Chapter 18

BASINS: Better Assessment Science Integrating point and Nonpoint Sources

Russell S. Kinerson, Ph.D.[1]
John L. Kittle, Jr.[2]
Paul B. Duda[3]

The U.S. Environmental Protection Agency's (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. It was developed by the EPA's Office of Water to facilitate examination of environmental information, to support analysis of environmental systems, and to provide a framework for examining management alternatives. BASINS integrates environmental data, analytical tools, and modeling programs to support development of cost-effective approaches to watershed management and environmental protection, making it possible to quickly assess large amounts of data in a format that is easy to use and understand. The BASINS system is configured to support environmental and ecological studies in a watershed context, with flexibility to support analysis at a variety of scales using tools that range from simple to sophisticated.

All versions of BASINS to date contain a suite of Geographic Information System (GIS) based tools and operate 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. By using open-source GIS tools and non-proprietary data formats, the core of BASINS is now independent of any proprietary GIS platform. As a result BASINS users are not limited by having to purchase expensive proprietary GIS software, and BASINS has greater stability and transparency, as the source code for all components is available to developers and end users alike.

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[1] Retired U. S. Environmental Protection Agency, 6527 El Reno Lane, Joplin, MO 64804, Phone: 417-627-0137, E-Mail: rskinerson@gotsky.com
[2] 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
[3] Senior Project Engineer, AQUA TERRA Consultants, 150 E. Ponce de Leon Ave, Suite 355, Decatur, GA 30030, Phone: 404-378-8337, E-Mail: pbduda@aquaterra.com

With each new version of BASINS additional data types have been added to the system. In addition, the analytical tools and techniques in BASINS themselves are continually evolving. The design of the watershed analysis system must support the addition of new data and new techniques for analyzing that data. BASINS is designed around an extensible architecture that allows for the addition of new data types and new tools. This flexibility enables BASINS to continue evolving to meet the changing needs of the watershed management community.

INTRODUCTION

The U.S. Environmental Protection Agency's (EPA's) Office of Water developed BASINS (US EPA, 2007) as a multipurpose environmental analysis system. As a multipurpose system, BASINS (http://www.epa.gov/waterscience/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. BASINS encompasses a suite of watershed models, from sophisticated broad-spectrum watershed models to agricultural models to planning and management level models, plus supporting tools and data, all within one package.

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. The user has the 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.

One of the major driving forces behind the need for watershed-based approaches is the legal requirement of Section 303(d) of the U.S. Clean Water Act of 1977, 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 to determine how much of a given pollutant may be assimilated without violating a given water quality standard. BASINS was originally designed to support the TMDL process, as through its watershed-based approach BASINS can differentiate and quantify the impacts of point and nonpoint sources. This approach provides the technical basis for a manager to determine, for an impaired waterbody, how much loading of a pollutant may be allowed and to allocate the load among 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.

The capabilities that make BASINS useful for TMDLs, especially differentiating and quantifying the impacts of point and nonpoint sources, also make it useful for other types of decisions. BASINS is commonly used for purposes as diverse as to understand the impacts of land and reservoir management operations, to perform future conditions analyses for both hydrology and water quality, to aide in the process of prioritizing watersheds for implementation strategies, and to recommend best management practices that will best enhance water quality. All of these decisions are guided through quantifying the loading contributions from different sources and tracking these constituents of concern throughout the watershed and associated waterbodies.

The main interface to BASINS is provided through a Geographic Information System (GIS) (Figure 18.1). GIS provides tools to display and analyze spatial information. 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 of the standard hydrologic cataloging units designated by the U.S. Geological Survey 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.

BASINS brings together a suite of interrelated components for performing a complete watershed analysis, from data compilation and source assessment, through model construction and alternatives analysis. The components include:

(1) national databases
(2) utilities to organize and evaluate data
(3) watershed delineation tools
(4) assessment tools for watershed characterization based on observed data
(5) a simplified GIS-based model that estimates nonpoint loads on an annual average basis
(6) a GIS-based hydrologic modeling system geared toward the arid southwestern United States
(7) and two watershed loading and transport models

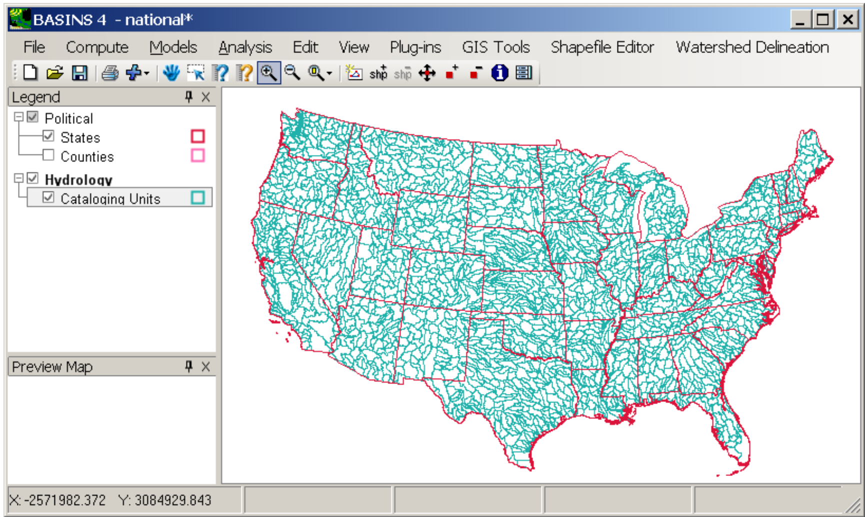

Figure 18.1: BASINS Geographic Information System Interface

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 based on observed data. 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 latest release of BASINS is Version 4.0. This version provides significant enhancements and functions beyond those provided by the earlier releases of BASINS, Versions 1.0 through 3.1, in an open-source environment. The continuing modification and enhancement of the system reflects the extensive comments and input provided by the user community since the initial versions, as well as the responsiveness of EPA to those comments and recommendations. Other enhancements have included adding additional types of data, higher-resolution data, additional models and analysis tools.

Version 4.0 of BASINS 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.

HISTORY AND CONTEXT

Development of GIS technology through early 1990s followed more than two decades of development of watershed models for personal computers, along with rapidly expanding public databases. Through the early 1990s researchers at institutions around the world recognized the potential for linking watershed models with GIS systems and databases. Concurrently, awareness of water quality issues and needs was growing as the Clean Water Act was enforced through TMDLs. BASINS was conceived during that time as a system that could combine models and data through GIS to make watershed assessment and TMDL development possible for agencies across the United States.

BASINS was developed to be a fully comprehensive watershed management tool, assisting the user through all of the steps typically involved in a watershed-based assessment. The system greatly reduces effort needed to prepare data, summarize information, and develop maps and tables. To that end, the GIS interface provides a conduit through which data can pass, setting up models of varying scopes. The system not only helps the user apply the model, but it helps interpret the model output as well. Instead of performing each step of a watershed assessment using a series of independent and informally connected computer programs, BASINS coordinates and integrates those steps, resulting in improved efficiency and greatly reduced user effort. As the analysis time is significantly reduced, the user is freed to answer a greater variety of questions in more detail.

BASINS has always been a dynamic system, with increased capabilities added as technology and needs demand. The first release of BASINS was in May of 1996, and the current version of BASINS is version 4.0, released in March 2007. Through each version new data and tools were added, and new modeling tools were added to expand the spectrum of models available from simple to sophisticated.

One of the most significant changes to the BASINS system throughout its history was a shift in data distribution. Older version of BASINS had been distributed as a set of CDs containing data for each EPA region. With unlimited data available on the World Wide Web, the static picture of data on CDs was no longer adequate. BASINS take advantage of the power of Internet connections to provide the users with much more dynamic data.

Prior to version 4.0, BASINS was dependent upon proprietary software from Environmental Systems Research Institute (ESRI), as most of the interface was built using the scripting components of the ArcView 3.x desktop GIS. In order to make BASINS system components most reuseable in later releases, components were gradually migrated away from use of proprietary software tools. The core GIS functionality was separated from the rest of the BASINS system components, which led to a smoother evolution to another GIS platform as well as managing changes in ESRI's software.

BASINS 4.0 is based upon an open source GIS package known as MapWindow. Moving to a non-proprietary GIS platform makes BASINS available to many new BASINS users who previously could not use this federally funded tool because of inability to purchase expensive proprietary GIS software. Additionally, the use of open source software provides BASINS with 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.

DESIGN CONSIDERATIONS

The design of BASINS has evolved in concert with the capabilities of desktop GIS and with identified user needs. Consistent throughout the history of the system has been the design decision to leave interfaces to the more significant modeling tools separate from the core GIS system. The more sophisticated models in BASINS, such as the Hydrological Simulation Program - Fortran (HSPF) (Bicknell, et al., 2005) and the Soil and Water Assessment Tool (SWAT) (Arnold, et al., 1998), are integrated through programming code that builds input for the models and then invoke the models themselves. The models are run in the native language of their development. 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 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 can 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.

Another major benefit of the BASINS extension architecture is that this design allows 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.

The current development approach within BASINS is a component-based architecture. BASINS system components are designed to be reusable and independent of GIS platform. BASINS GIS functions are separate from the rest of the BASINS system components, allowing for possible migration between different foundational GIS platforms.

Throughout recent BASINS development efforts, a design goal has been to only use the GIS platform when performing GIS functions, not as an environment for all BASINS functions. Following this design decision, utility tools and model interfaces have been created independent of the GIS platform. While these components are invoked seamlessly, 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 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 desktop GIS from ESRI was moving from ArcView 3.x to ArcGIS, and the BASINS development team recognized that as GIS users made this move 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 indicate 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 18.2).

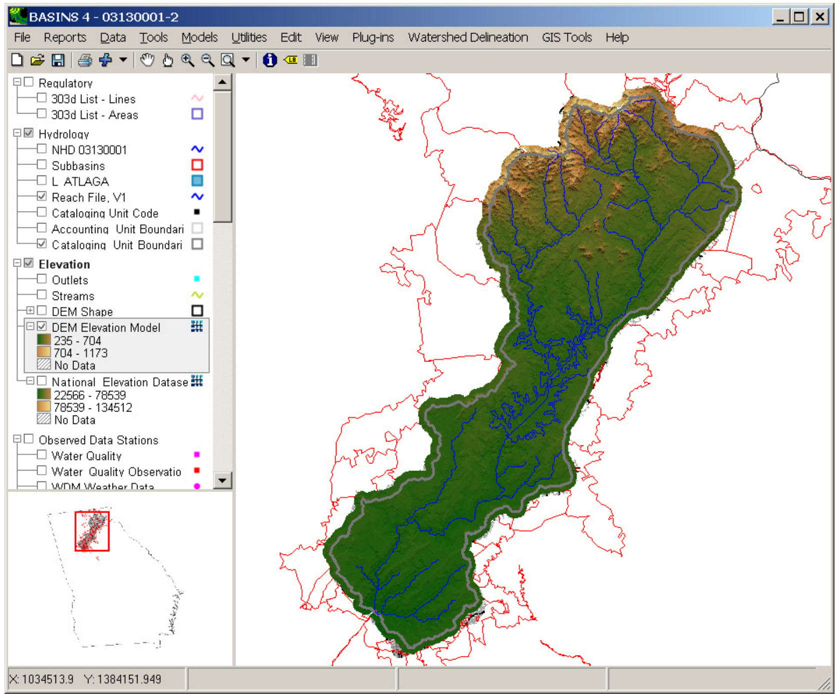

Figure 18.2: The BASINS 4.0 Interface built upon an Open Source Foundation

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 access to GIS features available in these systems that are not built into 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. Also, 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 18.3). 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 into a parallel component for MapWindow.

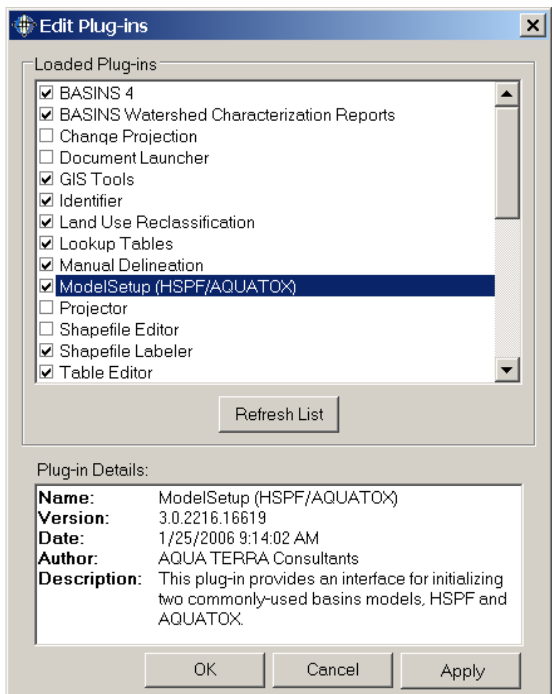

Figure 18.3: The MapWindow Plug-in Manager

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. While some advanced features of BASINS 4.0 may require proprietary products, the base BASINS 4.0 system does not require any run-time licensing or commercial software purchases.

BASINS DATA

The BASINS system includes a tool, known as the BASINS Data Download tool, for downloading and extracting a set of databases that facilitate watershed analysis and modeling. Some of the data downloaded using this tool have been preprocessed for use in BASINS. These prepared data are known collectively as the BASINS data holdings. Other data that can be downloaded using the Data Download tool have not been preprocessed and are extracted directly from the agency responsible for collecting the data.

The BASINS Data Holdings

These national databases, hosted on an EPA web server, were compiled from a wide range of federal sources and selected for inclusion in BASINS based on relevance to environmental analysis. The data prepared for BASINS provide a starting point for watershed analysis, but users are encouraged to add additional data sets where locally derived data may be at a higher resolution or compiled more recently.

The BASINS databases are compiled into compressed files according to geographic location, according to the 8-digit Hydrologic Unit Codes (HUCs) established for the United States by the USGS. A BASINS user begins a project by specifying one or more HUCs of interest, and data for those HUCs are downloaded and extracted for the project.

The types of data prepared and hosted for BASINS can be grouped into one of four classifications. These classifications include base cartographic data, environmental background data, environmental monitoring data, and point sources or loading data. Each type is described briefly below.

Base Cartographic Data

The base cartographic data in BASINS includes political and administrative boundaries (such as states and counties), hydrologic features and drainage boundaries, and major road systems. These data are useful for providing the base mapping data that gives the user a frame of reference for the rest of the data. Through these data the user can define and locate study areas and begin to further define watershed drainage areas.

Environmental Background Data

Environmental background data provide spatially distributed information to support watershed characterization and environmental analyses. These data include information on soil characteristics, land uses, topography, and stream hydrography. The BASINS tools use this information in performing technical assessments of watershed conditions and loading characteristics. To cite a common example, the BASINS topographic data are often used to determine subwatershed drainage boundaries using the BASINS delineation tools. Those boundaries are then combined with the land use layers to determine how much of each land use type is in each subwatershed, which is a critical piece for watershed modeling.

Environmental Monitoring Data

Several existing national databases of environmental observations were adapted and converted into BASINS data sets. These databases were converted into spatial data layers so the user can see where these observation stations are located in a given watershed, which facilitates the assessment of water quality conditions. Examples of these types of databases include the water quality monitoring data summaries, the water quality observation data from the EPA STORET system, and USGS flow and water quality data from the National Water Information System (NWIS). The water quality datasets can also be used to prioritize and target water bodies and watersheds for remediation, as well as to assess the current status and historical trends.

One of the most recent enhancements to BASINS is the extension and expansion of the national database of meteorological data in BASINS. BASINS contains a national database of meteorological data that are essential to the successful application of BASINS assessment models. To be effective, these data need to be of high quality, have thorough spatial coverage, and be current. As part of the ongoing BASINS version 4.0 development, an updated version of the meteorological database has been compiled. These data were acquired from NOAA's National Climatic Data Center (NCDC). This updated database brings all data up to the currently available time period and greatly expands the number of stations for which data are available. For instance, while BASINS previously provided access to roughly 500 hourly precipitation stations, that number has now expanded to over 2100.

Point Source/Loading Data

BASINS also includes data related to direct pollutant loading from point source discharges. The estimated loadings are provided along with the location and type of facility. These data were extracted from the EPA PCS database. The primary purpose of this loading data is to provide input for watershed models to represent the point source component, or point load allocation, of the pollutants.

Dynamically Downloaded Data

Since version 3.1 the BASINS system has included a tool for dynamically downloading data from an additional set of sources. In addition to downloading the BASINS data from the EPA web server, the Data Download tool (Figure

18.4) provides links to the federal agencies where certain data types are hosted, as well as tools to download the data and convert them into forms usable by BASINS. Since data available on the web are not static, this tool allows a user to check for more recent data and update the BASINS project data as appropriate.

When the Data Download tool is started, a window appears listing all of the available data types that the tool may add or update. The list of data types is determined at run-time, so this list may expand as new data-type components are created. The user chooses as many of the data types as desired, and the tool accesses the specified data through the World Wide Web and adds the data to the BASINS project.

Data types that are available for dynamic download include USGS flow data, the EPA Permit Compliance System (PCS) discharge data, the modernized EPA STORET system, the USGS water quality data, the National Hydrography Dataset, and the National Land Cover Database. BASINS is currently being enhanced to provide direct download of the NHDPlus database. Other data types will be added for dynamic download over time as resources allow.

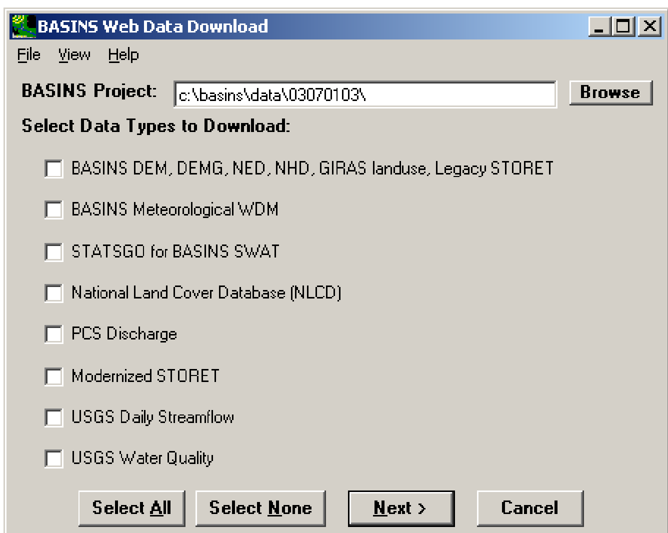

Figure 18.4: The BASINS Data Download Tool

A key feature of BASINS Web Data Download tool's architecture is the separation of the list of data types into individual components. For each data type available for downloading, there is a unique Dynamic Link Library (DLL). This design allows the list of data types to be populated at runtime, but it also greatly enhances the maintainability of the Web Data Download program. Very often the way the data are hosted on a web site changes over time. With this design, if a data type's web storage is changed, only the DLL for that data type will need to be updated and distributed, not the whole Web Data Download program.

This tool provides great flexibility in pulling data from a variety of sources. Instead of distributing all BASINS data through a specially compiled BASINS data holding, the data can be retrieved from the source of the data directly. This design makes the BASINS system easier and less expensive to maintain, since it eliminates having another copy of each dataset in the BASINS data holdings. In addition, updates to the data are available as soon as the agency producing the data makes the update available, making the most updated data available directly to the user.

BASINS MODELS

Watershed models predict loadings into surface waterbodies. Through the use of watershed models, one can simulate various point and nonpoint source loading scenarios and predict the impact of these loadings on the receiving waterbody. The most sophisticated watershed models operate on a continuous simulation basis, which is to say that the models run at a given time step (usually hourly or daily) for a number of years. Continuous simulation modeling is critical for watershed assessment because continuous simulations take into account both point and nonpoint loadings at a complete range of flow conditions.

In an ideal world one performing a watershed assessment would have an unlimited number of measurements of pollutant levels and flows both in the waterbody and exiting the land surface at an infinite number of locations for a very long period of record. With that amount of data, one could evaluate whether water quality criteria are being met, how often those standards are not being met, the duration of those exceedances, as well as investigate allocation scenarios that might lead to the standards being met in the future. Since that amount of data is impossible to obtain, continuously simulating values through a model is the best way to obtain the full range of data needed to perform a watershed assessment.

While continuous simulation models are the most powerful tools for assessing watershed loadings, they have some significant disadvantages. These models require large amounts of input data, including observations over periods of many years. The learning process involved in using these models is significant, and there is uncertainty inherent in input data, algorithms, and modeling assumptions.

BASINS reduces the disadvantages of using continuous simulation models by addressing each of these issues. BASINS provides a tremendous amount of input data so that the data gathering process is much less daunting. BASINS includes graphical user interfaces to the models to make the models easier to use, as well as analysis tools to help make model output easier to understand. BASINS also provides a suite of watershed models with a broad range of sophistication and complexity, so that the user can choose the model most appropriate for a given study or assessment.

Three models are integrated into BASINS to allow the user to simulate the loading of pollutants and nutrients from the land surface. These three models are spatially distributed, lumped parameter models, or in other words they may be used to analyze watersheds by subdividing the study area into homogenous parts. When deciding which model to use, one should consider factors such as the amount of data available, the processes to be modeled, the spatial and temporal resolution required, and the how the output results will be used. The integration of each model into BASINS is discussed individually below.

HSPF

The Hydrological Simulation Program Fortran (HSPF) (Bicknell, et al., 2005) is a continuous simulation watershed model that simulates nonpoint source runoff and pollutant loadings for a watershed and performs flow and water quality routing in stream reaches. HSPF can be used to estimate nonpoint source loads from various land uses, as well as fate and transport processes in streams and lakes.

The Windows interface to HSPF, known as *WinHSPF* (Duda, et al., 2001), was created for BASINS and works with the EPA-supported HSPF model (Figure 18.5). WinHSPF supports the full suite of the HSPF model capabilities. BASINS contains an extension that allows the user to open WinHSPF directly from the BASINS user interface, extracting appropriate information for the preparation of HSPF input files.

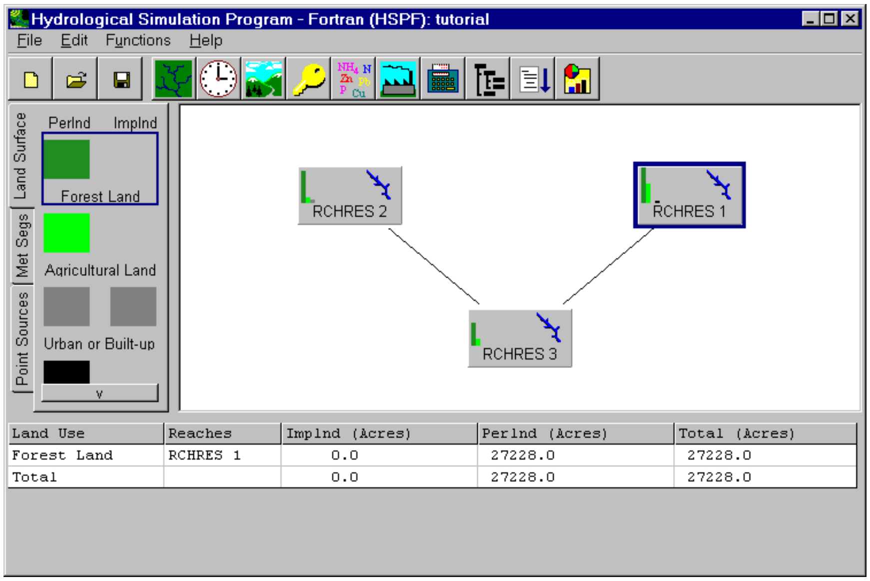

Figure 18.5: The WinHSPF Interface

WinHSPF is designed to interact with the BASINS utilities and data sets, including the BASINS watershed delineation tools. HSPF requires land use data, reach data, meteorological data, and information on the pollutants to be modeled. The reach network is automatically developed based on the subwatershed delineations. Users can modify and enhance input files based on land use, meteorological data, and other locally derived data sources through WinHSPF. WinHSPF works with postprocessing tools to facilitate calibration as well as display and interpretation of output data. The HSPF User's Manual is available for reference as a Windows-compatible Help file.

While HSPF is fully integrated into BASINS through the WinHSPF interface, the code base of HSPF is maintained separately. This separation is accomplished by compiling the HSPF model as a dynamic link library (DLL), called by WinHSPF for running a simulation. Maintaining HSPF as a separate DLL means that it can be enhanced independently of WinHSPF and BASINS. A revised DLL can be copied into place on the user's computer and the user will have access to the latest HSPF features. Input meteorologic data are provided to HSPF through the use of Watershed Data Management (WDM) files, available through the BASINS Data Download tool.

SWAT

The Soil and Water Assessment Tool (SWAT) model version 2000, (Arnold, et al., 1998), is a physically based continuous simulation watershed model developed by the USDA Agriculture Research Service (ARS). With its agricultural roots, it is most often used to predict the impact of land management practices on water, sediment, and agricultural chemical yields. The model can be used on complex watersheds with varying soils, land use, and management conditions. The model combines these loadings with point source contributions and performs flow and water quality routing in stream reaches.

The SWAT Extension in version 3.1 is an ArcView extension, built using the Avenue scripting language. The SWAT Extension provides input files that are sent to the SWAT executable file for simulation, and the SWAT model itself is distributed with BASINS in its native language. This design provides a fully integrated SWAT model, while still preserving the SWAT algorithms independently so that they can be maintained and enhanced outside of BASINS.

A SWAT Plug-in for BASINS 4.0 is currently under development. The SWAT interface in BASINS is designed to set up SWAT input files using BASINS watershed delineations and data sets. BASINS data including land use, soils, reach data, meteorologic data, and pollutant characteristics can be used, or the user can provide custom data. SWAT input files can be modified through BASINS to facilitate the calibration of the model based on site-specific conditions and data sources. The BASINS SWAT interface works with postprocessing tools to facilitate display and interpretation of output data.

Pollutant Loading Estimator (PLOAD)

The BASINS Pollutant Loading Estimator (PLOAD) is a simplified GIS based model originally developed by CH2M HILL for calculating pollutant loads from watersheds. PLOAD estimates nonpoint loads (NPS) of pollution on an annual average basis for any pollutant specified by the user. The NPS loads may be calculated using either the export coefficient or the EPA's Simple Method approach. Best management practices (BMPs) and point source inputs may also be included in computing total watershed loads. PLOAD results can be displayed as maps and tabular lists, and the model facilitates comparison of multiple scenarios.

PLOAD was designed to be simple so that it can be applied as a screening tool in typical watershed assessment or reservoir protection projects. As it operates on an average annual basis, it is not a continuous simulation model.

The PLOAD application requires spatial landuse data, subwatersheds, pollutant loading rate tables, impervious terrain factor tables, and optional spatial and tabular BMP and point source data. Landuse and point source data are provided with BASINS, and subwatersheds can be provided using the BASINS watershed delineation tools.

Unlike the other models in BASINS, PLOAD is entirely a BASINS plug-in. There is no executable model underneath the PLOAD interface running in its native language.

AGWA

The Automated Geospatial Watershed Assessment (AGWA) (Semmens, et al., 2004) tool, developed by the U.S. Agricultural Research Service's (ARS's) Southwest Watershed Resource Center, is a multipurpose hydrologic analysis system for performing studies ranging from watershed to basin scale. This tool was designed by ARS for use by watershed, water resource, land use, and biological resource managers and scientists. It provides the functionality to conduct a watershed assessment using SWAT and another model geared toward the arid southwest known as KINEROS2.

The BASINS AGWA extension was designed to interact with the BASINS utilities and data sets to provide the data needed by AGWA to parameterize either the KINEROS2 or SWAT model. AGWA was implemented as an ArcView extension in BASINS 3.1, which facilitates the transfer of data from BASINS to the core models. As with the HSPF and SWAT implementations in BASINS, these models are kept separate from the ArcView extension for maintenance and enhancement.

The incorporation of the AGWA extension demonstrated the strengths of the flexible design of the underlying BASINS architecture. Recognizing the power and convenience of the large databases provided through BASINS, ARS decided to adapt AGWA to be a BASINS extension so that AGWA users would have convenient access to BASINS data. With very limited support from the BASINS development team, the AGWA developers were able to adapt AGWA to be fully incorporated into the BASINS system, making that convenient access possible.

POSTPROCESSING AND ANALYSIS

For postprocessing and analysis of time-series data, BASINS includes the program *GenScn* (Kittle, et al., 1998) originally developed by the U.S. Geological Survey. GenScn stands for *Generation of Scenarios*, which was the original intent of the software as it was developed by the USGS; it is included in BASINS because of its excellent functionality for analyzing model simulation results including multiple model scenarios.

GenScn facilitates the display and interpretation of output data derived from model applications (Figure 18.6). This tool allows users to select time periods and locations of interest and displays results in graphical and tabular form. GenScn handles a broad range of data formats, including HSPF simulation output, BASINS water quality observation data, USGS flow data, and SWAT output data. It also performs statistical functions and data comparisons. Due to its ability to display and compare observed and modeled data, this postprocessor is a useful tool in model calibration as well as environmental systems analysis.

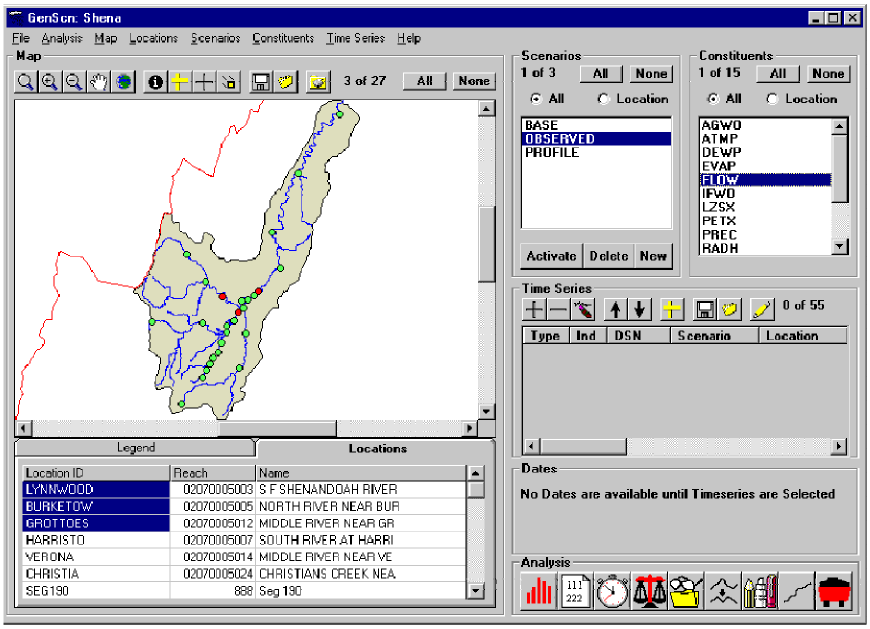

Figure 18.6: The GenScn Postprocessor

GenScn is distributed with BASINS, and may be invoked through the BASINS GIS interface, as well as through the WinHSPF interface. While it is fully integrated into BASINS, it is kept independent of the core BASINS system as its own separate executable program for maintenance and enhancement.

The time-series analysis features of GenScn are being migrated to direct access through the BASINS 4.0 MapWindow interface. The BASINS 4.0 MapWindow interface includes capabilities to list and plot time-series data from a variety of data formats. New time-series analysis tools added for BASINS 4.0 include the ability to generate and analyze time-series on a seasonal basis, create subsets of timeseries by date, and perform mathematical computations on time-series data.

One of the more recently added analysis tools in BASINS is known as the BASINS Climate Assessment Tool (CAT). CAT provides a flexible set of capabilities for representing and exploring climate change and its relationship to watershed science. Tools have been integrated into the BASINS system allowing users to create climate change scenarios by modifying historical weather data, and to use these data as the meteorological input to the Hydrological Simulation Program - FORTRAN (HSPF) watershed model. A capability is also provided to calculate specific hydrologic and water quality endpoints important to watershed management based on HSPF model output (e.g. the 100-year flood or 7Q10 low flow event). Finally, the CAT can be used to assess the outcomes of a single climate change scenario or to automate multiple HSPF runs to determine the sensitivity or general pattern of watershed response to different types and amounts of climate change.

Users can modify historical climate data using standard arithmetic operators applied monthly, seasonally or over any other increment of time. Increases or decreases in a climate variable (precipitation, air temperature) can be applied uniformly, or they can be selectively imposed on only those historical events that exceed (or fall below) a specified magnitude. This capability allows changes to be imposed only on events within user-defined size classes and can be used to represent the projected effects of 'intensification' of the hydrologic cycle, whereby larger precipitation events intensify, instead of events becoming more frequent. In addition, users are able to create time series that contain more frequent precipitation events. These capabilities provide users with an ability to represent and assess the impacts of a wide range of potential future climatic conditions and events. An example of the CAT window is shown in Figure 18.7.

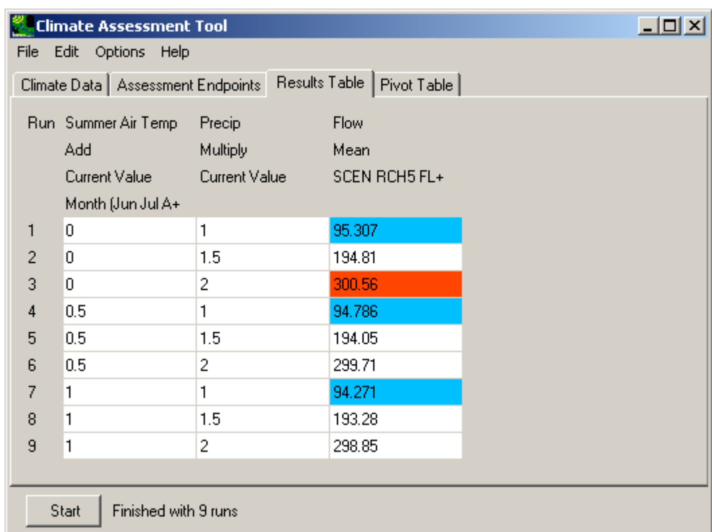

Figure 18.7: The BASINS Climate Assessment Tool (CAT)

BASINS CAT does not provide climate change scenario data. Rather, the tool provides a capability for quickly creating and running climate change scenarios within the BASINS system. Diverse sources of information such as records of historical and paleo-extreme events, observed trends, and projections based on global or regional scale climate models can be used to guide scenario development. Data requirements will vary depending on assessment goals. BASINS CAT provides capabilities to support a range of assessment goals, e.g. simple screening analysis, systematic sensitivity analysis, or implementing more detailed scenarios based on climate model projections.

Other advanced data analysis tools provided through BASINS include select functions of the USGS SWSTAT statistical software. The USGS Office of Surface Water's SWSTAT is a software package for statistically analyzing time-series data. A user interface to some functions of SWSTAT has been written as a BASINS plug-in (Figure 18.8). The available functions include frequency distribution, trend analysis, and n-day annual time series.

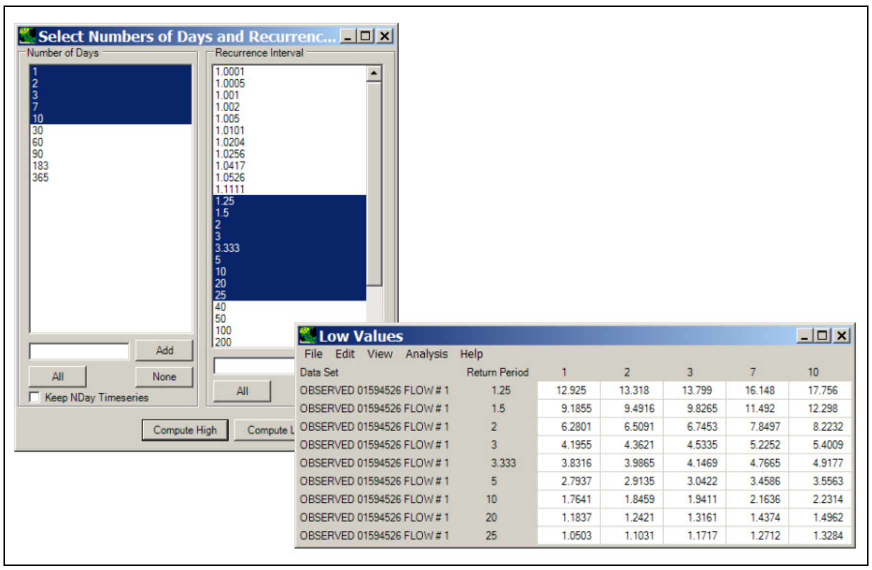

Figure 18.8: SWSTAT Frequency Analysis in BASINS

The BASINS system also includes tools designed to assist in preparing reports. A standard set of report scripts is included for inventorying and characterizing both point and nonpoint sources at the watershed and subwatershed scales. These watershed characterization reports can be used to evaluate the watershed condition, while providing the necessary information to assess monitoring programs, identify data gaps, and develop watershed-water quality modeling strategies.

The BASINS Watershed Characterization Reports operate within a user-defined area of interest. The reports are generated using .NET scripts, which the user can modify to provide customized reports. Output from the reports is displayed on the computer screen and is written to tab-delimited files. The scripting capabilities of BASINS allow users to generate reports based on any type of data, including GIS data and time-series data. Other types of reports commonly produced through BASINS include model results compiled as comparison statistics, watershed summaries, and constituent balances.

USER SUPPORT AND TRAINING

User support and training for BASINS is provided by EPA, often through a qualified contractor. Users receive responsive support related to all aspects of BASINS, including models, GIS, and BASINS utility programs. Web-based Frequently Asked Questions (FAQs) and BASINS Technical Notes are available on the BASINS web page (http://www.epa.gov/waterscience/basins/).

EPA sponsors BASINS workshops periodically, in various locations throughout the United States. The scopes of the workshops vary, with different workshops placing varying amounts of emphasis on BASINS components. Some of the workshops are general BASINS workshops, while many others focus on use of a particular model within BASINS. Recent workshops have focused on the use of HSPF, SWAT, or AQUATOX through the BASINS system. Hands-on experience with BASINS and its component models is provided during the extensive computer work sessions.

CASE STUDIES

Many examples of the use of BASINS are available. The BASINS website (http://www.epa.gov/waterscience/basins/) provides one particular case study on the Cottonwood Creek Watershed in Idaho County, Idaho, illustrating use of BASINS as a decision support system for TMDL development.

EPA's Office of Science and Technology was requested by the Idaho Division of Environmental Quality (IDEQ) to help develop a bacteria TMDL for Cottonwood Creek, Idaho. EPA's BASINS software was used to determine the source of the high bacteria concentrations, estimate bacteria loadings, and determine load reductions needed to meet State water quality criteria. The technical goals of the study were met and the State was able to issue the draft TMDL (US EPA, 2000).

At the request of the Idaho Department of Environmental Quality (IDEQ) and EPA's Region 10 Idaho Office, the EPA Office of Water headquarters conducted this study to model the loading of fecal coliform to creeks in the Cottonwood watershed, and to evaluate the level and types of controls required to reduce bacteria loading to acceptable levels. Data from a variety of sources, both within BASINS and outside of BASINS, were used to inventory and quantify point and nonpoint sources in the watershed. The Cottonwood wastewater treatment plant is the sole point source in this largely agricultural watershed. A fraction of the septic systems in this largely rural population were assumed to be failing. Livestock populations were known to be significant, and wildlife were known to be numerous in the area as well.

The BASINS Nonpoint Source Model (HSPF) was used to represent the Cottonwood watershed's hydrology and fecal coliform loads to the creek. The Cottonwood model hydrology was calibrated against measured Lower Cottonwood Creek flow gage data. A spreadsheet was used to calculate bacteria related HSPF input parameters, and then the model was calibrated against fecal coliform monitoring data. The model was rerun with a percent reduction to nonpoint source loads to creeks, in addition to cattle-in-stream and faulty septic system "point source" reductions, to determine nonpoint and point load reductions required to achieve the state water quality standard. Required nonpoint source load reductions ranged from 23% to 88%, when "cattle-in-stream" and faulty septic system loads were reduced by 80%-100%.

Additional control scenarios were run to evaluate the level of impact from individual sources, and the study arrived at the following key conclusions:

- The Cottonwood wastewater treatment plant is not a significant source of fecal coliform loadings in the subject creeks;
- The cattle-in-streams (or other) point source in the subject creeks, in late Spring, is a significant source of fecal coliform loadings during periods of dry weather;
- Accumulation of fecal coliform on land surfaces, due to both grazing/pasturing of cattle and manure spreading from hog and dairy operations, appears to be a significant source of fecal coliform loading to creeks, particularly during wet weather events; and
- Faulty septic systems appear to be a significant contributor to exceedances of the fecal coliform criteria in the watershed.

An implementation plan was developed to reduce bacteria loading to acceptable levels.

Other representative uses of BASINS include the following:

- HSPF Model of the Streamflow Simulation for the Lower Flint River Watershed (Wen, 2007). Agricultural irrigation in southwestern Georgia is one of the most important types of water use in the region. In this study BASINS/HSPF was used along with a groundwater model (MODFE) to understand the impacts of irrigation operations and the interactions between groundwater and surface water in the Lower Flint Watershed. The modeling results were used in the development of water management strategies.

- Calibration of a Watershed Model for Metropolitan Atlanta (Hummel, 2003). The Metropolitan North Georgia Water Planning District was created to provide a mechanism for regional coordination on water supply, wastewater treatment, and stormwater management. The District's first mandate included the development of a Watershed Management Plan (WMP) to provide for compliance with water quality standards that are associated with TMDLs, while allowing for continued sustainable growth in the region. BASINS/HSPF was used to provide a consistent modeling approach throughout the district. Along with the data layers provided in BASINS, local data were collected and compiled for meteorological, land cover, hydrology, water quality, point source, and water withdrawal data requirements. The model provides the ability to perform future conditions analyses for both hydrology and water quality, and it aides in the process of prioritizing watersheds for implementation strategies such that maximum benefit is achieved with limited financial resources.

- Modeling of Nonpoint Sources in Tickfaw River Watershed (Gala, 2006). The Tickfaw River watershed in the Lake Pontchartrain basin of southeastern Louisiana is especially challenged from rapid population growth, industrial activities, and agricultural use. Fish and wildlife propagation and primary contact recreation are not supported. There are many suspected sources of impairment, including agriculture, construction, forest management, and industrial sources. The specific objective of this study was to model the Tickfaw river watershed in order to quantify and differentiate the sources of pollution that arise from agriculture, forestry, urban storm water runoff, and other sources, making use of EPA's BASINS system. An assessment analysis can then be performed to enhance the water quality within the watershed by recommending best management practices.

CONCLUSIONS

Several decisions along the BASINS development path have been critical in making BASINS a leading system for watershed analysis decision support.

The design of a watershed analysis system must support the addition of new data and new techniques for analyzing that data. BASINS, through its extensible component-based architecture, is a dynamic system whose capabilities have increased as technology has allowed and needs have demanded. Another implication of the extensible architecture is that each BASINS tool can be developed independently of each other BASINS tool, greatly increasing the potential for independent groups to develop compatible BASINS extensions simultaneously. This flexibility enables BASINS to continue evolving to meet the changing needs of the watershed management community.

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. This design drastically simplifies maintenance and minimizes the cost of future enhancements. Moreover, this design standard 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.

By using open-source GIS tools and non-proprietary data formats, the core of BASINS is now independent of any proprietary GIS platform. As a result BASINS users are not limited by having to purchase any prerequisite software, other than the computer operating system. Just as important, BASINS has greater stability and transparency, as the source code for all components is available to developers and end users alike. 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.

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