LEVERAGING AN OPEN FRAMEWORK FOR EXPANDED MODELING CAPABILITIES IN BASINS 4.0

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ABSTRACT

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 under a Geographic Information System (GIS) environment to support development of solutions to watershed management problems and environmental protection issues, including development of Total Maximum Daily Loads (TMDLs).

BASINS encompasses a suite of water quality models, from sophisticated broad-spectrum watershed models to agricultural models to planning and management level models. The user has the flexibility to choose the model and tools best suited for the requirements of the study. The open-source framework of BASINS is designed around an extensible architecture that readily allows for the inclusion of additional models. Since the initial release of BASINS Version 4.0, several additional models are being added to the modeling suite in BASINS, including USDA's Soil and Water Assessment Tool (SWAT), EPA's Storm Water Management Model (SWMM), Penn State University's Generalized Watershed Loading Functions (GWLF), and EPA's Water Quality and Analysis Simulation Program (WASP). Each of these established models is being incorporated into the BASINS system through a plug-in. The plug-in for each model uses the BASINS GIS and meteorological data to assemble the required model input. The plug-in architecture allows BASINS capabilities to expand without issuing a new release each time a model is added to the BASINS modeling suite. This flexibility enables BASINS to continue evolving to meet the changing needs of the TMDL development community.

KEYWORDS

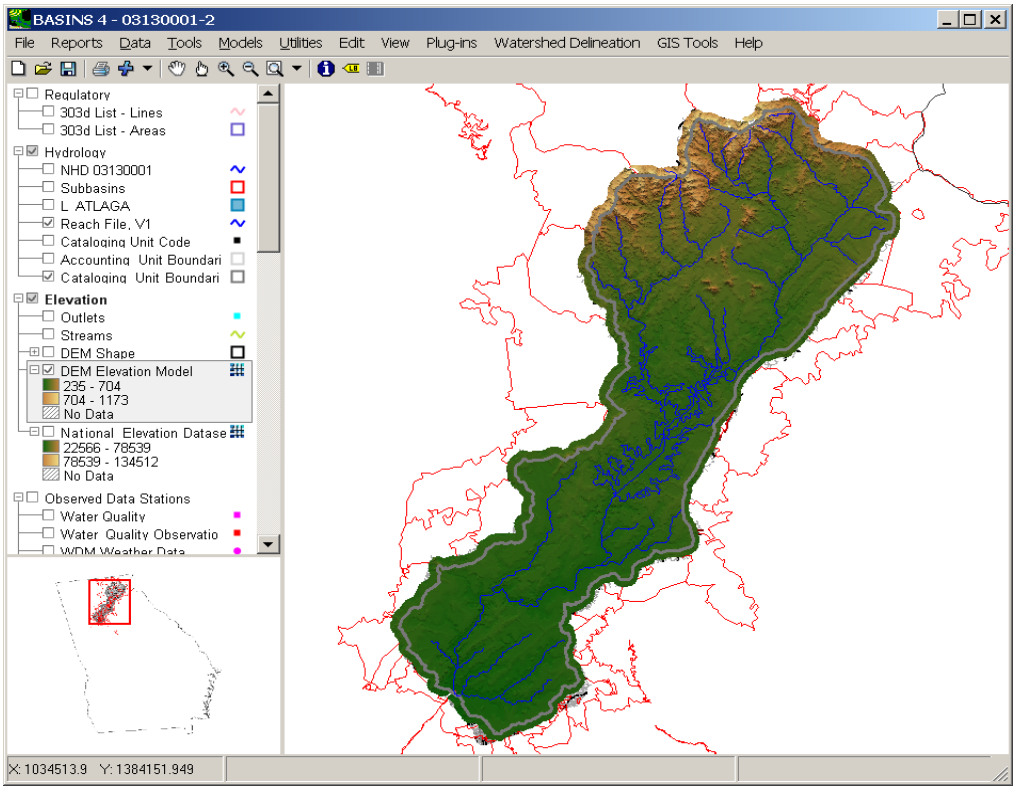
BASINS, Open GIS, Watershed Modeling, Environmental Databases, Modeling

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 framework 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.

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. Version 4.0 of BASINS (Kittle, 2006) 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 while still accommodating users of several different GIS software platforms. BASINS 4.0 is built as an extension to MapWindow, a non-proprietary, open-source GIS (http://www.MapWindow.org). The BASINS interface through MapWindow is shown in Figure 1.

Figure 1 – The BASINS 4.0 Interface Built Upon an Open Source Foundation



The extensibility of MapWindow is one of the main reasons why it was chosen as the GIS foundation for BASINS. MapWindow can be extended with plug-in components written in any Microsoft .NET language. The plug-in interface allows third-party developers to create plug-ins that become fully integrated into the BASINS interface. Plug-ins may be written to add additional functionality (models, special viewers, hot-link handlers, data editors, etc.) to BASINS, and may then be passed along to other clients and cooperators.

MODELS UNDER THE BASINS 'UMBRELLA'

BASINS encompasses a suite of water quality models, ranging from sophisticated watershed and agricultural models to planning and management level models. Given this suite of tools, the user has the flexibility to choose the model and tools best suited for the requirements of the study. All but the most simplistic of the models within BASINS are loosely coupled to BASINS through Plug-ins that prepare data for the core models, while the core models continue to be maintained by the corresponding model's development team. Since the core models are maintained separately from BASINS, updates to the core models come from the model developers themselves.

Since BASINS provides an over-arching structure to support users of these models, the BASINS development team sometimes refers to the models available within BASINS as models under the BASINS 'umbrella'. Each model under the BASINS 'umbrella' has been incorporated in collaboration with that model's development team.

The original release of BASINS 4.0 includes three models. These include two models that allow the user to simulate the loading of pollutants and nutrients from the land surface, and one model to simulate aquatic ecosystems. The integration of each model into BASINS is discussed briefly below.

The Hydrological Simulation Program Fortran (HSPF) (Bicknell, et al., 2005) is a continuous simulation watershed model that simulates non-point source runoff and pollutant loadings for a watershed and performs flow and water quality routing in stream reaches. HSPF can be used to estimate non-point source loads from various land uses, as well as fate and transport processes in streams and lakes. A BASINS plug-in allows the user to define which GIS and time series data shall be used in the HSPF model, extract appropriate information for the preparation of HSPF input files, and create the formatted model input. A Windows interface to HSPF, known as WinHSPF, was created for BASINS and works with the EPA-supported HSPF model. The core HSPF model is maintained separately from the plug-in, and can be updated without changing any other component of BASINS.

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 non-point loads (NPS) of pollution on an annual average basis for any pollutant specified by the user. 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. Land use and point source data for PLOAD are provided

with BASINS, and sub-watersheds 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.

AQUATOX (USEPA, 2004) is a chemical fate and ecological effects assessment model that simulates the simultaneous impacts of multiple environmental drivers and stressors on organisms in aquatic food webs. AQUATOX can simulate the impacts of nutrients, organic toxicants, and bio-accumulative compounds, as well as expected ecosystem responses to changes in pollutant concentrations. A BASINS plug-in allows the user to define the stream segment and associated GIS data to be used in the AQUATOX model, extract appropriate information for the preparation of AQUATOX input, and pass that information on to the AQUATOX user-interface. Additionally, a feature of WinHSPF allows a user to write time-series output from the HSPF land surface simulation to feed the AQUATOX model. The core AQUATOX model and its user interface are maintained separately from BASINS, and thus these components can be updated without updating BASINS.

ADDITIONAL MODELS

BASINS has always been a dynamic system, with increased capabilities added as technology and needs demand. With the extendable architecture of BASINS 4.0, its open-source plug-in framework and growing number of data sources, more than ever there is recognition that collaborative development between model developers and BASINS benefits all involved. As a model is incorporated into BASINS it becomes easier to set up, resulting in expanded user communities and improved model user experience. At the same time, as the suite of models under the BASINS 'umbrella' continues to grow, the user has increased flexibility in choosing the model best suited for a particular study.

Additional models can be added to BASINS 4.0 provided that the plug-in for that particular model is developed in a .Net compatible language following a few simple naming requirements so that the new plug-in is recognized by the BASINS system. When adding a new model to BASINS, the coordination with the BASINS development team can be extensive or limited, depending upon the needs of a particular model development community. Some coordination is required to make the plug-in a part of the BASINS distribution package, but a development group may choose to build a plug-in that may be installed following a BASINS installation without making that plug-in part of the full BASINS distribution package.

A number of additional models are being added to BASINS 4.0. These additional models include USDA's Soil and Water Assessment Tool (SWAT), EPA's Storm Water Management Model (SWMM), Penn State University's Generalized Watershed Loading Functions (GWLF), and EPA's Water Quality and Analysis Simulation Program (WASP). Each of these established models is being incorporated into the BASINS system through a plug-in, developed in collaboration with the model developer. In each case the plug-in for each model uses the BASINS GIS and meteorological data to assemble the required model input.

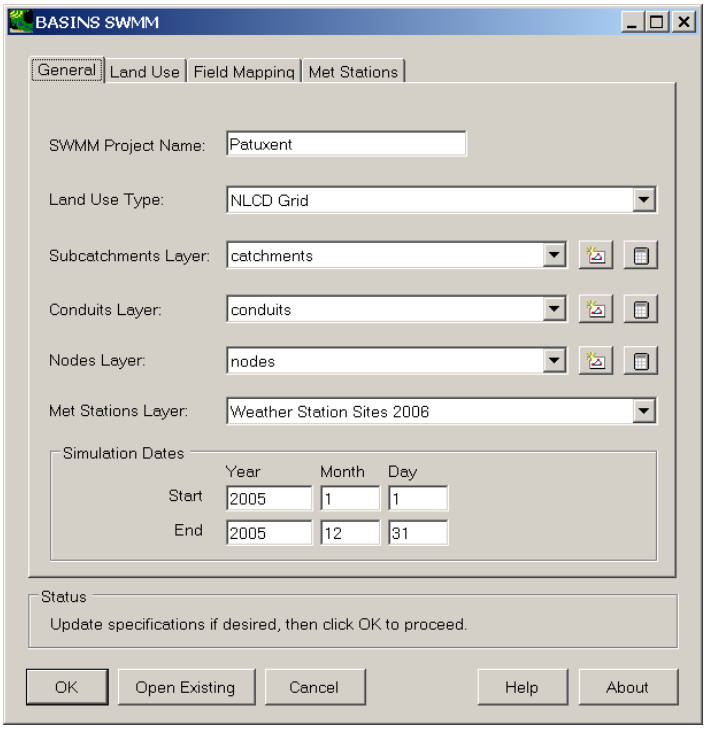
EPA's Storm Water Management Model (SWMM)

The EPA Storm Water Management Model (SWMM) (Rossman, 2007) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of sub-catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators.

SWMM is widely used throughout the world for planning, analysis and design related to storm water runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well. In addition to modeling the generation and transport of runoff flows, SWMM can also estimate the production of pollutant loads associated with this runoff.

The BASINS/SWMM Setup Plug-in (Figure 2) allows a user to set up a SWMM project using the GIS and meteorological time series data available within BASINS. This plug-in is normally used in conjunction with existing shapefiles of sub-catchments, conduits, and nodes, as might be available for an existing storm or sanitary sewer system. The GIS layers of sub-catchments, conduits, and nodes may also be created using the BASINS watershed delineation and/or shapefile editing tools.

Figure 2 – The BASINS/SWMM Plug-in User Interface



When using BASINS/SWMM to build an initial SWMM Project File, the sub-catchments, conduits, and nodes are provided as input GIS layers. A land use layer may be specified, and

this layer will be used in computing the area of each land use within each sub-catchment. A met data layer may also be specified, from which the user may select particular stations to use to supply time series of precipitation, air temperature, and evaporation. Land use and meteorological data layers may be downloaded using the BASINS Download Data tool.

BASINS/SWMM is designed to be flexible in its handling of GIS layers. While typically a BASINS user will use the USGS GIRAS or NLCD land use layers, BASINS SWMM supports use of other vector or raster land use layers. While the BASINS met data is typically used to provide input meteorological data, other WDM files of meteorological data may be used. The BASINS/SWMM Plug-in was a collaborative effort among the EPA BASINS development team and the EPA SWMM development team. Having SWMM available within BASINS expedites the set-up process for a SWMM user, and it expands the BASINS suite of models to include a premier urban drainage model.

Penn State University's Generalized Watershed Loading Functions (GWLF)

A continuing BASINS development goal has been to provide a suite of watershed models ranging from simple to sophisticated. The Generalized Watershed Loading Functions (GWLF) was identified as a mid-level model that enhances the analytical capabilities of BASINS. GWLF has previously been implemented as a GIS-based modeling system, known as AVGWLF (Evans et al., 2002), through the ArcView GIS software and the GWLF model developed originally by Haith and Shoemaker (1987). The GWLF model has undergone numerous upgrades in recent years, including the addition of a stream bank erosion routine (Evans et al., 2003), a BMP assessment module (Evans, 2005), and routines for handling farm animal loads, a pathogen load routine, and a specialized model for use in urbanized settings (Haith, 1993).

A Plug-in for BASINS similar to AVGWLF is being developed by Penn State for the MapWindow GIS package. This Plug-in will enable the user to parameterize input data for the GWLF model through BASINS. In utilizing this interface, the user is prompted to identify required GIS files and to provide other non-spatial information. This data is then used to derive automatically the values for required model input parameters. These values are written to the "transport" and "nutrient" input files needed to execute the GWLF model. Through the GWLF BASINS Plug-in, a user selects an area of interest, creates model input files, runs the simulation model, and views the output in a series of seamless steps.

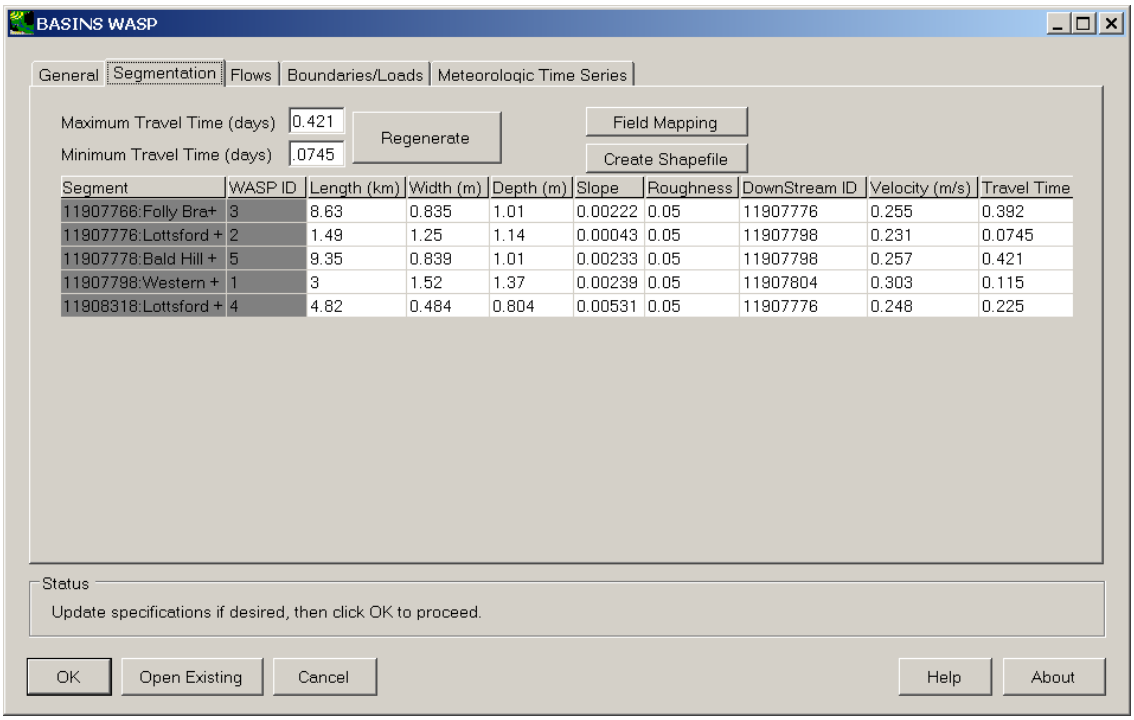
The BASINS/GWLF Plug-in is being developed by Penn State, through the BASINS contract and in collaboration with the EPA BASINS development team.

EPA's Water Quality and Analysis Simulation Program (WASP)

The EPA Water Quality Analysis Simulation Program (WASP) (Ambrose, et al., 1993) is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. This model helps users interpret and predict water quality responses to natural phenomena and manmade pollution for various pollution management decisions. WASP also can be linked with hydrodynamic and sediment transport models that can provide flows, depths velocities, temperature, salinity and sediment fluxes.

The BASINS/WASP Setup Plug-in (Figure 3) allows a user to set up a WASP project using the GIS and time series data available within BASINS. BASINS allows the user to build a new project and open WASP directly from the BASINS user interface. The NHDPlus Flowline Features, a GIS layer that is part of the NHDPlus download, are used by this plug-in. A met stations layer, such as that created by the Data Download tool when downloading meteorological data, is useful for locating possible met stations for the WASP model. As the BASINS/WASP Plug-in loads, the meteorological data is scanned to build the lists of available met data, and the other types of time series data in BASINS are scanned to build lists of available time series for input flows, loads, and boundary conditions.

Figure 3 – Segmentation Specification through the BASINS/WASP Plug-in User Interface



WASP segmentation is specified through the BASINS/WASP Plug-in user interface, to specify the properties of the WASP segments to be modeled. A travel time is estimated for each stream segment, and the user has the option to combine or divide segments as desired based on travel time.

The BASINS/WASP Plug-in was a collaborative effort among the EPA BASINS development team and the EPA WASP developers at EPA Region 4. Having WASP available within BASINS expedites the set-up process for a WASP user, and it expands the BASINS suite of models to include an established dynamic water quality model.

USDA's Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) model (Neitsch, et al., 2005) is a physically based continuous simulation watershed model developed by the USDA Agriculture Research Service (ARS). SWAT is 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.

SWAT was available in BASINS 3.1 as an ArcView extension, built using the Avenue scripting language. Since the user interface was closely tied to the ArcView scripting language, the effort involved in adapting this interface for MapWindow has been more extensive, and thus a SWAT plug-in was not available in the initial release of BASINS 4.0.

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, meteorological 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 Plug-in provides input files that are sent to the SWAT executable file for simulation. The SWAT model itself is distributed 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.

The BASINS/SWAT Plug-in was a collaborative effort among the EPA BASINS development team and the SWAT developers at Texas A&M University. Having SWAT available within BASINS expedites the set-up process for a SWAT user, and it expands the BASINS suite of models to include another sophisticated watershed model.

CONCLUSION

In order to meet the ever-changing needs of water resource investigations and to maximize the use of available information, 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 with capabilities that have increased as technology has allowed and needs have demanded.

With the extendable architecture of BASINS 4.0, its open-source plug-in framework and growing number of data sources, more than ever there is recognition that collaborative development between model developers and the BASINS team benefits all involved. As a model is incorporated into BASINS it becomes easier to set up, resulting in expanded user communities and improved model user experience. At the same time, as the suite of models under the BASINS 'umbrella' continues to grow, the user has increased flexibility in choosing the model best suited for a particular study.

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