Chapter 7

SWMM Graphics

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This chapter demonstrates applications of personal computer graphics in Storm Water Management Model (SWMM) modeling. Graphics are effective means of bridging the gap between the information and its recipients. It is demonstrated that integration or interfacing of computer graphics in SWMM models, in addition to the traditional tabular output, significantly improves the efficiency of modeling tasks. The graphics provide the modeler with more efficient and cost effective analysis, planning, design, and management tools. The proposed technique requires developing graphical user interfaces (GUI) for SWMM. Twenty five GUI features are recommended from a user's perspective. A software review of the available SWMM GUIs is provided. The advantages and limitations of various GUI techniques are identified and recommendations for future research and development are made from a user's perspective.

7.1 Introduction

Throughout history, tools have shaped almost every physical artifact made by man, and tools usually have had a profound effect on every area of human endeavor. This is no less true with computers and plotters than it was with pencils and vellum, or for that matter, lines in the dirt (Dakan, 1992). The advent of color

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graphics and powerful minicomputers in the 1970s moved mapping from pen-and-ink to keyboard, digitizer and stereographic viewers. The 1980s mark the revolution of the advent of personal computers (PC). In the past decade, powerful workstations and sophisticated software combined to bring mapping capability to any desktop. More recently, PCs have become so powerful that graphics software will now run on off-the-shelf computers. The current technology is already well beyond a simple electronic emulation of pencil lines on paper, yet many see it as merely an electronic drafting table. This technology is, in fact, much more: it is new tools, new design methodologies, new ways of visualization, new thought patterns, and new ways of doing business (Dakan, 1992).

Today, computers are so rapidly changing the way we do business that the day of the mainframe on the desk seems an inevitable reality. In the field of environmental cleanup the software boom has largely come in products that speed up or simplify data processing tasks such as tracking toxic releases and waste site samples; some more novel developments stem from the need to better visualize site information and even provide a peek at what may be lurking underground (Rubin and Powers, 1992). Once the province of accountants and administrators, computers are today infiltrating almost all areas of water and wastewater utility operations and management. From forecasting sewer flows to tracking water quality through the collection system to recording maintenance activities and supplies, computer systems are easing the jobs of supervisory and operational personnel through a broad range of state-of-the-art hardware and software. Since the PC was introduced in the 1980s, there have been many changes in sewer system modeling practice. A PC on every engineer's desk has encouraged even the small utilities to develop sewer system models.

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 the Storm Water Management Model (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. 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 up. It is much easier to graphically view a storm surge progress through a sewer, to pinpoint the areas of flooding and surcharging, than it is to digest reams of computer output, especially for *non-modelers*. The non-modelers are those people who are not the expert modelers but need to know the modeling results, such as the clients, project managers, politicians, and regulatory agencies, etc. The chip makers and the PC are the Henry Ford and Model T of this era and we can no longer afford to use the modern-day equivalent of buggy whips. This chapter demonstrates applications of personal computer graphics to revolutionize the way we perform SWMM modeling.

7.2 SWMM Problems

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 event and continuous simulation may be performed on sewersheds or natural watersheds for predicting 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 (RUNOFF, 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. The first PC version of EPA's SWMM was version 4, which was distributed in 1988 (Huber and Dickinson, 1988; Roesner et al., 1988). An excellent review of SWMM's development history can be found in a book by James (1993).

Most modelers have now become accustomed to the modern computer graphics features, such as pull down menus, spreadsheet data input and editing, color plots, on-line help, etc., 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 meaningless 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).

Visualization is the key to understanding the relationships among modeled components. Everyone believes that *a picture is worth a thousand words*. It is about time to realize that *a graph is worth a thousand numbers*. Just as

comfortably as an artist can paint a picture on a canvas, a modeler should be able to paint a model on a computer screen.

7.3 Graphical User Interface

A graphical user interface (GUI) is a computer program which acts as an interpreter between the user and a computer. The GUI replaces difficult-to-remember text commands by interactive computer graphics consisting of menus, dialog boxes, input and output windows, and icons. The main goal of GUIs is to develop user-friendly computer applications or to add the user-friendliness to the existing command driven applications. For example, Microsoft Windows is a GUI for DOS, and Netscape is a GUI for the internet.

A GUI can be employed to overcome SWMM deficiencies. A GUI stimulates user interest and facilitates interpretation of model results. There are two types of GUIs. An input interface (also called a front-end interface or pre-processor) usually converts graphics to text. It extracts SWMM input from existing drawings, maps, and databases to create SWMM's traditional ASCII input file. Some GUIs 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 the sewer segment lengths and manhole coordinates from existing CAD drawings. An output interface (also called a back-end interface or post-processor) usually converts text to graphics. It transforms SWMM's traditional ASCII output file to graphs, charts, and plots which can be easily understood by the users. GUIs provide the following benefits:

1. Users do not have to memorize the command syntax. The text commands are replaced by interactive graphics.
2. Users do not have to memorize the input format. The user input is facilitated by interactive graphics.
3. GUIs improve understanding and interpretation of model results. Tabular results are converted to meaningful graphs and charts which can be quickly and easily understood both by the modelers and non-modelers. More than just reams of computer paper, models become an automated system evaluation tool. In this way, GUIs bridge the gap between the SWMM output and its recipients.
4. Dynamic model results (e.g. time varying hydraulic gradient line or HGL) can be displayed through video-like animation. Engineers can view a storm surge progress through their system and immediately pinpoint areas of flooding and surcharging.
5. Connectivity data errors are easily detected and corrected. Instabilities in the model output, often the most difficult errors to find, are also easily located.

6. Input preparation, analysis, and output interpretation time is decreased, which reduces the total project cost.
7. Users become more productive. They devote more time to solving the problem and less time to mechanical tasks of data input and checking, program execution, and interpreting the output.
8. GUIs increase the confidence of the project team and reviewers in model configuration.

7.4 Recommended GUI Features

It is recommended that SWMM GUIs should have the following features from a user's perspective:

7.4.1 General

1. *Windows Application:* The GUI should be a Microsoft Windows application. Windows applications provide all the benefits of the Windows computing environment, such as a familiar and user-friendly desktop environment, convenient data transfer to and from other Windows applications via object linking and embedding (OLE), readily available access to a wide variety of display and printer drivers, and efficient utilization of computer resources, such as disk space and extended memory. DOS programs which can be launched from Windows do not qualify as Windows applications.
2. *Integration:* Various GUI modules should be seamlessly integrated in one program. Sequential batch processing of modules should be eliminated. Users should be able to perform various tasks (e.g. input, editing, execution, plotting, etc.) from within one program rather than having to run multiple programs to do various tasks.
3. *User Friendliness:* The GUI should include menus, dialog boxes, icons, and context sensitive on-line help to shorten the learning curve and guide users through the model development, execution, and interpretation without having to consult the users manual frequently.
4. *File Management:* SWMM generates a large number of intermediate files (interface files, hot restart files) which are shared among various SWMM blocks. Manual management of these files is cumbersome. Automatic organization, connectivity and manipulation of these files should be provided.

5. *Input Interface:* Preparation of SWMM's input file should be facilitated by pre-processors which will convert the graphics (e.g. existing CAD drawings) to SWMM's ASCII input file.
6. *Output Interface:* Interpretation of model results should be facilitated by post-processors which will convert SWMM's ASCII output file to graphics.

7.4.2 Model Development

7. *Graphical Input:* On-screen creation of a link-node model using simple drag-and-drop of icons should be provided. Nodes represent point and polygon features, such as sewersheds and manholes. Links connect two nodes of the network and represent features which have length and direction attributes, such as sewers, channel, or diversion. Model input should be facilitated through pop-up dialog boxes and data entry sheets. This approach eliminates network connectivity errors and shortens the model learning curve substantially.
8. *Graphical Editing:* On-screen editing of network elements using a point-and-click interface should be provided. For example, when a network link is clicked on with the mouse, a window resembling a

Figure 7.1 Graphical input and editing window in XP-SWMM.

data entry sheet should be displayed. The window should show link input parameters (e.g. length, shape, size, Manning's n , and slope, etc.) and allow on-screen editing. Figure 7.1 shows an example of a graphic editing window.

9. *Spreadsheet Editing:* For experienced users, graphical editing becomes a hurdle rather than an advantage, especially when numerous model parameters must be changed at once. For example, changing Manning's n for all the pipes of a 500 link model by graphical editing may require thousands of point-and-click, pan, zoom, and redrawing actions. To circumvent this problem, users should have an option to edit the input parameters in a spreadsheet with cut, copy, and paste capability.

7.4.3 Display Features

10. *Background Pictures:* Existing CAD drawings, maps, and digital aerial photographs should be imported and displayed as background pictures. Background pictures provide a passive backdrop with familiar surroundings, such as sewers, sewershed boundaries, city streets, buildings, rivers, and contours, etc., on which the network

Figure 7.2 Network model overlaid on a background picture in XPSWMM.

model may be overlaid. The background pictures should be organized in CAD-like *layers* for a convenient on-off control. Figure 7.2 shows an example of a network model draped on a background picture.

11. *WYSIWYG (what you see is what you get) Display*: The network model should resemble a scaled drawing or map in which various drawing elements represent the actual physical system components. For example, a node may represent a real manhole and a link may represent a real sewer pipe. This feature eliminates a need to prepare network schematic diagrams to visualize the network connectivity.
12. *Navigation*: CAD quality zoom and pan functions should be provided to navigate the network and background picture. This feature will allow networks of any size to be conveniently modeled and displayed on the computer screen.
13. *Spatial Searching*: This feature prompts the user to enter an ID number for a network element, locates that features, and brings it to the center of the screen.

7.4.4 Model Interpretation

14. *Results Review*: For the user-selected network elements, the model results should be displayed in both tabular and graphical formats. For example, for selected links the GUI should be able to display the model results:
 1. in a popup window showing summary results (e.g. time and amount of maximum computed flow and velocity),
 2. in a table showing intermediate results (e.g. time versus flow hydrograph data), and
 3. in a graph showing plotted results (e.g. plots of inflow and outflow hydrographs).

The tabular results are helpful in debugging the model and report preparation.

15. *Sensitivity Analysis*: The GUI should perform an automatic sensitivity analysis on user-specified input parameters of SWMM and display the sensitivity results as sensitivity gradient plots.
16. *Dynamic Plots*: HGL is the most informative EXTRAN block output. HGL elevations should be displayed in the plan view as vertical bars and in the profile view as line graphs. Dynamic HGL values should be displayed at each simulation time step to provide a video-like display of the HGL. With these model animations, users can view a storm surge progress through the system and immediately pinpoint areas of flooding and surcharging. Envelopes of peak HGL and flow during the entire simulation should also be provided.

17. *Thematic Plots*: This feature allows graphical encoding (color, type, shape, size, etc.) of network elements according to user specified themes (flow, velocity, surcharge, etc.) and facilitates rapid comprehension of model results. For example, sewers may be color-coded by surcharge for mapping severely surcharged sewers.
18. *Hydrograph Plots*: Time series scaled plots of flow, velocity and depth should be displayed and plotted for all the nodes and links of the model.
19. *Profile Plots*: Model profiles present information in a more natural manner which promotes a thorough understanding of system configuration. Users should be able to define and save a path (a sequence of links and nodes) through the network along which a profile view (section) can be drawn. The saved paths may be recalled later to plot CAD-quality profile plots showing model results (e.g. peak HGL and flows). Figure 7.3 shows a profile plot of HGL.
20. *Calibration Plots*: Observed and modeled hydrographs and pollutographs should be displayed on the same plot for model calibration and verification. Quantitative calibration measures should be provided to compare the observed and modeled

Figure 7.3 HGL profile plot in XP-SWMM.

hydrographs. The degree of calibration can be quantified by comparing three hydrograph parameters: volume, peak flow, and time to peak flow. However, because of the following reasons, this approach is quite subjective:

1. Generally, the three hydrograph parameters do not calibrate equally well. Is calibration acceptable, if the volumes are alike but the peak flows are different? Which parameter should be given a high priority?
2. There is no standard for the adequacy of calibration. For some users a 25% accuracy is adequate while others insist on 10%.

The integral square error (ISE) given by Equation 7.1 is a good measure of goodness-of-fit between observed and modeled hydrographs because it combines all the three hydrograph parameters (Marsalek et al., 1975).

$$ISE = \frac{\left[\sum_{i=1}^N (O_i - M_i)^2 \right]^{1/2}}{\sum_{i=1}^N M_i} \times 100 \quad (7.1)$$

where:

- O_i = observed hydrograph value at time I
 M_i = modeled hydrograph value at time i , and
 N = number of hydrograph values.

The calibration can be subjectively rated as excellent for $0 < ISE \leq 3$, very good for $3 < ISE \leq 6$, good for $6 < ISE \leq 10$, fair for $10 < ISE \leq 25$, and poor for $25 < ISE$.

7.4.5 Interface

21. *CAD Interface*: The GUI should import CAD drawings for displaying background pictures, and export model results (hydrographs, HGL profiles, etc.) as CAD drawings to aid in data exchange and report preparation using AutoCADTM DXF or other appropriate formats in common use.
22. *GIS Interface*: The GUI should provide an interface to a Geographic Information System (GIS), such as Arc/Info or ArcView. The interface should import SWMM input data from a GIS and export SWMM output data back to a GIS.

23. *AM/FM Interface*: The GUI should provide an interface to an automated mapping/facilities management (AM/FM) system, such as CASS Works or RJN. The interface should be able to import SWMM input data from an AM/FM and export SWMM output data back to an AM/FM.
24. *DBMS Interface*: The GUI should provide an interface to a data base management system (DBMS), such as dBASE. The interface should be able to import SWMM input data from a DBMS and export SWMM output data back to a DBMS.
25. *GIS Integration*: Total GIS integration offers an attractive alternative to developing separate interfaces for CAD, GIS, AM/FM, and DBMS. Most GIS programs have built-in interfaces for CAD, AM/FM, and DBMS packages. Therefore, once a SWMM GUI is an integral part of a GIS, it can share its interfacing functions also. In total integration, SWMM will become an add-on program to a GIS package as a new menu. SWMM networks will be created as a GIS coverage. Existing GIS coverages of streets, collection systems, and watershed boundaries, etc., will serve as excellent background pictures. SWMM execution will be launched from inside the GIS and SWMM output will be displayed as another GIS coverage.

7.5 GUI Review

This section provides a review of the available SWMM GUIs. The review of the first four GUIs (XP-SWMM, MTV, PCSWMM, and WSWMM) is based on the author's personal review. The review of the remaining GUIs is based on the technical and sales literature of the vendors. Products claims and sales hype commonly found in the brochures have been eliminated. Only the straightforward, no-nonsense explanation of each GUI's capabilities has been presented. Table 7.1 provides the address and phone number of the GUI distributors.

7.5.1 XP-SWMM

XP-SWMM was developed in 1988 by WP software of Canberra, Australia as an Apple Macintosh application. A DOS version was released in 1988. This program was developed under the technical guidance provided by Bob Dickinson, one of the co-authors of EPA's SWMM and EXTRAN programs. In the USA, the program is distributed by XP Software of Tampa, Florida (XP, 1995). All the reviewed features of XP-SWMM are listed in Table 7.2 (see section 7.6 Results). Only some special features are discussed below.

Table 7.1 GUI distributors.

No.	GUI	Contact / Address	Phone / Email / WWW
1	XP-SWMM	Robert Dickinson XP Software, 5553 West Waters Ave. #302, Tampa, Florida 33634	800-883-3487 xpsoft@shadow.net http://www.shadow.net/~xpsoft/
2	MTV	Mark TenBroek 10 Brooks Software, 3744 W. Huron River Drive, #200, Ann Arbor, Michigan 48103.	313-761-1511
3	PCSWMM	Robert James Computational Hydraulics Int., 36 Stuart Street, Guelph, Ontario, Canada N1E 4S5.	519-767-0197 info@chi.on.ca http://www.chi.on.ca
4	WSWMM	Ibrahima Goodwin U.S. EPA, Office of Science and Technology 401 M St. S.W. Washington, D.C. 20460	202-260-1308 Goodwin.Ibrahima@ epamail.epa.gov http://earth1.epa.gov/SWMM_WINDOWS/
5	SWMENU	Virgil C. Adderley Portland Bureau of Environmental Services 1120 SW 5th Ave. Portland, OR 97204	503-823-7866
6	CASS WORKS SWMM	Jeff Frauenfelder RJN Group, Inc. 200 West Front Street Wheaton, IL 60187	708-682-4700 (ext. 361)
7	SWMMDUET	Gray Curtis Madrigal Software Corp. P.O. Box 381710 Cambridge, MA 02238	617-876-3379
8	CASCADE	William James School of Engineering University of Guelph Guelph, Ontario Canada N1G 2W1	519-824-4120 (ext. 2433) james@net2eos.uoguelph.ca

XP-SWMM's graphics-based environment is the most user-friendly of all the urban stormwater system design codes (James, 1992). In addition to providing a GUI, XP-SWMM also includes significant modifications and enhancements to EPA's SWMM, such as, entrance/exit energy losses for the pipes. The XP-SWMM GUI has been written in the C programming language. The program offers a built-in decision support and guidance based on an embedded expert system designed to minimize the need for human experts. It incorporates both pre- and post-processors which use the expert knowledge of experienced

users. The expert shell acts as an interpreter between the user and the model. XP-SWMM's user interface utilizes the WIMP (Windows, Icons, Menus and Pointing devices) technology as the state-of-the-art intuitive user environment, but is not yet a Windows program. [written March 1996]

XP-SWMM utilizes a unique object-oriented graphical expert environment in which the user creates a link-node network interactively on the screen using a mouse and a toolbar. Background pictures may be imported from CAD packages to real world scale and used as a backdrop for laying out the network. Both the background picture and the network may be generated to scale. Once imported to scale, the areas and lengths may be computed directly from the plan view. The plan view may be output to plotters, printers, or a DXF file. Full CAD quality zoom and pan functions are available. Built-in knowledge-based rules continuously filter the user input and issue warning messages if incorrect data are entered. This expert data-checking capability eliminates data errors at the input level rather than the traditional run time diagnostics. Interpretation, identification, and correction of run time errors is much more difficult.

A major advantage of XP-SWMM is the integration of all the SWMM blocks with a common interface that manages all the data for various blocks from a central graphical database. The data in the graphical database is entered and retrieved through graphical dialog boxes or optional text files. XP-SWMM is the only commercial SWMM GUI with graphical model development and editing capability. A Microsoft Windows version is being developed which will allow multitasking and sharing of Windows resources, such as print manager and drivers. As of 1995, the program cost varies from \$2,495 for a 100 pipes version to \$9,495 for a 5,000 pipes version. The cost of program upgrades is \$295.

Figures 7.1 to 7.3 demonstrate examples of various XP-SWMM capabilities. Figure 7.1 is an example of a graphical editing dialog box. Figure 7.2 shows an example of how a network can be overlaid on a background picture. Figure 7.3 shows a profile plot of HGL.

7.5.2 Model Turbo View (MTV)

Model Turbo View (MTV) was developed in 1990 by 10 Brooks Software of Ann Arbor, Michigan (10 Brooks, 1995). MTV is a post-processor and does not provide an input interface for creating SWMM's input file. The code has been written in Pascal programming language. MTV provides two separate GUIs for SWMM's RUNOFF and EXTRAN blocks, called MTRV and MTVE, respectively. This review is based on MTVE. All the reviewed features of MTV are listed in Table 7.2. Only some special features are discussed below.

MTV provides a viewing port to standard SWMM input and output files. The complex model networks are often difficult for the user to visualize. MTV, however, can be used to view the network in a schematic format. MTV allows the user to supply and edit coordinate data for the nodes and the links. This

provides the user with the opportunity to view how the system is connected, based on the model input data file. Connectivity errors are often easily detected and solutions to setup problems quickly formulated. MTV can define any path through the network and display the profile for that path. This often proves valuable when seeking errors in the elevation input data (which can produce unusual results). MTV portrays dynamic SWMM results in the form of HGL plan and profile views. Figure 7.4 shows an example of a HGL plan view. One of the major concerns in SWMM EXTRAN is numerical instability which is often caused by very steep pipes or chambers with small storage. In large models it is difficult to isolate and correct the network elements responsible for numerical instabilities. MTV searches the entire network and highlights all unstable links. Any of the MTV screens can be printed to a LaserJet compatible printer. Plan and profile plots can be saved as AutoCAD DXF files. The user can then add additional information to these AutoCAD drawing files for inclusion in the project report. The program cost is \$850 and the cost of program upgrades is \$180.

Figure 7.4 Plan view of HGL in MTVE.

7.5.3 PCSWMM

PCSWMM was developed in 1988 by Computational Hydraulics Int. of Guelph, Ontario (Computational 1995). All the reviewed features of PCSWMM are listed in Table 7.2. Only some special features are discussed below.

PCSWMM is a post-processor and does not provide an interface for creating SWMM's input file. PCSWMM is a Microsoft Windows application programmed in Visual Basic which is the language of choice for developing attractive and effective GUIs to meet the specific application needs. Windows Visual Basic applications can communicate with other Windows applications through a mechanism called dynamic data exchange (DDE). While one can easily exchange information by copying and pasting data between applications, DDE automates this process, providing a direct link between the Visual Basic and other DDE applications. This capability of PCSWMM is very valuable for future enhancements and integrations with other CAD, GIS, AM/FM, and DBMS applications.

PCSWMM is developed as a decision support system for SWMM. It is designed to simplify the SWMM environment, speed up execution, and help interpret the SWMM output. It provides fast editing of data files, sophisticated file management, fast and simple graphically oriented execution of SWMM engine, fast and high resolution plotting of hydrographs and pollutographs generated by all blocks of SWMM, automatic sensitivity analysis, calibration and error analysis, field data management, and on-line help. Designed especially for the Microsoft Windows operating system, PCSWMM offers a drag-and-drop icon-oriented environment that greatly simplifies the routine editing, execution, and output interpretation for SWMM, especially long-term simulations. The program cost is \$200 and the cost of program upgrades is \$100.

Figure 7.5 PCSWMM sensitivity analysis results.

7.5.4 WSWMM

SWMM for Windows or WSWMM was developed in 1994 for the Office of Science and Technology, Standards and Applied Science Division of EPA to assist them with the Total Maximum Daily Load (TMDL) program (US EPA, 1995). The reviewed features of WSWMM are listed in Table 7.2. Only some special features are discussed here.

The WSWMM GUI was developed to assist the user in data input and model execution, and to make a complex model user-friendly. As the name indicates, this GUI is a Microsoft Windows application. It integrates SWMM and its data handling needs. A pre-processor helps to generate SWMM's input via data sheets and forms. A post-processor is provided which performs the following functions:

1. displays six different types of graphs: hydrograph, pollutograph, loadgraph, flow volume, mass, and landuse;
2. creates calibration plots; and
3. displays summary tables for flow rate (or volume) and pollutant concentrations (or loads) for desired inlets.

WSWMM is public-domain software and can be obtained without cost from EPA.

A key feature of WSWMM is the separation of meteorological data from the RUNOFF Block. A new block called MET has been provided to create and edit meteorological data. The goal of this block is to consolidate user interaction and input of meteorological data into one separate module. Selection of meteorological data for use in a RUNOFF run will occur as part of the RUNOFF block. From

Figure 7.6 Flow chart of WSWMM execution sequence.

a user’s perspective all meteorological data will be accessed unambiguously by a single file name. This, therefore, eliminates meteorological data entry in the Runoff input file. Similar consideration made in the TRANSPORT and EXTRAN blocks is the separation of user defined hydrographs and pollutographs from the TRANSPORT and EXTRAN user input (US EPA, 1995). A block called USEHP was developed to handle all user-supplied flows and concentrations. Figure 7.6 shows the execution sequence of WSWMM. Figure 7.7 shows an example of WSWMM input interface using a data sheet.

Figure 7.7 WSWMM input interface through data sheets.

7.5.5 SWMENU

SWMENU was developed in 1991 by the Portland Bureau of Environmental Science, Portland, Oregon to model the city’s combined sewer overflow (CSO) system using SWMM (Adderley et al., 1994). Due to the intense use and modifications of the CSO models and data, this menu-driven GUI was developed to automate generation and execution of the models, link the model database to other structural databases, and provide for future expansion or linkage to a GIS. Automating the modeling processes required that a relational database system be developed to link the model databases to the independent databases that contain information about the collection system. Using these database links, SWMENU generates SWMM input data files that reflect specific conditions of the collection system.

SWMENU incorporates both pre- and post-processors, and therefore provides interfaces both for creating SWMM’s input file and graphing SWMM’s output file. SWMENU is a Microsoft Windows application which was developed using Microsoft’s Visual Basic for Windows. Database access capability was developed using Q+E/VB by Pioneer Software which supports both dBASE III+ and IV formats. As mentioned previously, Window’s Visual Basic programming environment is very valuable for future enhancements and integrations with other CAD, GIS, AM/FM, and DBMS applications.

SWMENU’s interface and its relationship to the different components of the Portland CSO modeling system is shown in Figure 7.8. SWMENU is able to access the various databases of the CSO system. It can update the modeling databases and generate new SWMM input files as needed to reflect changes in the system data or possible changes in the settings of Portland’s 200 diversion structures. During model simulations, SWMENU launches a modified version of SWMM in a background DOS shell while keeping track of the success of each

Figure 7.8 SWMENU interface structure.

run. Post-processors and macros are used to import the results into Excel and generate tables, summary statistics, and time series plots of depth and flow. Future enhancements of SWMENU will include integration with Microsoft Access, a relational database management system for Windows. The SWMENU GUI is a public-domain program and is free.

7.5.6 CASS WORKS SWMM

This GUI has been developed by RJN Group, Inc. of Wheaton, Illinois, as a CASS WORKS module. CASS WORKS is an integrated infrastructure management software for water distribution, sanitary sewers, storm drainage, treatment facilities, parks and recreation, GIS, and AM/FM applications. Also known as CASS WORKS' Sewer Hydraulic Modeling Module, the GUI employs SWMM's TRANSPORT block to model network capacity, perform gradient analysis, incorporate time routing of flows, and predict system needs based on future growth or demands. This module can link elements of an SSES type database to hydraulic profile characteristics of a sanitary sewer system. RJN has also developed another module called GeoCAD that can integrate the TRANSPORT module with the leading GIS software programs that use ORACLE. This integration allows the TRANSPORT module to run within GIS programs. Using ANSI SQL RDBMS standards, RJN has integrated CASS WORKS with ARC/INFO and ArcView, the world's leading GIS software programs developed by the Environmental System Research Institute (ESRI). The ability of both systems to access the same database increases the value of the data, eliminates database inconsistencies, allows for both graphic and nongraphic representation of data, and eases implementation issues and costs. The cost of CASS WORKS' TRANSPORT and GeoCAD modules is \$4,400 and \$2,200, respectively. A \$4,400 core module which provides the ORACLE support should also be purchased to run the TRANSPORT and GeoCAD modules.

The CASS WORKS SWMM interface was used by the Massachusetts Water Resources Authority (MWRA) to conduct their Sewerage Analysis and Management System (SAMS) project. The goal of the SAMS project was to provide the MWRA with the capability to efficiently and accurately evaluate both short-term and long-term needs of the MWRA sanitary sewer interceptor system, which serves over two million people in 43 communities in the Boston Metropolitan area. In order to create a geographically correct modeling schematic and simplify the process of geographically representing the modeling results, MWRA plans to link SWMM's EXTRAN block with SAMS inventory database and ARC/INFO GIS. ARC/INFO GIS will be used to create a link between the TRANSPORT data and computerized maps of the MWRA interceptor system and communities serviced.

7.5.7 SWMMDUET

SWMMDUET was developed in 1993 by Madrigal Software Corporation for the Delaware Department of Natural Resources and Environmental Control (DNREC). DNREC's goal was to promote state-wide use of SWMM to obviate the need for Delaware municipalities to make separate efforts to satisfy the requirements of Section 6217 of the Coastal Zone Management Act and the Clean Water Act. SWMMDUET was developed to increase the productive use of SWMM and aid modelers in meeting mandated obligations (Curtis, 1994).

SWMMDUET integrates SWMM with ARC/INFO GIS software, and quite appropriately, has been written in ARC/INFO's native ARC Macro Language (AML). It creates a computing environment that does not require arcane knowledge of SWMM and ARC/INFO. This GUI 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 defines 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 was 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, allowing hydrologists to concentrate on hydrologic matters. Future development plans of SWMMDUET include ArcView functionality, automatic watershed delineation from USGS Digital Elevation Model (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).

7.5.8 CASCADE and CASCADE2

These programs provide an interface to SWMM utilities. The utility programs aid the development and execution of SWMM models. In the past, the main argument against using continuous SWMM modeling has been the difficulty of managing large amounts of input and output data. CASCADE programs are time series data managers (TSM) for SWMM which facilitate continuous SWMM modeling. They also provide easy data export/import capability to/from other TSMs.

CASCADE was developed by Michael Gregory, a graduate student of the University of Guelph, Guelph, Ontario. CASCADE provided a SWMM interface with the USGS TSM called ANNIE. CASCADE2, which is also a Microsoft Windows application, has been developed by Yiwen Wang, another University of Guelph graduate student. CASCADE2 provides a SWMM interface with the US Army Corps of Engineers' TSM called HECDSS (see Chapter 3).

Both programs also provide a statistical analysis utility to compute storm event statistics by interfacing with SWMM's RAIN and STATS blocks.

7.6 Results

In order to quantify the available GUI features and identify the future improvements, a side-by-side comparison of the available GUIs was performed. Table 7.2 provides a comparison of the first four GUIs discussed in the previous section (XP-SWMM, MTV, PCSWMM, and WSWMM). These GUIs were included in the comparison because detailed information about their features was available from the author's personal experience. The last four GUIs were not included because their review is based on the sales literature rather than the author's personal experience.

The eight reviewed GUIs illustrate the wide variety of functions that can be performed. It is difficult to compare them with one another because of the large number of features and options that each one offers. Therefore, it is very important to assess needs and preferences and compare the various GUI programs to those needs, rather than to one another. The author does not intend to imply that these eight are the only products to be considered when selecting a SWMM GUI. Users are encouraged to supplement this review with the latest information, especially if they are reading this article long after publication.

Table 7.2 is intended to demonstrate a method of comparing the GUIs. The comparison is based on the existing features. Planned future improvements were not included. Due to some limitations of this simple comparison technique, Table 7.2 may not be used for the final GUI selection and purchase. However, as described below, most of these limitations can be easily eliminated by the users. The total score is based on assigning an equal score of one to each feature. In the real world, different features will have a different value to different users. For instance, the graphical model development feature may be the most valuable feature for some users worth 5 or 10 points. Users are encouraged to apply a custom scoring system reflecting their personal modeling needs and preferences. Another limitation of Table 7.2 is its inability to compare the relative quality of a feature in different GUIs. For instance, all the GUIs offering automatic file management were assigned the same score of one regardless of their relative file management capability. Users are encouraged to contact the GUI vendors for

Table 7.2 SWMM GUI comparison.

No.	Feature	XP-SWMM	MTV	PC-SWMM	WSWMM
1	Windows application			●	●
2	Integration	●	●	●	●
3	User friendliness	●	●	●	●
4	File management	●		●	●
5	Input interface	●			●
6	Output interface	●	●	●	●
7	Graphical input	●			
8	Graphical editing	●			
9	Spreadsheet editing				●
10	Background pictures	●	●		
11	WYSIWYG	●	●		
12	Navigation	●	●		
13	Spatial searching	●	●		
14	Results review	●	●	●	●
15	Sensitivity analysis			●	
16	Dynamic Plots	●	●		
17	Thematic plots	●	●		
18	Hydrograph plots	●	●	●	
19	Profile plots	●	●		
20	Calibration plots	●	●	●	
21	CAD interface	●	●		
22	GIS interface				
23	AM/FM interface				
24	DBMS interface				
25	GIS integration				
	Cost	\$2,500 to \$9,500	\$850	\$200	Free

a detailed comparison of the GUI features. Finally, the GUI comparison was based only on the 25 recommended features. Many GUIs provide additional features which may be valuable to some users and should be included in the comparison process.

7.7 Recommendations

1. It is recommended that all the GUIs should move to Microsoft Windows. This will benefit both the developers and the users. Developers will be able to focus on the GUI development rather than creating device drivers and fonts which are already available in Windows to be shared by all the Windows applications. There will be no concerns about the GUI compatibility with a wide variety of monitors, pointers, printers, and plotters. As long as a GUI will be compatible with the Windows standards, it will be compatible with all the Windows device drivers.
2. The programming language should be chosen carefully. It may not be appropriate to continue to program in Fortran 77 to develop the Windows applications. It is recommended that scripting and object orientated programming languages, such as Visual Basic and Visual C++ should be used to provide efficient third party interfacing capability.
3. The GUIs should be flexible and modular to allow third party interfaces. Developers should maximize the use of off-the-shelf software. This would obviate a need to recreate functions which are available in commonly used applications such as Lotus 1-2-3 or Microsoft Excel.
4. Table 7.2 indicates that the GUIs lack GIS, AM/FM, and DBMS interfaces. It is recommended that these features be provided. A batch-oriented approach in which users must write their own programs or use other software (e.g. spreadsheets) to import (export) from (to) SWMM ASCII files is not recommended. The interface feature should be an integral part of the GUI, possibly appearing as *import* and *export* options under the *files* menu. The interface should not be application dependent. The internal structure of the software should allow communication both to and from any standard CAD, GIS, AM/FM, or DBMS. If this is not done, the vendors will have to develop separate interfaces for different packages.
5. As an alternative to developing separate interfaces for CAD, GIS, AM/FM, and DBMS, total GIS integration may be implemented. This feature is not currently available in commercial GUIs. It is important to understand the difference between a GIS interface and a GIS integration. The GIS interface is simply a file menu option in a SWMM GUI to transfer data to/from a GIS. The GIS integration, is a combination of a SWMM GUI and a GIS such that the combined program offers both the GIS and the SWMM functions.

6. Since users will always have more confidence in EPA's official release of SWMM, it is recommended that the GUIs should preserve SWMM's solution algorithms. Users should be able to obtain identical results from SWMM and the GUIs. Using the example problems from the SWMM's distribution diskettes or user's manual, each new version of a GUI should demonstrate that its output is identical to SWMM's output. Any modifications and enhancements made to SWMM's code should be offered as separate user options. This recommendation can be easily implemented if the users are given a choice to use EPA's official SWMM.EXE file in place of the modified SWMM.EXE file provided by the GUI.
7. The GUIs are 100% dependent on the SWMM version. The GUIs read specific data at specific locations in SWMM's ASCII files. For this reason, a GUI must be reprogrammed every time the format of SWMM's input or output file has been changed. For example, even one extra space in just one line of the output file has a potential to upset the normal execution of a GUI. Therefore, each new SWMM version will require a corresponding new GUI version. This limitation does not create a problem because in the last 25 years, EPA has released only four SWMM versions. However, sub-versions (e.g. 4.1, 4.2, etc.) have been released more frequently. It is recommended that, to the maximum extent possible, EPA should not change the input and output formats of the sub-versions. This will avoid the need to purchase a GUI upgrade for each SWMM upgrade.

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