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The First Step: Utility Asset Management with GIS

(ESRI 2003 User Conference Paper #518)

The Augusta Utilities Department (AUD) in Augusta, Georgia is committed to maintaining a sound, functional Water/Sewer Utility GIS with a high level of integrity. This paper will discuss how together, KHAFRA and AUD are leveraging the latest available technologies to capture legacy information and organizational knowledge in a comprehensive GIS. Topics will include customizing ArcGIS to capture data from scanned record drawings, using handheld DGPS units with ArcPad for field verification, developing applications to incorporate new features, quality control considerations, capturing organizational knowledge from personnel, and establishing procedures to keep the gathered information current.

Introduction

Augusta-Richmond County began the process of developing a comprehensive GIS database for both their sanitary sewer collection and water distribution systems after merging City and County governments in 1996. Located in eastern Georgia along the Savannah River, Augusta is the second oldest city in the state as well as its second largest municipality. The Augusta Utility Department serves over 200,000 residents through 1,200 miles of water distribution mains and 850 miles of sewer collection pipelines. Nearly 60% of the sewer system and 75% of sewer structures have been inventoried through basin studies; however, collecting attribute information on those features was not the focus of those studies. As a result, the features had little or no information associated with them and served only as a graphical representation of the system. AUD had very little GIS data for their water distribution system. The richest source of utility information available to County personnel was the thousands of record drawings stored at several facilities throughout the County.

When the decision was made to improve their maintenance operations through the use of maintenance management software, AUD realized they would need a robust GIS database of their utility assets to serve as the foundation for their efforts. They felt that a comprehensive asset inventory would assist their field maintenance crews in locating system features to expedite repair times and enhance their preventative maintenance efforts through readily accessible information and a more complete representation of their collection and distribution systems.

KHAFRA Engineering Consultants, Inc. (KHAFRA) began working with AUD in 2000 to incorporate water and sewer information from Augusta's record drawings into the GIS. Over 8,000 drawings have been scanned and georeferenced to the County's base layers and captured into the GIS by our technicians through a custom suite of tools we developed. Once this information was captured, it was field-verified using map-grade Differential GPS. As technology improved, we began using ArcPad as our field data collection software and developed custom tools within ArcPad to ease our efforts.

Nevertheless, this was only part of the solution. For any utility department, the greatest challenge is maintaining a current inventory and incorporating changes to the system quickly and accurately. To assist AUD with this effort, we expanded our tools for ArcPad to include the ability to capture linear features and to intelligently populate feature attributes as they are captured. This paper discusses the challenges in accurately capturing water distribution and sanitary sewer collection systems in the field and our approach to addressing these challenges.

Data Extraction from Record Drawings

In order to meet the first goal of this project (to include information from 8,000+ record drawings in the GIS) the following approach was chosen:

- Acquire existing record drawings and GIS data from AUD

KHAFRA obtained relevant base GIS layers from AUD including street centerlines, edge of pavement, building outlines, parcels, topography, known sewer lines, water lines, and aerial photography.

- Scan drawings into electronic image files

  Using a large-format scanner, Beam Technical Services captured the hard copy record drawings into JPEG images at a resolution of 150 dpi. This resolution allowed for manageable file sizes while maintaining sufficient image quality to capture all details of the original drawing. As each drawing was scanned, details of the drawing were entered into a Microsoft Access database that included the drawing filename, date, engineering company, contractor, and drawing title.

- Clean images

  The scanned images were then sent to KHAFRA where the brightness and contrast were adjusted to optimize the image's legibility. ACDSee, Adobe Photoshop, and Corel products were each used as appropriate.

- Georeference image files to the County's GIS basemap information

  Georeferencing is the process by which a GIS computes the real world coordinates of a digital image and positions it in its correct location in the GIS. KHAFRA utilized both the Image Analysis extension in ArcView 3.2 and later the georeferencing capabilities of ArcGIS 8.2 to facilitate this image-to-map rectification and to store the rectified images as "Imagine" files. Features in the GIS basemap data (such as street centerlines, parcel boundaries, and building outlines) were used as references for this process. Whenever possible, third-order polynomial transformations were used to achieve the best fit of the image with the GIS basemap data.

- Create Spatial Index of Images

  During Phase I, an application was developed that automatically generated a polygon feature representing the spatial extent of each georeferenced image. These polygons were stored in a shapefile called "ibounds.shp". Information from the database populated during the scanning process was automatically pulled into the shapefile's attributes to complete the spatial index. The digitizing tools that associate information such as the date of construction with digitized features use this file. It also allows the creation of automated image loading and drawing status tracking.

- Digitize Features from Record Drawings

  Once all drawings in an area were scanned and georeferenced, GIS technicians digitized the sewer and water features into the appropriate ArcView shapefiles and recorded all information requested by AUD.

Digitizing

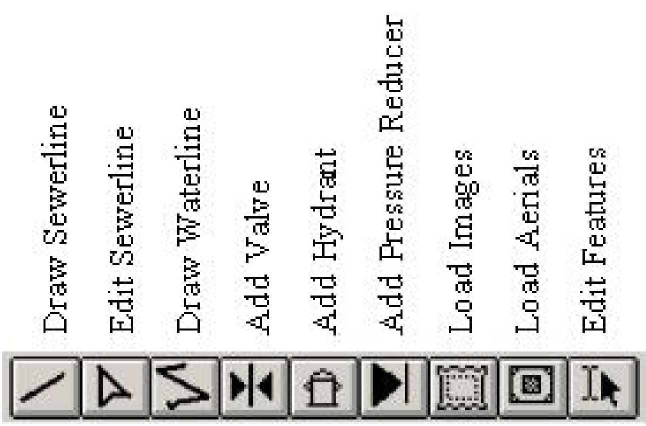

Figure 1: ArcView 3.x Tools (Similar Tools have since been created for ArcView 8.x)

To facilitate the capture of information from the scanned images into the GIS, KHAFRA created a suite of digitizing tools for AUD (Figure 1). The following steps were used to capture information from record drawings:

1. Load Image: A status field in the "Ibounds" shapefile was used to track the status of each image throughout the digitizing process. The Ibounds theme was classified using the status field to enhance workflow by showing only images that had not already been incorporated into the GIS. The "load image" tool allowed a user to select a point or area on the map and see all drawings relating to that area. The drawing "filename", "date", and "digitizing status" would all be displayed. The user simply selected the drawing he wished to load and it was added to the view (Figure 2). Drawings were captured in reverse-

chronological order with emphasis given to large-scale maps covering smaller areas. Small-scale maps such as countywide tax maps lacked important attribute information and refined detail so they were incorporated at the end of the project to fill in gaps in the system. A second button was added to the interface that could launch the original scanned image (non-georeferenced) in an external image viewer on a separate monitor. This allowed the user to zoom in and pan around a drawing to locate attribute information such as material and elevations for features being digitized.

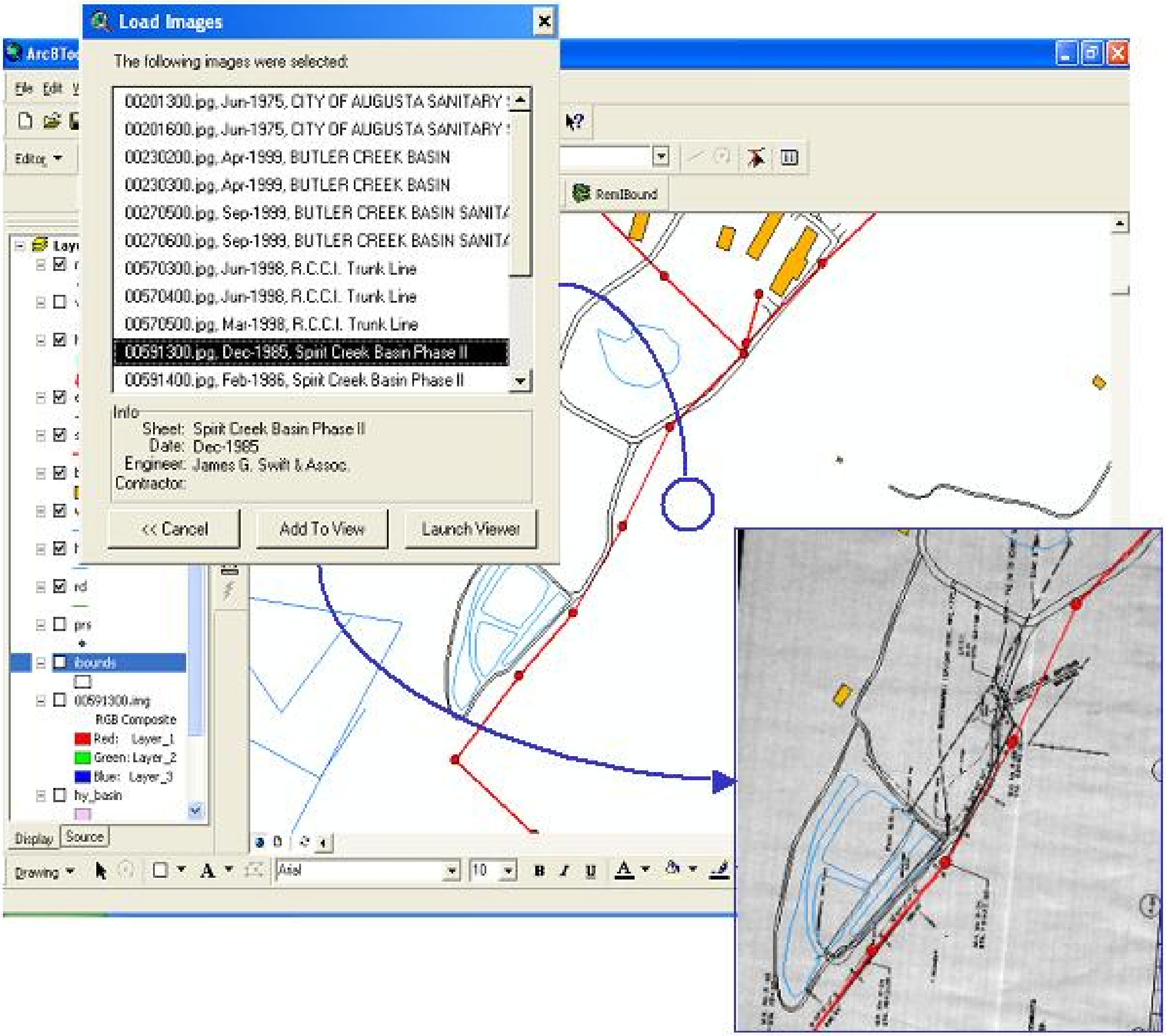

Figure 2: Load Image Tool

2. Capture Sanitary Sewer Collection Features: Once an image was added to the view, the Add Sewer tool was used to trace over a sewer line from the upstream node to the downstream node. The user was then prompted for information about the line such as upstream and downstream invert elevations, the rim elevation of the upstream manhole, pipe size and pipe material. Other information taken from the image database was used to populate fields storing construction date, image filename, and engineering company. Because sewer manholes occur at the endpoints of sewer lines, it was unnecessary to capture them independently. A customized application was developed that extracted the sewer line endpoints and automatically created manhole features from them. Information taken from the sewer lines was used to automatically populate the manhole's attributes to complete the layer.
3. Capture Water Distribution Features: Water mains were captured using a tool that allowed the user to trace along a multi-vertexed line. The waterline database was populated with relevant attributes collected from the record drawing. Water valves were digitized using a custom "Add Valve" tool that snapped the valve to a point along a water line. The line size was then

automatically associated with the valve to minimize data entry errors. Valve manufacturer, open direction, and status were also collected when specified on the record drawing. Fire hydrants were digitized similarly and such information as manufacturer, size, and flow data were captured when available. The final water feature captured from record drawings was pressure reducers that had such attributes as manufacturer, PSI high and low, operation status, and size. Again, the user simply selected a point along a water line to add the features.

4. Unload Image: After all water and sewer features had been captured from an image, it was removed through a custom tool that allowed the user to confirm the image status. The image's record in the ibounds shapefile was updated to indicate both water and sewer information had been captured along with the date and user's initials. This automated process eliminated possible errors and ensured the accurate representation of a record drawing's progress through the digitizing process.

Internal QA/QC

Once information from all drawings had been collected, both automated and manual reviews of the data were used to identify possible data inconsistencies or other problems.

Automated Data Scans

Utilizing Avenue, KHAFRA wrote routines necessary to conduct automated data scans to identify the following sanitary sewer system problems:

- Any positive slopes in the line segments
- Discontinuous lines
- Inconsistent line invert information
- Decreasing downstream pipe sizes
- Extreme elevations
- Illogical manhole depths

The results of these scans were captured in new shapefiles that provided quality control fields used to track the date a problem was discovered and its resolution status. Furthermore, the individual who addressed the problem was identified for future reference.

QA/QC routines were applied to the water system to identify the following:

- Water valve sizes were appropriate to the water line they were associated with
- Water valves lie directly on water mains or branches
- Fire hydrants fall at the end of water lines and are sized accordingly
- Water main pipe sizes follow logical progressions
- Water system nodes such as valves, tees, crosses, wyes, etc. define separate water main lines

Similar to the sewer system, any problems identified through these routines were captured in a quality control shapefile, addressed, and tracked.

Manual Review

In addition to the automated QA/QC routines, maps were plotted for each feature type per drainage basin and reviewed by senior GIS specialists and the project manager. This review was qualitative in nature and used to identify illogical system components or other areas of concern. Problems located were further researched through the record drawings and modified as appropriate. Following all in-house reviews, KHAFRA produced draft utility maps at a scale of 1"=200' for AUD staff to review. Because of their familiarity with the system as well as their experience, the staff review represented one of the most important aspects of this asset inventory project. By capturing the organizational knowledge carried by department personnel, the GIS database can reflect system changes that were not documented elsewhere and identify discrepancies between information collected from record drawings and real-world observations.

Field Verification

Following the development of the utility GIS layers, our focus shifted to field verification efforts. For the data to be of the greatest use to AUD, it was deemed appropriate to adjust the horizontal location of point features using a Map-Grade Differential Global

Positioning System receiver. During the early part of this effort, ArcPad was only capable of correcting the position of point features in the field. We therefore used our GPS units to correct the location of node features such as water valves, pressure reducers, hydrants, and sanitary sewer manholes. The line work associated with these features were then adjusted accordingly using scripting for ArcGIS and manual manipulation in the office. This method proved to be effective for improving positional accuracy of digitized features; however, it became time-consuming and confusing when used to collect new features in the field that had not already been digitized. This led us to determine that AUD would need a more robust ArcPad application to empower their inspectors and maintenance staff with the ability to capture new utility components as they are installed. To accomplish this, KHAFRA created an ArcPad applet using ArcPad Studio that provided custom toolbars and tools for maintaining the County's water distribution and sanitary sewer collection systems layers.

Maintaining Utility Asset Inventory Using ArcPad Applets

There were a number of important issues that had to be addressed by the tool suite. First, AUD wanted to track who collected the data or made any changes to the utility layers. Because they would have around 12 handheld DGPS units in use by late 2003, it was imperative that any changes made to the layers on the units be flagged for auditing and indicate which field crew made the changes or additions. It was also important to simplify data management on the units so the end-user could not accidentally overwrite data or lose work due to improper file management. To address these concerns, routines were added upon launching ArcPad that requires the crewmembers to identify themselves. The list of available crewmembers can be modified as necessary; however, ArcPad will not run unless the crew is defined. If the user cancels the screen, they are prompted to "Close ArcPad?" and given the opportunity again to define the crew (Figure 3). To simplify data management, one source folder was added to the permanent memory of each unit (referred to as the "disk"). When the tools are used, the map is checked to ensure all of the necessary layers are loaded. If they are not, the user receives the dialog in Figure 4 and is asked to identify either an existing dataset or to create a new one. The datasets are folders defined under the source folder that contains all of the relevant shapefiles associated with an area. If the user would like to create a new folder to capture new information in a development, they can do so by entering a folder name and pressing the "Make New" button. If they do, the folder is created under the source folder and a set of template shapefiles are copied into the folder. The templates are empty shapefiles that contain all of the fields and customizations needed by the tools to work properly. This method allows AUD to make adjustments to the customized forms associated with the shapefiles without having to reprogram any of the scripts or tools.

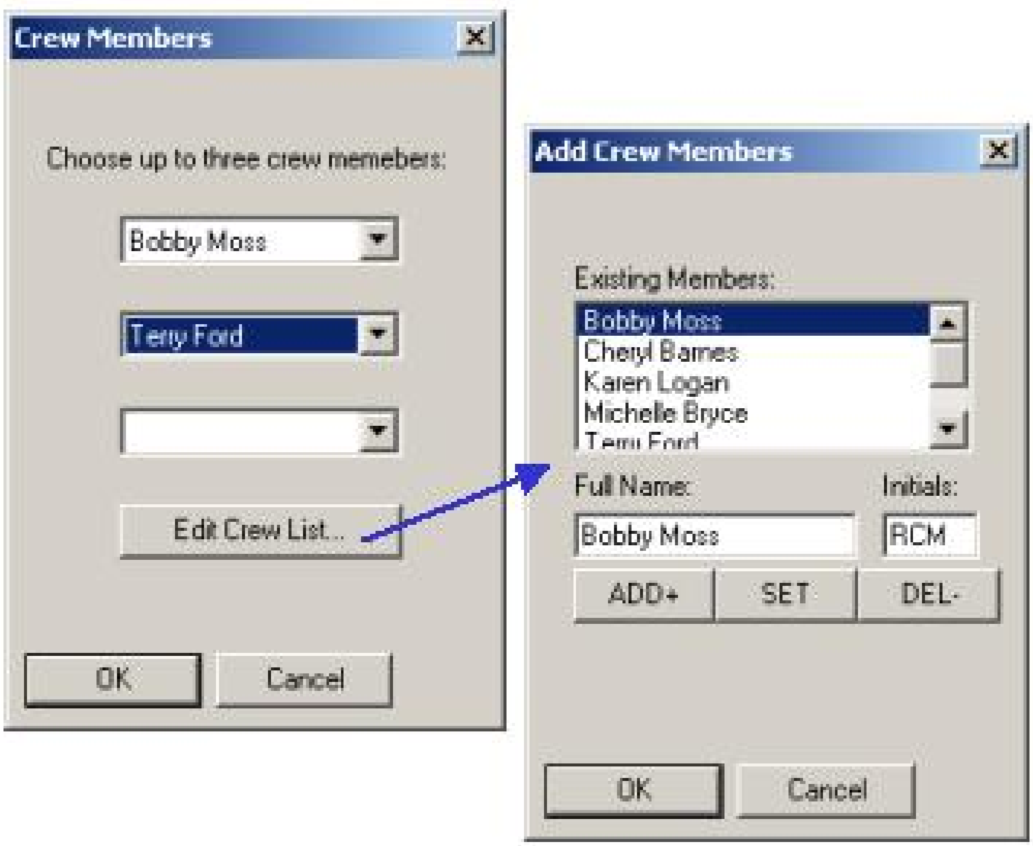

Figure 3: Assign Crew Members

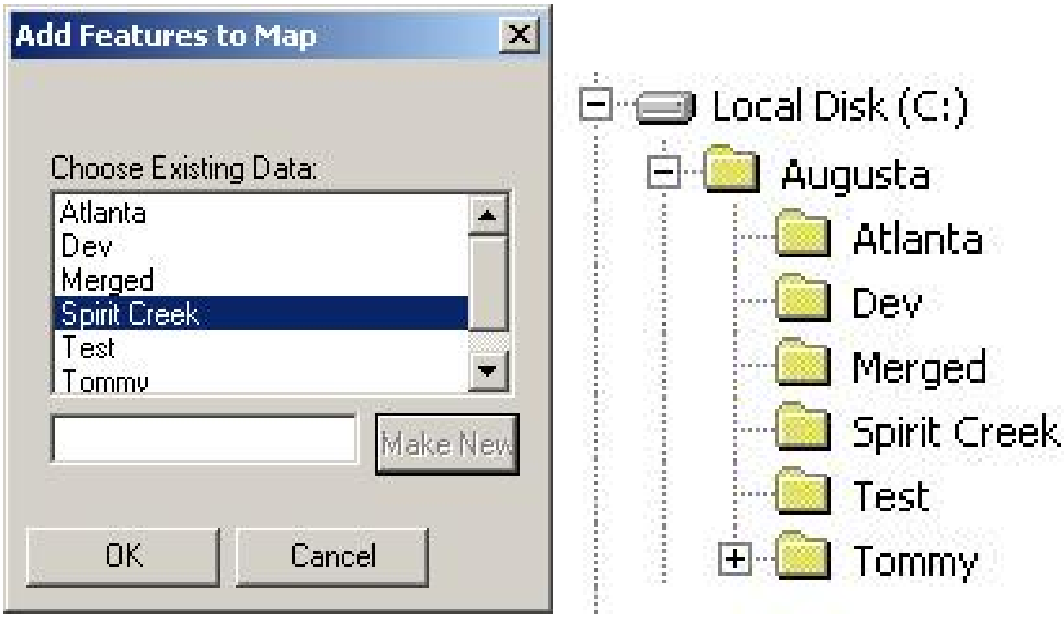

Figure 4: Data Management

Sewer Tools

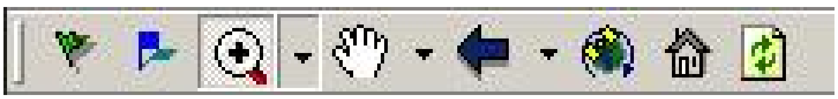

Figure 5: Utility Toolbar

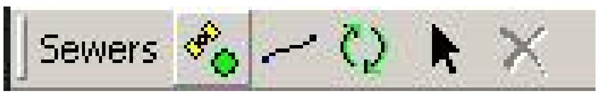

Figure 6: Sewer Toolbar

Once in ArcPad, the crew is presented with the custom toolbar illustrated in Figure 5. The first button launches the Sewer Toolbar shown in Figure 6 and hides the Water Toolbar if it is visible. The first tool allows the capture of sanitary sewer manholes using the GPS location. The crew simply holds the unit over the manhole and taps this button to begin capturing the point. While the unit acquires the point, the crew is able to enter key information about the manhole into the custom form shown in Figure 7. Because there are times when it is unsafe or impractical to gain direct access to the manhole, we added an offset tab that allows the crew to enter a distance and bearing to the manhole from their unit's location. To reduce positional error, the offset distance is limited to no more than 25 feet. Once the point has been captured, ArcPad returns to the map and allows the crew to continue to the next feature.

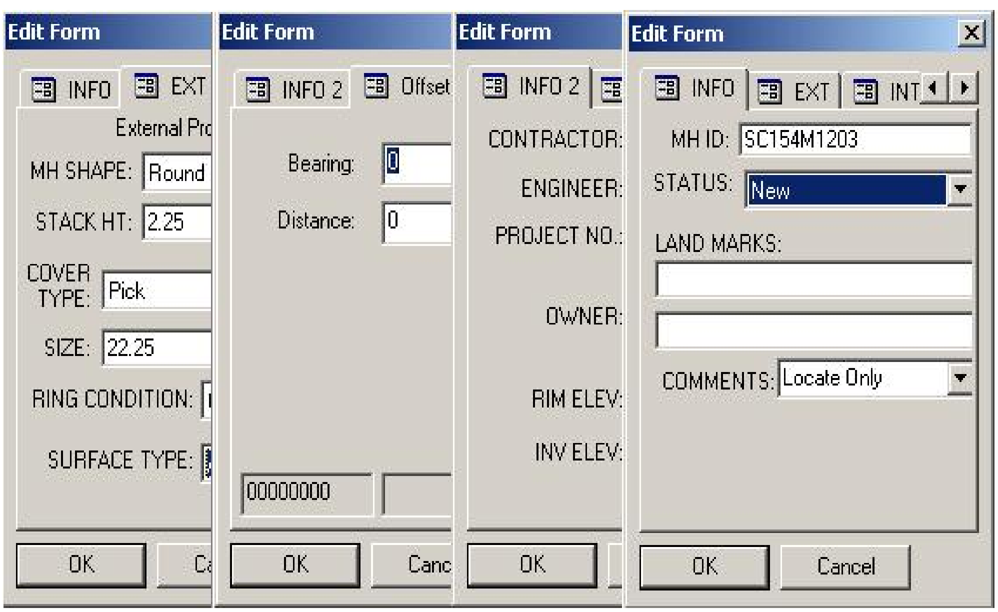

Figure 7: Sewer Manhole Edit Form

Once two or more manholes have been captured, the Draw Sewerline tool can be used to connect them or to join them to existing structures. The crew simply draws a line from upstream to downstream to connect the manholes. The tool captures information from the affected manholes, assigns that data to the sewerline, and performs some basic calculations such as line length and slope (Figure 8). If the resulting slope is negative (or indicates the line is flowing uphill), the crew is prompted to verify flow direction. The third tool is used to reverse the flow direction of the line by swapping its endpoints and recalculating its slope. Again if this change results in a negative slope, the crew is prompted to verify connectivity.

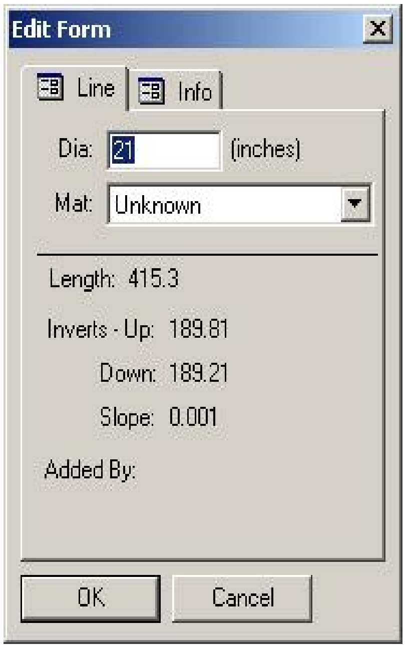

Figure 8: Sewerline Edit Form

The next tool is a custom select tool that controls the order in which manholes and sewer lines are selected. This tool has proven useful in the field to speed the updating of existing features. We also added routines that adjust sewerline endpoints whenever an associated manhole is repositioned in the field and recalculates the line's length and slope. This real-time updating allows the crew to ensure the changes they have made are correct while on location. The final tool on the Sewer Toolbar is a delete feature tool that allows for the deletion of erroneous lines from the database. This is also used whenever a new manhole is added to an existing line to allow the crew to simply delete the old sewerline and draw the two new segments. Because most of the information for the sewerline is taken directly from the manhole information, it was deemed unnecessary to create a separate tool for this purpose.

Water Tools

Figure 9: Water Toolbar

The second button on the Augusta Utility Toolbar is the Water Tools button. This displays the Water Toolbar seen in Figure 9 and conceals the Sewer Toolbar, if visible. Due to the complex nature of water distribution systems, the water tools proved to be a much greater challenge. Together with AUD, we decided to collect water mains, valves, hydrants, and nodes. The water node layer stores information on tees, wyes, crosses, bends, ells, etc…. For AUD's purposes, water mains will always run between water nodes. A line will start at a tee or cross or similar feature and travel through bends and ells until it reaches another node. To capture water information, the crew begins by adding a water node using the Add Node button. If they are within 5-feet of an existing node, they are prompted to use that node as their starting point. If the node was previously captured using GPS, it can be used without being re-shot. Otherwise, the crew will be asked to update the location with GPS. The node's edit form in Figure 10 shows the possible node types being collected by the crews. Once the starting node has been identified, the crew simply moves on to the next key node on the line such as a bend or intersection.

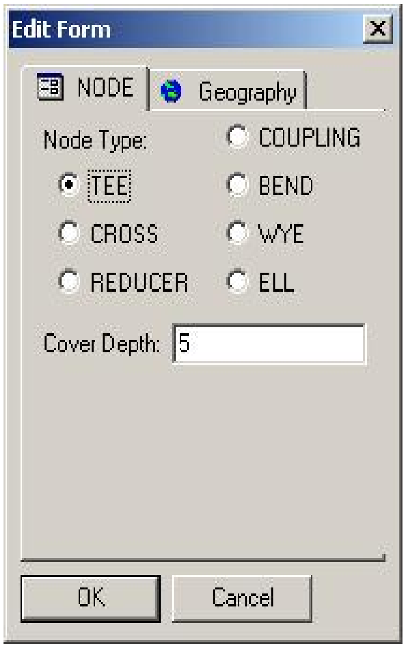

Figure 10: Water Node Edit Form

The crew then uses the appropriate button to identify whether the next vertex feature is a node, valve or hydrant. If the user indicates the point is simply a vertex in the line such as a bend or ell, that vertex is added to the line and the user moves on. However, if the user indicates that the vertex is the end of this line segment by indicating a valve, tee, cross, wye, or the like, then the user is allowed to enter the relevant information for the point-feature and is prompted with the edit form for the line itself. Once the line size and material has been identified, the node-features associated with it are then updated to reflect that information. If the line started at a Tee, the Tee node's description will be adjusted to indicate that instead of an 8x?x8 Tee, it is actually an 8x6x8 Ductile Iron Tee. This eliminates redundant data entry and ensures consistency between feature classes. Figure 11 shows the edit forms for other water features collected.

If a water feature is already in the GIS but needs to be moved or corrected, the Select Tool is used to select the nodes and/or features along the water main. Similar to the Sewer's Select Tool, it will select water point features such as nodes or valves and then look for waterlines. The tools were built to enforce a type of topology between the nodes and linear features so if a node is repositioned, the corresponding line is adjusted. Likewise, if a vertex of the line is moved using the Edit Vertex tool, the associated nodes will be adjusted accordingly. The ability to perform these functions in real-time is a great improvement over earlier versions of ArcPad where such adjustments had to be made in the office where the user lacked crucial real-world references.

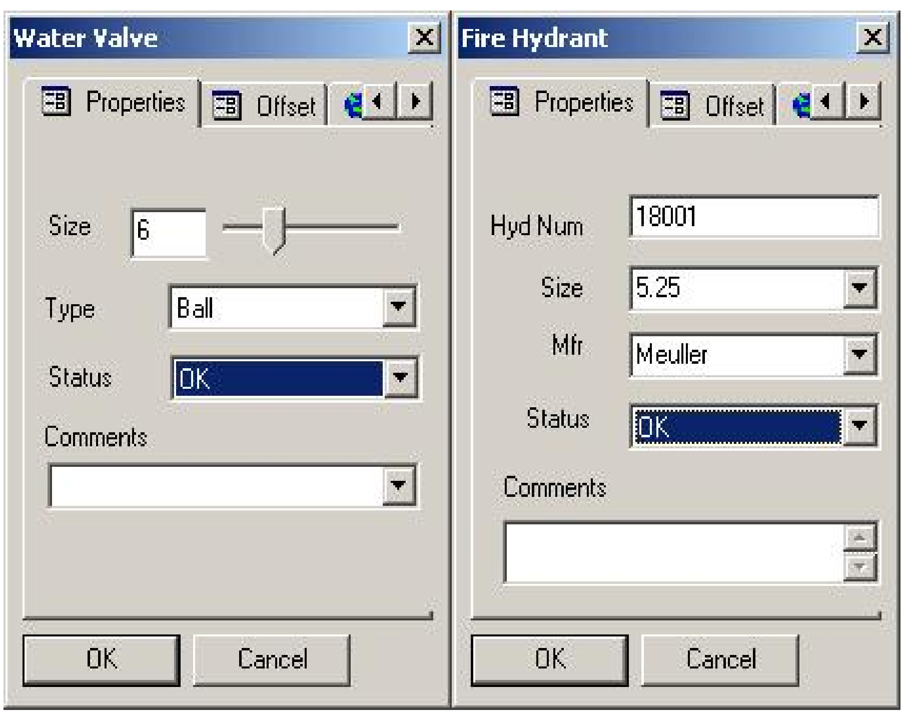

Figure 11: Water Valve and Fire Hydrant Edit Forms

Data Synchronization/Management

The final aspect of using handheld devices for utility asset management is the development of data synchronization tools as well as ArcGIS tools to allow for effective data management. Due to the large number of field crews that will ultimately be collecting information in the field, it is important to outline clear data management procedures that will enable the key people in AUD who bear ultimate responsibility for the data to review field data and incorporate it into the GIS. Our approach is to enhance Microsoft ActiveSync's synchronization functions to allow the source folder on each unit to be synchronized with a corresponding folder on AUD's network. In this way, a docking station can be used to sync the units when they come in from the field so the network folder is updated and AUD's Computer Maintenance Management System (CMMS) Managers can assign data that needs to be field-verified to a crew's folder so they have the information the next time they synchronize their unit.

To clearly delineate what new information was added in the field, the identifier field is left empty by the handheld units and an audit field is flagged as the information is captured. Once the data is available to the CMMS Managers, they verify the validity of the data and launch a check-in tool in ArcGIS that assigns a unique identifier based on AUD's naming convention and resets the audit field. AUD's GIS is then updated with the new information. In this way, multiple crews can be working with the same base data without the chance of losing work due to file overwrites or other data management pitfalls.

Conclusion

A multi-pronged approach to utility asset management is necessary to successfully develop a comprehensive inventory and maintain its veracity. While ArcView and record drawings provided a good base from which to build the County's utility GIS layers, fieldwork was necessary to give them a complete picture of their utility assets. ArcPad proved to be a powerful tool that allowed controls to be put in place to mitigate common data collection problems and to simplify the work of the field crews.

Acknowledgments

Much of the work performed throughout the project illustrated in this paper would not have been possible without the assistance of the Augusta Utility Department staff. With their outstanding cooperation, KHAFRA was able to gain a clear understanding of the issues AUD wanted to address with their GIS data and design our approach accordingly. Also, their knowledge of their utility system provided invaluable guidance to our crews throughout our field-location efforts.

We would like to particularly acknowledge the contributions of the following people for their time and assistance:

N. Max Hicks, P.E., Director
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