PRACTICAL APPLICATIONS OF GIS FOR WATER RESOURCES GWINNETT COUNTY CASE STUDY

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Abstract: This paper aims to describe the implementation of Geographic Information Systems (GIS) in the engineering practices of water resources management using Gwinnett County, Georgia as a case study. The availability of sophisticated GIS data sets by local, state, federal and private agencies and the development of standardized data models like ArcHydro have provided a wealth of valuable data enabling the generation of watershed simulation models in a GIS environment. Many of the traditional tasks that engineers and scientists have performed manually can be automated allowing the modeler to perform detailed hydrologic and hydraulic studies in more depth, in less time and of superior quality. Over the past five years, Dewberry has been using Gwinnett County's GIS datasets to model seven large watersheds within the county providing floodplain maps for both existing and future watershed conditions.

INTRODUCTION

As land use patterns change and influence the hydrology of watersheds, old floodplain maps become outdated and fail to accurately identify flood hazard areas resulting in flood looses outside of the Special Flood Hazard Area (SFHA) or 100-year floodplains determined by FEMA. In order to stay abreast of land use changes and their hydrologic effects, Gwinnett County became a Cooperating Technical Partner (CTP) with FEMA in 2001 shortly after they began their initiative to modernize their floodplain maps that were last updated in the 1970's and 1980's. Traditionally, ground surveys and USGS quad maps were used to determine topography and land use patterns that enabled hydrologic and hydraulic simulation models to be built and to determine floodplains and base flood elevations. The availability of sophisticated GIS data sets held by Gwinnett County provided a wealth of valuable data thus enabling Dewberry to map floodplains using GIS as both a pre and post processor for engineering modeling applications. GIS based modeling has enabled automation of many of the traditional engineering techniques, reducing time and cost and has dramatically improved the quality of hydraulic and hydrologic simulation models by allowing modeling in greater detail with much improved accuracy and efficiency.

TERRAIN MODELING USING LIGHT DETECTION AND RANGING

One of the greatest developments for water resources has been the use of Light Detection and Ranging (LiDAR), which has provided accurate topographic data suitable for delineating floodplains, delineating watersheds, extracting cross section information and identifying structures and obstructions. The ability of LiDAR to receive multiple returns and the near vertical nature of capturing data compared to stereo oblique imagery used in photogrametric surveying allows good quality bare earth survey even in wooded areas. LiDAR has reduced the amount of detailed surveying needed to determine the geometry of rivers and structures and can be used to accurately delineate floodplains. A single laser pulse fired from an aircraft may generate multiple returns. This is because as the pulse travels towards the earth, it spreads out slightly. In areas where vegetation or obstructions exist, it is possible that the single pulse will capture various elevations. Taking the example of a pulse hitting a tree, part of the pulse may hit the top of the tree producing the first return, another part of the pulse may hit a branch creating a second return and hopefully the last return of the pulse will hit the bare earth. The last return provides a great starting point to producing a terrain model that represents the bare earth that can be used for hydrologic and hydraulic modeling. Because some pulses may never reach the ground, post processing is needed to create a bare earth surface. Automated techniques have been developed that are able to identify sudden changes in elevation between adjacent points indicating part of an obstruction that may have been the only return or where no returns reached the bare earth. Flat areas of rectilinear shape commonly indicate buildings which must be removed to generate a bare earth terrain model. Automated post processing of LiDAR typically only cleans up approximately 90% of obstructions. Careful inspection of the terrain model must be conducted before using the data in order to ensure that all buildings and vegetation are removed and that topographic features are preserved. Traditionally many floodplain studies were limited by funding available for detailed surveying which severely impacted the accuracy of the models. During the Gwinnett County Flood Studies, the use of LiDAR enabled additional cross sections to be determined with no additional survey cost and only minimal engineering cost which included field verification and sub water-surface geometry assumptions to be made. Comparisons between LiDAR data and survey data have proven that LiDAR is an effective way of capturing floodplain geometry with only minor adjustments being required to capture sub water-surface geometry. The accuracy of LiDAR sections is often reduced in densely vegetated areas where fewer returns reach the bare earth and the random nature of vegetation makes automated post processing of data more difficult. Small channels also reduce the accuracy of LiDAR sections since higher numbers of points are required to define the channel. Simple field measurements of channel depth from the top of banks was sufficient to complete the sub water-surface geometry of cross sections cut from LiDAR data terrain models in most areas of Gwinnett County.

HYDROLOGIC MODELING USING GIS

Digital terrain modeling technologies has allowed the often tedious task of watershed delineation to be automated. By generating a digital elevation model (DEM) and using GIS applications, drainage paths, stream junctions and watersheds can be determined and used to create a hydrologic stream network. Man-made alterations to watersheds and natural sink areas can cause problems when automating watershed delineations and require hydrologic correction. Hydrologic correction is the process where a terrain model is forced to allow any hypothetical raindrop on the DEM to runoff to the outlet of the watershed. Road embankments and natural sinks in a DEM create a trap for raindrops for which there is no way out. To hydro correct a DEM, any natural sinks need to be artificially filled in the DEM to allow a raindrop to runoff downstream. Any form of embankment or dam across a valley requires either breaching in the DEM to allow it to drain or if suitable, filling of the area behind it to create a flat surface for which a raindrop can find a way out. This obviously changes the DEM significantly which is why breaching of the embankment is preferable to minimize any changes from the original data. Any spatial lines representing culvert barrels, stream centerlines or manually specified breach lines can be used to burn holes through embankments allowing full drainage of the sink while minimizing changes to the DEM. This process is often referred to as DEM Reconditioning. Careful reconditioning of the digital terrain model is the most effective way to ensure that the automated delineations are accurate and will not require manual clean up.

Digital land use maps for both existing and future conditions and soil maps enable detailed rainfall-runoff relationships to be developed for watersheds in high detail. In Gwinnett County, the use of the digital land use maps allowed the watershed sub-basins to be overlaid on both the land use and the digital soil maps and referenced to a database to automatically determine the Natural Resources Conservation Service's (NRCS) Curve Numbers. Simple geo-processes allow watersheds, land use and soil types to be unioned and cross referenced with a predefined curve number table to calculate composite curve numbers for individual sub watersheds. The existing land use was later substituted with future land use to determine curve numbers for future conditions. The ability to determine future curve numbers by simply substituting existing land use with future land use allowed Gwinnett County to meet the floodplain mapping requirements of both FEMA who requires existing conditions floodplains and the Metropolitan North Georgia Water Planning District who require both existing and future condition floodplains.

HYDRAULIC MODELING USING GIS

GIS can be used as a preprocessor for simulation models like HEC-RAS and EPA-SWMM. Digital terrain points and breaklines provided by traditional ground surveying or remote sensing can be used to generate a Triangulated Irregular Network (TIN) which can be used to generate the geometry required for cross sections and structure modeling. Digital stream centerlines, bank lines, flow path lines, land use polygons and structure survey information allows the automated generation of HEC-RAS geometry in HEC-GeoRAS, a pre and post processor GIS application designed specifically for HEC-RAS hydraulic models. GeoRAS includes the ability to generate cross section station/elevation data, calculate channel and overbank reach lengths from flow lines, bank station location and Manning's N value assignment based on land use as well as storage area volumes and levee alignment. This can be easily imported into HEC-RAS to perform hydraulic simulations. Using GIS based methods to construct hydraulic models has dramatically improved the consistency of models and increased the level of detail and accuracy of data generated.

POST PROCESSING OF HYDRAULIC MODELING

GIS also provides a very useful mechanism for post processing of hydraulic simulations by exporting the simulation results back into the GIS system for analysis and mapping. Probably the most significant use of GIS for post-processing is that for automated floodplain delineation. Assigning the calculated water surface elevations to the spatial cross sections in the GIS environment, allows an artificial 3-d water surface digital terrain model to be created and overlaid on the bare earth digital terrain model. Intersecting the water surface model and the bare earth model allows the flood plain to be determined and converted into a polygon which can be used to generate floodplain maps.

HYDROLOGIC DATA MODELS AND DATA STORAGE

Geodatabase developments have provided a new way to store hydrologic data in a way that is easy for both engineers and GIS specialists to use. The ArcHydro data model developed at the University of Texas enables a watershed to be described in a single geodatabase which can be used by GIS based hydrologic and hydraulic models to simulate watersheds. A data model is different from a simulation model since it provides a standardized framework for storing data which simulation models can both pull from and write to. If implemented effectively, ArcHydro becomes a good hydrologic information system for retrieving and analyzing hydrologic data. The ArcHydro data model divides water resources data into five components:

- Network – connected sets of points and lines showing pathways of water flow.
- Drainage – drainage areas and stream lines defined from surface topography.
- Channel – A 3-d line representation of the shape of river and stream channels.
- Hydrography - the base data from topographic maps and tabular data inventories.
- Time series – Tabular attribute data describing time-varying water properties for any hydro feature. (Maidment, 2002).

The ArcHydro Toolset enables the automation of drainage area delineation, streamlines and building of a stream network. This data is automatically stored in an ArcHydro geodatabase. Alternatively ArcCatalog, a data management application which is part of ArcGIS desktop, can be used to manage and import existing datasets into an ArcHydro geodatabase.

As flood events occur as experienced during Hurricane Ivan in 2004 and the flood events in the summer of 2003, recorded measurements from rainfall gages, radar, high-water marks and flow/stage gages, provide valuable data that can be used to calibrate and verify hydrologic and hydraulic models. The ArcHydro time-series component will provide an effective way to store hydrologic time series including NEXRAD Radar Rainfall information. NEXRAD data provides spatially distributed rainfall data for the entire United States which can be used to simulate observed rainfall events for calibration and verification. When analyzed, NEXRAD rainfall data can provide gridded rainfall data for observed storm events that can be imported into ArcGIS for analysis. Typically storm events that occurred over the last 2 years can be obtained in 1 kilometer grid cell sizes at 5 minute time intervals. Older data is typically available in 2 kilometer grid cell sizes at 15 minute time intervals (Curtis, 2004).

Geodatabases provide a very efficient way of storing spatial data by reducing multiple datasets to one single database file from many individual files. The arrival of ArcGIS 8.x and 9.x has allowed geodatabases to be implemented into GIS systems using these platforms. Previous versions of ArcGIS commonly used shapefiles. A single shapefile consisted of a minimum of 3 individual files making up the one set of spatial data. A watershed model could typically consist of 15 or more shapefiles amounting to a minimum of 45 individual files. Transferring this data to a geodatabase would reduce these 45 files to just one file. A common platform for a geodatabase is the Microsoft Access database environment. Microsoft Access has some limitations including having a 2GB data size limit which can quickly be exceeded if large raster datasets are used. Also the inability for multiple users to access the database simultaneously creates a serious limitation for an enterprise where multiple users are likely to be working on the same project. Where multiple users require access to the database and data sizes are likely to get large, Microsoft SQL Server and Oracle databases are able to be used in conjunction with ESRI’s Spatial Database Engine (SDE) which acts as a bridge between an enterprise wide database and GIS applications.

For the Suwannee Creek Flood Study which has recently been conducted by Dewberry, GeoRAS version 8 was used to develop the geometry for the HEC-RAS hydraulic models. GeoRAS version 8 is currently in beta testing but when tested by Dewberry has proved to be robust enough to use on this flood study. GeoRAS version 8 enabled Dewberry to use a geodatabase based around the ArcHydro methodology to store geometric data in a GIS environment. This data could then be exported to HEC-RAS to determine flood elevations. This single database approach to watershed modeling reduced the number of individual files and enabled data to be easily located by numerous engineers working on the project.

The HEC-RAS and HEC-HMS Interface Data Models (IDMs) currently being developed at the University of Texas at Austin, expand on the ArcHydro methodology and will provide a portal for transferring data between both simulation and data models. As time progresses and flood maps once again become outdated, these geodatabases will allow new and updated datasets to substitute older data sets and allow simulation models to be rerun to determine new floodplains at a fraction of the expense and effort of the earlier studies.

READILY AVAILABLE DATASETS

There are a number of national datasets available including the National Elevation Dataset (NED) which is a DEM of varying grid size covering the entire United States. Although this data is typically of low detail (commonly 30-meter grid cells), this is often sufficient for automated hydrology to determine watersheds or for studies that do not require a high level of detail. The NED was used several times where rivers in Gwinnett had contributing watersheds upstream of the Gwinnett County boundary where the county's LiDAR data was not available. Since only hydrologic modeling was performed beyond the county line, detailed topography was not needed. The national hydrology dataset is also another very useful tool which can be used to identify the hydrography of a watershed. The United States Geological Survey Digital Ortho Quarter Quadrangles (DOQQs) provide aerial imagery which can be used to identify any features like reservoirs or other structures that may be of interest for analysis of a watershed. This can dramatically reduce the amount of time spent conducting field reconnaissance before performing a study of a watershed. Often local data generated by local communities or state organizations is of greater detail and more up to date than readily available national data sets. In the metro Atlanta area, the Atlanta Regional Information System (ARIS) produced by the Atlanta Regional Commission provides numerous GIS datasets including hydrography, DOQQs, and land use polygons. A full investigation into available data should be carried out before conducting any study and implementing GIS in engineering and scientific practices to ensure that the best available data is used.

THE FUTURE OF GWINNETT COUNTY'S HYDROLOGIC AND HYDRAULIC MODELS

Since Gwinnett County is now close to completing its restudy of the county's watersheds, the focus now moves from building models, to maintaining them and keeping them up to date with current land conditions. A small number of watersheds studied in Gwinnett used more traditional methods to build the hydraulic and hydrologic models. To achieve a common county wide geodatabase, these models will need to be spatially referenced and imported from the HEC-RAS and HEC-HMS models. The HEC-RAS and HEC-HMS IDMs should provide an effective portal for this transfer of the models into a GIS environment.

Gwinnett County is re-flying LiDAR in 2005 which will provide newer topographic data and base map data reflecting all developments that have occurred since the last flight in 2000. Using the GIS based models for the numerous watersheds within the county will allow the effects of these developments to be easily determined by substituting the existing geometry with the newer information from the 2005 flight to generate revised flood elevations and floodplain delineations.

The GIS based models will allow the user to quickly modify the models if greater detail is needed in a localized area. This could include determining the effects of a proposed bridge or culvert on the flood elevations to ensure that it does not have any adverse effects on surrounding properties.

CONCLUSION

Implementing GIS in the Gwinnett County Flood Studies enabled watersheds to be simulated in the level of detail once only imaginable with a limitless budget and project duration. As part of Gwinnett County's Cooperating Technical Partner agreement with FEMA, the flood studies conducted in the county are now becoming part of the new Gwinnett County Flood Insurance Study, being produced as part of the state of Georgia's effort in FEMA's Flood Map Modernization Program.

In the future, enterprise geodatabases will enable multiple users and applications to access the most up to date data concurrently for analysis. The cost of model maintenance will be drastically reduced as revised data will be able to be substituted for older data enabling simulation models to be run with only minor preparation work. In Gwinnett County the test of time will prove the performance of the watershed models generated using GIS compared to those that were generated using traditional methods.

REFERENCES

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