# ACES: Analytical Framework for Coastal and Estuarine Study

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**Abstract**: Assessment of coastal environments is traditionally tackled with complex supercomputer–based modeling techniques due to complex geomorphology, hydrodynamics and biogeochemistry. While these technologies provide useful results, they are unavailable to most coastal professionals. In a pioneer effort, the Analytical Framework for Coastal and Estuarine Studies (ACES) was developed to support coastal studies by a team of academic, governmental, and industry experts. ACES is composed of 1) a GIS-based database of spatial and temporal data that describe the environment, and 2) an accompanying ESRI ArcMap-based toolset.

ACES creates an environment where data from diverse sources can be synthesized. The methodology focuses on first-principles-analysis of the estuary. Bulk parameters related to shape, residence time, and flushing potential are derived; the relative importance of tidal versus terrestrial flow on estuarine hydrodynamics is assessed. ACES is designed to augment the successful Arc Hydro data model with a coastal feature dataset that works with the Arc Hydro schema. This paper describes the ACES development process.

## Introduction

Estuarine and coastal assessment is generally considered to be difficult due to the complex geomorphology, hydrodynamics and biogeochemistry. Traditionally, this assessment has been done with complex hydrodynamic models, which are typically out of the reach of most coastal scientists. This paper will focus on a collaborative effort taken by the St. Johns River Water Management District, and including a large team of coastal and estuarine experts from academia, industry, and government agencies, to build a solution for simple assessment of the processes that influence water quality along the coast.

In 2003, the Surface Water Quality Monitoring (SWQM) program of the St. Johns River Water Management District (SJRWMD) (figure 1) adopted Arc Hydro as a tool for

District-wide water quality and quantity assessment. Arc Hydro is an ArcGIS data model for hydrologic information developed by the Center for Research in Water Resources (CRWR) at the University of Texas and ESRI (Maidment, 2002). Initially developed for improved determination of drainage areas for the SWQM program's 73 water quality monitoring sites, the Arc Hydro geometric network and associated landscape features (catchments) work well in areas with approximately dendritic drainage patterns (Fox et al., 2007; Fox and Bourne, 2007). Application of Arc Hydro to coastal areas is problematic because there is no intrinsic means to account for tidal influence, which is critical to water quality assessment in estuarine waters.

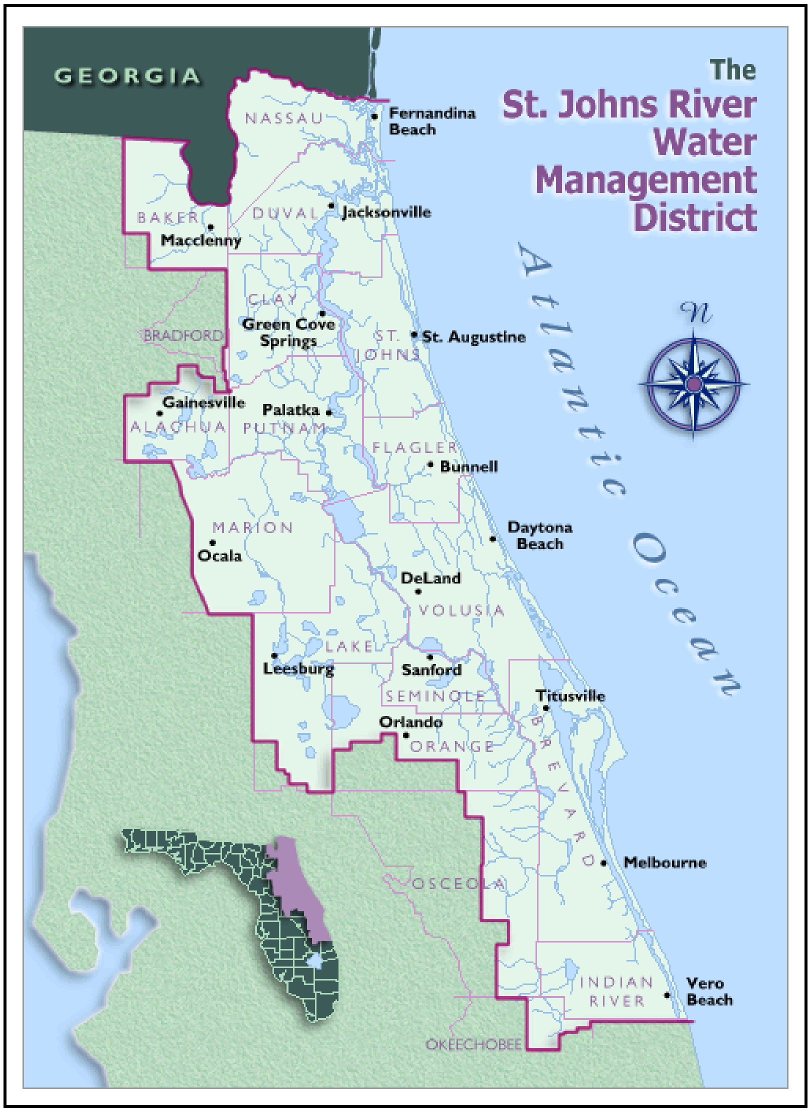


**Figure 1. Map of the St. Johns River Water Management District in northeast Florida.** The Surface Water Quality Monitoring (SWQM) program is a District-wide program, with water quality monitoring sites throughout the area.

In coastal areas flow from multiple directions can occur; in addition to the surface water flow from inland areas, the incoming tide and flow from lateral directions such as the Intracoastal Waterway, must be considered. In some coastal areas, it may be necessary to consider groundwater flow as well. Figure 2 displays the multiple sources of pollutants that can influence water quality at an estuarine water quality monitoring site through surface water flow. The Arc Hydro geometric network requires flow to be limited to a single direction, which meets the needs of most of the SWQM program and SJRWMD area, but does not work well along the coast. In order to assess water quality at estuarine sites, the 2007 SWQM Arc Hydro customization project focused on using GIS to better understand the processes that influence water quality along the coast.

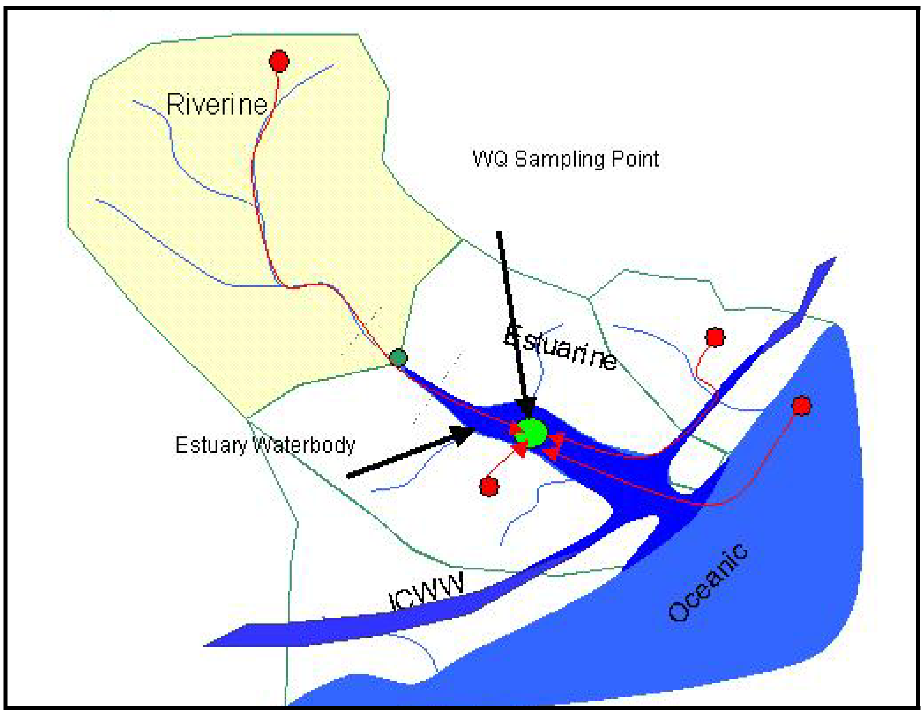


Figure 2. **The estuary physical model:** A representation of the water quality assessment problem being addressed by the SWQM program's 2007 Arc Hydro customization project: ACES, the Analytical Framework for Coastal and Estuarine Study.

The general requirements for developing the coastal enhancement to Arc Hydro (later to be called ACES) were that it would:

- Be GIS based and applicable to all SJRWMD estuaries.
- Include existing GIS-based tools and the enhanced Arc Hydro geodatabase developed by SWQM.
- Use classical analysis techniques (analytical, empirical or (statistical), or numerical) to solve the problem.

- Give preference to simple solutions that still achieve the stated goals of defining drainage areas (areas of influence) and exploring processes that influence water quality.

A recent proceedings paper from the 2008 American Water Resources Association, Specialty Conference for GIS and Water Resources, addresses many of the technological aspects of the ACES project and describes the creation of a pilot "virtual estuary" for the St. Augustine Inlet located south of Jacksonville, FL (Fox et al., 2008). The focus of this paper will be on the ACES development process, which was notable in its use of a development team comprised of experts in estuarine science and engineering, as well as software development. The team consisted of members from academia, governmental agencies and the private sector. The success of the ACES project is largely due to this collaborative approach to solution development.

**ACES Development Approach: Collaboration**

Over the course of several years (2004 – 2007), the SWQM program has developed a number of specialized tools to work with Arc Hydro: 1) a spatial data summary tool that summarizes vector and raster data using Arc Hydro generated drainage areas (Ceric et al., 2006; Fox, 2006); 2) an automated pollution load screening model that uses the Arc Hydro geometric network to accumulate pollution loads (Fox et al., 2007); 3) a disconnected editing tool that allows working sub-geodatabases to be checked out (and checked back in as necessary) of the Districtwide SDE Arc Hydro geodatabase for modeling or editing purpose (Fox and Bourne; 2007); and 4) a file inventory tool that links files of various types to features in the Arc Hydro geodatabase (Fox and Bourne, 2007). Additionally, a peer review of the SWQM Arc Hydro geodatabase was performed under contract with ESRI (ESRI, 2005). All of these projects were conducted by a SJRWMD work order manager – a subject matter expert in the field for which the tool is being developed. The SJRWMD work order manager would work directly with a software development consultant, who would help to plan out data model enhancements and/or tool design. The project would be overseen by a SJRWMD project manager. In-house review meetings with one or two SWQM staff and one or more Information Resources (IR) staff would be held at various points in the development process, to build enterprise understanding of the tool being developed and to consider how the tool may be adopted by the enterprise. Occasionally, additional consulting staff were involved. Thus, what little collaborative effort that was designed into the project was entirely within SJRWMD and was primarily limited to SWQM and IR, with the possible exception of additional staff from the consulting firm.

Because of the complexity of the task of building a GIS-based tool to better understand the processes that influence water quality along the coast, it was determined very early on that the project would benefit greatly from a wider source of input. A committee of experts from SJRWMD, academia, and industry, were convened to collaboratively design the tool. The list of participants (the Technical Expert Team and the Review Team) and their affiliations is shown in Table 1.

**ACES Technical Expert Team (Development)**

**SJRWMD**

- **Environmental Assessment Section, Division of Environmental Sciences, Department of Water Resources**
  - Sandra Fox
  - Aisa Ceric
  - Palmer Kinser, *Technical Program Manager*
- **Division of Engineering, Department of Water Resources**
  - Pete Sucsy

**University of Florida**

- **Department of Environmental Engineering Sciences**
  - Clay Montague
- **Department of Civil and Coastal Engineering**
  - Ashish Mehta

**The Nature Conservancy**

- Michael McManus

**U.S. Geological Survey**

- Michael Turtora

**Post, Buckley, Schuh and Jernigan**

- Stephen Bourne

**ACES Review Team**

**SJRWMD**

- **Environmental Assessment Section, Division of Environmental Sciences, Department of Water Resources**
  - Steve Winkler
  - Nathan Martin
  - Adrian Lin
- **Indian River Lagoon Section, Division of Environmental Sciences, Department of Water Resources**
  - Joel Steward, *Technical Program Manager*
  - Whit Green

**Center for Research in Water Resources, University of Texas as Austin**

- Tim Whiteaker
- David Maidment

**U.S. Army Corps of Engineers, Engineer Research and Development Center**

- Rob Wallace

**Post, Buckley, Schuh and Jernigan**

- Jack Hampson

**Table 1. The ACES collaboration teams.**

As it was understood that the tool to be developed to assess water quality in SJRWMD estuaries had the potential to be a general tool for estuarine analysis, a first task in the development process was to design a master plan for the complete arc of tool development – from proof-of-concept to full production tool. Figure 3 shows a summary of the plan. The process consists of two phases. In initial development (the “alpha” phase), a prototype data model and toolset is produced specifically to solve the problem put forth by a single developing agency. Advising agencies are brought in to assist in the solution design process. Specifically, the SJRWMD acted as the developing agency, and put forth the problem of assessing water quality in estuaries. The technical expert team represented the various advising agencies for the “alpha” prototype. In the “beta” phase, the prototype is put to the test to see if the solution developed is general enough to support assessment of a broader class of estuarine and coastal analysis. The test is in the form of proving ground projects, which are a variety of coastal and estuarine assessments provided by a broader group of agencies. The prototype is further refined/enhanced based on the results.

A collaborative approach to GIS data model and tool development is not new: it is the method that was used for the development of Arc Hydro (Maidment, 2002). There are many advantages to this approach. First, because the design of the data model and associated tools is done by a committee, where each committee member focuses on the applications for which they need the new tool, the resulting product serves a variety of applications from the outset, or is at least general enough to expand to new applications easily. Second, because the tool is the result of committee interaction, the committee members are motivated to use the tool, for their own analysis, and for sharing analyses. A third advantage to the collaborative design approach is that including experts in a broad variety of areas of estuarine science and management results in multi-disciplinary synergies that quite often reveal simple and powerful new techniques for studying estuaries. Finally, and perhaps most importantly, the collaborative approach results in communication and a collegial spirit among the committee members.

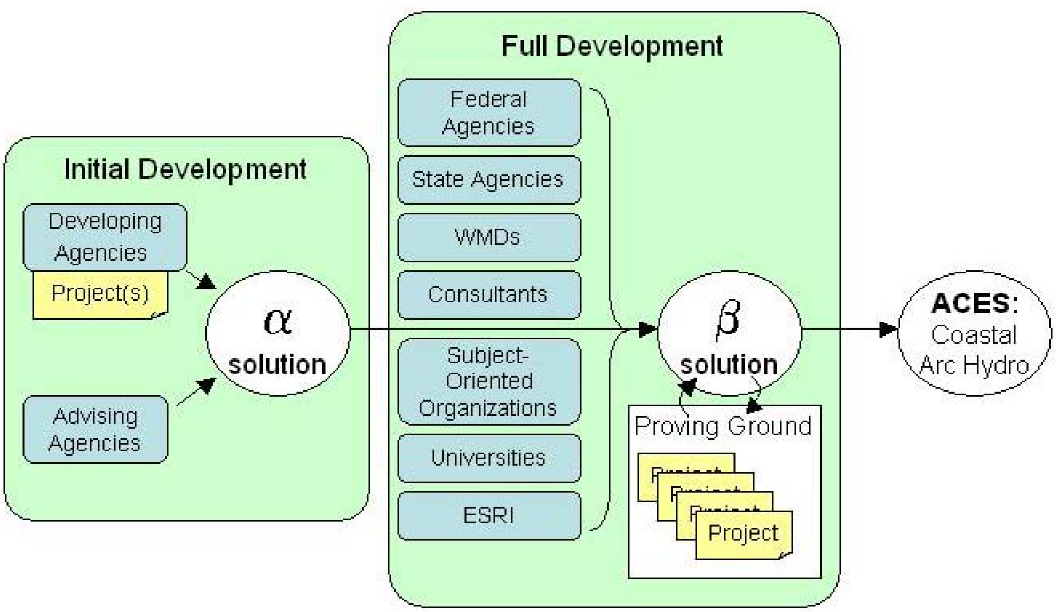


**Figure 3. Ideal ACES Development Process**

The main tool used for collaborative design was brainstorming sessions conducted by the committee. Each brainstorming session was carefully designed with a specific goal in mind. An initial brainstorming session in February 2007 helped to define the problem and set the general course of the project. The name, Analytical Framework for Coastal and Estuarine Study (ACES) was decided on at this brainstorming session as the name for the data-model and toolset solution to be developed. Based on the guidance of the Technical Expert Team, a literature review was undertaken that focused on the nature of an estuary, estuarine hydrodynamics, estuarine classification, existing GIS-based modeling technologies for estuaries and synthetic modeling of water quality in estuaries (PBS&J, 2007a).

**Literature Review**

The literature review was undertaken to build a general body of knowledge on estuaries and water quality assessment within them. This body of knowledge informed the conceptual approach and solution and provided the ACES development team and SWQM Program staff with a general reference on estuary research.
The literature review focused on the following:

1. Methods for estimating estuary properties, especially their geomorphology, hydrodynamics, and sediment transport properties,
2. How estuary properties may be quantified and used to suggest modeling approaches for water quality on an estuary-by-estuary basis,
3. The various water quality modeling approaches, their data needs, and which are pertinent to SJRWMD, and
4. Previous GIS-based approaches to water resource and environmental analysis.

The literature review in its entirety and complete references are contained in Appendix B of ACES documentation, Part1: Conceptual Approach (PBS&J, 2007a).

**Summary of Literature Review Findings**

The literature review focused on building a general knowledge base about estuaries and how they are analyzed as they relate to the development of the ACES solution. The findings are summarized as follows:

- Estuaries are traditionally characterized according to their geomorphology, because this is the most easily measured characteristic.

- Bulk parameters based on estuary geomorphology, mean inflow and tidal cycle can be used to characterize estuaries at a coarse scale.
- Estuaries can be classified according to their hydrodynamics. Simple bulk parameters based on measured inflows can help with understanding hydrodynamics in the estuary water body.
- Sediment transport can be viewed as a unifying means of understanding estuary geomorphology and hydrodynamics. Residence times of sediment are a key parameter.
- Data modeling involves the design and construction of geographically informed databases to hold data relevant to a physical subject. The Arc Hydro schema is an example of data modeling of hydrology. Estuary modeling is not tackled with the Arc Hydro data model because the influence of tide is not addressed. Data modeling of coastal and marine environments has recently been completed with the Arc Marine schema. The Arc Marine data model is more centered on general coastal and oceanic data storage and does not address the complex estuarine environment.
- Currently, the SWQM Program is using the concentrations of multiple constituents at monitoring points within estuaries to evaluate water quality.
- The delineation of coastal basins especially in Florida requires high-accuracy DEM data (high spatial resolution and high accuracy in elevation measurement) due to the generally flat terrain in these environments.
- Hobbie (2000) defines synthesis as the bringing together of existing information in order to discover patterns, mechanisms, and interactions that lead to new concepts that can be used to develop models. Synthetic modeling, therefore, uses varied and disparate datasets as input and aims to build new knowledge about a phenomenon through model output. There are many examples of synthetic models that have been used to estimate pollutant loadings derived from land cover and rain using hydrologic networks. These models can be classified as either process based or correlative. In process-based models, the physical and chemical processes at work are explicitly modeled. In contrast, correlative models search for similarities in the variability of the inputs, in relation to the physical processes and the outputs from those physical processes. Correlative models are attractive because they require fewer data for calibration than process-based models. Correlative

models, however, don't imply causality. A good compromise is the construction of correlative models based on qualitative knowledge of the physical and chemical processes at work.

**Solution Design and Development**

Fueled by the estuary physical model (figure 2), discussion in the first brainstorming session and the ensuing literature review, a conceptual model (based on a control volume) for possible source of flow and pollutants was developed (figure 4). From the literature review and ACES committee findings it was clear that the first step in approaching the study of estuaries was the creation of a GIS-based workbench tool to:

- Integrate data from multiple sources,
- Allow creation of virtual estuaries and estimation of bulk parameters of the estuaries.
- Facilitate development and integration of other models into the same framework.

With this in mind, a prototype solution was developed. A rapid prototype development process brought into reality the envisioned solution quickly; through demonstrations of the prototype during the brainstorming sessions, the prototype helped to guide refinement of the project solution (PBS&J, 2007b).

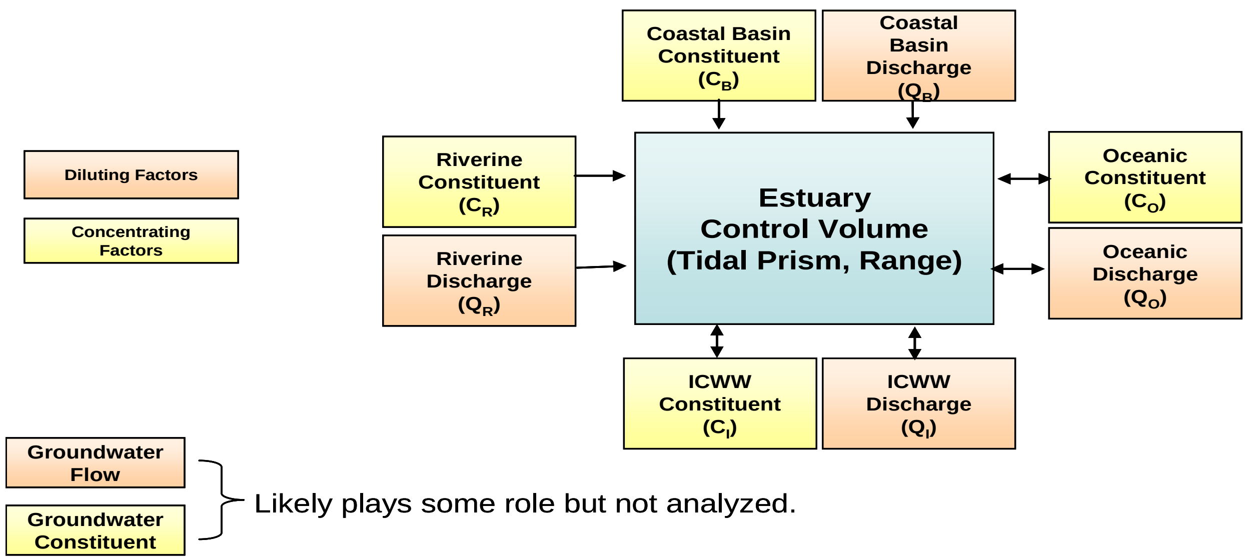


**Figure 4. Estuary Control Volume conceptual model.** Note the correspondence between the features in the estuary physical model (figure 1) and the elements contributing to the control volume above. Groundwater influence was not included in the initial application based on the consensus of the development team that it does not play a significant role in the pilot area.

In this initial development phase of the ACES project, a simple multiple linear regression (MLR) tool for evaluating relationships between constituents emanating from drainage areas and the measured values of water quality in the control volume was included. Through an iterative process comparing predicted and measured values and modifying the drainage area contribution, a more robust estimate of contributing areas may be obtained. A more detailed description of the ACES functionality can be found in Fox et al, 2008 as well as in the project documentation (PBS&J 2007a, 2007b).

**Brainstorming Sessions and Subsequent Review**

The first brainstorming session provided the background for problem definition and helped to set the direction for project development. A second on-site brainstorming session brought consensus on several fronts (method of estuary polygon delineation, bulk parameter calculation, etc.) and furthered the discussion without reaching accord on only one major issue (modeling approach). A key factor to the success of the second brainstorming session was the availability of the prototype solution, which provided a tangible element to fuel discussions. The committee members had something to view rather than just a description or a blueprint. Throughout the project, the Technical Expert Team communicated extensively regarding various topics ranging from the deceptively simple (definition of estuary) to complex and controversial (modeling approach). Because this project was designed to be completed in a single year, deliberations had to stop and the proposed solution had to meet with examination by the Review Team (Table 1). Over the course of the last few months of the project, the ACES software solution and geodatabase were completed, the documentation compiled, reviewed and modified, and the tool and geodatabase delivered for evaluation.

**Future Development**

Undoubtedly, an undertaking such as the development of ACES could not be adequately addressed in such as short time period as one year. It will take multiple years and ideally multiple partner agencies to help develop a GIS-based toolset to tackle even a single coastal issue such as water quality, let alone the myriad of other topics that are of interest to coastal professionals. Because ACES began with the input of experts from a variety of backgrounds and was based on a first principles approach (Fox et a., 2007; Bourne et al., 2007; PBS&J 2007a and 2007b) it could easily be expanded to many other arenas of estuarine study besides water quality. An additional development pathway not developed in figure 3 would be applications in education, where students could study estuarine processes using the ACES tools and geodatabase.

## Comments on collaborative GIS development

Based on the experience of working on several projects designed to be implemented with Arc Hydro (briefly described in the introduction), a few words on the benefits, as well as the drawbacks, of working with a fairly large development team from disparate agencies or organizations are in order. The potential disadvantages can be summarized as follows: 1) it may take more time to work with a group, thus firm and consistent time management during brainstorming sessions, as well as during follow up communication, is essential; 2) the old adage that "too many cooks spoil the broth" might be interpreted as scope creep, finding the project diverging when it needs to be focused, again requiring good work management; 3) a possible dilution of expertise may occur when the team has not been carefully selected; and 4) all team members must be adequately educated in the process of development shown in figure 3 so that appropriate expectations for tool maturity are held at each development stage. Having successfully navigated the collaborative approach to developing ACES, the advantages far outweigh the disadvantages.

## Conclusions

The ACES project brought together individuals dedicated to the study of estuaries, some with little prior experience with GIS, yet possessing great knowledge and experience in estuarine science, engineering and management. The collaborative approach proved to be greatly beneficial to this project; the individuals on the Technical Expert (development) Team worked very well together and seemed to genuinely enjoy the discussions in the brainstorming sessions as well as those that followed through email. The project was fortunate to have these individuals, as well as the Review Team members, involved. Additionally, the availability of the prototype solution for the second brainstorming session greatly enhanced discussion. Perhaps the greatest outcome of this project was to spark future interest in tackling estuarine science and engineering problems using GIS. A software solution such as ACES will provide an opportunity for exploration and study of estuaries that is only limited by the imagination.

## Acknowledgments

The Surface Water Quality Monitoring program of SJRWMD - Aisa Ceric, Program Manager, provided funding for the development of the ACES project. Dr. Palmer Kinser of the Environmental Assessment Section, which includes the SWQM Program, played an integral role in keeping the ACES project on track. The ACES project would not have been possible without the involvement of Drs. Clay Montague and Ashish Mehta of the University of Florida, Pete Sucsy of the St. Johns River Water Management District, Dr. Michael McManus of the Nature Conservancy and Mike Turtora of The United States Geological Survey. We are also indebted to the review team: Dr. Rob Wallace of the Army Corps of Engineers, Drs. Tim Whiteaker and David Maidment of CRWR, Steve Winkler, Joel Steward, Whit Green, Nathan Martin, and Adrian Lin of SJRWMD, and Jack Hampson of PBS&J. As always, development of GIS-based projects at SJRWMD would not be possible without the support of the Information Resources Department, with special thanks to Christine Mundy, Amanda Mitchell and Peggy White.

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