Arc Hydro in Florida: Lessons Learned and Emerging Technologies

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The Water Institute
Wendy Graham, Director

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and
Department of Water Resources, St. Johns River Water Management District
Arc Hydro is the meeting ground for two worlds – Water Resources and Relational Database Architecture. To the new user, who is typically familiar with one but not both worlds, Arc Hydro concepts can seem like esoteric knowledge; obscured in a mixture of terms and concepts that are rapidly taken for granted by the experienced users; frequently left unexplained to the new users.

Here is your chance to get many of those annoying questions answered, and to listen smugly as I explain the other half, to which you know the answers already, to the other people.

What is meant by Arc Hydro? Is it a database, or a computer program? What is a data model, and how is it different from a simulation model like SWMM or HEC-RAS? I know what a data model is, what is a simulation model? And just what is a relational geodatabase anyway? What is meant by “relationships” and how do I get one? What are the relationships in Arc Hydro, how are they created, and what are they good for?

Figure 1. Example of using a database relationship to link a watershed to its stream network.

A Watershed is a polygon which is connected to the hydro network through a relationship to the HydroJunction at its outlet.

The HydroID of the HydroJunction is assigned to be the JunctionID of the Watershed.

Figure 1. Example of using a database relationship to link a watershed to its stream network.

Before we get to this slide, we will explain what are Hydro ID’s and Hydrojunctons.

Courtesy: Dr. David Maidment. Center for Research in Water Resources

Presenter: Jack Hampson, CFM, CMS; National Project Director-Water Resources Technologies; PBS&J; 5300 West Cypress Street; Tampa, FL 33607; jchampson@pbsj.com; 813-281-8368.
Florida Arc Hydro History 101: Overview of the implementation of Arc Hydro at Florida Water Management Districts

Jim Cameron
South Florida Water Management District

In addition to providing a brief history of Arc Hydro development in Florida, this talk will cover how the Florida Arc Hydro Working Group (FAHWG) and the Florida Arc Hydro Users Group (FLAHUG) came in to being and what they are accomplishing for the benefit of water resource management in Florida.

Both FAHWG and FLAHUG are composed of individuals actively using and developing Arc Hydro from Florida’s Water Management District’s, State of Florida Department of Environmental Protection, various county and local government agencies, universities and private business interests.

The objectives of FAHWG include: Development of a common collection of core datasets to support each stakeholder’s requirements and enable data exchange; Identify common core fields maintained within these core datasets; and Identify data maintenance methodology for support of these core datasets.

FLAHUG’s objectives include: Provide a forum for the exploration of barriers to, and potential solutions for implementing the Arc Hydro water resources model in Florida; Increase the educational level of Arc Hydro throughout the state; Facilitate Arc Hydro training opportunities in Florida; and Create a community to provide feedback to the FAHWG for tool and database issues.
In 2003, the South Florida Water Management District (SFWMD) began developing the Arc Hydro Enhanced Database (AHED) as the storehouse for District hydrological feature locations. AHED is based on the Arc Hydro model, an ArcGIS data model for hydrologic information developed by the Center for Research in Water Resources (CRWR) at the University of Texas and ESRI in collaboration with representatives from academic, government agencies, and private sector resources. CRWR, ESRI, and PBS & J all acted as consultants with the District in developing the AHED prototype. As part of the prototype, the District and consultant team developed four hydrologic modeling tools that have overlapping data needs that can be met through the common AHED data structure:

1. Hydroperiod Tool: to help determine the time pattern of inundation over a selected spatial region;
2. Operations Decision Support System: to allow the integration of Operations decisions with GIS;
3. Flood Hydrology and Hydraulics: to link flood models to GIS for better flood management
4. Regional Simulation Model: to coordinate RSM development with AHED

Database population for a small part of the District was implemented as part of the AHED Pilot project.

In the current timeframe, we have moved on to the first phase of wide-scale AHED database population. The current data ingestion process will input all hydrological features contained within the blue area in the illustration to the right into a common Arc Hydro schema in a common ArcSDE database environment. This will mark a significant improvement over the current District storage methods for its hydrological feature location data and data on structures. Rather than having layers distributed among different databases, the AHED project will establish a single database of record for District features to be available to District users, partners, and projects. The project is also expected to improve data quality and reduce data redundancy by focusing quality efforts and governance processes on this single database-of-record. Part of the challenge of this project beyond the sheer volume of data that must be input into the new schema, is in changing our data management and governance processes to allow for efficient use of the new system.

The first data ingestion phase is expected to be finished by the end of calendar year 2007, and further phases will follow until all District hydrologic features are part of the database.
Since the establishment of the Southwest Florida Water Management District (District) in the 1960s, the District has been involved in evolving efforts to understand how a watershed responds to the hydrologic cycle. These efforts include data analysis and modeling, which are some of the components in the Watershed Management Program (WMP) as administered by the Resource Management Engineering Section. As a result of these efforts, a centralized, standardized database supporting business and spatial data was identified as necessary for the storage, sharing, maintenance, and history requirements of the WMP.

The Geographic Watershed Information System (GWIS) design originated from the ArcHydro surface water resources data model as developed by the Center for Water Resources Consortium and Environmental Systems Research Institute (ESRI). In 2004, the “core” ArcHydro data model was evaluated for District surface water requirements and has since been expanded on to meet the user requirements and business processes of the WMP. Initial database design efforts were completed by ESRI staff, however, elaboration of requirements necessitated enhancements and modifications completed by District staff.

Enhancements and modifications were made to two areas of the “core” ArcHydro tools and database to customize it to the SWFWMD’s needs. (1) Custom tools were constructed to produce hydrologically correct flow direction grids in the deranged terrains found in south-central Florida, and (2) a new feature class, the HydraulicElementPoints, was created to model below surface connectivity (culverts, etc.) between catchments.

GWIS/ArcHydro development team (SWFWMD): Gordon McClung, Jamison Janke, Diana Burdick, and Al Karlin
Consultants contributing: Dean Djokic, Christine Dartiguenave, Sreeresh Sreedhar (ESRI) and Alan Foley (Jones, Edmunds and Assoc.)
In November 2006, the St. Johns River Water Management District (SJRWMD) began construction of an Arc Hydro-based geodatabase, called the Water Resources Geodatabase, using high resolution NHD and SJRWMD data layers. The first version is now complete, although the repair of known errors is still ongoing, and further development will occur in 2008.

Prior to this project, staff in the SJRWMD’s Surface Water Quality Monitoring Program had successfully proven the utility of the Arc Hydro data structure for supporting GIS analyses related to water quality. This success enabled funding for construction of the higher resolution geodatabase, for use by a wider District audience. In the new geodatabase, the focus continues to be the incorporation of monitoring stations, as well as core hydrographic layers such as waterbodies.

The geodatabase was constructed using NHD Flowlines, Areas, and Waterbodies, SJRWMD drainage basins, and point layers from internal SJRWMD tabular databases. The most time consuming task was the development of waterbody outlets, one of the primary inputs to the HydroJunction feature class. The most challenging task was development of the monitoring station point layers, which were derived from very complex and multi-purpose tabular database tables.

The biggest problem we encountered was caused by duplicate and overlapping features in the NHDWaterbody and NHDArea layers, which are inputs to our Waterbody feature class. Prior to the project, SJRWMD had spent significant resources revising the NHDFlowline layers; this investment paid off in that the resulting HydroEdges required very little repair. But we had not revised the NHDWaterbody or NHDArea layers.

The District is also developing a tool for cataloging and visualizing Hydrologic Simulation Program Fortran (HSPF) model results, using the Water Resources Geodatabase as the spatial reference. The short-term goal is to enable ArcMap users to access and query HSPF model results; the long term goal is to provide this information in a web-based application.

The presentation will also address other lessons learned, known errors in the geodatabase that are being fixed, and what the next steps in the project will be.

Project team:

- SJRWMD staff: Christine Mundy, Ellen Dean, Chun Chen
- Contracted staff: Sumit Sharma, Doug Campbell
- HSPF tool consultants: HydroGeologic, Inc. and AquaTerra
With continued development in coastal environments, on-going assessment of their health is important but has been difficult due to the complex geomorphology, hydrodynamics and biogeochemistry of these systems. Assessment has traditionally been tackled with commensurately complex supercomputer-based modeling techniques. While these technologies provide useful results, their computational, intellectual, and financial expense renders them unavailable to most coastal professionals.

To better understand estuarine systems the Surface Water Quality Monitoring Program at the St. Johns River Water Management District developed a new methodology, the Analytical Framework for Coastal and Estuarine Study (ACES), with the assistance of a team of academic, governmental, and industry experts. ACES is designed to augment the successful Arc Hydro data model that falters in coastal applications by creating an environment where data from diverse sources can be synthesized. ACES is composed of 1) a GIS-based database (schema) of spatial and temporal data that describe the environment, and 2) an accompanying ESRI ArcMap-based toolset, or workbench, employing first-principles modeling tools.

The methodology focuses on first-principles-analysis of the estuary. First, the relative importance of tidal versus terrestrial flow is assessed using bulk parameters derived from geomorphology and measured flows in the estuary. Then, a control volume is defined by intersecting the tidal-plane and estuary bathymetry. Boundaries of the control volume are user-defined through qualitative knowledge of the flow field.

Regression or other model approaches aimed at finding the correlative relationships between the influential factors of upstream riverine drainage, coastal drainage, and estuarine non-point source pollution are subsequently derived.

A pilot case study applying the methodology to the Guana-Tolomato-Matanzas (St. Augustine inlet) estuary is under development. The multiple linear regression modeling capabilities of the ACES Workbench will be used to evaluate the relationship between discharge and salinity data for the pilot estuary. The required data for the remaining SJRWMD estuarine areas will be compiled and loaded into the ACES geodatabase, as well. Application of the ACES workbench to other estuarine areas, particularly by other members of the development team is anticipated. (As with Arc Hydro, the ACES toolset is considered to be in the public domain.)
One of five water management districts in Florida, the South Florida Water Management District (SFWMD) is responsible for regional flood control, water supply and water quality protection as well as ecosystem restoration in the Southern portion of Florida. Operationally, this responsibility translates to real-time control of 168 water control systems (WCS). Analogous to watersheds in most respects, the water control systems differ in that they have control structures to regulate flow between the systems and out of SFWMD boundaries. Efficient control of these structures ensures that the multiple water resources objectives are met.

SFWMD is building an operational decision support system (ODSS) for control of its water-control systems. A critical source of information for the ODSS is a water-budget-based real-time assessment of system state, which is implemented as the WCS Tracker application. As an extension to ESRI’s ArcMap software coupled with an enterprise geo-database, the WCS Tracker application receives real-time measurements of gage and radar-based rainfall, gage-based evapotranspiration, and flow and stage measurement of the WCS control structures. By way of various interpolation schemes, this input is re-analyzed into a regular time interval and used in a water budget equation to evaluate the storage of water in the water control system. This storage term is an indicator of oncoming overland flow and thus provides advanced warning to aid in control structure decisions.

The WCS Tracker application applies several concepts including water budget theory and uncertainty and error analysis of both the measured and calculated water budget terms. Additionally, the application implements several new technological ideas for broker-driven data supply, hydrologically-derived GIS-based data structures and their attendant relationships, time series management, and GIS-based application development.
The National Science Foundation has funded 11 WATERS Test Bed projects to test various aspects of observatory design and operation. All Test Bed sites are beta test locations for the deployment of a hydrologic information system (HIS) and related project server that enables the Test Beds to archive and publish their own data on the World Wide Web in a standardized relational database schema known as the Observations Data Model (ODM).

The Santa Fe basin Test Bed has published groundwater levels, nitrate sensor data, and individual investigator data in a map interface called DASH. National datasets are also published on the Test Bed HIS systems including data sources such as the USGS National Water Information System (NWIS) and the EPA Storage and Retrieval System (STORET).

The HIS is a geographically distributed network of hydrologic data sources and functions that are integrated using web services. It enables you to query networks of observation sites and to extract observation data from them in the form of time series of measurements at individual sites or collections of them. The goals of the HIS are to unite the nation’s water information, to make it universally accessible and useful. It is a geographic, consistent, efficient way for investigators to share research data and related metadata to enable the synthesis, visualization and evaluation of the behavior of different hydrologic systems.

HIS for Santa Fe Testbed Florida: Wendy Graham, Kathleen McKee
HIS development team: see http://www.cuahsi.org/his/projteam.html

Online Links:
http://ees-his06.ad.ufl.edu/dash/
http://www.cuahsi.org/his/
Arc Hydro Groundwater (AHGW) has been under development for the past three years as an extension or companion to the Arc Hydro surface water data model. This data model will also be published in a book titled "Arc Hydro Groundwater" that will document the data model and provide a series of sample applications. The data model is designed to support various types of groundwater data, including well/borehole data, 3D representations of hydrostratigraphy, and data from simulation models (Strassberg et al. 2007). It is fully compatible with the surface water data model and consists of six primary components:

1. Framework data model. This feature data set is shared with the new Arc Hydro surface water data model and consists of surface water features including streams, lakes, and watershed boundaries. It also includes wells and aquifer boundaries.

2. Wells and boreholes. This component features a vertical measurements table for storing borehole logs and a set of 3D points and lines for rendering well logs in ArcScene.

3. Hydrostratigraphy. This component includes multi-patches, 3D polygons, and rasters for representing geologic volumes and cross sections.

4. Geology. A feature data set used to store geologic maps.

5. Time series. A standardized set of features for storing transient data. Patterned after the time series tools used with the surface water data model.

6. Simulation. A feature data set for storing groundwater simulation models, including both the finite difference and finite element format.

We are currently developing a MODFLOW data model which is an extension to the Simulation component of the AHGW data model. The MODFLOW data model consists of a series of tables and relationships and it supports the storage of an entire MODFLOW simulation within a geodatabase. Having the model in the geodatabase makes it possible to utilize mapping and plotting capabilities of ArcGIS and to develop queries and tools, including tools for populating the MODFLOW package tables using data from the Arc Hydro groundwater and surface water data models. The MODFLOW data model provides an archival tool for models facilitating permissions, check-in/check-out capabilities, and web services.

Arc Hydro Groundwater development team: Norm Jones (BYU – Provo, UT), David Maidment (University of Texas – Austin, TX), Gil Strassberg, Mike Kennard, Alan Lemon, Doug Gallup (Aquaveo – Provo, UT). (SJRWMD, 4049 Reid St., Palatka, FL, 32177)

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Why the Digital Watershed?
Presented to the Florida Arc Hydro Symposium
November 16, 2007

At the heart of Arc Hydro’s reason-for-being lies the Digital Watershed concept. The Digital Watershed binds together the hundreds of data sources needed for a comprehensive approach to Water Resources management. This integrated approach to Water Resources management, built on a shared platform, is the key to balancing the conflicting needs of environmental protection, flood risk protection, and water supply planning.

Creating a digital watershed means creating a realistic representation of a watershed in a spatial database – providing a non-proprietary, widely accessible structure to underlie dynamic decision support applications. To be “dynamic”, a decision support tool must provide the ability to constantly update an easily-understood digest of time-varying data. This capability in turn permits users to track past performance of existing decisions, and to predict future performance of proposed decisions. Underlying dynamic decision support for Water Resources is the concept of the Digital Watershed. The digital watershed integrates time-varying data about water and related environmental conditions in a geographic context, and provides the ability to track the movements of water through the landscape. This is the stated goal of the Arc Hydro data model.

Collaborative projects with universities, state and local agencies and consultants are providing new examples of how relational spatial data models can integrate both measured and predicted water resources data, and feed dynamic-decision-support applications for a growing list of decision support needs. In this way data from many sources, modeled and measured, can be compared statistically in water-balance equations, as hydroperiods, or as ongoing measurements of the effectiveness of water policy decisions. These digested results can be used to support real-time decisions as well as planning decisions for water resources operations, watershed planning, environmental restoration, basin management action plans, emergency response plans, flood risk mapping and more. Once time-varying data are mapped into a relational geodatabase, then ongoing updates to the data tables – both measurements and forecasts – provides the input for dynamic monitoring, tracking, integration and data analyses in a vast array of potential digital watershed applications. The power of the integrated approach being pursued by the Florida Arc Hydro consortium is just beginning to be realized.

Presenter: Jack Hampson, CFM, CMS; National Project Director-Water Resources Technologies; PBS&J; 5300 West Cypress Street; Tampa, FL 33607; jchampson@pbsj.com; 813-281-8368.
Arc Hydro in Florida: what works and what hasn’t (yet).

Alan Foley, P.E.
Jones Edmunds and Associates, Inc.

The Arc Hydro data model has evolved from beginnings as a watershed-scale surface water modeling pre-processor to an enterprise geodatabase schema capable of supporting users and data at multiple scales. The evolution of Arc Hydro has been user driven through trial and some error. Florida Arc Hydro users have pushed significant elements of the Arc Hydro evolution. Just as the Florida landscape was formed through a unique combination of geologic and climatic events, the Florida Arc Hydro experience has been formed through a unique combination of community structure and needs. This presentation will discuss formation of the user community within Florida; some of the significant elements of Arc Hydro data model and tool evolution within Florida; and considerations for continued evolution and community growth.
What’s new in Arc Hydro
ESRI Water Resources Team
Christine Dartiguenave
Redlands, CA

The Arc Hydro tools were originally developed to support dendritic terrain and did not provide a good fit for Florida. As part of a project with Southwest Florida Water Management District, new tools have been developed and incorporated in the Arc Hydro tools to model flat/pitted terrain (a.k.a. deranged terrain) as well as a combination of deranged and dendritic terrains. In parallel to the development of the new tools, a document presenting workflows and alternatives to process the terrains was developed. Work is currently under way to move the terrain preprocessing functions to the toolbox environment and provide users with more flexibility to develop workflows for their organization.

Bringing it all together – “Next steps in Florida”

NOTES: