GIS and Water Resources Modeling: State-of-the-Art

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This chapter presents an overview of the latest GIS and water resources modeling integration approaches and software. The objective of integration is to estimate physical input parameters of the computer models used in water resources modeling. The chapter presents the watershed GIS database development procedures and methods of integrating GIS and modeling.

5.1 GIS and Modeling Integration

Rapidly developing computer technology has continued to improve the modeling necessary for water resources management. The use of GIS provides an accurate and manageable way of compiling and evaluating modeling parameters such as land use, slope, and soil types. Each parameter can be digitized from existing maps, aerial photographs, or satellite images and stored in “layers” on a computer. Each layer can then be easily combined for input into a hydrologic model. The use of GIS, as a side benefit, provides water resources managers with an easily updated database for other planning activities not directly related to water resources (Jostenski, 1988).

Effective water resources management requires the linking of specialized computer modeling to the GIS. At present, GIS primarily offers front-end or back-end applications to existing hydrologic models. Front-end applications

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include the computation of watershed parameters for existing lumped-parameter hydrologic models. Back-end applications include the cartographic display of computed hydrologic data (Maidment, 1993). There are three methods of integrating GIS in water resources modeling: interchange, interface, and integration. Each method is discussed below in detail.

5.2 Interchange or Data Transfer Method

The interchange method employs a batch process approach to interchange (transfer) data to and from a computer model. In this method, there is no direct link between the GIS and the model. Both the GIS and the model are run separately and independently. A GIS data base is processed to extract model input parameters. GIS data are first saved to ASCII files or spreadsheets, and subsequently appended to the model's ASCII input files. Similarly, the model's ASCII output data is appended to a GIS database to map the model results. All these operations are manual, and therefore, very laborious. Despite its cumbersome nature, this is the most practiced method at the present time because it does not require any additional computer program other than modeling and GIS software.

Any GIS software can be used in the interchange method. A GIS with both the vector and raster capability provides more interchange options. For example, ARC/INFO® and ArcView® vector GIS software products from Environmental Systems Research Institute (ESRI) can be used. ArcView 3.0 has introduced a raster *extension* (add-on) called *Spatial Analyst*® (ESRI, 1996). This extension provides tools to create, query, analyze, and map cell-based data and to perform integrated analysis using feature-based and cell-based (grid) themes. Spatial Analyst must be purchased separately. It can be used for slope and aspect mapping and for several other hydrologic analyses, such as:

- to derive watershed boundaries.
- to model stream flow.
- to investigate accumulation.

ESRI's web site (<http://www.esri.com/scripts/avenue3/samples.html>) provides a "Hydrologic Modeling" or *Hydro* extension which extends the Spatial Analyst user interface for hydrologic modeling. Hydro extension requires that Spatial Analyst be already installed. Hydro will automatically load the Spatial Analyst if it is not loaded.

The Hydro extension will install a menu and two tools into View Graphical User Interface (GUI). The Hydro menu has choices to set properties, Fill depressions in an elevation grid theme, calculate Flow Direction, calculate Flow Accumulation, calculate Flow Length, and delineate Watershed. Properties sets the flow direction and accumulation grid themes to be used for Watersheds and the two tools. Fill works off an active elevation grid theme. Flow Direction works

off an active elevation grid theme that has been filled. Flow Accumulation works off an active flow direction grid theme. Flow length works off an active flow direction grid theme. Watershed works off an active flow accumulation grid theme and Properties must be set. Watershed finds all basins in the data set based on a minimum number of cells in each basin.

The two tools added require Properties to be set. The Watershed tool works off an active elevation grid theme that has been filled. It will create a watershed from a point specified on the view. The Raindrop tool works off of an active elevation grid theme that has been filled. It will trace the path of flow from a point specified on the view to an outlet.

Some examples of data exchange are described below:

5.2.1 Subbasin Data Exchange

Most rainfall-runoff models (SWMM, PSRM, HEC-1) need input for area, overland flow width, and slope of the modeled subbasins. Area is readily available as a feature attribute for all the polygons. Width can be measured interactively in any direction (e.g. along a stream or a sewer) by using GIS software's tool bar. For example, in ArcView the *Drawing Tool* can be used for on-screen measurement of distance. Subbasin slope can be estimated by an analysis of a USGS digital elevation model (DEM). Since DEM images are raster coverages, one needs to work in a raster based GIS for estimating subbasin slopes. A raster coverage for subbasin slope is created by overlaying the raster coverages for subbasins and DEM. For example, in ERDAS (a digital image processing program from Earth Resource Data Analysis System, Atlanta, Georgia) the function SLOPE is used to compute percent slope by fitting a plane to a pixel elevation and its eight neighboring pixel elevations. The difference in elevation between the low and the high points is divided by the horizontal distance, and multiplied by 100 to compute percent slope for the pixel. Pixel slope values are averaged to compute the mean percent slope of each subbasin. DEM elevation and slope analysis can be conducted in ArcView's Spatial Analyst extension.

For large watersheds which may have thousands of subbasins, manual delineation and digitization of subbasins may be too hectic and laborious. This problem is usually handled by reducing the number of subbasins by lumping the small subbasins into large basins. This aggregation approach can significantly reduce the accuracy of the model results. Access to greater computing power has alleviated the task of aggregation. Modeling of the hydrologic processes for each subunit (subbasin) may now be carried out at much smaller scales. For example, availability of DEMs suggest that it is now possible to consider runoff generation for units as small as 30 x 30 m (Quimpo, 1993). GIS manages and provides tools for analysis of spatial data such as DEMs (Vieux, 1993). DEMs can also be used to generate triangulated irregular networks (TINs) which in turn are being used

for automatic basin delineation and integrated hydrologic simulation (Nelson et al., 1993). Figure 5.1 shows DEM derived subbasin and stream coverages for a small part of the Monongahela River Basin located in south western Pennsylvania. The DEM analysis was conducted using the Spatial Analyst extension of the ArcView software using a 500 ft (150 m) pixel size (ESRI, 1996). This method works well for the natural mountainous watersheds like those located in Pennsylvania where subbasin boundaries are well defined and distinct due to highly variable topography.

Figure 5.1 DEM based watershed and stream coverages.

5.2.2 Water Quality Modeling Data Exchange

Some urban runoff quality models, such as the TRANSPORT Block of SWMM, can use curb length as a model input parameter which can be estimated from a coverage for roads. Curb length can be estimated by performing an overlay analysis of streets and subbasin coverages. For example, in ArcView curb length can be estimated by performing a *theme-on-theme* selection using roads as the target theme and subbasins as the selector theme. Alternatively, for large areas such tasks can be handled more efficiently in ArcView's *Network Analyst*[®] extension, which is designed to solve problems related to street, highway, and other networks. Like Spatial Analyst, Network Analyst must also be purchased separately.

5.2.3. Percent Imperviousness Data Exchange

Most rainfall-runoff models need an input for the subbasin percent imperviousness which can be estimated by processing the land use coverage. The U.S. Soil Conservation Service (SCS) has published tables which provide average percent

imperviousness for different land uses (Urban, 1986). Table 5.1 shows the SCS percent imperviousness and runoff curve number data for fourteen land use classes. A subbasin percent imperviousness coverage is created by overlaying the coverages for subbasins and land use to delineate the percent imperviousness polygons. Each polygon has two attributes: subbasin ID and land use. The land use-percent imperviousness matrix is then used to assign percent impervious values to the polygons. Polygon percent imperviousness values are area weighted to compute the mean percent imperviousness for each subbasin. This task can be done in ArcView, but for large areas an ARC/INFO production shop will be more efficient.

Table 5.1 SCS runoff curve numbers.

Watershed Land Use Class	SCS Equivalent Land Use Class	% Imper-viousness	Runoff Curve Number			
	Hydrologic Soil Group		A	B	C	D
High density residential	Average lot 506 to 1012 m ² (0.125 to 0.25 acres)	51	69	80	87	90
Medium density residential	Average lot 1349 to 2024 m ² (1/3 to 1/2 acres)	28	56	71	81	86
Low density residential	Average lot 4047 to 8094 m ² (1 to 2 acres)	16	49	66	78	83
Commercial	Commercial and business	85	89	92	94	95
Industrial	Industrial	72	81	88	91	93
Parks, cemeteries, ballfields, etc.	Open space	0	39	61	74	80
Schools	Average lot 1349 to 2024 m ² (1/3 to 1/2 acres)	28	56	71	81	86
Wooded	Woods (good condition)	0	30	55	70	77
Brush	Brush (good condition)	0	30	48	65	73
Meadow	Meadow	0	30	58	71	78
Agricultural	Row crops average	0	64	75	83	87
Farmstead	Farmstead	51	59	74	82	86
Disturbed	Newly graded areas	35	77	86	91	94
Water	None	100	100	100	100	100

5.3 Interface Method

The interface method provides a direct link between a GIS and a computer model of the watershed. It consists of at least the following two components: (i) a pre-processor which analyzes the GIS data to create model input files, and (ii) a post-processor which imports the model output and displays it as GIS themes. The major difference between the interchange and interface methods is that the model

input file creation and model output file processing requires a manual and laborious batch processing approach in the interchange method whereas these tasks are as simple as point-and-click in the interface method. Although the interface method automates input file development within GIS, it cannot run the model from within GIS. To run the model, one needs to perform the following steps:

1. Enter the GIS and export model input data.
2. Exit GIS and create a header file containing model execution and output instructions
3. Append the header file to the GIS export file.
4. Run the model.
5. Re-enter the GIS and import the model output.

The interface method offers an attractive alternative to the interchange method. Modeling tasks are incorporated in the GIS software as a new menu (Shamsi, 1998). Model network (schematic) is created as a GIS coverage. Existing GIS coverages of streets, collection system, and watershed boundaries, etc., serve as excellent backdrops. Model output is displayed as a GIS theme. This method requires an interface program in addition to modeling and GIS software. Some interface examples are given below.

5.3.1 SWMM and ArcView® Interface

A sample interface developed for the EXTRAN Block of SWMM based on Tasks 1 and 2 described above is shown in Figure 5.2 (Shamsi, 1998). The interface adds a SWMM menu to ArcView's main menu. The SWMM menu has the following items: Make Input File, Read Output File, Result Join, Unjoin Results. The menu functions from a view. The interface allows a user to independently create input files, translate result files, join results to the themes, and remove the results joined to the themes.

Figure 5.2 ArcView and SWMM interface.

5.3.2 DHI ArcView Interfaces

The Danish Hydraulic Institute (DHI) (<http://www.dhi.dk>) has developed three ArcView GIS interfaces for hydraulic and hydrologic modeling. These interfaces are described below. A fourth DHI software called MIKE BASIN based on full GIS integration is described in the next section.

MOUSE GIS

MOUSE is a package for the simulation of surface runoff, flow, water quality and sediment transport in urban catchments and sewer systems. MOUSE GIS is an application linking the MOUSE numerical sewer modeling system with ArcView. The MOUSE GIS interface is used for pre-processing external database information into MOUSE data sets. Once the link to an external database has been established, manhole, link, weir, pump, and catchment data can be uploaded. The entire data base can be used for the model networks or a subset can be selected. The selected set can subsequently be simplified (nodes excluded) to reduce the model size. MOUSE GIS also act as a post-processor for simulation results. Pipe flow results (max pipe filling, time series of stage and discharge, surcharge, flow depth, flooding) can be displayed and overlayed with other GIS data. Mouse GIS also provides an interface to MIKE SWMM, DHI's implementation of the SWMM model.

MIKE 11 GIS

MIKE 11[®] is a package for the simulation of surface runoff, flow, water quality and sediment transport in channels, rivers and flood plains. MIKE 11 is developed as a fully integrated ArcView interface. MIKE 11 GIS is ideally suited as a spatial decision support tool for river and flood plain management. To develop a MIKE 11 GIS application, essential information comprising a MIKE 11 river network, a MIKE 11 simulation and a digital elevation model (DEM) are required. For further analysis, information such as maps/themes of rivers, infrastructure, land use, satellite/radar images and other spatial data can be included. The river network of a MIKE 11 model is geo-referenced in MIKE 11 GIS through the Branch Route System (BRS). Linking a MIKE 11 Result file to the BRS, MIKE 11 GIS produces three types of flood maps. These are depth/area inundation, duration and comparison/impact flood maps. The flood maps produced by MIKE 11 GIS are generated applying an automatic interpolation routine. From a series of flood maps MIKE 11 GIS generates a highly visual video animation which is suitable for presentation purposes. MIKE 11 GIS also outputs graphs of water level time series, terrain and water level profiles and flood zone statistics. The MIKE 11 GIS topographical module facilitates accurate and automatic extraction of flood plain topography (flood plain cross-sections and

area elevation relations) from the DEM. The extracted flood plain topography can readily be imported into a MIKE 11 cross section database. Mike 11 GIS interface is shown in Figure 5.3.

Figure 5.3 MIKE 11 GIS interface.

MIKE SHE

MIKE SHE[®] (Refsgaard and Storm, 1995) is a deterministic, fully distributed, and physically based modeling system for describing the major flow processes of the entire land phase of the hydrological cycle. MIKE SHE solves the partial differential equations for the processes of interception, evapotranspiration and snow melt, overland and channel flow, unsaturated zone flow, saturated zone flow. The flow equations are solved numerically using finite difference methods. In the horizontal plan the catchment is divided into a network of grid squares. River branches are assumed to run along the boundaries of the grid squares or if the river is wider than one grid, the river may occupy a number of grids. MIKE SHE uses ArcView GIS as a pre- and postprocessor to facilitate data management and assimilation of the model results. Input maps can be established in the GIS environment and used in MIKE SHE. Outputs from MIKE SHE can be analyzed and overlaid with other distributed data layers for further spatial data analysis. MIKE SHE also includes an internal pre- and post-processing package, including interpolation programs, polygon makers, a sub-model module, which provides facilities similar to GWZOOM, a water balance program and various modules for manipulating 2-dimensional data or time-series data. In addition graphical editors are available for editing 2-dimensional data and for setting up a river system in MIKE SHE. Comprehensive on-line help facilities are implemented in the MIKE SHE user interface.

5.3.3 PCSWMM GIS '98

Computational Hydraulics Int.'s (<http://www.chi.on.ca>) PCSWMM GIS program acts either as a stand-alone package or as a plug-in for the PCSWMM '98 graphical decision support system. PCSWMM GIS links SWMM/PCSWMM with a large variety of popular GIS/AM/FM/CAD systems, and is used for pre-processing external database information into SWMM Runoff, Transport and/or Extran datasets. Conduit, manhole and catchment data can be uploaded, and the entire data base can be used for model development or a subset can be selected. Selected entities can be quickly aggregated to reduce model complexity using a flexible, rules-based wizard. PCSWMM GIS '98 also acts as a dynamic post-processor for visualization of simulation results. Flexibility is it's main strength with many types of overlays being supported, including ArcView shape files (see Figure 5.4), AutoCAD DWG & DXF, MapInfo and MicroStation formats and a variety of other vector and raster formats.

Figure 5.4 A portion of the PCSWMM GIS '98 interface.

5.3.4 GIS-Hydrology (GH) Interface

A noteworthy research on GIS and modeling interface development is being conducted by a team of researchers led by Dr. David R. Maidment at the Center for Research in Water Resources (CRWR), University of Texas at Austin (Utexas). A community of graduate students, research scientists and faculty in CRWR and the Department of Civil Engineering of Utexas have developed a prototype Spatial Hydrology Analysis System (Maidment, 1997). The system consists of eight GIS-Hydrology (GH) modules. These modules, more than computer programs, are a methodological approach to solve a specific type of hydrologic problem using GIS. The modules contain tools including programs

(mostly Avenue and/or AML scripts), example exercises, demos, data, and/or papers. The modules of special interest to water resources management modeling are:

1. *GH-Terrain*. This module describes a set of methods for doing calculations on a DEM to derive drainage patterns and delineate streams and watersheds. The module includes an "ArcView3-based Watershed Delineation Application" to perform analysis of DEMs for watershed and stream network delineation. This application, representing a joint research effort by ESRI and CRWR, uses the functionality provided by the ArcView Spatial Analyst Extension® (ESRI, 96) and, therefore, this extension is required to use this application. The application provides interactive tools for delineating areas draining to points, areas draining to stream line segments, and areas draining to and from polygon features. The application includes a customized GUI which adds to but does not modify the standard ArcView GUI and functionality.
2. *GH-Prepro*. This module is a procedure for connecting GIS to external models. Consisting of Avenue and AML scripts, it is designed to transform a subbasins and streams network into a schematic model of the hydrologic elements of a watershed. It was initially developed as a preprocessor for COE's new Hydrologic Modeling System (HEC-HMS), which will replace the standard HEC-1 model. GH-Prepro takes stream and subbasin GIS data layers and analyzes them to produce a schematic model which defines and spatially connects seven types of hydrologic elements in the landscape: subbasins, reaches, junctions, diversions, reservoirs, sources, and sinks.

At the present time, GH modules are in development and testing stage and some are in the interface form. It is anticipated that eventually they will take the form of fully integrated ArcView and ARC/INFO applications. The web site address for finding more information on the GH modules is <http://www.ce.utexas.edu/prof/maidment/gishyd97/gishyd97.htm>.

5.3.5 ARC/INFO Interface with HEC-1 and HEC-2

Another example of the interface method is the ARC/INFO and HEC-1 and HEC-2 interface developed by Woolpert (Phipps, 1995). In the HEC-1 interface model uses vector coverages for streams and open channels and the ARC/INFO networking function to show the locations of and the relationships between different types of flows: sheet flow, shallow channel flow, and concentrated channel flow. The ARC/INFO and HEC-1 linkage allows users to see graphically, on a map, how fast the three flow types are moving at different locations within the model (volume/time). These unit hydrographs generated in the HEC-

1 hydrologic model are then used to feed the HEC-2 hydraulic model. The ARC/INFO and HEC-2 interface allows graphical display of the 2-, 10-, 25-, 50-, 100-, and 500-year frequency flood profiles for the streams and open channels within the watershed. It was found that the interface allowed for easier model development and calibration which resulted in substantial savings in the cost of modeling.

5.3.6 GeoSelect Interface for Rainfall Data

All rainfall-runoff models need rainfall input data. Continuous simulation, now becoming more common, requires hourly or 15-minute rainfall data for many (1-50) years (Shamsi and Scally, 1998). GIS can link the raingage locations with the rainfall data base to facilitate raingage selection and data retrieval. Figure 5.5 shows such a utility called GeoSelect[®]. GeoSelect consists of the following two parts (Hydrosphere, 1996):

- Hydrodata: A standalone windows software consisting of a relational database model and interface to retrieve stations and rainfall time-series data;
- ArcData: GIS coverage for raingages, rivers, lakes, watersheds, and counties; and an ArcView interface for transferring data to/from Hydrodata.

Historical rainfall and GIS data for an entire state is provided on a CD ROM. The rainfall data corresponds to the National Climatic Data Center (NCDC) archives of National Weather Service (NWS) gaging stations. The hourly data on these files date from as early as 1900, with most stations' digitized records dating

Figure 5.5 ArcView and raingage interface.

from 1948. The 15 minute data date from 1971. GeoSelect can export rainfall data in standard NCDC formats which can be read by computer models. For example, events rainfall data exported in the "NCDC" format can be read directly by SWMM as "Post 1980 NWS Format." In GeoSelect, Hydrodata and GIS are not integrated. Both, the ArcView and Hydrodata must be run separately. The main purpose of the ArcView interface is to select stations for data retrieval in Hydrodata. The ArcView interface adds two new menu items and two new buttons to ArcView's standard interface: Export Selection (E button) and Import Selection (I button). Export Selection will transfer a list of selected raingage stations from ArcView to Hydrodata. Import Selection will transfer a list of selected raingage stations from Hydrodata to ArcView.

5.4 Integration Method

Note that in the interface method, options for data editing and launching the model are usually not available. The user should exit the GIS and manually create and append a header file to the GIS export file before running the model. It is important to understand the difference between the interface and integration methods. An interface is simply a menu option in a GIS to transfer data to/from a computer model. GIS integration, on the other hand, is a combination of a model and a GIS such that the combined program offers both the GIS and the modeling functions. There are two methods for integrating GIS and models:

1. **GIS Based Integration:** In this method water resources modeling modules are developed in or are called from a GIS. All the four tasks of creating model input, editing data, running the model, and displaying output results are conducted from GIS. There is no need to exit the GIS to edit the data file or run the model.
2. **Model Based Integration:** In this method GIS modules are developed in or are called from a water resources model.

At present the routines or development tools within most GIS are only capable of relatively simple modeling, and therefore, the second approach can provide more modeling power. However, it would be very difficult to replicate all the GIS functions and operations in a hydrologic model. Thus, the modeling power of model based integration method will have to come at the cost of reduced GIS capability. Furthermore, the availability of the source codes for a large number of public domain water resources models makes the first approach more feasible. An example of a model based integration method is presented in a separate chapter "Runof97: A GIS-based, distributed, surface-runoff model" of this volume (Ritter and Gallie, 1998). Some GIS based integration examples are given below.

5.4.1 MIKE BASIN®

MIKE BASIN® is a relative of DHI interfaces MOUSE GIS®, MIKE 11 GIS®, and MIKE SHE® discussed earlier. MIKE SHE is a water accountability model entirely developed as an ArcView extension. The MIKE BASIN code is a generalized river basin network simulation modeling system for regional water resources allocation of complex systems. The MIKE BASIN can be used to analyze water supply capabilities in connection with water rights for municipal and industrial water supply, irrigation and multiple multi-purpose reservoir operations. MIKE BASIN uses a graphical user interface (GUI), which links MIKE BASIN to ArcView. Mike BASIN is fully integrated into ArcView. The interface is developed as a customized ArcView GIS environment and works using the full set of ArcView GIS functionality. The core is developed in object oriented C++ programming language, which allows easy implementation of new features. Setting up models directly on-screen may be facilitated by using images and other GIS-based information. The GIS interfacing is an important asset, which allows direct use of data, stored in GIS/database and use of other GIS capabilities, e.g. DEMs to delineate watershed sub-areas along the network. MIKE BASIN applications provide a first step to a broad scale hydrological modeling at river basin level, and may serve as a basic framework for the decision support process in water resources planning and management. An important advantage in the modeling/management process is the vertical compatibility among the suite of DHI modeling systems, which allows the use of several modeling tools of various complexity at different stages of a project cycle. MIKE BASIN can be used in conjunction with other DHI models when detailed studies of specific problems are required. Examples are: (i) ground water quality and quantity including interaction with surface water systems (MIKE SHE); and (ii) detailed modeling of river hydrodynamics and water quality (MIKE 11), or in bays and estuaries (MIKE 21).

5.4.2 GeoSTORM® Integration

An example of ARC/INFO and modeling integration is the GeoSTORM® package by Innovative System Developers, Inc., Columbia, Maryland. GeoSTORM computes subbasin runoff, performs flow routing through reach and reservoir networks, and analyzes river hydraulics using Soil Conservation Service's Technical Release 20 (TR-20) and Technical Release 55 (TR-55), and US Army Corps of Engineers' HEC-2 computer programs. All of these models are contained within a graphical user interface environment within the ARC/INFO GIS. The software is written in AML, the ARC/INFO fourth generation language. There are external calls to the operating system only to execute the computer programs. The common interface provides easy interaction between

the models and switching between the models is hardly noticeable, and output from one model is used as input to another model. The TR-55 model has been embedded within the TR-20 model. The outputs from the TR-55 model become input to the TR-20 model. The TR-20 model provides the discharge values for input to the HEC-2 model, while the output from the HEC-2 model can be directly inserted into the TR-20 model as rating table information. All the applications are accessible from Geo-GUIDE, an ARC/INFO Graphical User Interface (GUI). The models are embedded within Geo-GUIDE which provides plotting, reporting, and querying capabilities for the stormwater modeling software suite.

5.4.3 ARC/HEC-2 Integration

ARC/HEC-2 is an integration between ARC/INFO and HEC-2 developed at the University of Texas at Austin. ARC/HEC2 facilitates floodplain analysis in a GIS environment. It allows direct usage of ARC/INFO coverages for development of HEC-2 input, running HEC-2 from within ARC/INFO, and for conversion of HEC-2 water surface elevations computed at each cross-section into an ARC/INFO coverage representing the floodplain. There are two main data requirements for ARC/HEC-2 to operate: (i) a terrain representation in the form of constructed TIN or contours; and (ii) channel centerline (thalweg). ARC/HEC2 consists of three separate modules: preprocessor, postprocessor, and a viewer. Preprocessor creates a complete HEC-2 input file ready to run. This file can be either modified to add additional profile types and features that ARC/HEC-2 does not handle at this moment or run as is. Thus, for complex HEC-2 models, manual editing of the input file may be required, in which case ARC/HEC-2 will serve as an interface rather than an integration. Postprocessor uses the HEC-2 output to determine water surface elevation at each cross section, and based on that information, find the outline of the flooded area in the form of a lattice and a polygon coverage. This lattice and coverage can be immediately used in ARC/INFO with all other pertinent coverages for the area. Viewer is an AML that allows simple viewing of the main input and output coverages in 2D and 3D (Djokic et al., 1993).

5.4.4 BASINS Integration

The U.S. EPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) program is an example of GIS integration with multiple models. BASINS integrates ArcView GIS with national watershed data, and state-of-the-art environmental assessment and modeling tools into one convenient package. Overcoming the lack of integration, limited coordination, and time-intensive execution typical of more traditional assessment tools, BASINS makes watershed and water quality studies easier by bringing key data and analytical components together "under one roof." Three models (NPSM, TOXIRoute, and QUAL2E) are integrated into BASINS within an ArcView GIS

environment. This allows the user to assess watershed loadings and receiving water impacts at various levels of complexity. ArcView geographic data preparation, selection routines, and visual output streamline the use of the models. A post-processor graphically displays model results. Figure 5.6 shows the target feature of the BASINS program which broadly evaluates a watershed's water quality and point source loadings.

BASINS (Version 1.0) was originally released in September, 1996 (Lahlou, 1996) for ArcView Version 2.1. It was distributed on a CD ROM containing the BASINS program and data for an EPA region of interest. The program could also be downloaded from the BASINS' web site. A beta test version of BASINS 2 has recently been released for ArcView 3.0a. The final version of BASINS 2 is expected to be released in the Spring of 1998. The new features of version 2 will include a watershed delineation tool, a landuse reclassification tool, an HSPF interface, watershed characterization report on STORET water quality data, DEM elevation data, and USEPA Reach File Version 3 Alpha (RF3 Alpha). The web site address for the BASINS program is: <http://www.epa.gov/OST/BASINS/>.

Figure 5.6 ArcView and BASINS integration.

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