are broached in the MetroGIS mission statement:

“The mission of MetroGIS is to provide an ongoing, stakeholder-governed, metro-wide mechanism through which participants easily and equitably share geographically referenced data that are accurate, current, secure, of common benefit and readily usable. The desired outcomes of MetroGIS include:

- Improve participant operations.
- Minimize stakeholder expense and duplication of effort.
- Support cross-jurisdictional decision making.
To fulfill these goals, the policy board of MetroGIS developed a web page and made the data available via the Internet. This relatively new medium provided an easier means of data submission, the ability to adjust data as they change over time, and to access the data from any computer at any time (MetroGIS 2001). These features make the MetroGIS system a model for data management.
Section 3
Database Design

General Observations

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 subjected to scrutiny and evaluation throughout the duration of 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 in time will reduce the amount of time and money spent collecting either useless or additional data.

Feature and Attribute Selection

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.

Features

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. The seven structure types are as follows:

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 pre-cast 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. These attributes are defined in the next section.

Attributes

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 in the future be expanded to support their activities. Detailed information regarding the attributes of each feature included in the database allows maintenance personnel to better understand its physical configuration and the surrounding conditions. This aids accurate decision-making and maintenance crew staffing, and hence leads to a more efficient maintenance program.

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

Data Compatibility

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 rules in Table 3-1.

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<td>• Tables should have unique names</td>
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<td>• Columns within a table should have unique names</td>
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<tr>
<td>• A row must have a primary key</td>
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<tr>
<td>• There should be no redundant data in the database</td>
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<td>• There should be no repeating attributes in a row</td>
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<tr>
<td>• A field should not contain coded data</td>
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<tr>
<td>• Rows should contain attributes specific only to the entire primary key</td>
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</tbody>
</table>

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 a maximum of flexibility and is capable of dealing with specific requests for information.
Section 4
Interface Development

Introduction

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 a GIS, which stores, manipulates, and displays both a digitized base map and overlain stormwater features and attributes.

GIS

A GIS geographically references features represented geometrically by points, lines, or polygons. Data (i.e., geographical locations) of features are displayed graphically on a base map. Along with the graphic image of the features, a GIS also manages the associated attribute database. This allows a system user to query or manipulate the data and examine the results from various scenarios. A GIS also provides the ability to group common features in layers that can be turned on or off depending on the analyses being performed.

Once collected, data representing stormwater system features and attributes can be converted into any desired GIS format. ArcView GIS3.2a is the GIS platform that has been employed for this project. It was chosen for its widespread use and support; its relatively inexpensive cost; and for its display, storage, manipulation, and query capabilities.

Base Map

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 have the ability to 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 enables 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 points, lines, or polygons are given in Table 4-1.

Table 4-1. Examples of map layers available as points, lines, and polygons

<table>
<thead>
<tr>
<th>Map Symbol</th>
<th>Map Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Points</td>
<td>Cities, Landmarks, Airports, Miscellaneous</td>
</tr>
<tr>
<td>Lines</td>
<td>Roads, Rivers, Streams, Rail Roads</td>
</tr>
<tr>
<td>Polygons</td>
<td>Lakes, Parks, County Lines, City Limits</td>
</tr>
</tbody>
</table>

The base map employed for this project is a digitized map of Tuscaloosa County in State Plane NAD83 Alabama west coordinates. The map is illustrated in Figure 4-1. 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., for $1,050.
Figure 4-1. Base map of Tuscaloosa County
Section 5
Data Collection

Introduction

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. For the stormwater infrastructure system to fulfill its potential, it is essential that data collection personnel be diligent in their efforts to locate and record the attributes of each and every stormwater feature.

Study Area

The area designated for data collection in this project, illustrated in Figure 5-1, 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 approximately 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 in length depending upon the density of features and difficulty in traversing the terrain, but it was not uncommon 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 storm water 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 activity was not continuous from one day to the next, and occurred on both weekends and weekdays over the course of about a four-month period. 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.
GPS Unit Selection

The stormwater maintenance system developed in this project is capable of accommodating the 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. It can be expected that the accuracy of hand-held GPS units will increase and that their prices will decrease as technology advances over time.

Five types of GPS units were tested by Graettinger and Anderson (2000). Two of those tested units were employed in this project: the Trimble GeoExplorer 3C and the Garmin GPS 12 MAP. Table 5-1 lists costs and properties of the two units.

**TABLE 5-1. Comparison of two GPS units**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Price</th>
<th>Average Lock Time</th>
<th>Map Display/Display Accuracy</th>
<th>Automatic Download</th>
<th>Power Source</th>
<th>Ease of Use</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garmin GPS 12 Map</td>
<td>$350 GPS</td>
<td>27.5 sec</td>
<td>Yes 0.1 sec</td>
<td>Easy transfer of data from unit to computer.</td>
<td>4 AA batteries</td>
<td>Simple</td>
<td>Small – easy to handle</td>
</tr>
<tr>
<td></td>
<td>$130 software</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>hand-held</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trimble GeoExplorer 3C</td>
<td>$3380 w/software</td>
<td>*62.5 sec</td>
<td>Yes 0.001 sec</td>
<td>Easy transfer of data from unit to computer. Exportable in many formats.</td>
<td>Rechargeable battery</td>
<td>Relatively Complicated</td>
<td>*May change with GPS precision settings. Must be in open area for satellite lock- at least five satellites</td>
</tr>
<tr>
<td></td>
<td>hand-held</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Trimble GeoExplorer 3C**

The GeoExplorer 3C, illustrated in Figure 5-2, was used to collect data along Alabama State Highway 69. This device was developed by Trimble to specifically handle the rugged conditions of field data collection. It is rain, shock, and vibration resistant, in addition to possessing a slip-resistant grip. The GeoExplorer 3C has one megabyte of memory allowing for the collection of one thousand named locations in addition to storing the data dictionary. It is equipped with a Li-Ion rechargeable battery located within the device that provides eleven watt-hours of power. The device is accurate to 5 m and can be purchased for $3,380 (Trimble 2002).
Device Configuration The initial step in collecting data is configuring the GPS device. With the GeoExplorer 3C, loading the data dictionary is the first step. The manufacturer of the GPS device, Trimble, produces data processing software called Pathfinder Office. The data dictionary is entered into Pathfinder Office and then can be downloaded to the GeoExplorer 3C. Second, the coordinate system used in data collection must be selected. Once again, it saves time and reduces the possibility of error if the coordinate system chosen coincides with that of the base map. Next, the user must determine the number of satellites from which to receive signals. The minimum possible for any GPS device is three satellite signals. The addition of each satellite signal beyond three increases accuracy, but also increases the time to receive the signals and record the coordinates. All feature coordinates collected with the GeoExplorer 3C had a minimum of five satellites. After configuring the GPS device, data may be collected in the field.

Field Data Collection To collect the coordinates associated with a feature, the field GPS operator must position the GeoExplorer 3C directly above the feature and wait for the designated number of satellite signals to be received. After receiving the satellite signals a single button push records the GPS unit location. Once the coordinates are loaded in the GPS device, the attributes may be recorded. The GeoExplorer 3C allows the user to toggle through various screens to make attribute selections from the loaded data dictionary. It is also equipped with a screen that contains the individual letters of the alphabet, numbers, and various symbols that the user can toggle through to select and enter data. After each session of collecting data in the field, the device is transported to the office to download the data for processing.
**Data Processing** To process the data, the GPS device is linked to the computer operating the Pathfinder Office software and having the office support module connected. The office support module is used as a docking port to download data and also to recharge the GPS battery. Once the GeoExplorer 3C is linked to the computer, the data are downloaded into the Pathfinder Office program. The program converts the data from the GPS format it was collected in to the ASCII format. Converting the data to ASCII format enabled the data to be further processed using a Fortran 77 code, which was necessary to establish a consecutive numbering system for the features and to create accurate connectivity between two features with the same coordinates, such as inlets and outlets with pipes. The Fortran 77 code is reproduced in Appendix A. After the data are processed using the Fortran 77 code, they are transferred to an Excel Spreadsheet. This permits changing their format from ASCII to a database format, DBF. This allows the data to be loaded into the ArcView GIS software. Finally, the feature map is generated in ArcView and the points and lines are projected onto the base map.

**Fortran 77 Code** A consecutive numbering system is necessary to give unique identification numbers to each feature. After each field data collection session and subsequent download of data, the GeoExplorer 3C initializes its internal numbering system back to one. The data could be displayed accurately on the base map, but numerous features possessed the same identification number. While organizing the data with the Fortran 77 code, each feature is assigned each feature a unique identification number, thereby enhancing query possibilities and limiting confusion between features.

A problem with connectivity became apparent when the data were projected onto the base map and two features (e.g., the end of a pipe and an inlet to which it is connected) appeared to be several feet apart. This problem is caused by inaccuracies inherent to the GPS data collection devices. To solve this problem, the Fortran 77 code was written to search the data and locate points that are within a specified distance of one another. For this work, distances between 20 and 70 feet were used. The distance over which a search is made may be specified by the user and may vary from one data set to another. When the Fortran 77 code has identified nearby features that are physically connected, it averages their \((x,y)\) coordinates and places the features at the averaged location. Figures 5-3 and 5-4 show a pipe and inlet before and after their coordinates have been processed using the Fortran 77 code.
Quality Assurance/Quality Control  For quality assurance and quality control with the GeoExplorer 3C, a hard copy of each feature and its associated attributes was collected with pen and paper in addition to those stored in the GPS device. After the data were completely processed, the final information located within the GIS was checked for accuracy against the hard copy of collected data. Approximately five percent of the features were randomly checked, as were data that appeared abnormal or misplaced.
The majority of the errors found were the result of data improperly entered into the GeoExplorer 3C by the data collector. Although human error is certain to occur, it can be limited by careful attention to unit operation while in the field.

**Garmin GPS 12 MAP**

The GPS 12 MAP, shown in Figure 5-5, was used to collect data along U.S. Highway 43. This device was developed by Garmin and has the capacity to store 500 locations. It is rain resistant and about half the size of the GeoExplorer 3C. The Garmin GPS 12 MAP operates on four AA batteries, which translates into approximately 36 hours of use. The device and software can be purchased for $480 (Garmin 2002).

![Garmin GPS 12 MAP](image)

**Device Configuration** The initial step with the Garmin GPS 12 MAP, as with the GeoExplorer 3C, involves configuring the GPS device. First, a coordinate system must be selected. As before, it is suggested that the coordinate system chosen coincides with that of the base map. The number of satellite signals the device receives is automatically set to three and cannot be changed. This potentially reduces the accuracy achieved, but not to an unacceptable level. According to Graettinger and Anderson (2000), this unit is accurate to within 10 meters 76 percent of the time.
Field Data Collection. After configuring the device, data may be collected. The differences in data collection procedures between the two GPS units are evident during feature collection. The Garmin GPS 12 MAP does not possess the capability to store a data dictionary or record features and attributes internally. Therefore, a field data sheet was developed so the data could be manually recorded. The field data sheet, Figure 5-6, was designed to give the Garmin GPS 12 MAP operator the ability to collect the same features and attributes as the GeoExplorer 3C operator. In addition, space is provided for a sketch of the feature that can be scanned and linked to the GIS at a later date. The only information provided by the Garmin GPS 12 MAP device is the feature location. The collection of data with pen and paper gives the user tangible records that must be entered into the maintenance system at a later time. The paper copy may be kept on file for future reference.

Data Processing. After the data are collected, they are entered into an Excel Spreadsheet. Once again, this permits conversion of the information into a DBF format, which allows for input into ArcView. Then, the feature map is generated in ArcView and the points and lines are projected onto the base map.

The problems of consecutive number assignment and connectivity faced by the GeoExplorer 3C do not exist with the Garmin GPS 12 MAP. Since the data are entered manually, each feature is assigned an identification number with each additional feature collected being numbered consecutively. Connected features are recorded as having the same coordinates, thus eliminating any connectivity problems.

Quality Assurance/Quality Control. For quality assurance and quality control with the Garmin GPS 12 MAP, approximately five percent of the points were recorded a second time in the field and compared against the previously collected data. In addition, after the data were completely processed, the final information was visually examined for inaccuracies.

The majority of the errors found in the data collected with the Garmin GPS 12 MAP were the result of data improperly entered onto the field data sheet by the data collector. More specifically, it was the inaccurate recording of the geographic feature locations. The state plane coordinates for each feature consists of two numbers with seven significant figures each. Repeatedly recording fourteen digits for each feature opened the door for an abundance of errors. These errors can be limited by attention to detail by the data collector.
**STRUCTURE INVENTORY FIELD DATA SHEET**

<table>
<thead>
<tr>
<th>Date</th>
<th>Structure Sketch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Maintenance Dept.**

<table>
<thead>
<tr>
<th>Field Crew</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
</tr>
</tbody>
</table>

**Structure Type**

<table>
<thead>
<tr>
<th>Year Constructed</th>
<th></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Lat./Northing</th>
<th>Lat./Northing</th>
<th>Lat./Northing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long./Easting</td>
<td>Long./Easting</td>
<td>Long./Easting</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Road Number</th>
<th>Mile</th>
<th>Condition</th>
<th>good</th>
<th>bad</th>
<th>fair</th>
</tr>
</thead>
</table>

**Pipes & Culverts**

<table>
<thead>
<tr>
<th>Width</th>
<th>Length</th>
<th>Rise</th>
<th>Slope</th>
<th>Object Above</th>
</tr>
</thead>
</table>

**Open Channels**

<table>
<thead>
<tr>
<th>Width</th>
<th>Length</th>
<th>Depth</th>
<th>Slope</th>
<th>Riprap?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Near Side Slope</td>
<td>Far Side Slope</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Street Inlet / Junction Box / Manhole**

<table>
<thead>
<tr>
<th>Width</th>
<th>Length</th>
<th>Inside Diameter</th>
<th>Surrounding Material</th>
</tr>
</thead>
</table>

**Culvert Inlet / Outlet**

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Depth of Cover</th>
<th>Surrounding Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headwall?</td>
<td>Riprap?</td>
<td>Skew Angle</td>
<td>Right Wingwall Angle</td>
</tr>
</tbody>
</table>

| Right Wingwall Length | Left Wingwall Angle | Left Wingwall Length |

**COMMENTS**

---

Figure 5-6. Field inventory data sheet
Section 6

Results

At the conclusion of this project, a total of 1,307 features and their associated attributes had been inventoried and included in the database. Figure 6-1 is a projection of all 1307 features onto the base map. Figures 6-2 through 6-8 are projections of each feature onto the base map. A detailed list showing the distribution of the features is located in Table 6-1.

Table 6-1. Distribution of features along Highways 69 and 43

<table>
<thead>
<tr>
<th>Highway</th>
<th>Pipe or Culverts</th>
<th>Culvert Inlets</th>
<th>Culvert Outlets</th>
<th>Street Inlets</th>
<th>Junction Boxes</th>
<th>Open Channels</th>
<th>Manholes</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL 69</td>
<td>283</td>
<td>51</td>
<td>52</td>
<td>115</td>
<td>1</td>
<td>58</td>
<td>23</td>
</tr>
<tr>
<td>US 43</td>
<td>351</td>
<td>146</td>
<td>143</td>
<td>50</td>
<td>1</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>TOTALS</td>
<td>634</td>
<td>197</td>
<td>195</td>
<td>165</td>
<td>2</td>
<td>88</td>
<td>26</td>
</tr>
</tbody>
</table>
Figure 6-1. All collected stormwater features
Figure 6-2. All pipes or culverts along Highway 69 and Highway 43
Figure 6-3. All paved open channels along Highway 69 and Highway 43
Figure 6-4. All street inlets along Highway 69 and Highway 43
Figure 6-5. All manholes along Highway 69 and Highway 43
Figure 6-6. All junction boxes along Highway 69 and Highway 43
Figure 6-7. All culvert inlets along Highway 69 and Highway 43
Figure 6-8. All culvert outlets along Highway 69 and Highway 43
Section 7
Conclusions

This project has successfully developed and demonstrated the foundation of a GIS-based maintenance system for stormwater infrastructure by recording geographic coordinates and attributes for selected stormwater drainage system features along U.S. Highway 43 and Alabama State Highway 69 in Tuscaloosa County, Alabama. This GIS application has the capability of storing, manipulating, analyzing, and displaying data associated with storm water infrastructure. The management system also has the capability of aiding maintenance personnel by providing accurate and precise data regarding attributes of the stormwater infrastructure before leaving the yard to perform maintenance activities. This information should reduce the number of trips to retrieve additional equipment, and should also be of help in staffing maintenance crews, thereby improving both the effectiveness and efficiency of maintenance and reducing costs.

During the developmental stages of this project, previously accomplished stormwater infrastructure projects by others were examined to gain insight and develop focus. Valuable techniques regarding data collection, database design, sharing and maintaining data across boundaries, and system organization were gleaned from these projects. In addition, state-of-the-art equipment used in these projects was assessed. The equipment included customized software, hand-held computers with pen-enabled screens, and the internet.

A firm grasp of current stormwater infrastructure needs, combined with a sense of future needs, is essential for designing the database. Communication with the ultimate end user of a system and brainstorming sessions are also needed when selecting features and their associated attributes for the maintenance system. Creating a database with clear and unique features and attributes allows the system flexibility and ensures unlimited manipulation possibilities.

The interface is comprised of a GIS and a digitized base map. This GIS was chosen for its ability to store, manipulate, and geographically display the stormwater features and the attributes linked with each. The capability of visual analysis and logical linking of data is what sets the GIS apart from alternative types of information storage systems. The digitized base map is the canvas with a selected coordinate system for the geographic data. Map layers that best allow the data to be analyzed should be chosen for display.

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 and Garmin GPS 12 MAP, 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.

**Proceeding With the Maintenance System**

After reviewing the project, if the decision is made to go forward the end user will be provided with the essential elements from this study. These include: a detailed procedure manual, an inventory of data collected along Alabama State Highway 69 and U.S. Highway 43, any technical support needed, and additional training as necessary.

**Future Work**

The management system developed in this project has the capability of recording 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 are capable of handling 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.

To be successful, and eventually save hours of maintenance personnel time and taxpayer dollars, a commitment must be made to support the stormwater infrastructure maintenance system. Individuals with a vision of the future benefits of such a system must work to supply the necessary resources to cover both startup and operational costs. Rewards of such a system will never come to fruition without a commitment from ALDOT.
Section 8
References


PROGRAM trimble
 c reassign ID and coordinate based on shortest distance
 c this program can process up to 500 id for each feature
 c VARIABLES

 integer*8 i, j, k, m, n, np, ni, nj, nm, nk, nc,
 &sp, sl, sj, sm, sci, sco, sc, b(500),e(500),
 &milep(500),milei(500),milej(500),milem(500),mileci(500),
 &mileco(500),milec(500),tol,tol2,
 &yearp(500),yeari(500),yearj(500),
 &yearm(500),yearci(500),yearco(500),yearc(500)

 real*8 widthp(500),risep(500),lengp(500),slopep(500),
 &widthi(500),lengi(500),width1(500), width2(500),diam(500),
 &widthc(500),depthc(500),sidslopc(500),fsidesl(500),
 &lengc(500),slopec(500),
 &depcovci(500),inwci(500),inhci(500),lwlenci(500),rwlencci(500),
 &depcovco(500),inwco(500),inhco(500),lwlenco(500),rwlencco(500),
 &a(500),d(500),dist(500,500),distx(500,500),disty(500,500),
 &coordx(500),coardy(500)

 character*5 pe_id(500), pe_st(500),pe_end(500),
 &in_id(500),jc_id(500),mn_id(500),ci_id(500),co_id(500),
 &pc_id(500)

 character*3 roadp(500),roadi(500),roadj(500),roadm(500),
 &roadci(500),roadco(500),roadc(500),headci(500),headco(500),
 &wingwci(500),wingwco(500),riprpci(500),riprpcco(500),
 &conni(500),connj(500),connm(500),connnci(500),connncoc(500),
 &lwangci(500),rwanngci(500),skewci(500),
 &lwangco(500),rwanngco(500),skewco(500),
 &conps(500),conpe(500)

 character*20 typep(500),typei(500),typeci(500),typeco(500),
 &commp(500),commi(500),commj(500),commc(500),commci(500),
 &commco(500),c(500),f(500)

 character*10 matc(500),objp(500),condp(500),mainp(500),
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 &condj(500),mainj(500),surmatj(500),
 &matm(500),condm(500),mainm(500),surmatm(500),commm(500),
 &riprapc(500),condc(500),mainc(500),
 &surftyci(500),surftyco(500),condci(500),mainci(500),
&condco(500), mainco(500)

double precision northp(500), eastp(500), northp2(500),
& eastp2(500), northi(500), easti(500), northj(500),
& eastj(500), northci(500), eastci(500), northco(500),
& eastco(500), northm(500), eastm(500),
& northc(500), eastc(500), northc2(500), eastc2(500),
& northc3(500), eastc3(500), northc4(500), eastc4(500),
& northc5(500), eastc5(500), northc6(500), eastc6(500),
& northc7(500), eastc7(500), northc8(500), eastc8(500),
& northpo(500), eastpo(500), northpo2(500), eastpo2(500)

c *********************************************** *************
c...Read feature's field data, assign id, and write them as location
c...file and attribute files.
c...For pipe or culvert

   print *, 'specify number of data for pipe'
   read *, np

   if (np.ne.0) then
      print *, 'specify start id for pipe'
      read *, sp
      open (unit = 31, file = 'pipeorcu.pos')
      do 10 i = sp, np+sp-1
         read (31,*) roadp(i), milep(i), typep(i),
         & widthp(i), risep(i), lengp(i), slopep(i), objp(i),
         & condp(i), yearp(i), mainp(i), commp(i)
         read (31,*) northp(i), eastp(i)
         read (31,*) northp2(i), eastp2(i)
      10   continue
   endif

   c...For street inlet

   print *, 'specify number of data for street inlet'
   read *, ni

   if (ni.ne.0) then
      print *, 'specify start id for street inlet'
      read *, si
      open (unit = 41, file = 'street_i.pos')
      do 20 i = si, ni+si-1
         read (41,*) roadi(i), milei(i), widthi(i), lengi(i), mati(i),
         & typei(i), condi(i), yeari(i), maini(i), commi(i)
         read (41,*) northi(i), easti(i)
         conni(i)='n'
      20   continue
   endif

   c...For junction box
print *, 'specify number of data for junction box'
read *, nj
if (nj.ne.0) then
print *, 'specify start id for junction box'
read *, sj
open (unit = 51, file = 'junction.pos')
do 30 i = sj, nj+sj-1
read (51, *) roadj(i), milej(i), width1(i), width2(i),
&condj(i), yearj(i), mainj(i), surmatj(i), commj(i)
read (51,*) northj(i), eastj(i)
connj(i)='n'
30   continue
endif

For manhole

print *, 'specify number of data for manhole'
read *, nm
if (nm.ne.0) then
print *, 'specify start id for manhole'
read *, sm
open (unit = 61, file = 'manhole.pos')
do 40 i = sm, nm+sm-1
read (61, *) roadm(i), milem(i), diam(i), matm(i),
&condm(i), yearm(i), mainm(i), surmatm(i), commm(i)
read (61,*) northm(i), eastm(i)
connm(i)='n'
40   continue
endif

For culvert inlet

print *, 'specify number of data for culvert inlet'
read *, nk
if (nk.ne.0) then
print *, 'specify start id for culvert inlet'
read *, sci
open (unit = 66, file = 'culverti.pos')
do 45 i = sci, nk+sci-1
read (66, *) roadci(i), mileci(i), depcovci(i), surftyci(i),
&typeci(i), headci(i), inwci(i), inhci(i), wingwci(i), lwangci(i),
&lwenci(i), rwangci(i), rwlenci(i), skewci(i), riprpci(i),
&condci(i), yearci(i), mainci(i), commci(i)
read (66,*) northci(i), eastci(i)
connci(i)='n'
45   continue
endif

For culvert outlet
print *, 'specify number of data for culvert outlet'
read *, nw

if (nw.ne.0) then
print *, 'specify start id for culvert outlet'
read *, sco
open (unit = 71, file = 'culvert.o.pos')
do 50 i = sco, nw+sco-1
  read (71, *) roadco(i), mileco(i), depcovo(i), surftco(i),
  typeco(i), heacdco(i), inwco(i), inhco(i), wingwco(i), lwangco(i),
  lwlenco(i), rwangco(i), rwlenco(i), skewco(i), riprpo(i),
  condco(i), yearco(i), mainco(i), commco(i)
  read (71,*) northco(i), eastco(i)
  connco(i)='n'
  50 continue
endif

c...For paved open channel

print *, 'specify number of data for paved open channel'
read *, nc

if (nc.ne.0) then
print *, 'specify start id for paved open channel'
read *, sc
open (unit = 81, file = 'openchan.pos')
do 60 i = sc, nc+sc-1
  read (81, *) roadc(i), milec(i), matc(i),
  widthc(i), depthc(i), sidslopc(i), fsidesl(i), lengc(i),
  slopec(i), riprapc(i),
  condc(i), yearc(i), mainc(i), commc(i)
  read (81,*) northc(i), eastc(i)
  read (81,*) northc2(i), eastc2(i)
c  read (81,*) northc3(i), eastc3(i)
c  read (81,*) northc4(i), eastc4(i)
c  read (81,*) northc5(i), eastc5(i)
c  read (81,*) northc6(i), eastc6(i)
c  read (81,*) northc7(i), eastc7(i)
c  read (81,*) northc8(i), eastc8(i)
  60 continue
endif

*****************************************************************
c...Calculate distance
c...pipe and other point features

print *, 'specify the tolerance for distance at start point'
read *, tol
print *, 'specify the tolerance for distance at end point'
read *, tol2

do 70 i = sp, np+sp-1
  a(i)=0.0
  c(i)='none'

37
conps(i)='n'

do 105 n = sci, nk+sci-1
    distx(i,n)=(northp(i)-northci(n))**2
    disty(i,n)=(eastp(i)-eastci(n))**2
    dist(i,n)=sqrt(distx(i,n)+disty(i,n))
    if ((dist(i,n).lt.tol).and.(connci(n).ne.'y')) then
        if (a(i).gt.0.0) then
            if (dist(i,n).lt.a(i)) then
                a(i) = dist(i,n)
                b(i) = n
                c(i) = 'culvert inlet'
                connj(n)='y'
                conps(i)='y'
            else
                a(i) = dist(i,n)
                b(i) = n
                c(i) = 'culvert inlet'
                connj(n)='y'
                conps(i)='y'
        endif
    endif
105 continue

if (conps(i).ne.'y') then
    if (nj.ne.0) then
        do 90 k = sj, nj+sj-1
            distx(i,k)=(northp(i)-northj(k))**2
            disty(i,k)=(eastp(i)-eastj(k))**2
            dist(i,k)=sqrt(distx(i,k)+disty(i,k))
            if (dist(i,k).lt.tol) then
                if (a(i).gt.0.0) then
                    if (dist(i,k).lt.a(i)) then
                        a(i) = dist(i,k)
                        b(i) = k
                        c(i) = 'junction'
                        connj(k)='y'
                    else
                        a(i) = dist(i,k)
                        b(i) = k
                        c(i) = 'junction'
                        connj(k)='y'
                endif
            endif
        90 continue
    endif
    if (ni.ne.0) then
        do 80 j = si, ni+si-1
            distx(i,j)=(northp(i)-northi(j))**2
            disty(i,j)=(eastp(i)-easti(j))**2

if (ni.ne.0) then
    do 80 j = si, ni+si-1
        distx(i,j)=(northp(i)-northi(j))**2
        disty(i,j)=(eastp(i)-easti(j))**2
dist(i,j) = sqrt(distx(i,j) + disty(i,j))

if (dist(i,j).lt.tol) then
  if (a(i).gt.0.0) then
    if (dist(i,j).lt.a(i)) then
      a(i) = dist(i,j)
      b(i) = j
      c(i) = 'street inlet'
      conni(j) = 'y'
    endif
  else
    a(i) = dist(i,j)
    b(i) = j
    c(i) = 'street inlet'
    conni(j) = 'y'
  endif
endif
80 continue
endif

if (nm.ne.0) then
  do 100 m = sm, nm+sm-1
    distx(i,m) = (northp(i) - northm(m))**2
    disty(i,m) = (eastp(i) - eastm(m))**2
    dist(i,m) = sqrt(distx(i,m) + disty(i,m))
    if (dist(i,m).lt.tol) then
      if (a(i).gt.0.0) then
        if (dist(i,m).lt.a(i)) then
          a(i) = dist(i,m)
          b(i) = m
          c(i) = 'manhole'
          connm(m) = 'y'
        endif
      else
        a(i) = dist(i,m)
        b(i) = m
        c(i) = 'manhole'
        connm(m) = 'y'
      endif
    endif
    100 continue
  endif
endif

  print *, i, b(i), c(i)
  if (c(i).eq.'street inlet') then
    if (conni(b(i)).ne.'y') then
      coordx(i) = (northp(i) + northi(b(i)))/2
      northp(i) = coordx(i)
      northi(b(i)) = coordx(i)
      coordy(i) = (eastp(i) + easti(b(i)))/2
      eastp(i) = coordy(i)
      easti(b(i)) = coordy(i)
    else
      print *, i, b(i), c(i)
    endif
  endif

northp(i) = northi(b(i))
eastp(i) = easti(b(i))
endif
   if (b(i).lt.10) then
      write (100,1030) b(i)
   else
      if (b(i).lt.100) then
         write (100,1040) b(i)
      else
         if (b(i).lt.1000) then
            write (100,1050) b(i)
         endif
      endif
   endif
endif

if (c(i).eq.'junction') then
   if (connj(b(i)).ne.'y') then
      coordx(i) = (northp(i)+northj(b(i)))/2
      northp(i) = coordx(i)
      northj(b(i)) = coordx(i)
      coordy(i) = (eastp(i)+eastj(b(i)))/2
      eastp(i) = coordy(i)
      eastj(b(i)) = coordy(i)
   else
      northp(i) = northj(b(i))
      eastp(i) = eastj(b(i))
   endif
   if (b(i).lt.10) then
      write (100,1060) b(i)
   else
      if (b(i).lt.100) then
         write (100,1070) b(i)
      else
         if (b(i).lt.1000) then
            write (100,1080) b(i)
         endif
      endif
   endif
endif

if (c(i).eq.'manhole') then
   if (connm(b(i)).ne.'y') then
      coordx(i) = (northp(i)+northm(b(i)))/2
      northp(i) = coordx(i)
      northm(b(i)) = coordx(i)
      coordy(i) = (eastp(i)+eastm(b(i)))/2
      eastp(i) = coordy(i)
      eastm(b(i)) = coordy(i)
   else
      northp(i) = northm(b(i))

endif
eastp(i) = eastm(b(i))
endif
if (b(i).lt.10) then
write (100,1090) b(i)
else
if (b(i).lt.100) then
write (100,1100) b(i)
else
if (b(i).lt.1000) then
write (100,1110) b(i)
endif
endif
endif
endif
if (c(i).eq.'culvert inlet') then
coordx(i) = (northp(i)+northci(b(i)))/2
northp(i) = coordx(i)
northci(b(i)) = coordx(i)
coordy(i) = (eastp(i)+eastci(b(i)))/2
eastp(i) = coordy(i)
eastci(b(i)) = coordy(i)
if (b(i).lt.10) then
write (100,1115) b(i)
else
if (b(i).lt.100) then
write (100,1125) b(i)
else
if (b(i).lt.1000) then
write (100,1135) b(i)
endif
endif
endif
endif
endif
if (c(i).eq.'none') then
write (100,*), c(i)
endif
70    continue
rewind (100)
do 130 i = sp, np+sp-1
   read (100,*), pe_st(i)
130    continue

rewind (41)
rewind (51)
rewind (61)
rewind (71)
rewind (81)
do 140 i = sp, np+sp-1
d(i)=0.0
f(i)='none'

if (nw.ne.0) then
  do 190 n = sco, nw+sco-1
  distx(i,n)=(northp2(i)-northco(n))**2
  disty(i,n)=(eastp2(i)-eastco(n))**2
  dist(i,n)=sqrt(distx(i,n)+disty(i,n))
  if ((dist(i,n).lt.tol2).and.(connco(n).ne.'y')) then
    if (d(i).gt.0.0) then
      if (dist(i,n).lt.d(i)) then
        d(i) = dist(i,n)
        e(i) = n
        f(i) = 'culvert outlet'
        connco(n)='y'
        conpe(i)='y'
      endif
    else
      d(i) = dist(i,n)
      e(i) = n
      f(i) = 'culvert outlet'
      connco(n)='y'
      conpe(i)='y'
    endif
  endif
  continue
190 enddo
endif

if (nj.ne.0) then
  do 160 k = sj, nj+sj-1
  distx(i,k)=(northp2(i)-northj(k))**2
  disty(i,k)=(eastp2(i)-eastj(k))**2
  dist(i,k)=sqrt(distx(i,k)+disty(i,k))
  if (dist(i,k).lt.tol2) then
    if (d(i).gt.0.0) then
      if (dist(i,k).lt.d(i)) then
        d(i) = dist(i,k)
        e(i) = k
        f(i) = 'junction'
      endif
    else
      d(i) = dist(i,k)
      e(i) = k
      f(i) = 'junction'
    endif
  endif
  continue
160 enddo
endif

if (ni.ne.0) then
  do 150 j = si, ni+si-1
  distx(i,j)=(northp2(i)-northi(j))**2
  disty(i,j)=(eastp2(i)-easti(j))**2
  dist(i,j)=sqrt(distx(i,j)+disty(i,j))
  if (dist(i,j).lt.tol2) then
    if (d(i).gt.0.0) then
      if (dist(i,j).lt.d(i)) then
        d(i) = dist(i,j)
        e(i) = j
        f(i) = 'junction'
      endif
    else
      d(i) = dist(i,j)
      e(i) = j
      f(i) = 'junction'
    endif
  endif
  continue
150 enddo
endif

disty(i,j) = (eastp2(i) - easti(j))**2
dist(i,j) = sqrt(distx(i,j) + disty(i,j))
if (dist(i,j).lt.tol2) then
  if (d(i).gt.0.0) then
    if (dist(i,j).lt.d(i)) then
      d(i) = dist(i,j)
      e(i) = j
      f(i) = 'street inlet'
    endif
  else
    d(i) = dist(i,j)
    e(i) = j
    f(i) = 'street inlet'
  endif
endif
150 continue
endif

if (sm.ne.0) then
  do 180 m = sm, nm+sm-1
    distx(i,m) = (northp2(i) - northm(m))**2
    disty(i,m) = (eastp2(i) - eastm(m))**2
    dist(i,m) = sqrt(distx(i,m) + disty(i,m))
    if (dist(i,m).lt.tol2) then
      if (d(i).gt.0.0) then
        if (dist(i,m).lt.d(i)) then
          d(i) = dist(i,m)
          e(i) = m
          f(i) = 'manhole'
        endif
      else
        d(i) = dist(i,m)
        e(i) = m
        f(i) = 'manhole'
      endif
    endif
  180 continue
  endif
endif

if (f(i).eq.'street inlet') then
  if (conni(e(i)).ne.'y') then
    coordx(i) = (northp2(i) + northi(e(i)))/2
    northp2(i) = coordx(i)
    northi(e(i)) = coordx(i)
    coordy(i) = (eastp2(i) + easti(e(i)))/2
    eastp2(i) = coordy(i)
    easti(e(i)) = coordy(i)
  else
    northp2(i) = northi(e(i))
    eastp2(i) = easti(e(i))
  endif
  endif
write (150,1030) e(i)
else
  if (e(i).lt.100) then
    write (150,1040) e(i)
  else
    if (e(i).lt.1000) then
      write (150,1050) e(i)
    endif
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ENDIF
else
   if (e(i).lt.1000) then
      write (150,1110) e(i)
   endif
endif
endif
endif

if (f(i).eq.'culvert outlet') then
   coordx(i) = (northp2(i)+northco(e(i)))/2
   northp2(i) = coordx(i)
   northco(e(i)) = coordx(i)
   coordy(i) = (eastp2(i)+eastco(e(i)))/2
   eastp2(i) = coordy(i)
   eastco(e(i)) = coordy(i)
   if (e(i).lt.10) then
      write (150,1120) e(i)
   else
      if (e(i).lt.100) then
         write (150,1130) e(i)
      else
         if (e(i).lt.1000) then
            write (150,1140) e(i)
         endif
      endif
   endif
endif
endif
endif

if (f(i).eq.'none') then
   write (150,*) f(i)
endif
140   continue
rewind (150)
do 200 i =sp, np+sp -1
   read (150,*) pe_end(i)
200   continue
rewind(31)
do 210 i=sp,np+sp -1
   read (31,*) roadp(i), milep(i), typep(i),
      &widthp(i), risep(i), lengp(i), slopep(i), objp(i),
      &condp(i), yearp(i), mainp(i), commp(i)
   read (31,*) northpo(i), eastpo(i)
   read (31,*) northpo2(i),eastpo2(i)
210   continue

do 220 i=sp,np+sp -1
   write (900,*) i, pe_st(i), pe_end(i), a(i), d(i)
   if (pe_st(i).eq.pe_end(i)) then
      if (a(i).le.d(i)) then

pe_end(i)='none'
northp2(i)=northpo2(i)
eastp2(i)=eastpo2(i)
else
pe_st(i)='none'
northp(i)=northpo(i)
eastp(i)=eastpo(i)
endif
endif

220   continue

c***************************************** ******************
c write readme file

c 1) to check sufficiency of the specified tolerance

c 2) report the start ID of each type of feature for the next run

open (unit=160, file='readme.txt')
countst=0
countend=0
do 230 i = sp, np+sp-1
if (c(i).eq.'culvert inlet') then
  countst=countst+1
endif
230   continue
if (countst.lt.nk) then
  write (160,*) 'specify tolerance distance for start node again'
  write (160,*) 'the new tolerance should be >',tol,')'
endif
do 2100 i = sp, np+sp-1
if (f(i).eq.'culvert outlet') then
  countend=countend+1
endif
2100   continue
if (countend.lt.nw) then
  write (160,*) 'specify tolerance distance for end node again'
  write (160,*) 'the new tolerance should be >',tol2,')'
endif
write (160,*) 'For the next run,'
if (np.ne.0) then
  write (160,*) 'the start ID for pipe is',np+sp
endif
if (ni.ne.0) then
  write (160,*) 'the start ID for street inlet is',ni+si
endif
if (nj.ne.0) then
  write (160,*) 'the start ID for junction box is', nj+sj
endif
if (nm.ne.0) then
  write (160,*) 'the start ID for manhole is', nm+sm
endif
if (nk.ne.0) then
  write (160,*) 'the start ID for culvert inlet is',nk+sci
endif
if (nw.ne.0) then
write (160,*) 'the start ID for culvert outlet is',nw+sco
endif
if (nc.ne.0) then
write (160,*) 'the start ID for open channel is', nc+sc
endif
close (160)
c**********************************************************
cWRITE OUTPUT FILE
c for pipe or culvert
if (np.ne.0) then
do 270 i = sp,np+sp-1
if (i.lt.10) then
write (32,1000) i
else
if (i.lt.100) then
write (32,1010) i
else
if (i.lt.1000) then
write (32,1020) i
endif
endif
endif
270 continue
rewind(32)
do 280 i = sp,np+sp -1
read (32,*) pe_id(i)
280 continue
open (unit = 33, file = 'pipeatt.txt')
write (33,800)
800 format ('id,',pipe_id,',start_node,end_node,,
road#,mile#,type,width,rise,length,slope,object above,condition,year,maint_section,comments')
do 290 i = sp, np+sp-1
write (33,1190) i,pe_id(i),pe_st(i),pe_end(i),
roadp(i),milep(i),typep(i),
widthp(i),risep(i),lengp(i),slopep(i),objp(i),
condp(i),yearp(i),mainp(i),commp(i)
290 continue
open (unit = 34, file = 'pipepos.txt')
do 295 i = sp, np+sp-1
write (34,*) i
write (34,1180) eastp(i),northp(i)
write (34,1180) eastp2(i),northp2(i)
write (34,*) 'end'
295 continue
write (34,*) 'end'
endif

c for street inlet
    if (ni.ne.0) then
        do 300 i =si,ni+si-1
        if (i.lt.10) then
            write (42,1030) i
        else
            if (i.lt.100) then
                write (42,1040) i
            else
                if (i.lt.1000) then
                    write (42,1050) i
                endif
            endif
        endif
    endif
    300   continue
    rewind(42)
    do 310 i =si,ni+si-1
        read (42,*) in_id(i)
    310   continue
    open (unit = 43, file = 'street_inlet.txt')
    write (43,810)
    810   format ('inlet_id',',','east',',','north',',',
        &'road#',',','mile#',',','width',',','length',',','material',
        &',',',',',',',',',',',',',',coments')
        do 320 i = si, ni+si-1
            write (43,1200) in_id(i),easti(i),northi(i),
            & roadi(i),milei(i),widthi(i),lengi(i),mati(i),
            & typei(i),condi(i),yeari(i),maini(i),commi(i)
        320 continue
    endif

c for junction box
    if (nj.ne.0) then
        do 330 i =sj,nj+sj-1
        if (i.lt.10) then
            write (52,1060) i
        else
            if (i.lt.100) then
                write (52,1070) i
            else
                if (i.lt.1000) then
                    write (52,1080) i
                endif
            endif
        endif
    endif
    330   continue
    rewind(52)
    do 340 i =sj,nj+sj-1

read (52,*) jc_id(i)
340 continue

open (unit = 53, file = 'junction.txt')
write (53, 820)
820 format ('junction_id,' 'east,' 'north,' & 'road#,' 'mile#,' 'width1,' 'width2,' 'condition,' & 'year,' 'maint_section,' 'surrounded material,' 'comments')
do 350 i = sj, nj+sj-1
   write (53, 1210) jc_id(i), eastj(i), northj(i), & roadj(i), milej(i), width1(i), width2(i), & condj(i), yearj(i), mainj(i), surmatj(i), commj(i)
350 continue
endif
c for manhole

if (nm.ne.0) then
do 360 i = sm, nm+sm-1
   if (i.lt.10) then
      write (62, 1090) i
   else
      if (i.lt.100) then
         write (62, 1100) i
      else
         write (62, 1110) i
      endif
   endif
endif
360 continue
rewind(62)
do 370 i = sm, nm+sm-1
   read (62,*) mn_id(i)
370 continue

open (unit = 63, file = 'manhole.txt')
write (63, 830)
830 format ('manhole_id,' 'east,' 'north,' 'road#,' 'mile#,' & 'inside diameter,' 'material,' 'condition,' & 'year,' 'maint_section,' 'surrounded material,' 'comments')
do 380 i = sm, nm+sm-1
   write (63, 1220) mn_id(i), eastm(i), northm(i), roadm(i), milem(i), & diam(i), matm(i), condm(i), yearm(i), mainm(i), surmatm(i), commm(i)
380 continue
endif
c...For culvert inlet
if (nk.ne.0) then
do 385 i = sci, nk+sci-1
   if (i.lt.10) then
      write (67, 1115) i
   else
      if (i.lt.100) then
         write (67, 1125) i
   endif
endif
else
  if (i.lt.1000) then
    write (67,1135) i
  endif
endif
endif
endif
385 continue

rewind(67)
do 390 i = sci,nk+sci-1
  read (67,*) ci_id(i)
390 continue

open (unit = 68, file = 'culvertin.txt')
write (68,840)
840 format ('culvert inlet_id,','east,','north,','road#,','mile#,','
  depth of cover,','surface type,','inlet type,','headwall,','
  inlet width,','inlet height,','wingwall,','
  left wingwall angle,','left wingwall length,','
  right wingwall angle,','right wingwall length,','skew angle,','
  riprap,','condition,','year,','maint_section,','comments')
do 395 i = sci, nk+sci-1
  write (68,1230) ci_id(i),eastci(i),northci(i),roadci(i),
  &mileci(i),depcovci(i),surftyci(i),
  &typeci(i),headci(i),inhci(i),wingwci(i),iwangci(i),
  &lwleni(i),rwangci(i),skewci(i),riprpci(i),
  &condci(i), yearci(i), mainci(i), commci(i)
395 continue
endif
c...For culvert outlet
if (nw.ne.0) then
do 400 i =sco,nw+sco-1
  if (i.lt.10) then
    write (72,1120) i
  else
    if (i.lt.100) then
      write (72,1130) i
    else
      if (i.lt.1000) then
        write (72,1140) i
      endif
    endif
  endif
endif
400 continue

rewind(72)
do 410 i =sco,nw+sco-1
  read (72,*) co_id(i)
410 continue

open (unit = 73, file = 'culvertout.txt')
write (73,845)
845 format ('culvert outlet_id,','east,','north,','road#,','mile#,','
  depth of cover,','surface type,','inlet type,','headwall,','
  inlet width,','inlet height,','wingwall,','
  left wingwall angle,','left wingwall length,','
  right wingwall angle,','right wingwall length,','skew angle,','
  riprap,','condition,','year,','maint_section,','comments')
do 395 i = sci, nk+sci-1
  write (73,1230) co_id(i),eastci(i),northci(i),roadci(i),
  &mileci(i),depcovci(i),surftyci(i),
  &typeci(i),headci(i),inhci(i),wingwci(i),iwangci(i),
  &lwleni(i),rwangci(i),skewci(i),riprpci(i),
  &condci(i), yearci(i), mainci(i), commci(i)
do 415 i = sco, nw+sco -1
   write (73,1230) co_id(i),eastco(i),northco(i),roadco(i),
     &mileco(i),depcovco(i),surftyco(i),
     &typeco(i),headco(i),inwco(i),inhco(i),wingwco(i),lwangco(i),
     &lwlenco(i),rwangco(i),rwlenco(i),skewco(i),riprpco(i),
     &condco(i), yearco(i), mainco(i), commco(i)
415 continue
endif

   for paved open channel
   if (nc.ne.0) then
      do 420 i =sc,nc+sc -1
         if (i.lt.10) then
            write (82,1150) i
         else
            if (i.lt.100) then
               write (82,1160) i
            else
               if (i.lt.1000) then
                  write (82,1170) i
               endif
            endif
         endif
      endif
      rewind(82)
      do 430 i =sc,nc+sc -1
         read (82,*) pc_id(i)
      430 continue
      open (unit = 83, file = 'openatt.txt')
      write (83,850)
850   format ('id,','chan_id,','road#,','mile#','type','width','depth','near sideslope','
     &far sideslope','length','slope','condition','year','maint_section','
     &comments')
      do 440 i = sc, nc+sc-1
         write (83,1240) i,pc_id(i),roadc(i),milec(i),matc(i),
          &widthc(i),depthc(i),sidslopc(i),fsidesl(i),lengc(i),
          &slopec(i),condc(i),yearc(i),mainc(i),commc(i)
440 continue
      open (unit = 84, file = 'openpos.txt')
      do 450 i = sc,nc+sc-1
         write (84,*) i
         write (84,1180) eastc(i),northc(i)
      450 continue
   endif

51
WRITE (84, 1180) EASTC3(I), NORThC3(I)
WRITE (84, 1180) EASTC4(I), NORThC4(I)
WRITE (84, 1180) EASTC5(I), NORThC5(I)
WRITE (84, 1180) EASTC6(I), NORThC6(I)
WRITE (84, 1180) EASTC7(I), NORThC7(I)
WRITE (84, 1180) EASTC8(I), NORThC8(I)
WRITE (84, *) 'end'
450   CONTINUE
WRITE (84, *) 'end'
ENDIF
1000   FORMAT ('PE', I1)
1010   FORMAT ('PE', I2)
1020   FORMAT ('PE', I3)
1030   FORMAT ('IN', I1)
1040   FORMAT ('IN', I2)
1050   FORMAT ('IN', I3)
1060   FORMAT ('JB', I1)
1070   FORMAT ('JB', I2)
1080   FORMAT ('JB', I3)
1090   FORMAT ('MN', I1)
1100   FORMAT ('MN', I2)
1110   FORMAT ('MN', I3)
1115   FORMAT ('CI', I1)
1120   FORMAT ('CO', I1)
1125   FORMAT ('CI', I2)
1130   FORMAT ('CO', I2)
1135   FORMAT ('CI', I3)
1140   FORMAT ('CO', I3)
1150   FORMAT ('PC', I1)
1160   FORMAT ('PC', I2)
1170   FORMAT ('PC', I3)
1180   FORMAT (F12.3, ',', F12.3)
1190   FORMAT (I5, ',', A7, ',', A7, ',', A3, ',', I5, ',', A25, ',', 
&   F5.2, ',', F5.2, ',', F7.2, ',', F4.2, ',', A10, ',', A10, ',', I4, ',', 
&   A5, ',', A50)
1200   FORMAT (A7, ',', F12.3, ',', F12.3, ',', A3, ',', I5, ',', F5.2, 
&   ',', F5.2, ',', A10, ',', A20, ',', A10, ',', I4, ',', A5, ',', A25)
1210   FORMAT (A7, ',', F12.3, ',', F12.3, ',', A3, ',', I5, ',', F5.2, ',', F5.2, 
&   ',', A10, ',', I4, ',', A5, ',', A10, ',', A25)
1220   FORMAT (A7, ',', F12.3, ',', F12.3, ',', A3, ',', I5, ',', F5.2, ',', 
&   A10, ',', I4, ',', A5, ',', A10, ',', A25)
1230   FORMAT (A7, ',', F12.3, ',', F12.3, ',', A3, ',', I5, ',', F5.2, ',', A10, 
&   ',', A20, ',', A1, ',', F5.2, ',', A1, ',', A2, ',', F5.2, ',', 
&   A2, ',', F5.2, ',', A2, ',', A1, ',', A10, ',', I4, ',', A5, ',', A25)
1240   FORMAT (I5, ',', A7, ',', A3, ',', I3, ',', A8, ',', F5.2, ',', 
&   F5.2, ',', F5.2, ',', F4.2, ',', F7.2, ',', F4.2, ',', A10, ',', I4, 
&   ',', A5, ',', A25)
close (31)
close (41)
close (51)
close (61)
close (66)
close (71)
close (81)