GEOGRAPHIC INFORMATION SYSTEMS AND WATER RESOURCES IV
AWRA SPRING SPECIALTY CONFERENCE
Houston, Texas
May 8-10, 2006

THE BASINS WATERSHED ANALYSIS SYSTEM -- INTEGRATING WITH OPEN SOURCE GIS

John L. Kittle, Jr., Paul B. Duda,
Daniel P. Ames, Russell S. Kinerson*

ABSTRACT: EPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) is a multipurpose environmental analysis system designed for use by regional, state, and local agencies performing watershed and water quality-based studies. This system makes it possible to quickly assess large amounts of data in a format that is easy to use and understand. BASINS integrates environmental data, analytical tools, and modeling programs to support development of cost-effective approaches to watershed management and environmental protection. All versions of BASINS to date have included a suite of Geographic Information System (GIS) based tools and have operated in a GIS environment, using the GIS interface as the front end, graphical user interface. The current release of BASINS, version 4.0, is the first to be primarily based on a non-proprietary, open-source GIS foundation. A careful analysis of BASINS' needs revealed a relatively small number of critical core GIS functions, all of which could be provided through publicly available algorithms and source code. By using open-source GIS tools and non-proprietary data formats, the core of BASINS becomes independent of any proprietary GIS platform while still accommodating users of several different GIS software platforms. The underlying software architecture provides a clear separation between interface components, general GIS functions, and GIS platform-specific functions. Separating these components and functions provides a future migration path for using core GIS functions from other GIS packages or for accommodating future updates to the already-supported GIS packages. The open source GIS tool, MapWindow, was chosen for use in BASINS 4.0 for three primary reasons: 1) it is fully extensible using a plug-in extension interface; 2) it has an active and supportive international developer community; and 3) it supports both vector and raster data manipulation in most common file formats. We expect that this effort will encourage many new BASINS users who previously could not use this federally funded tool because of inability to purchase expensive proprietary GIS software. Additionally, it is anticipated that the use of open source software will provide BASINS with somewhat greater stability and transparency because the source code for all components—including the foundational GIS software—will always be available to end users and the federal government.
KEY TERMS: BASINS, watershed analysis, watershed modeling, open-source GIS

INTRODUCTION

The U.S. Environmental Protection Agency's (EPA's) Office of Water developed BASINS (US EPA, 2004a) as a multipurpose environmental analysis system. As a multipurpose system, BASINS was designed to support watershed and water quality-based studies by facilitating examination of environmental information, by supporting analysis of environmental systems, and by providing a package to examine management alternatives.

State and local agencies are finding that water quality standards cannot be met merely by controlling the point source discharges into that waterbody. Therefore agencies are deciding that a watershed-based approach is the only way to meet water quality standards. BASINS is configured to support environmental studies by including information and tools applicable to the entire watershed. The system is designed to be flexible by including a wide range of tools so that it can support analyses for study areas of widely varying size and composition. Users have flexibility to choose the model and tools best suited for the requirements of the study, for example from a screening-level tool to a full continuous simulation watershed model.

* Respectively, Senior Vice President, AQUA TERRA Consultants, 150 E. Ponce de Leon Ave, Suite 355, Decatur, GA 30030, Phone: 404-378-8337, E-Mail: jlkittle@aquaterra.com; Water Resources Engineer, AQUA TERRA Consultants, 150 E. Ponce de Leon Ave, Suite 355, Decatur, GA 30030, Phone: 404-378-8337, E-Mail: pbduda@aquaterra.com; Ph.D., Assistant Professor, Idaho State University, Department of Geosciences, Campus Box 8072, 785 S. 8th Avenue, Pocatello, ID 83209, Phone: 208-282-3365, E-Mail: amesdani@isu.edu; Ph.D., U. S. Environmental Protection Agency, 1200 Pennsylvania Avenue NW, Washington, DC 20460, Phone: 202-566-0392, E-Mail: Kinerson.Russell@epamail.epa.gov

One of the major driving forces behind the need for watershed-based approaches is the legal requirement of Section 303(d) of the Clean Water Act, which requires states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that do not meet water quality standards. TMDLs are developed by assessing both point and nonpoint sources of pollutants into a waterbody. Because of its watershed-based approach, BASINS can differentiate and quantify the impacts of point and nonpoint sources. Thus the system allows users to explore and research different techniques for reducing the impacts of those pollutants, while facilitating the exploration of alternative management scenarios.

BASINS brings together a suite of interrelated components for performing a complete environmental analysis. The components include national databases, utilities to organize and evaluate data, watershed delineation tools, assessment tools for watershed characterization, and a suite of watershed models that operate at various levels of sophistication. The assessment and modeling tools work together, allowing users to evaluate study areas quickly and easily. The assessment tools provide means to identify and prioritize waterbodies with water-quality issues. As point and nonpoint sources are characterized and evaluated, the appropriate level of modeling may be considered. Once a model has been used to simulate loadings and in-stream processes, potential control strategies can be compared for effectiveness. At each step of the process the tools within BASINS provide graphics and tabular results useful for communicating and explaining results and recommendations to stakeholders.

The main interface to BASINS is provided through a Geographic Information System (GIS). Because GIS combines mapping tools with a database management system, it provides the integrated framework necessary to bring modeling tools together with environmental spatial and tabular data. Through this GIS foundation, BASINS has the flexibility to display and analyze diverse data at a user-chosen scale. That scale can range from one or more USGS 8-digit Hydrologic Units down to a site of only a few acres. BASINS includes tools that operate on large or small watersheds, and thus BASINS is flexible in its support for a broad user community. Adding locally developed, high-resolution data sources to existing data layers is an additional option that expands the local-scale evaluation capabilities.

COMPONENT ARCHITECTURE AND CHANGING GIS PLATFORMS

The first three releases of the BASINS software were built on top of the proprietary ArcView desktop GIS package from Environmental Systems Research Institute (ESRI). ArcView contains a scripting language known as Avenue, through which programmers can customize the GIS interface. In those versions of BASINS almost the entire user interface was written in Avenue scripts (Figure 1), with the exception being the interfaces to some of the modeling tools that had been incorporated into the BASINS system.

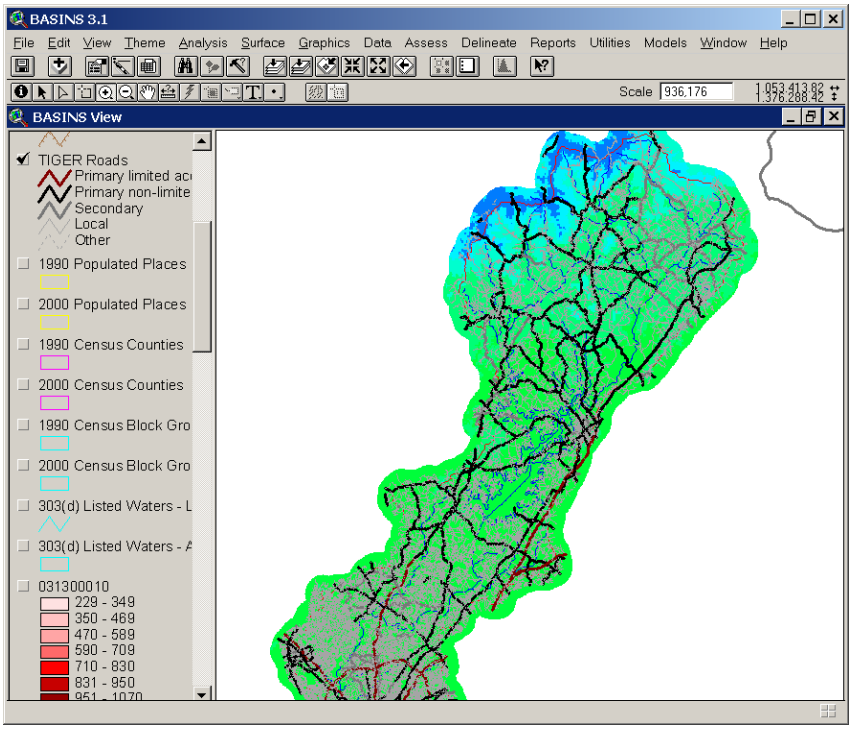

Figure 1: The BASINS 3.1 User Interface

The more sophisticated models in BASINS, such as the Hydrological Simulation Program - Fortran (HSPF) (Bicknell, et al., 2001) and the Soil and Water Assessment Tool (SWAT) (Arnold, et al., 1998), are integrated through Avenue scripts that build input for the models and then invoke the models themselves. The models are run in the native language of their development. Thus, in the case of HSPF for instance, the original FORTRAN code base of HSPF is maintained. The sophisticated watershed models are fully integrated, and yet they remain separate from the core BASINS system for development purposes.

One of the most significant design achievements of the BASINS system is the extension architecture that was engineered for version 3.0. Prior versions of BASINS had all customized components of the GIS interface combined into one ArcView project file. A number of serious consequences arose from that design decision. The project file was quite large, and it was slow to load. Perhaps more importantly, the original design required extensive coordination among BASINS developers, and it restricted the ability to provide updates to existing BASINS projects. Starting with version 3.0, all customized components of BASINS were developed as independent extensions, loaded through an extension manager. One BASINS tool could be developed independently of another BASINS tool, greatly increasing the potential for independent groups to develop compatible BASINS extensions simultaneously. Another important implication is that users then had the capability to load only a subset of the BASINS extensions, so they could load only those needed for their BASINS project.

This extension architecture also allows the BASINS system to operate at several levels of hardware and software sophistication. Some BASINS extensions require additional ArcView extensions, or 'add-ins' from ESRI. With this extension architecture different BASINS users can make different decisions about how advanced an ArcView configuration they would like to have, based on the BASINS extensions they would like to use. These users can purchase only those ArcView extensions needed to support those BASINS extensions. A very common example of this flexibility is related to the ArcView Spatial Analyst extension. Users sometimes decide not to acquire Spatial Analyst if they do not intend to use BASINS components that require Spatial Analyst, for instance if they already have watersheds delineated at a level appropriate for modeling and thus do not need to use the BASINS automatic delineation extension.

Another major benefit of the BASINS extension architecture is that this design has allowed other groups not directly affiliated with the BASINS development team to develop tools for the BASINS system. An example of a model extension added to BASINS through the benefits of the extension architecture is the AQUATOX model (US EPA, 2004b). This model is distributed independently of BASINS, yet if a user has both BASINS and AQUATOX installed, the user can proceed from the BASINS GIS directly into AQUATOX.

BASINS Version 3.1 is the last release of BASINS built entirely upon ArcView 3.x. This release represents a shift in development approach to a more component-based architecture that is less dependent on the ArcView 3.x Avenue programming language. This shift was made recognizing that the Avenue language is not supported in later versions of ESRI GIS software (e.g. ArcMap). The BASINS development team observed that BASINS system components would be most reusable in future releases if components evolve away from use of proprietary software tools. Working towards this end, core BASINS GIS functions were separated from the rest of the BASINS system components, allowing for future smooth migration between different foundational GIS platforms.

Throughout recent BASINS development efforts, a design goal has been to only use the GIS platform (e.g. ArcView) when performing GIS functions, not as an environment for all BASINS functions. Following this design decision, utility tools and model interfaces have been created using other programming languages, independent of the GIS platform. While these components are invoked seamlessly through Avenue scripts, the component code is not dependent upon the GIS environment. This design decision facilitates implementation of BASINS in any GIS environment, and has been particularly advantageous in the recent migration to an open source GIS platform.

MOVING TO OPEN SOURCE

Beginning in 2004, BASINS development efforts have focused on a new version of BASINS, known as BASINS 4.0. The major design consideration governing the development of BASINS 4.0 was the issue of the changing underlying GIS platform. The BASINS development team recognized that as GIS users moved from ArcView 3.x to ArcGIS, BASINS would have to somehow accommodate users of both GIS platforms. The issue is particularly complicated considering that each current BASINS user would be making decisions regarding that switch on their own schedule, as organizational budgets allowed.

The BASINS 4.0 development presented the challenge of building a system that would accommodate both ArcView 3.x and ArcGIS as GIS analysis tools. Early BASINS 4.0 prototypes included what was called the System Application to handle transfer of BASINS projects between the ArcView 3.x platform and the ArcGIS platform. The system application, while including a mapping interface, did not use any proprietary mapping tools, so this application would not require any run-time licensing.

A key advantage to this approach was the removal of ArcView 3.x as a prerequisite to the use of BASINS, though allowing for its continued use according to the desires of end-users. Through the System Application, the BASINS system was to be available with very limited GIS functionality to a user without either ArcView 3 or ArcGIS. All of the functionality from the BASINS 3 ArcView interface would still be available, while components for ArcGIS were being developed and rolled out to the user community. The System Application would identify which (if any) GIS software products are available on the user's computer, and thus indicates the GIS-based functionality available to the user. In this way the design provided a migration path from the ArcView 3.x components to the ArcGIS components.

While the BASINS System Application was being designed, the BASINS development team created a list of all GIS related functionality needed in BASINS. This list consisted of the specific GIS functions that were needed for BASINS, including for example such functions as determining which polygon contains a given point, identifying which feature of a layer was selected, and overlaying one polygon layer with another. At the time this list was developed it was thought it would help the development team decide which basic GIS functionality should reside in the system application and which should be left to be done by the GIS foundation.

The final list of core required GIS functionality was more limited than originally expected. Some of the items on the list were fairly trivial, others could be written with very modest effort, and for others there were already established open-source solutions available. With this realization it followed then that BASINS could be developed completely independent of any proprietary GIS software, making use of open-source GIS tools and non-proprietary data formats. These observations together with an interest in providing BASINS users a fully functional tool with no third party software purchase requirements (except for Microsoft Windows) drove a decision to migrate BASINS 4.0 to a non-proprietary, open-source GIS foundation (Figure 2).

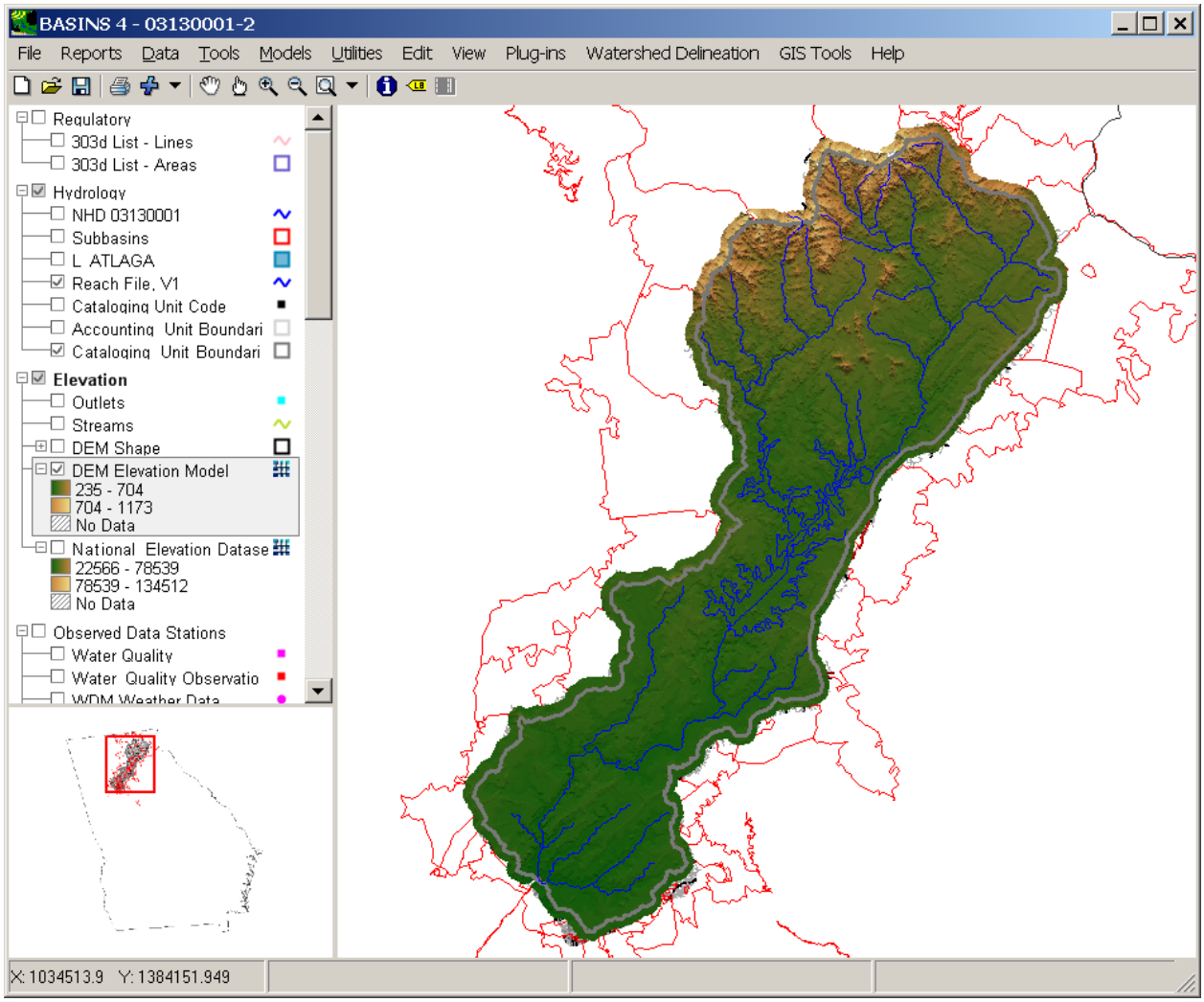

Figure 2: The BASINS 4.0 Interface built upon an Open Source Foundation

A major benefit of being independent of any proprietary GIS software is that the BASINS system can now be available to any user without cost. No prerequisite commercial software is required, so there are no financial hurdles to impede use of the BASINS system by anyone who wants to use it. But perhaps more importantly, the move away from proprietary GIS means that all source code upon which BASINS is dependent is open and freely available to the federal government and end users. The implications of this fact are significant in light of the necessary migration from ArcView 3.x to ArcGIS. With the source code freely available, EPA now has the ability to maintain and/or upgrade core GIS functions as needs and budgets permit, not as dictated by the commercial GIS market.

While not being dependent upon any proprietary GIS platform, the core of BASINS 4.0 is designed to complement and interoperate with enterprise and full-featured GIS systems. BASINS 4.0 can import and export projects from ArcView 3.x and ArcGIS 9.0. This interoperability allows users access to features available in these systems but not BASINS 4.0.

Learning from the challenges posed in migrating from one foundational GIS to another, the BASINS development team was able to institute a strict architectural standard for BASINS 4.0. Through this standard, general GIS functions are separated from GIS platform specific functions. The component-based architecture requires the programmer to use an intermediate generic class for GIS functions, which are then implemented through a specific GIS platform. For instance every time the programmer intends to overlay one GIS layer with another, all BASINS code uses one specific method in a class. The specific method then accesses the GIS foundational algorithm to do that overlay task. The major implication of this design is that in the future any change in the foundational GIS will have to be implemented in only one place in the BASINS source code, drastically simplifying maintenance and minimizing the cost of future enhancements. Following this design standard, a future migration path is provided for using core GIS functions from other GIS packages or for accommodating future updates to the already-supported GIS packages.

USING A LIGHTWEIGHT, OPEN-SOURCE GIS FOUNDATION

With the realization that BASINS could be written to be completely independent of proprietary GIS software, the BASINS development team examined existing open-source GIS tools. MapWindow GIS (http://www.MapWindow.org) was identified as a product that met the criteria of being a lightweight open source GIS with the necessary BASINS functionality already built-in, or as enhancements planned shortly thereafter.

MapWindow provides BASINS with a fully functional GIS foundation, including a complete GIS application programming interface (API) for both vector (shapefile) and raster (grid) data. MapWindow is a component based GIS platform that includes a core standalone library of GIS functions and an end-user graphical user interface with a plug-in architecture. As an open source end user GIS tool, MapWindow builds upon and takes advantage of several underlying GIS data and geoprocessing libraries including GDAL, GPC, PROJ4 and others, allowing it support both raster and vector data manipulation in most common file formats. MapWindow includes standard GIS data visualization features (zoom, pan, layer management, etc) as well as DBF attribute table editing, shapefile editing, and grid importing and conversion. And because of its open source distribution, a worldwide development community is contributing to the already wide feature set contained in MapWindow.

By building on existing open source libraries, MapWindow supports over 3,000 mapping projections, can be used internationally with multiple languages supported, and includes a scripting interface for running scripts written in VB.NET or C#. Its functionality has been extended to support GeoTiff as a grid file format, and it includes tools for clipping and merging raster and vector data. The platform has been adopted by several private companies, government agencies and universities as a GIS foundation for distributing data, models and research tools.

The extensibility of MapWindow is one reason why it was identified as an excellent candidate GIS foundation for BASINS. MapWindow can be extended with plug-in components written in any Microsoft .NET language. The plug-in interface operates much like the extension interface in ArcView, allowing third-party developers to create plug-ins that become fully integrated into the BASINS interface (Figure 3). This means that third parties can write plug-ins to add additional functionality (models, special viewers, hot-link handlers, data editors, etc.) to BASINS and pass these tools along to other clients and cooperators. The MapWindow interface not only operates very similarly to the extension interface in BASINS, but each BASINS GIS component has now been converted in to a parallel component for MapWindow.

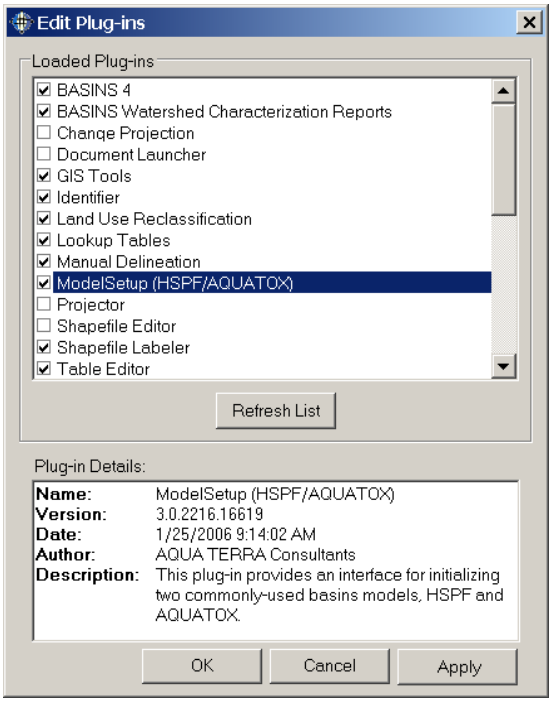

Figure 3: The MapWindow Plug-in Manager

Following the architectural design described in the previous section, the BASINS GIS components have been re-factored for MapWindow. The GIS-related functionality has been separated from the user-interface and data management functionality, providing for easier maintenance and upgrades in the future. Some advanced features of BASINS 4.0 may require proprietary products, but the base BASINS 4.0 system does not require any run-time licensing or commercial software purchases.

The BASINS development team expects that the development track of BASINS 4.0 will encourage many new BASINS users who previously could not use this federally funded tool because of inability to purchase expensive proprietary GIS software. While a user may choose to perform some GIS analysis in a proprietary system such as ArcMap, and BASINS will support such an activity, it will not be required to use BASINS. Additionally, it is anticipated that the use of open source software will provide BASINS with somewhat greater stability and transparency because the source code for all components—including the foundational GIS software—will always be available to end users and the federal government.

REFERENCES

Arnold, J.G., Srinivasan, R., Muttiah, R.S., and Williams, J.R. 1998. Large area hydrologic modeling and assessment part I: model development. J. American Water Resources Association 34(1):73-89.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle Jr., T.H. Jobes, and A.S. Donigian, Jr. 2001. Hydrological Simulation Program - Fortran (HSPF). User's Manual for Release 12. U.S. EPA National Exposure Research Laboratory, Athens, GA, in cooperation with U.S. Geological Survey, Water Resources Division, Reston, VA.

US EPA, 2004a. Better Assessment Science Integrating point and Nonpoint Sources -- BASINS Version 3.1. EPA-823-C-04-004. U.S. Environmental Protection Agency, Office of Water, Washington, DC. Available at: http://www.epa.gov/waterscience/basins/.

US EPA, 2004b. AQUATOX Release 2 – Modeling Environmental Fate and Ecological Effects in Aquatic Ecosystems. EPA-823-C-04-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.