Chapter 11

ArcView Applications in SWMM Modeling

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This chapter presents applications of ArcView Geographic Information System (GIS) in developing SWMM (Storm Water Management Model) computer models. Three types of ArcView applications are presented: interchanging, interfacing, and integrating. Interfacing or integrating SWMM models with GIS can significantly improve the modeling efficiency because a GIS environment provides a modeler with efficient model development, execution, and analysis tools. ArcView is a user-friendly desktop mapping and GIS program which can be learned by most modelers without extensive training and experience. Avenue, ArcView's object-oriented development language, can be used to interface or integrate ArcView and SWMM software. Due to its low cost, ease of use, and Avenue programming capability, ArcView is a suitable tool for developing SWMM interfaces and integrations. This chapter describes how ArcView can be used to develop SWMM computer models. The chapter also provides a software review of available SWMM/GIS interfaces. The advantages and limitations of various techniques are identified and recommendations for future research and development are made from a user's perspective.

11.1 Introduction

SWMM is a large and complex model which simulates the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units and finally to receiving waters. Both single

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event and continuous simulation may be performed on sewersheds or natural watersheds for computing flows and pollution concentrations. SWMM can be used for both planning and design. The planning model is used for studying urban runoff problems and abatement options. The design model performs event simulations using a detailed sewershed schematization and shorter simulation time steps. The SWMM program consists of four computational blocks (RUN-OFF, TRANSPORT, EXTRAN, and STORAGE/TREATMENT) and five service blocks (STATISTICS, GRAPH, COMBINE, RAIN, and TEMP).

SWMM is a public-domain computer program, originally developed by the U.S. Environmental Protection Agency (EPA) in 1969-1971 as a mainframe computer program. At that time SWMM was one of the first of such models. Versions 2, 3, and 4 of SWMM were distributed in 1975, 1981, and 1988, respectively. The first batch mode microcomputer version of SWMM (version 3.3) was released by EPA in 1983. The first conversational ("user-friendly") mode PC version of SWMM known as PCSWMM was commercially distributed in 1984 by Computational Hydraulics Inc. of Guelph, Ontario (Computational, 1995). The first PC version of EPA's SWMM was version 4, which was distributed in 1988 (Huber and Dickinson, 1988; Roesner et al., 1988). A review of SWMM's development history can be found in a book by James (1993).

Most modelers have now become accustomed to modern computer graphics features, such as pull down menus, spreadsheet data input and editing, color plots, on-line help, which are not currently available in SWMM. SWMM was developed in an era when input files were created on punched cards. After 25 years, SWMM now runs on PCs, but it is still a text based, non-graphical, DOS program. It reads ASCII input to produce ASCII output which is most suitable for mainframe line printers. SWMM's ASCII format output is long, boring, difficult to interpret, and not very useful for non-modelers. Creating computer models and reviewing the model results is often slowed by our inability to see the system being modeled. It is up to the modeler to review SWMM's voluminous output and construct a mental image of the physical system being modeled. Often, the limitation in understanding the model output has been the modeler's own comprehension of the output, not the model itself. Quite frequently, it is impossible for the modeler to absorb the large amount of information contained in the model output (TenBroek and Roesner, 1993).

No one said mathematical modeling would be easy, but preparation of input data and interpretation of output data required by the ever changing complexities of a complex computer model like SWMM has been mind boggling. The good news is that, the model building and interpretation of the results is now easier than ever before, thanks to advances in computer graphics and the desktop GIS. An assembly of model input data by traditional manual map measurements is just too time-consuming and difficult to justify now that the cost of computers is coming down and their capabilities and speed are going up. It is much easier to see a color-coded map of surcharged sewers to pinpoint the areas of flooding and surcharging

than it is to digest reams of computer output, especially for non-modelers. *Non-modelers* are those people who are not expert modelers but who need to know the modeling results, and include clients, project managers, politicians, and regulatory agencies. GIS technology is an effective means of bridging the gap between the information and its recipients. This chapter demonstrates applications of a desktop GIS called ArcView to revolutionize the way SWMM modeling is performed. The chapter describes how ArcView can be used to develop SWMM computer models. The chapter also provides a software review of available SWMM/GIS interfaces. The advantages and limitations of various techniques are identified and recommendations for future research and development are made from a user's perspective.

11.2 ArcView

Most GIS packages are designed for technicians who perform heavy duty production work on work stations, and therefore, they are not very user-friendly for the casual PC user. Some of the leading GIS products are ARC/INFO by Environmental Systems Research Institute (ESRI), Geo/SQL by Generation 5 Technology, GENEMAP by Genasys, and MGE by Intergraph. ARC/INFO, PC ARC/INFO, ArcCAD, Geo/SQL, GENEMAP, and MGE are complex software systems that require substantial technical skills. Most SWMM modelers do not have the technical expertise to develop, run, and maintain a complex GIS like ARC/INFO. ArcView, on the other hand, is a user-friendly desktop mapping and GIS tool which can be learned by most modelers without extensive training and experience. ArcView is a sophisticated desktop mapping and GIS application which promises to bring the power of GIS to the average PC user. ArcView's object oriented development language, gives modelers the ability to create custom applications and user interfaces. Due to its low cost, ease of use, and compatibility with the ARC/INFO file format, ArcView is a suitable tool for developing a SWMM interface.

ArcView can be used to develop a SWMM Graphical User Interface (GUI). A GUI is a computer program which acts as an interpreter between the user and a computer. A GUI can be employed to overcome SWMM's input/output deficiencies. A GUI stimulates user interest and facilitates interpretation of model results. A GUI replaces difficult to remember text commands by interactive computer graphics consisting of menus, dialogue boxes, input and output windows, and icons. The main goal of GUIs is to develop user-friendly computer applications or to add user-friendliness to existing command driven applications. For example, Microsoft Windows is a GUI for DOS, and Netscape is a GUI for the Internet. Two types of GUIs can be employed for ArcView and SWMM integration. An input interface (also called a front-end interface or pre-processor)

extracts SWMM input from ArcView themes and creates SWMM's traditional ASCII input file. Input GUIs can also provide graphical tools to draw a network model which is subsequently converted to SWMM's ASCII input file. For example, an input interface may extract sewer segment lengths and manhole coordinates from existing sewer and manhole themes. An output interface (also called a back-end interface or post-processor) usually converts text to graphics. It can convert SWMM's traditional ASCII output file to graphs, charts, plots, and thematic maps which can be easily understood by users. For a detailed description of GUI benefits and recommended GUI features the readers are encouraged to read Chapter 7 "SWMM Graphics" in Volume 5 of this series of monographs (Shamsi, 1997).

ARC/INFO, PC ARC/INFO, ArcCAD, and ArcView are the leading desktop GIS software products developed and distributed by ESRI. ESRI is recognized as the leading supplier of topologically structured GISs. The main features of ArcView are:

- ArcView is very user-friendly and provides context sensitive on-line help;
- ArcView is available for Windows, Mac, and UNIX operating systems;
- ArcView can access and link documents, images, tables, text, graphics, spreadsheets, maps, multimedia, and CAD drawings in an integrated and comprehensive way;
- ArcView provides routine display and plotting of collection system maps and provides tools to query the GIS database;
- ArcView helps a user to quickly select and display different combinations of data for creative visualization of mapping data;
- ArcView is compatible with the ARC/INFO, PC ARC/INFO, and ArcCAD file formats;
- ArcView can directly use AutoCAD drawings (DWG files) or AutoCAD interchange files (DXF files);
- ArcView uses dBASE format files for data management and can access information from other applications such as FoxPro, Lotus 1-2-3, and Microsoft Excel;
- ArcView can link map information to SQL databases which are common in local governments, such as ORACLE, INGRES, INFORMIX, and SYBASE;
- GIS data can be explored and retrieved by selecting features or formulating logical expressions;
- the GIS data can be displayed as pie charts, bar charts, or tables for presentations and reports;
- Avenue, ArcView's object oriented development language, or Microsoft Visual Basic can be used to create custom applications and user interfaces;

- ArcView supports Dynamic Link Libraries (DLL) and Dynamic Data Exchange (DDE) which can be used to provide efficient third party interfacing and integration capability;
- ArcView provides editing tools for creating new maps and modifying existing ones;
- ArcView provides address geocoding and address matching capability, i.e., tabular data containing street addresses can be displayed as points on a map;
- many ArcView add-ons or extensions are available to supplement its standard capabilities, such as Spatial Analyst for performing hydrologic analyses in a raster GIS; and
- costing approximately \$1,000, and running on off-the-shelf PCs, ArcView is affordable. (*In this chapter \$ = US\$*).

The above features make ArcView a cost-effective tool for developing computer models. A limitation of ArcView is that it is not intended to support a GIS production shop. In the last release of ArcView (Version 2) paper maps could not be digitized directly in ArcView. Although the most recent release (Version 3) is capable of digitizing, there is limited feature editing capability. Therefore, ArcView's best applications lie in management, manipulation, and modification of existing GIS coverages. The coverages can be produced in ARC/INFO, especially for large systems, and imported to ArcView. Users who do not have an in-house ARC/INFO site can hire consultants for converting existing maps to ARC/INFO coverages by scanning and digitization. The widespread use of ARC/INFO among government agencies, coupled with a wide range of exchange formats supported by ARC/INFO, makes it highly probable that most third-party data providers will be running ARC/INFO and as such be able to directly supply data in either ARC/INFO coverage or ArcView shape file (ArcView's native format). If spatial data in whatever format are available for a project, it can be converted to ArcView format via ARC/INFO (Hutchinson and Daniel, 1995). ESRI publishes a catalogue of ArcView compatible data sources called *ArcData*. ArcData is a collection of digital information products developed cooperatively by ESRI and more than 30 data providers. Included are data sets for such applications as urban and transportation planning, natural resources, environmental, agriculture and demographics. Some specific example of ArcData are Digital Line Graphs (roads, railroads, rivers, lakes, streams, wetlands, contours, states, counties, cities, etc.), TIGER files (census blocks, census block groups, roads, railroads, hydrography, political boundaries, etc.), and Climate data (monthly summaries of meteorological data).

There are three methods of using a GIS in SWMM computer modeling: interchange, interface, and integration. Each is discussed in detail in the following section.

11.3 Interchange

The interchange method employs a batch process approach to exchange (transfer) data to and from SWMM. A GIS database is processed to extract SWMM input parameters. In this method, there is no direct link between the GIS and SWMM. Both GIS and SWMM are run separately and independently. GIS data are first saved to ASCII files or spreadsheets, and subsequently exported to SWMM's ASCII input files. This is the easiest method of combining GIS and computer models, and is the most practiced method at the present time. Some examples of data exchange include:

1. Subarea Characteristics: SWMM's RUNOFF Block needs input for area, overland flow width, and slope of the modeled drainage areas (subareas). Area is readily available as a feature attribute for all the polygons either digitized in ArcView or imported from ARC/INFO. Width can be measured interactively in any direction (e.g., along a stream or a sewer) by using ArcView's *Drawing Tool*. Subarea 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 subarea 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 subarea. ArcView 3.0 has introduced a raster *extension* (add-on) called *Spatial Analyst*. 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, automatic delineation of watershed boundaries.
2. Water Quality Data: The TRANSPORT Block of SWMM needs curb length for water quality modeling which can be estimated from a coverage for roads. In ArcView, curb length can be estimated by performing a *theme-on-theme* selection using roads as the target theme and subareas 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

having to do with street, highway, and other networks. Like Spatial Analyst, Network Analyst must also be purchased separately.

3. Land Use: SWMM's TRANSPORT Block needs input for the land use designation of modeled subareas. The subareas should be classified as having one of the five land use classes: single family residential, multi-family residential, commercial, industrial, or open space. Most existing land use maps or databases have more than these five land use classes. However, this not a problem in ArcView. Using ArcView, the existing classes can be easily consolidated into the five SWMM land use classes. Figure 11.1 shows an ArcView screen for a land use coverage. The land use coverage was prepared in ARC/INFO from a manual interpretation of NHAP (National High Altitude Photography) aerial photographs of the study area. Initially, seven major land use types were classified: low density residential, medium density residential, high density residential, commercial, industrial, open space, and water. Subsequently, the initial land use classes were reclassified in the five land use types required for SWMM input.

Figure 11.1 Landuse interchange example.

4. Percent Imperviousness: SWMM's RUNOFF Block needs an input for the subarea percent imperviousness which can be estimated by processing the land use coverage. U.S. Soil Conservation Service (SCS) has published tables which give average percent imperviousness for different land uses (Urban, 1986). A subarea percent imperviousness coverage is created by overlaying the coverages for

subareas and land use to delineate the percent imperviousness polygons. Each polygon has two attributes: subarea 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 value for each subarea. This task can be done in ArcView, but for large areas it is better suited for an ARC/INFO production shop.

5. Demographic Data: SWMM's TRANSPORT Block may need some or all of the following demographic parameters: dwelling units, persons per dwelling unit, market value of average dwelling unit, and average family income. In U.S.A. digital demographic data are easily available in Bureau of Census *TIGER files*. TIGER is an acronym for the Census Bureau's Topographically Integrated Geographic Encoding Referencing System. TIGER is the new digital map database that automates the mapping and related geographic activities required to support the census and survey programs of the Census Bureau. A TIGER file is an extract of selected geographic and cartographic information from the TIGER database. The TIGER file contains digital data for the 1990 census map features (such as roads, railroads, and rivers) and the associated collection geography (such as census tracts and blocks), political areas (such as cities and townships), feature names and classification codes, and within metropolitan areas, address ranges and ZIP Codes for streets. Outlines of the various census blocks are included in the TIGER file. The demographic parameters are extracted at the block level from public law demographic database. The population (or other demographic parameters) within each subarea is estimated by determining the census blocks or their portions comprising each subarea. Block level data are area weighted to estimate mean subarea values for demographic parameters. For small areas, this can be done using ArcView's *polygon-on-polygon* selection using census blocks as the target theme and subareas as the selector theme. Alternatively, for large areas such tasks can be handled more efficiently in ARC/INFO.

11.4 Interface

An interface provides a direct link between a GIS and SWMM. An interface consists of at least the following two components: (i) a pre-processor which analyzes the GIS data to create SWMM input files, and (ii) a post-processor

which imports the SWMM output and displays it as themes. Interface offers an attractive alternative to interchange. SWMM becomes a new ArcView menu. SWMM network is created as a GIS coverage. Existing GIS coverages of streets, collection system, and watershed boundaries, etc. serve as excellent background pictures. SWMM output is displayed as a GIS coverage. Development of an interface requires the following tasks:

Task 1: Create SWMM input files by exporting ArcView data to ASCII files. This task requires that ArcView compatible data sets exist with attribute fields for all model parameters. The interface generated input file could be appended to a *header* input file which contains model control parameters, such as A1 and B0 to B8 lines. A simplified EXTRAN example is given below:

Given: ArcView coverages for:

- Manholes with attributes: ID, bottom elevation, top elevation, inflow.
- Sewers with attributes: ID, upstream manhole, downstream manhole, type (circular, rectangular, etc.), depth, width, length, material, date installed, upstream invert elevation, downstream invert elevation.

Create: An ASCII file for EXTRAN input showing:

- Junction (usually manhole) data: Data type (D1 for junctions), ID, top elevation (GR-EL), bottom elevation (INV-EL), inflow, initial depth (Y0 usually 0.0).
- Conduit (usually sewer) data: Data type (C1 for conduits), ID, upstream junction (FR), downstream Junction (TO), initial flow (Q0, usually 0.0), type (1 for circular, 2 for rectangular, etc.), Area (0.0 for circular and rectangular), depth (DEEP=diameter for type 1, depth for type 2), width (WIDE=width for type 2), length (LEN), ZP1 (upstream invert elevation minus upstream node bottom elevation), ZP2 (downstream invert elevation minus downstream node bottom elevation), N (roughness factor, a function of pipe material and age), STHETA and SPHI (usually zero, required for open channels only). Note that ZP1, ZP2, and N are not part of the given sewer's data, but can be estimated in ArcView from the given data. For example, if the material is concrete and age of the pipe is less than ten years (fair condition), then ArcView can use a lookup table to estimate N as 0.015. ZP1 and ZP2 can be similarly estimated from the upstream and downstream manhole data.

Task 2: Create SWMM output coverages in ArcView by importing SWMM ASCII output files to ArcView. This task would link the SWMM output file to an ArcView coverage. A database table of the relevant results is created from the ASCII output file. The output database file is then temporarily joined to input ArcView coverages. The linked output results can then be queried or used to classify a legend. A simplified EXTRAN example follows:

Given: ASCII output for Junctions and Conduits:

Create: ArcView coverages for SWMM output for junctions and conduits.

The above tasks are done by customizing ArcView using Avenue. Avenue is ArcView's native scripting language built into ArcView. A scripting language is a programming language that is (usually) embedded in another product. Examples of other scripting languages include the ESRI Arc Macro Language (AML), Microsoft Visual Basic, and AutoLISP by Autodesk. Avenue's full integration with ArcView benefits the user in two ways: first, by eliminating the need to learn a new interface; secondly, by letting the user work with Avenue without exiting ArcView (ESRI, 1995). Figure 11.2 shows ArcView's integrated programming interface using Avenue. A sample interface developed for the EXTRAN Block of SWMM is described below.

Figure 11.2 Arcview's integrated programming interface using Avenue.

11.4.1 Sample SWMM Interface

As shown in Figure 11.3, the interface adds a SWMM menu to ArcView's main menu. The SWMM menu has the following items: Make Input File, Read Output, Join Results, 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. All model runs which have been translated are eligible to be viewed. Data for each model run are stored in a separate sub directory. A description of the SWMM menu items follows.

Figure 11.3 Sample SWMM interface.

Make Input File: This SWMM menu choice creates a SWMM input file for the Conduit and Junction data types. The user is prompted for a model input “name.” The input file is placed in a subdirectory called “name” which is under the project directory. If the directory does not exist, it is created. The input file is called “name.inp.” The tool prompts for a description of the model run. It is a string which is attached to the input file as a comment line. The tool prompts for an optional header file to attach to the input file. The header files have an extension of .hdr and are created separately by the user in a text editor. The header file contains EXTRAN input file data other than C1 and D1 records which are already stored in the “name”.inp file.

Read Output: This SWMM menu choice translates a SWMM report (output) file to database files. The tool prompts for a report file (.rpt) to translate. The program assumes the user has run the SWMM model from the input file created previously. The report file should be located in the same subdirectory as the input file and must have the name “name.rpt.” The program translates the Conduit Summary and Junction Summary Statistics into databases named condsum.dbf and junctsum.dbf which are located within subdirectory “name” which contains the input and report files. The routine also writes a file “name.res” in the project directory. The .res file contains the absolute path to the directory where the model results are stored. This file indicates that a model has been translated. It is used to find all model runs available for linking.

Result Join: This SWMM menu choice temporarily joins the translated SWMM output to ArcView attribute tables of the Manholes and Interceptors. The tool prompts the user to select a model run to link. The list of model runs is formed from the .res files. The routine temporarily links the result databases to the attribute data. The result data can now be queried, listed, or used to classify a legend. Figure 11.4 shows ArcView database tables showing imported SWMM results. Figure 11.5 shows a thematic map of maximum sewer flows based on classifying Q(max) output variable from SWMM output.

Figure 11.4 SWMM results in ArcView.

Figure 11.5 Thematic map of maximum sewer flow.

Unjoin Results: This SWMM menu choice reverses (unjoins) the link between the SWMM output and ArcView attribute tables established by the Results Join menu choice. The purpose of this menu choice is to *undo* the last import of SWMM output to ArcView if the user does not like the SWMM results and wants to rerun SWMM and import the output again.

11.5 Integration

It is important to understand the difference between an interface and an integration. An interface is simply a menu option in a GIS to transfer data to/from SWMM. GIS integration, on the other hand, is a combination of a SWMM GUI and a GIS such that the combined program offers both the GIS and the SWMM functions. In an ArcView and SWMM integration, all the four tasks of creating SWMM input, editing data, running SWMM, and displaying output results should be conducted from ArcView. Note that in the above interface example, data editing and launching SWMM were not available. The user had to separately create a header file containing SWMM execution and output instructions.

An example of SWMM and GIS integration is SWMMDUET. This program integrates SWMM with ARC/INFO GIS software and, quite appropriately, has been written in ARC/INFO's native AML. It creates a computing environment that does not require arcane knowledge of SWMM and ARC/INFO. SWMMDUET incorporates both pre- and post-processors, and therefore, provides interfaces both for creating SWMM's input file and graphing SWMM's output file. SWMMDUET takes advantage of the graphical paradigm around which ARC/INFO is constructed and utilizes the relational database capabilities to organize the data. Beyond data management, the program uses expert system logic to assemble data that define the modeling process, prepares SWMM input, executes the SWMM program, and converts the output into meaningful graphical displays. Data entry sheets and forms eliminate the need for the modeler to know detailed ARC/INFO processing techniques. Similarly, feature selection, spatial joins, and processing commands and options of ARC/INFO are specified and executed for the user. Hyetographs are related to rain gages where rainfall data were recorded. The storms are selected simply by a georeference to the gages. Time series data are stored as sequential records in the database files. SWMMDUET has significantly simplified the management of vast amounts of hydrologic data and it lets the hydrologist concentrate on hydrologic matters. Although SWMMDUET is an ARC/INFO rather than an ArcView application, future development plans include an ArcView version. Other features planned for future releases include automatic watershed delineation from USGS DEM, and a linkage to EPA's WASP (Water Analysis Simulation Program) water body receiving model. The SWMMDUET software is in the public domain and can be obtained for the cost of distribution (Curtis, 1994).

An example of an ArcView and SWMM integration is software called AVsand developed by Cedra Corporation, Rochester, New York. AVsand can be used for modeling sanitary sewers using a simplified implementation of SWMM's TRANSPORT Block. Storm and combined sewers are not modeled using SWMM; the Rational Method or surface hydrographs are used instead. Not all of the SWMM Blocks and capabilities are available. AVsand accepts user model

input via a series of dialogue boxes. AVsand also provides model development and editing tools, such as a *Service Area Tool* to define service areas, a *Node Definition Tool* to define nodes, and a *Pipe Definition Tool* to define pipes between nodes. A *Wastewater Loads Tool* enables the user to introduce wastewater loads at the selected nodes. A *Query* menu option helps the user to create themes from the model output. A profile view plot of the Hydraulic Gradient Line (HGL) can be created. This information is based on AVsand's literature and demo program. This program offers only a limited SWMM modeling capability.

11.6 Summary

The ArcView GIS environment provides SWMM modelers with efficient data input, output analysis, and mapping tools. There are no ArcView and SWMM interfaces or integrations available in the public domain. Several proprietary interfaces have been developed by consultants. Integrations are very scarce. Integrations are more complex than interfaces and, therefore, more difficult and expensive to develop. However, integrations are more efficient than interfaces. Total integrations offering joint capabilities of CAD, GIS, AM/FM, and DBMS are not available and should be developed. Raster GIS has a tremendous potential in hydrology applications, however, no SWMM and raster GIS interfaces are currently available. It would, therefore, be useful to integrate SWMM with Spatial Analyst, ArcView's raster GIS extension.

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References

- Computational Hydraulics Int. 1995. PCSWMM, Users Manual, 36 Stuart Street, Guelph, Ontario, Canada N1E 4S5.
- Curtis, T.G. 1994. SWMMDUET: Enabling EPA SWMM with the ARC/INFO Paradigm, ARC News, Environmental Systems Research Institute, Redlands, California, Spring 1994, p20.
- ESRI Educational Services. 1995. Introduction to Avenue, Environmental System Research Institute, Redlands, California.
- Huber, W.C., and R.E. Dickinson. 1988. Storm Water Management Model. User's Manual, Version 4, Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, Georgia.

- Hutchinson, S., and L. Daniel, 1995. Inside ArcView. Onward Press, p329.
- James, W. 1993. Introduction to SWMM. Chapter 1 in New Techniques for Modelling the Management of Stormwater Quality Impacts. Edited by William James, Lewis Publishers, Boca Raton, Florida, p1-28.
- Roesner, L.A., J.A. Aldrich, and R.E. Dickinson. 1988. Storm Water Management Model. EXTRAN Addendum, User's Manual, Version 4, Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, Georgia.
- Shamsi, U.M. 1997. "SWMM Graphics." *Journal of Water Management Modeling* R195-07. doi: 10.14796/JWMM.R195-07.
- TenBroek, M.J. and L.A. Roesner. 1993. MTV - Analysis Tool for Review of Computer Models. in Proceedings, Conference on Computers in the Water Industry, Water Environment Federation, Santa Clara, California, August 8-11, 1993, p173-181.
- Urban Hydrology for Small Watersheds. (1986). Technical Release 55, Soil Conservation Service, U.S. Department of Agriculture, Washington, D.C., p2.5-2.8.