The BASINS Watershed Analysis System -- Evolving to Embrace New Data and Techniques

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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 allows the user to assess water quality at selected stream sites or throughout an entire watershed. This invaluable tool 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 contain a suite of GIS-based tools and operate in a GIS environment, using the GIS interface as the front end of the user interface. 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 design has proven effective during the development of versions 3.1 and 4.0. The National Elevation Dataset (NED) and National Hydrography Dataset (NHD) are examples of data types recently added for version 3.1. Currently additional data are being added from the U.S. Census of Population and the U.S. Census of Agriculture. New analytical tools have also been added, such as USDA-ARS's Automated Geospatial Watershed Assessment

(AGWA). The core BASINS software does not have to be enhanced to support any of these new data types or tools. This flexibility enables BASINS to continue evolving to meet the changing needs of the watershed management community.

Introduction to BASINS

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. 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 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.

The main interface to BASINS is provided through a Geographic Information System (GIS) (Figure 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 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.

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.

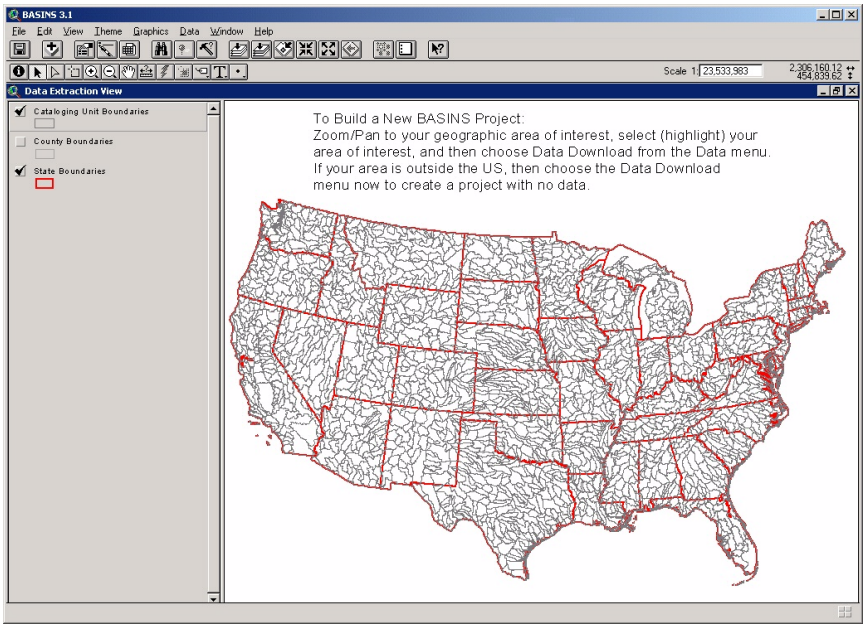

Figure 1. BASINS Geographic Information System Interface

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. 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 3.1 (http://www.epa.gov/waterscience/basins/). This version provides some significant enhancements and functions beyond those provided by the earlier releases of BASINS, Versions 1.0 through 3.0. 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. Enhancements have included adding additional types of data, higher-resolution data, additional models and analysis tools. In addition to those types of enhancements, in the future the system will be enhanced to accommodate additional GIS platforms.

Extensible Architecture

The BASINS system combines national environmental databases with watershed characterization and assessment tools, watershed models, and other supporting software. These components are linked together through the BASINS customized Geographic Information System (GIS) environment. ArcView version 3.x, developed by Environmental Systems Research Institute, Inc., is the GIS platform upon which BASINS is built.

The customized GIS platform is created using the Avenue scripting language that is a standard part of ArcView. Many of the tools and supporting BASINS utilities have been created entirely using Avenue scripts. 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 Avenue scripts pull data from the national databases and feed that data into intermediate text files. Those text files are then read and converted into the input format of the model itself. With this design, the models 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 sprang 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 (Figure 2). 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.

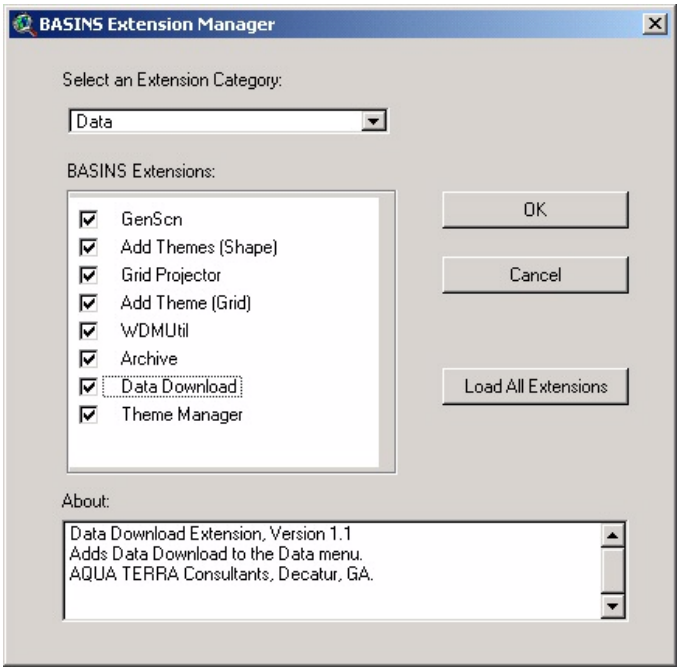

Figure 2. The BASINS Extension Manager

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. The PLOAD model and the AGWA system (see *Additional Tools*, below) are examples of extensions that were developed with very limited coordination and support from the BASINS development team. Those extensions are now distributed with BASINS. Another 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.

An additional design consideration influencing current development is the transition within ESRI away from ArcView 3.x to ArcGIS. The customization environment is completely different at the next generation of ArcView. Throughout the more recent BASINS development efforts, a design goal has been to perform only those operations dependent upon GIS within ArcView. Utility tools and model interfaces have been created using other programming languages. While these components are

invoked seamlessly through the Avenue scripts, the component code is not dependent upon the GIS environment. This design decision will have a considerable payoff when BASINS components are migrated to new GIS platforms.

The BASINS Data Download tool, included with the BASINS system for downloading and extracting data, provides a strong example of flexible and extensible architecture. Some of the data downloaded using this tool have been preprocessed for use in BASINS. Other data that can be downloaded using the Data Download tool has not been preprocessed and is extracted directly from the agency responsible for collecting the data.

The Data Download tool (Figure 3) provides links to the federal agencies where certain data types are hosted, and it downloads that data and converts it 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.

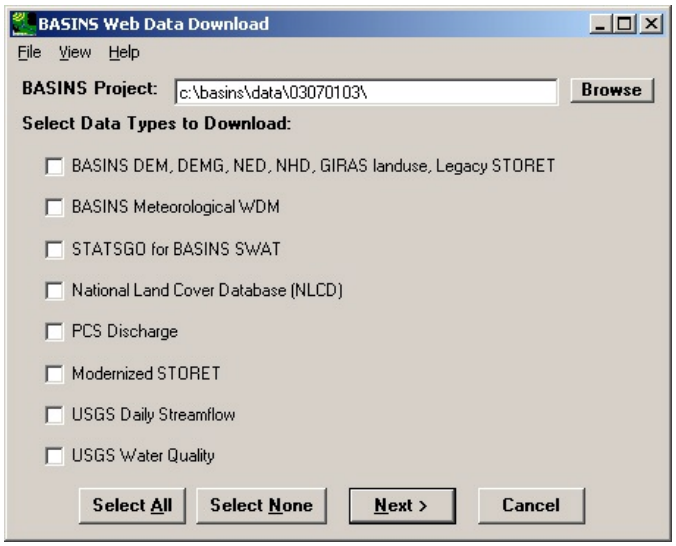

Figure 3. The BASINS Data Download Tool

The download types preprocessed for use in BASINS 3.1 include Digital Elevation Model (DEM) in shapefile and ESRI Grid format, the National Elevation Dataset (NED) (described in more detail below), the National Hydrography Dataset (NHD), USGS GIRAS Landuse, STORET data from EPA's legacy system, Meteorologic

Watershed Data Management (WDM) files, and STATSGO soils data for SWAT. Data types downloaded directly from other federal agencies include the National Land Cover Database (NLCD), EPA's Permit Compliance System (PCS) data, the modernized EPA STORET system, USGS Daily Streamflow values, and USGS Water Quality data.

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.

New Data Types

To better meet watershed modeling and analysis needs, new and improved datasets are routinely added to the BASINS system. The component-based design of BASINS allows for new datasets to be added without requiring redistribution of the entire package. If an existing dataset is updated and has either its location or format modified, only that dataset's download component will need to be modified and redistributed. Likewise, adding a new dataset is accomplished by developing a new component to download and incorporate the data into BASINS. In either case, only the updated or newly created component needs to be distributed. The Web Data Download Tool will recognize the new component at run-time and make the data available for downloading and incorporation. The following sections describe datasets recently or soon to be made available in BASINS.

U.S. Census of Agriculture

USDA's Census of Agriculture (USDA, 2004) is the leading source of statistics about the Nation's agricultural production. Data in the census include number of farms, farm characteristics, crops, livestock, irrigation, chemical and fertilizer use, and agricultural land use. The data are available by state and county as well as by five-digit postal ZIP Code and Congressional district for all 50 states. Data from the 2002 census are now available and are being incorporated into BASINS.

U.S. Census of Population

A number of geospatial coverages from the 1990 and 2000 U.S. Census Dataset (US Census Bureau, 2002) have been incorporated into BASINS. Boundary information has been incorporated for the following scales, ranging from largest to smallest:

- State and County
- Zip Codes
- Census Tracts
- Block Groups

Along with the boundary data, 2002 TIGER line data has also been incorporated. These data depict roads, railroads, and other similar information. The boundary and line data provide a more precise reference for locating watershed features and boundaries or data collection sites.

Along with the geospatial coverages, 1990 and 2000 population and 1990 water supply and sewerage data have also been incorporated (water supply and sewerage data was not collected in 2000). Among other purposes, these data provide a method for estimating pollutant loads from sewer and septic systems.

National Hydrography Dataset (NHD)

The National Hydrography Dataset (NHD) (USGS, 2004) is a comprehensive set of spatial data that contains information about surface water features such as lakes, ponds, streams, rivers, springs and wells. The dataset is being updated to include higher resolution data and to store all data in ESRI's GeoDatabase format. Once the user has downloaded data in the new format, the Web Data Download Tool may be used to incorporate it into BASINS.

National Elevation Dataset (NED)

The USGS has merged the highest-resolution, best-quality elevation data available across the United States into a seamless raster format. The resulting product is the National Elevation Dataset (NED) (USGS, 2003). NED provides 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous United States. With NED now available in BASINS 3.1, end users will benefit from NED's improved resolution when performing watershed delineation.

Additional Tools

For version 3.1 of BASINS, several tools have been added to enhance the watershed modeling and analysis functionality of BASINS. The component-based design of BASINS allows for these additional tools without modifying the core BASINS

software. The following sections describe the watershed management tools added for the most recent version of BASINS.

Automated Geospatial Watershed Assessment (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 all phases of a watershed assessment using SWAT and another model geared toward the arid southwest known as KINEROS2.

The BASINS AGWA extension is 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 (Figure 4). AGWA is implemented as an ArcView extension, 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.

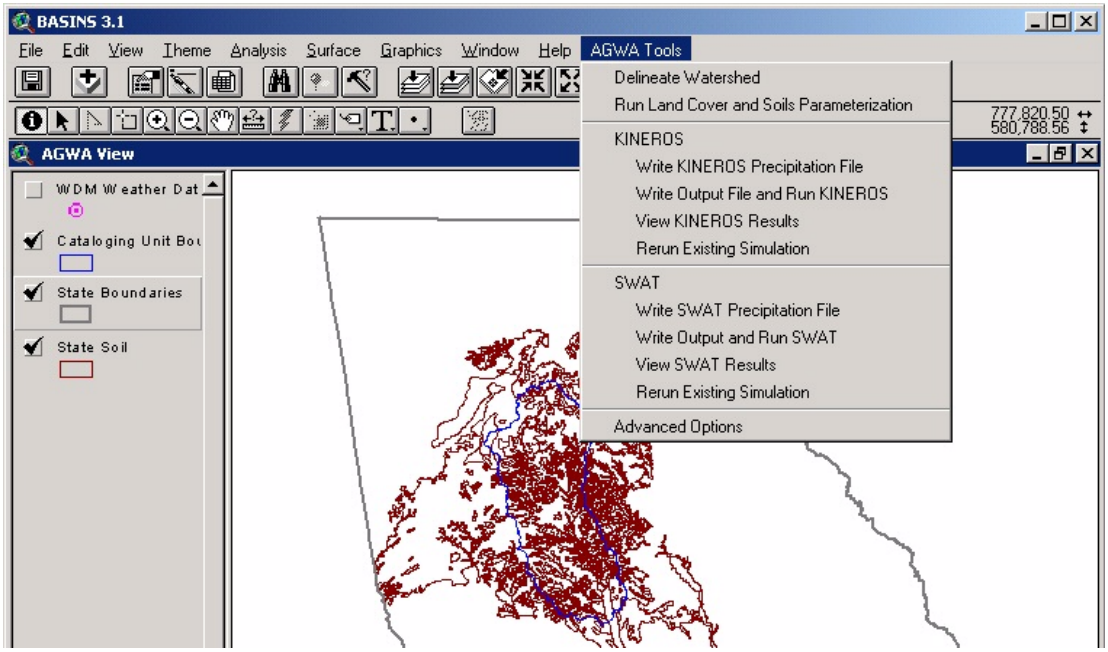

Figure 4: AGWA View and Tools Within BASINS 3.1

The AGWA extension demonstrates 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.

Model Parameter Optimizer Tool

In order to assist with model calibration, BASINS 3.1 also includes an integration of a model-independent parameter optimizer known as PEST. Targeted initially toward the HSPF model, BASINS-PEST takes an HSPF User Control Input (UCI) file, along with simulated and observed data sets, and creates all input files needed by PEST. PEST can then be run from the WinHSPF (Duda, et al., 2001) program within BASINS. Other input files required by PEST include the suite of HSPF parameters to be optimized. Initial versions of these files are provided in the BASINS package and may be updated by the user as needed.

Detailed knowledge of PEST and HSPF are essential for successful application, but much of the tedium of setup has been removed. The HSPF code has been updated to support the use of PEST supplemental files. All calibration parameters in the PERLND, IMPLND, and RCHRES blocks of HSPF may be optimized by PEST. The optimized parameter set resulting from a PEST run may then be saved as a unique HSPF UCI file.

Watershed Characterization System Report Generator

The Watershed Characterization System (WCS) is designed to provide users with tools for characterizing and thereby understanding their watersheds. It can be used to assist with the watershed characterization phase required in developing Total Maximum Daily Loads (TMDLs). Output reports may include the following:

- Characterization of the physical and hydrologic properties of the watershed, such as soil, land use, elevation, climate, and stream flow.
- Evaluation of ambient water quality conditions, including inventory of monitoring stations and statistical analysis of observed data.
- Assessment of potential sources of impairment, such as permitted dischargers, crop and livestock agriculture, mining, and populated places, and preliminary estimation of pollutant loads from these sources.

The system is applicable to a broad range of TMDLs since the characterization process is relatively uniform and can be standardized regardless of the waterbody type and pollutant. Similarly, the results of a BASINS watershed characterization may be used to support other programs such as basin-wide planning and monitoring, nonpoint source programs, and waterbody assessments.

Conclusion

The BASINS system continues to evolve to adapt to new data types and improved techniques for watershed management and modeling. Because of its component-based architecture, these new data types and techniques can be added without changing the core BASINS system. This flexibility enables BASINS to continue evolving to meet the changing needs of the watershed management community.

Acknowledgements

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