Chapter 8

Management Of Time-Series Data For Long-Term, Continuous Stormwater Modeling

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Long-term, continuous modeling is essential for simulating the long-term impacts of urban drainage systems on aquatic ecosystems. Managing time-series data for periods of three human generations, or 75 years, is a critical task requiring specialized data management systems. Typical engineering design offices do not have adequate tools or resources to manage such data. As a further complication, many North American agencies are now offering public access to their data through modern media, such as the Internet and CD-ROM.

To identify current needs and preferences of practicing stormwater modelers, a survey was conducted. Results show that practitioners generally agree that continuous modeling is necessary, contrary to numerous planning and design manuals that proclaim continuous modeling is neither desirable nor feasible for stormwater modeling. Furthermore, many favour software tools that aid in their data collection and modeling exercises.

Accordingly, this study investigates the utility of linking a continuous stormwater model (SWMM) with a standard time-series data management system (ANNIE), thereby integrating a widespread and diverse collection of stormwater modeling applications. By means of a new graphical user-interface, efficient manipulation and transfer of time-series data was demonstrated, as measured in terms of computer storage space and processing speed.

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8.1 Introduction

In this section, issues related to the practice of modeling urban stormwater drainage systems are reviewed. Continuous simulation is shown to be a fundamental component for reliably modeling nonpoint source pollution and its long-term effects on aquatic habitat. Results from a survey of stormwater modelers are also given.

8.1.1 Long-Term, Continuous Modeling

Besides creating new and diverse pollutant sources, urbanization has eliminated many of the natural pathways for runoff to reach receiving channels. Infiltration of stormwater into the ground not only reduces surface runoff volumes, but acts as a natural treatment mechanism, supplying lakes and rivers with cleaner, cooler water (Thompson, 1995; Shahin, 1994). Through a combination of poor planning, short-sighted engineering design, and impervious construction materials, much of the original infiltration capacity of urban land surfaces has been removed. Cities yield increasing volumes of runoff, which is dirtier and hotter in summer months, compared to conditions prior to any landscape interventions (Xie, 1993).

Essentially, storm events stir up and wash off the dirt that accumulates in cities. Polluted runoff is collected by urban drainage systems, and is quickly and efficiently delivered to aquatic ecosystems, many of which are sensitive to these stressors (Xie, 1993). Stormwater runoff pollution cannot be attributed to a single source, it is rather the diffuse product of all the tributary land surfaces. Known as nonpoint source pollution, control regulations are now beginning to address this problem (Schueler, 1987).

Due to the variability of urban stormwater runoff effects, nonpoint source pollution is very site-specific; there are notable differences in land development practices, public attitudes, drainage systems, and rainfall characteristics. Because of this, and also “because of differences in sampling procedures and the common practice of pooling data from various sites, or conditions” (Pitt, 1995), efforts to quantify relationships between observed aquatic habitat effects and stormwater runoff have not been conclusive. Better field monitoring studies and more appropriate computer modeling methods are needed.

Computer modeling techniques used by practicing engineers are diverse. An element of discord has arisen in the modeler’s choice of either event or continuous methods. Event models only compute a hydrological response during a single, wet weather event. Statistical properties of the input rainfall hyetograph are unrealistically assumed to be representative of the computed output hydrograph. As a result, event models require estimates of antecedent conditions. Such prior hydrological conditions are not dependent on rainfall characteristics,

and are therefore not generally predictable (James and Robinson, 1986). Furthermore, event-based hydrology relies on the illusory concept of a *design storm*, which is based on simple statistical properties of rainfall, and has been widely criticized (Adams and Howard, 1985; James and Robinson, 1986; Huber et al., 1986; Medina, 1987).

Continuous models simulate hydrological processes during wet and dry weather periods, and thus avoid the problem of specifying arbitrary antecedent conditions (Donigian and Linsley, 1979). They are so named for their ability to model hydrological response using continuous meteorological datasets, several decades in duration (James and Robinson, 1986).

Continuous modeling is an essential component in the assessment of nonpoint source pollution impacts (Litwin and Donigian, 1978; Donigian and Linsley, 1979; Pitt, 1994). Whereas traditional, event-based hydrology has been more concerned with efficient drainage objectives during rare storm events, most of the pollutants in runoff are associated with the relatively common storm events (Pitt, 1994). Investigations in Wisconsin have shown that water quality standards were often violated during small storms, generally two inches (50 mm) or less in depth (Pitt, 1986).

Given the variability of nonpoint source pollution in urbanized watersheds, effective management plans require that the probability of occurrence of undesirable water quality conditions be considered. Donigian and Linsley (1979) argue that only continuous simulation can provide the necessary information.

Surprisingly, continuous simulation is discouraged by numerous design manuals and stormwater management planning guides. For example, a popular Canadian hydrology manual declares that “for most cases of flood analysis and design, use of continuous models is either not feasible or prohibitively expensive or both” (Associate Committee on Hydrology, 1989). Common arguments against continuous modeling include:

- Timesteps that are too long for small urban catchments. Accurate simulation is not possible when the modeling timestep is longer than the watershed response time, or “time of concentration”. Arguments evidently arose from rural watershed models whose minimum timestep was one hour, a resolution too coarse for quickly-responding drainage systems (James and Robinson, 1986). Continuous models such as SWMM and HSP-F are able to simulate timesteps as small as one minute, or even one second, if necessary.
- Costly computing time. This argument becomes weaker as faster, less expensive computers reach the marketplace (Ormsbee, 1989; Kuch and James, 1993). Typically, when computing times are critical, variable timesteps are often employed (longer timesteps during dry weather), or critical design events are screened so that they can be studied in more detail (Ormsbee, 1989).

- Lack of available data. Arguments still persist that continuous models require large input datasets that are impractical to use (Marsalek and Sztruhar, 1994; Cao et al., 1994). New media, such as CD-ROM and the Internet, challenge such complaints, having greatly increased engineer's access to digital data.
- Inability to manage the large, hydro-meteorological input datasets and even larger simulation output data.

In summary, long-term continuous modeling naturally leads to an appreciation of long-term environmental consequences (Pitt, 1995). "The principal argument in favour of design storm methods is design economy, but cheap stormwater drainage design is an avoidance of consideration of the inevitable long-term ecological impacts of that design, tantamount to a deliberate decision to remain ignorant of the impacts of urban drainage design" (James, 1994).

8.1.2 Survey Of Stormwater Modelers

As part of this study a survey was undertaken, the purpose of which was twofold. First, it was designed to provide a mechanism for obtaining the opinions of stormwater modelers. Second, the survey was designed to assess the need for software tools for continuous stormwater modeling.

The 1995 Stormwater and Water Quality Management Modeling Retreat in Toronto, Ontario provided an excellent opportunity to determine needs and preferences of stormwater modelers, since participants were diversified in their experience and professional background. In total, 57 of 124 surveys were completed and returned, a response rate of 46%.

By far, engineers comprised the majority of participants; only six of 57 respondents (11%) were not engineers. Two-thirds of all respondents (67%) were employed as consultants, and nearly one-third (30%) were government employees. IBM-compatible personal computers were the overwhelming favourite of all participants (91%). Of 57 respondents, 47 (82%) used IBM-compatible machines alone, and only five (9%) used multiple computer types at work.

There were a number of significant findings, summarized as follows:

- Generally, stormwater modelers agree that continuous modeling is a necessary task. A surprising number are experienced in both continuous simulation and managing long-term precipitation records.
- Development of utility tools that assist continuous modeling tasks is a desirable, and perhaps necessary, undertaking. Applications should be appropriate for IBM-compatible personal computers (also the conclusion of a recent survey of 200 water quality agencies in the United States (Saito et al., 1994)).
- By far, the majority of stormwater modelers would adopt continuous modeling if datasets were more readily accessible. Most believe

that the Internet is an important resource and would prefer to access Internet data, rather than purchasing datasets on CD-ROM.

- Stormwater modelers have many preferences for Internet services, however, there is a slight preference towards technical assistance.

8.2 Information Acquisition and Exchange

This section focuses on data resources for stormwater modeling applications. The acquisition and exchange of hydrological data is rapidly evolving - traditional data sources are quickly being replaced with modern technologies such as CD-ROM and the Internet. Data types are being merged as well: textual data, audio, video and other multi-media digital data are becoming readily-available to a widely-distributed community of users. It certainly seems timely to consider merging stormwater management modeling needs (continuous, long-term data) with this evolving environment.

8.2.1 Types Of Hydrological Data

Digital data, whether it is observed or simulated, comes in many formats, from many sources, and with varying degrees of quality assurance. Consequently, fulfilling the data needs of continuous hydrological models can be a very time-consuming task. Three general types of data must be managed in the course of modeling urban drainage systems:

- Spatial data. This data type includes any elements that are referenced to a system of spatial coordinates. Examples include the layout and connectivity of urban drainage systems and tributary catchment areas. Geographic Information Systems (GIS) have recently become a useful aid in the management and visualization of spatial data in hydrological modeling studies (Kutsal and Johnson, 1993).
- Parameter data. Spatially and temporally-averaged process coefficients, state variables, and other parameters are included in this category. Examples are catchment imperviousness, the average catchment slope and width of overland flow. Parameter data can be managed effectively with various commercial data management software, or as GIS attribute tables.
- Time-series data. Included in this category are any data elements that change with time, or observations that have been made sequentially in time (Chatfield, 1989). Timestep refers to the interval of time between successive data values. Examples of time-series data include observed flowrate and meteorological measurements

(precipitation, air temperature, potential evaporation, solar radiation, and wind velocity). Specialized management software is required for time-series data, management that is not offered by either GIS or the commercial database systems that individually address data elements in related tables.

Each data type has its own unique management needs, although all types are related, since each makes reference to a spatial coordinate system, either directly or indirectly. Furthermore, it is anticipated that any distinction between data types will eventually be obsolete. In fact, the union of hydrological data types has already been described as imminent (Nicolini, 1995).

Modern weather radar is an example of hydrological data that combines aspects of both time-series and spatial data. Typical radar systems offer data resolution at a spatial scale of two kilometres, and a ten-minute temporal scale. Current Doppler imagery, however, has increased the resolution to one kilometre, every five minutes. The US Army Corps of Engineers is currently developing methods for collecting, managing, and presenting radar rainfall data (Nicolini, 1995).

8.2.2 Sources of Data

There has been an overwhelming increase in the demand and availability of hydrological data from global sources. Within the past decade, technological advances have resulted in cheaper, quicker, and more personal access to information. Modern hydrological instruments and observational systems have heightened the demand for data with increasingly finer spatial and temporal scale resolution (Heler, 1979; Faas and Snodgrass, 1994). In addition, information can now be exchanged across different media, languages, and political borders, and the technology continues to advance daily.

Archival datasets of water-environment data are maintained by a number of North American agencies, including the Canadian Atmospheric Environment Service (AES), the US Geological Survey (USGS), the US Environmental Protection Agency (USEPA), and the National Weather Service (NWS).

The USGS has operated the National Water Data Exchange (NAWDEX) since 1976. It is intended to provide the linkage between those who acquire and those who use water data, by identifying sources of data, indexing data holdings of members, and assisting in data searches and access to files (Edwards, 1987). The Water Resources Division of USGS, through its NAWDEX Program Office, provides central management and coordination of NAWDEX services. These services are available through a network of nearly seventy Assistance Centres throughout the US. Members are required to register with the Program Office, and are encouraged to participate in data response and referral mechanisms, as well as take an active role in the formulation of policies, procedures, and

standards. NAWDEX includes many organizations from all levels of government as well as from the private sector. Based on 1987 statistics, water data was available from 450,000 sites, collected from 450 organizations (Edwards, 1987).

NAWDEX also provides access to water data, including the WATSTORE and STORET systems. The National Water Data Storage And Retrieval System (WATSTORE) was established in 1971 to store and disseminate water data acquired by the USGS. Data are collected from a variety of monitoring stations including stream, river, and reservoir gauging stations; surface water quality stations; groundwater level observation wells; and groundwater quality wells (Showen, 1985). In addition to its data storage, retrieval, and processing functions, WATSTORE features utility software for assisting with data entry and retrieval, and for presenting graphs, tables, and statistics (US Geological Survey, 1985).

The USEPA maintains and operates the Storage And Retrieval (STORET) system for water quality data. It was developed under the auspices of the Public Health Service in 1962, and was put into production in 1964. Users require a system account, and the proper telecommunications software in order to access the system. STORET has evolved into a comprehensive information management system for water quality data. It is perhaps the largest such database facility, as it currently contains over 200 million individual water quality observations (some dating back to the late 1950s) that have been collected on behalf of many federal and state organizations. Data have originated from 35 million samples taken at 800,000 collection points across the United States (US Environmental Protection Agency, 1992).

The National Climatic Data Centre (NCDC) has the basic responsibility of collecting, archiving, processing, and disseminating climatological data in association with the National Weather Service (US National Weather Service, 1985). It is the largest climatic centre in the world, and provides historical weather information dating back to the 1800s, originating from international sources. In addition to providing access to data, the NCDC also provides specialized analysis, interpretation, searches, and certifications of recorded data.

There are an increasing number of international agencies that provide environmental information services. The Great Lakes Information Network (GLIN) and the Consortium For International Earth Science Information Network (CIESIN) are two such agencies. Both are comprised of members from an international array of government agencies, universities, research organizations, and private corporations.

8..2.3 Modern Information Exchange Technologies

Laser optic devices such as Compact Disc-Read Only Memory (CD-ROM) and Videodiscs have recently challenged conventional magnetic media in the storage of digital data. Both removable magnetic tapes and floppy discs suffer

from shorter storage lives, slower access times, and smaller storage capacity than CD-ROM (Hendley, 1988). Typical CD-ROM discs can hold about 660 megabytes of digital data, or roughly 70 minutes of high quality audio (Priestley, 1988).

CD-ROM sales are rising dramatically. Price cuts have recently made recordable CD-ROM technology openly available, and prices are expected to drop below \$1,000 by the end of this year (Bournellis, 1995).

Hydrological datasets are available on CD-ROM from many of the public agencies mentioned earlier, most notably the USGS and NCDC. A national dataset of daily mean streamflow discharge values from 1,659 sites (73,231 water-years of record) is provided on CD-ROM by the USGS. Data have been compiled from the WATSTORE database, and are given in various binary and ASCII text file formats (Slack et al., 1993).

The Internet is the largest, fastest growing, and most widely used computer network in the world. Despite its name, the Internet is not simply an international network of computers, but rather, a network of networks. Linked together by common communications protocols, the Internet is really a conglomerate of computer networks whose origins are found in government agencies, educational institutions, and commercial and private organizations.

Once a connection has been established, Internet services are freely accessible to the public. Management of the Internet is highly decentralized, and there are few standards of practice; no single group is fully responsible for overseeing its daily operations. Because of this, the novice user might find the Internet intimidating and frustrating, described as "essentially an anarchy that depended on cooperation among its users" (Miller, 1994).

In the beginning, Internet services were accessed using UNIX commands that were often arcane and difficult to learn. Friendlier navigation tools are evolving, especially in the form of mouse-driven graphical aids and user-interfaces. Although it is becoming easier to manoeuvre between Internet networks, file management and information exchange standards are still lacking. What would appear to be relatively simple searches might take hours to locate and retrieve. It is hoped that increased demands will continue to promote the development of better standards and interaction between network facilities.

Among the most popular Internet features are:

- Electronic mail (e-mail), where users have personal addresses, and can send or receive messages almost instantly.
- Newsgroups and mailing lists, which permit group discussions among participants with e-mail access.
- Remote computer login, which allows access to other computers on the Internet.
- Transfer of digital files, even between computers with different operating systems, using the File Transfer Protocol (FTP). FTP

software can be used to retrieve all types of computer files from archive collections on Internet FTP servers. Anonymous FTP permits the retrieval of files by allowing users to login without a password.

- File and data searching tools, which are widely available and very useful given the size of the Internet. Many Internet software products feature built-in searching tools, however, there are many tools that allow custom searches to be performed. Known as “Web Explorers”, “Net Crawlers”, and even “Spiders”, such software can be used to search Internet documents for specific keywords, building a searchable database of the information it has found.
- The World-Wide Web is one of the newest and most popular Internet utilities. The Web allows users to view documents that have links to other Web documents on the Internet. These documents, known as home pages, may feature embedded graphics, audio, or video, and can be accessed with public-domain software that recognizes the Hypertext Transfer Protocol (HTTP), such as Netscape. HTTP is a language standard through which World-Wide Web client and server programs can communicate.

As an emerging on-line information system, the Internet is quickly changing the way research is being conducted: away from the university libraries and toward personal access from home and office computers. Research groups are increasingly using the Internet as a means of communication among themselves and others (Belk and Heathcote, 1995). The ability to search data archives quickly and interactively has made traditional microfilm and paper searches less attractive (Hendley, 1988).

Numerous disadvantages and drawbacks persist, however. Economics of on-line systems prevent very large and specialized databases from being placed on the Internet. It is simply not economical to provide such data unless “the relatively small number of potential users would be prepared to pay a large premium for accessing it” (Hendley, 1988). Indeed, it is the urgent desire for specialized data that is prompting some third party vendors to sell public data archives on CD-ROM, forcing agencies to consider withdrawing their World-Wide Web home pages and anonymous FTP servers.

A further reality of Internet data archives is the lack of quality assurance and data integrity measures. Currently, digital data that is publicly available cannot be assured by the data observer. It is anticipated that this situation will change as new Internet security procedures are developed.

A directory of Internet services related to stormwater and water resources data is provided in the Appendix, current as of August 25, 1995. Internet services are highly dynamic, where addresses change frequently, and servers are often

unavailable under high-demand conditions or for maintenance reasons. Therefore, the directory is not exhaustive and some addresses might become invalid.

Both CIESIN and GLIN offer their data holdings on World-Wide Web home pages. Various Environment Canada and National Weather Service home pages feature weather forecasts, satellite imagery, publications and other environmental data archives. Daily rainfall and temperature data can generally be found, but hourly records are very scarce.

Software, manuals, publications, general information, events and announcements, and other items of interest to stormwater modelers can be found in the Web pages of the Hydrologic Engineering Centre (US Army Corps of Engineers), USGS, and the USEPA.

The National Climatic Data Centre has a variety of on-line data systems that are accessible via telephone, modem, and the Internet. Many datasets are available through anonymous FTP for immediate downloading. Large datasets, CD-ROM, and other off-line data can be ordered from NCDC by e-mail (orders@ncdc.noaa.gov). Delivery costs depend on data formats and quantity desired. As an alternative to NCDC data holdings, the National Centre for Atmospheric Research (NCAR), offers meteorological data archives on the Internet, and at reasonable cost for other off-line datasets.

The University of California at Davis operates a mailing list in which water-related Internet information sources are discussed (Water On-Line). Additionally, a mailing list specifically devoted to stormwater management modeling (SWMM-Users) has been in operation at the University of Guelph since 1993. In July 1995, there were approximately 140 subscribers from around the world.

Internet newsgroups are another useful resource for stormwater modelers. There are hundreds of newsgroups to which one can subscribe, however, the authors have found sci.engr.civil and sci.geo.meteorology to be the most helpful for discussion on stormwater modeling data issues. The meteorology newsgroup regularly posts an updated listing of Internet data resources.

8.3 Time Series Data Management

Data management includes the collation, organization, identification, presentation, and archiving of discrete datasets (Saito et al., 1994). In the previous section, it was mentioned that information technology has generated a dynamic and continually-evolving data environment. As data availability and exchange of information progresses, data management techniques are also evolving. During a national survey, it was found that several water quality agencies were planning changes to their data management systems (Saito et al., 1994). Indeed, both the WATSTORE and STORET systems are scheduled for complete modernization (NAWDEx Newsletter, December 1993; Hoelman, 1994).

8.3.1 Introduction

Long-term, continuous modeling requires that large amounts of time-series data be managed; large hydro-meteorological datasets are required as input, and large datasets are created as output. Time-series data must be managed differently than other types of hydrological data. Spatial and parameter data are effectively managed with commercial database or GIS systems that individually address data elements in related tables. Time-series data are effectively managed as contiguous blocks of related data (US Army Corps of Engineers, 1991). Accordingly, special techniques are required, whereby large blocks of time-series data are manipulated concurrently, rather than as individual data elements (Unal, 1986).

Both SWMM and HSP-F are hydrological models that feature their own internal time-series management functions and utilities. Before describing these programs, the different types of hourly rainfall data formats that were tested in this study are illustrated. Figure 8.1 presents sample rainfall datafiles in these formats.

National Weather Service Hourly Rainfall Data (Fixed-Length Records)

In SWMM, this format (NWS Tape Deck 3240 or 3260) has been identified as IFORM = 0. This style features fixed-length records, where one precipitation entry is included per line. All NWS weather stations are given unique six-digit identification numbers. As shown in Figure 8.1, the station number (No. 080211) is included in character positions 4 to 9 in IFORM = 0 files. Rainfall dates and times are provided in character positions 18 to 34, including, from left to right, the year, month, day, hour and minute.

The time of rainfall (character positions 31 to 34) actually refers to the end of the interval. For example, 19:00 indicates an hourly period ending at 7 p.m. For most other file formats, the time of rain implies the start of an interval.

IFORM = 0 files include a single hourly rainfall depth on each line, and only for those hours when rainfall occurred, with the exception of null values that occur on the first hour of each month. All NWS formats described here report rainfall depths in units of 0.01 inches. For example, the first line of the IFORM = 0 file in Figure 8.1 indicates that 0.02 inches of rain fell in the hour that ended at 7 p.m. on April 27, 1964.

Special data quality codes are reported in the 41st character position of each record, and represent values that are missing, incomplete, or are accumulated totals over a specified time period. No such codes are shown in the sample file in Figure 8.1, however such codes are always present in long-term records.

National Weather Service Hourly Rainfall Data (Variable-Length Records)

This IFORM = 1 format is similar to the IFORM = 0 style, except that variable-length records are provided, where multiple precipitation entries are

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National Weather Service Format, IFORM = 0
HPD08021100HPCPHI19640400270011900 00002   &&&
HPD08021100HPCPHI19640400270012000 00004   &&&
HPD08021100HPCPHI19640400270012100 00003   &&&
HPD08021100HPCPHI19640400270012200 00001   &&&

National Weather Service Format, IFORM = 1
HPD12425900HPCPHI19870400150031300000002 1600000005 25000000007
HPD12425900HPCPHI19870400160041100000003 1200000003 15000000001 25000000007
HPD12425900HPCPHI19870400270030400000010 0500000012 25000000022
HPD12425900HPCPHI19870500010020100000000 25000000000

Pre-1980 National Weather Service Format, IFORM = 2
2154356001011- - - - - - - - - - - - -
21543560010120020020030030020030020050030020030010031 02
2154356001021002001001002004002002002001- - -
2154356001022- - - - - - - - - - - - 0017 04

User-Defined Format, IFORM = 3
61533009      70 06 26 15 00 0013
61533009      70 06 26 16 00 0006
61533009      70 06 26 17 00 0004
61533009      70 06 26 18 00 0017

Pre-1980 Atmospheric Environment Service Format, IFORM = 5
61533009700513123 0 0 0 0 0 0 0 0 0 0 0 23 5 0 0 5 0 3 3 0 0 0 0 0 0 0
61533009700514123 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
61533009700515123 3 3 13 25 41 25 18 33 8 0 0 0 0 0 0 0 0 0 0 0 0 0 15 10 0
61533009700516123 0 0 0 0 0 0 0 3 0 5 3 0 0 13 36 0 3 0 0 0 0 0 0 0 0 0

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Figure 8.1 Sample Hourly Rainfall Datafiles.

included on each line of the file. Station numbers and rainfall dates are in the same character positions as IFORM = 0 files.

The number of data values for each line is given in character positions 28 to 30 (this is always “001” in IFORM = 0 files). Each data value consists of 11 characters: comprising the time of rainfall (4 digits, which also refers to the end of the interval, same as with IFORM = 0), the rainfall depth (6 digits), and the last character includes a special code, if necessary. These values are repeated for each hour of rain in the day. The final value begins with the time “25:00”, and indicates the daily rainfall total. For example, the first line of the IFORM = 1 file indicates that 0.02 inches of rain fell in the hour that ended at 1 p.m., and 0.05 inches of rain fell in the hour that ended at 4 p.m. on April 15, 1987, a daily total of 0.07 inches.

Pre-1980 National Weather Service Hourly Rainfall Data

This is a discontinued NWS format (NWS Card Deck 488, and IFORM = 2 in SWMM), though many rainfall records are still available in this style. Each line begins with the six-digit station number, followed by the date and time in character positions 7 to 12 (two digits each for the year, month, and day).

Twelve hourly rainfall depths are given on each line: two lines describe each day, and the 13th character position indicates whether the twelve values are in the a.m. (=1) or p.m. (=2). Records are given only for those days when rainfall occurred, with the exception of rainless days that occur on the first day of a month. Hourly rainfall values are given in sets of three characters, and a dash is used in place of any null values. The daily rainfall total follows the hourly values, and monthly accumulation totals are similarly listed beside the daily total, but only on the last day of each month. The final column of numbers in the file indicates the next day for which hourly rainfall values are given. The example in Figure 8.1 indicates that no rain fell between midnight and noon, and 0.31 inches fell in the hours between 12:00 and 24:00 on January 1, 1960. The final number on the second line, “02”, indicates that the next rainfall record occurs on January 2.

User-Defined Hourly Rainfall Data

The format shown in Figure 8.1 is the standard style used by the time-series management module developed as part of this study, referred to as IFORM = 3 in SWMM. Each record begins with the station number, followed by the two-digit year, month, day, hour, and minute. The final four digits represent the rainfall depth in units of 0.01 inches. The example in Figure 8.1 indicates that 0.13 inches fell on June 26, 1970 between 15:00 and 16:00.

Pre-1980 Canadian Atmospheric Environment Service Hourly Rainfall Data

This is a discontinued AES format (IFORM = 5, in SWMM). Each line begins with the eight-digit station number, followed by the date and time in character positions 9 to 14 (two digits each for the year, month, and day). The

code “123” in character positions 15 to 17, indicates AES hourly rainfall, other codes are used to represent other meteorological time-series data..

Twenty-four hourly rainfall depths are given on each line, in sets of four digits. All days of record are included regardless of whether it rained or not. AES rainfall depths are measured in units of 0.1 millimetres. The example in Figure 8.1 indicates that 2.3 mm of rain fell on May 13, 1970 between 10:00 and 11:00.

It should be noted that version 4.30 of SWMM recognizes the old AES format. Current AES formats represent hourly rainfall in sets of seven digits (a leading digit for the sign, five digits for the depth, and a trailing flag character used to indicate estimated, missing, or snowfall-adjusted values). Additionally, AES station identification numbers are seven digits, not eight, as is interpreted by the RAIN module (the eighth digit actually describes the century, where “973” denotes the year 1973). Users should be aware that, although new AES format files can be read by SWMM 4.30, no warning is given that the data has been improperly processed.

8.3.2 Time-Series Management In Existing Hydrology Models

For this study, two popular continuous modeling programs were selected: the Storm Water Management Model (SWMM), and the Hydrological Simulation Program - FORTRAN (HSP-F). Both models feature extensive support and documentation; established user groups, regular workshops, and conferences; non-proprietary software and available source code. Each program specializes in a different aspect of urban drainage system modeling: HSP-F is better than SWMM for simulating pollutant transport and shallow groundwater flows, and SWMM is better than HSP-F for simulating the hydraulics of municipal infrastructure systems.

Both SWMM and HSP-F feature their own internal time-series management functions and utilities, and these are briefly described below.

SWMM

Communication between SWMM modules is accomplished through binary interface files. Interface files begin with a block of header information, followed by flow or pollutant time-series data for every timestep at each location of interest (Roesner et al., 1989).

In addition to the computational modules of SWMM (RUNOFF, TRANSPORT, EXTRAN, and STORAGE), there are several time-series management modules (Huber and Dickinson, 1988):

- **RAIN.** This module is used for processing precipitation datasets. It is able to read a variety of file formats, and create an interface file that can be used by RUNOFF.

- TEMP. Similar to RAIN, this module is used for processing air temperature datasets. Use of TEMP is required for simulating snowmelt.
- STATS. This module is used for calculating various time-series data statistics. Pre-defined statistical functions have been provided for analyzing rainfall, simulated or observed streamflows and water quality parameters.
- COMBINE is used for editing, collating, combining or otherwise manipulating SWMM interface files.

In this study, only the RAIN and STATS modules of SWMM were used, and only hourly rainfall datafiles were tested, although SWMM is able to handle continuous rainfall time-series with other timesteps.

HSP-F

Compared to SWMM, HSP-F provides superior time-series data management facilities. Time-series data used by HSP-F can reside in four types of storage:

- Watershed Data Management (WDM) File. This is the principal storage facility for time-series data. WDM files were developed for the ANNIE system, which is described later in this section.
- Time-Series Store. This was the original time-series storage available to HSP-F users. Like WDM files, the Time-Series Store is a large, random-access file.
- Sequential Files. These are ASCII text files (non-binary, unlike WDM or Time-Series Store files). The “PLTGEN” operation of HSP-F generates an ASCII text file (or “flat file”), and the “MUTSIN” operation reads in these ASCII flat files. Examples include rainfall datafiles available from the National Weather Service, as shown in Figure 8.1.
- Internal Scratch Pad. Often, time-series data are passed between HSP-F operations using an internal scratch pad, which basically acts as a large time-series data buffer (Bicknell et al., 1993).

HSP-F has a number of time-series management modules, enabling the user to copy, transform, plot, or tabulate time-series; import or export sequential files; and perform duration analyses.

Data management utilities in HSP-F are presently being modified. The most notable change will be the replacement of the Time-Series Store with both the ANNIE/WDM system from the USGS (Bicknell et al., 1993), and the HECDSS system from the USACE (Lumb, 1995).

8.3.3 External Time-Series Management Systems

The data processing techniques employed by SWMM and HSP-F have been found to be inefficient for long-term, continuous modeling (Unal, 1986). Furthermore, modeling for aquatic habitat inference often requires the application of several different programs, for example, linking a surface water hydrology model with a receiving channel model. Incompatible file formats and data structures often hinder efforts to merge hydrology models. Because of this, it becomes increasingly important to use external time-series management systems that are independent of the hydrology models (Lumb et al., 1990).

The two most widely-used systems developed specifically for managing hydrological time-series data are ANNIE and HECDSS.

ANNIE

ANNIE is a non-proprietary computer program from the US Geological Survey, and is used for performing interactive hydrological analyses and data management functions. Development began in the mid-1980s, and was essentially aimed at replacing the internal data manager of HSP-F.

Hydrological data are stored in standard Watershed Data Management (WDM) files. Time-series data are arranged into groups called datasets, and each dataset is identified by a number of attributes. WDM files may contain up to 32,000 datasets and timesteps can vary from one second to one year. Datasets may be compressed, if desired, and individual records may be tagged with a data quality flag in order to highlight assumed, missing, or suspect data. Files as large as 8000 megabytes can be managed with ANNIE, although the actual maximum size is determined by physical device and system limitations.

WDM files allow a variety of modeling programs to interact via a common input/output file handling interface. In this way, different data types and temporal resolutions can be managed and processed in a common database environment. Disk storage space for the WDM file is dynamically allocated as needed; datasets can be added, deleted, or modified without restructuring the file.

ANNIE began as a single program, but has since grown into a number of utility programs which provide the user with an expanding library of programming subroutines for building custom applications (Flynn et al., 1995). ANNIE comes equipped with a user-interface, which is invoked with each program application, consisting of various character-based windows that bear context-sensitive function commands and options, as well as assistance and instruction screens.

The complete ANNIE package consists of three main modules (ANNIE, IOWDM, and SWSTAT); the latest version (Version 2, June 1994) is available for personal computers from the Office of Surface Water, Water Resources Division of the USGS. The ANNIE module is the central component, providing data management functions including the ability to create, modify, or manage

time-series data and WDM files; display selected time-series, or any subsets of this data in either list or table format; produce time plots, scatter plots, probability and frequency-duration plots.

The IOWDM module allows users to create new WDM files, or to append datasets to existing WDM files. IOWDM is able to import both WATSTORE and HSP-F files, as well as user-defined file formats. Statistical options from previous versions of ANNIE were recently incorporated into a stand-alone program called SWSTAT. This program is used for statistical analyses, including frequency duration (trend) analysis, error analysis, and fitting probability distributions.

Figure 8.2 depicts an ANNIE import file in which hourly rainfall data for Port Arthur, TX is represented. This sequential ASCII file format is used to import datasets directly into WDM files. Users also have the option of using HSP-F or the IOWDM module to import datasets. The first 23 lines of this file include

```

DATE
WDMSFL
SYSTEM
COMMENT
  Contents of Dataset No. 41 in "TEXAS.WDM", 27-Jul-95, MAG.
END COMMENT
DSN          41      TYPE TIME   NDN   1   NUP   1   NSA  35   NSP  70   NDP 150
LABEL
  TCODE      2
  TGROUP     6
  TSFORM     1
  COMPG      1
  VBTIME     1
  TSBYR      1947
  TSSTEP     60
  PARMCD     45
  STATCD     6
  TSFILL     -99999.0
  STAID      417174
  TSTYPE     PRCP
  STANAM     Hourly Rainfall Data: Port Arthur, TX (2)
END LABEL
DATA          STARTS: 1947 11 30 24 0 0 0 ENDS: 1992 4 29 24 0 0
  1947 11 30 24 0 0 3 1 0 175 1 0.0000
  1947 12 8 7 0 0 3 1 0 2 1 1.0000E-02
  1947 12 8 9 0 0 3 1 0 2 0 0.0000 0.3000
  1947 12 8 11 0 0 3 1 0 4 1 0.0000
  1947 12 8 15 0 0 3 1 0 2 0 3.0000E-02 5.0000E-02
  1947 12 8 17 0 0 3 1 0 15 1 0.0000
  1947 12 9 8 0 0 3 1 0 8 0 1.0000E-02 8.0000E-02
  2.0000E-02 0.2100 0.1000 1.0000E-02 0.0000 1.0000E-02
  1947 12 9 16 0 0 3 1 0 2 1 0.0000
(interpolating records deleted)
  1992 4 25 7 0 0 3 1 0 94 1 0.0000
  1992 4 29 5 0 0 3 1 0 12 0 3.0000E-02 0.0000
  0.3400 6.0000E-02 2.0000E-02 3.0000E-02 2.0000E-02 8.0000E-02
  0.0000 0.2700 0.0000 6.0000E-02
  1992 4 29 17 0 0 3 1 0 7 1 0.0000
END DATA
END DSN

```

Figure 8.2 Sample ANNIE import file.

header information; the line that begins with “DSN” (line 7) defines the unique dataset number (No. 41 in this case) and gives an assortment of pointers that are used to locate this dataset in the binary WDM file. Various parameter labels are given in lines 9 to 21 (described in detail by Flynn et al., 1995).

Time-series data are represented in a novel manner. The first line of time-series data (line 24), begins with the date and time stamp (“11 30 24” indicates the 24th hour on the 30th day of the 11th month, which, in ANNIE, describes midnight on December 1st). The “3 1” grouping identifies an hourly timestep.

By default, precipitation time-series are measured in inches, and data are represented by the number of repeating or unique values. For example, the “175 1 0.0000” grouping on the first line of time-series data declares 175 consecutive null hourly rainfall depths; the “2 1 1.0000E-02” grouping on the second line means that two consecutive hourly rainfall depths of 0.01 inches have occurred; and the “2 0 0.0000 0.3000” grouping on the third line of time-series data indicates two unique data values, zero and 0.3 inches respectively. Data values between December 9, 1947 and April 25, 1992 are not shown in Figure 8.2.

ANNIE also exports sequential files according to the import file format. Data are written independently of the time-series type, that is, precipitation and streamflow files have the same format, only the measurement units and label parameters differ.

Figure 8.3 shows a variety of output files that were generated by ANNIE and SWSTAT modules. The first table gives a simple summary of the WDM file including: the unique dataset number assigned to the datafile, the period of record, a geographic location identifier, and the NWS station identification number. The next table in Figure 8.3 shows a summary of daily rainfall depths for one of the years of record. Hourly data was accumulated into daily totals, and simple monthly statistics were calculated by ANNIE. The final table in Figure 8.3 shows simple statistics for the dataset, including the smallest, largest, average, standard deviation, and total count of hourly rainfall depths. These statistics match those computed by the SWSTAT module of SWMM: the largest hourly rainfall depth was 4.57 inches, and the mean (0.00616781 inches, although only three decimal places are given in the output file) multiplied by the number of data values in the dataset gives a total rainfall depth of 2,401.3 inches.

HECDSS

The Hydrologic Engineering Centre (HEC, of the US Army Corps of Engineers) has developed a Data Storage System (HECDSS) for linking data with watershed modeling applications. Despite its development on the opposite side of the continent, HECDSS is very similar to the ANNIE system. Begun in the early 1980s, this system was designed as a tool to manage the storage and retrieval of hydrological and meteorological time-series data.

Like ANNIE, HECDSS is non-proprietary and written in FORTRAN. It has primarily been used on UNIX-based computer systems, although DOS

versions are becoming popular among users. Datasets are stored in records, identified by a unique name, called the pathname. HECDSS performs its searches based on this pathname reference, which includes the project name, station identification, time-series type, starting date, timestep, and an additional user-defined descriptor (US Army Corps of Engineers, 1990). Similar to WDM files, time-series records begin with a header array, describing general information about the time-series data.

HECDSS maintains a library of subroutines that enable various HEC programs to be interfaced with federal databases. Nearly two dozen utility programs and user-interfaces are available, some of these are described briefly below (US Army Corps of Engineers, 1990):

- DSSUTL is a general utility program that allows users to manipulate or edit data in HECDSS files. Like ANNIE, datasets may be exported or imported with sequential ASCII text files. Records may be compressed, and a summary table of attributes can easily be generated.
- DISPLAY enables users to graphically display or tabulate time-series data. Users can enlarge or reduce plots, and edit data directly on-screen.
- DSSMATH provides utilities for mathematically manipulating time-series data, or for computing statistics. This is similar to the “GENERATE” option of ANNIE.
- There are many data entry programs providing utilities that can enter regular or irregular timestep data; daily or hourly meteorological data in National Weather Service formats; daily streamflow data from WATSTORE; and Standard Hydro-meteorological Exchange Format (SHEF) files.

8.4 Design and Testing of a Time-Series Manager

In this section, the design and development of a graphical user-interface is presented, offering an easy-to-use tool for managing and applying long-term data for urban stormwater management modeling. This time-series manager is referred to as CASCCADE (Co-evolving Assistant Software for Changing Computational And Data Environments), an acronym that recognizes the co-evolving nature of computer modeling, data acquisition and management.

8.4.1 Time-Series Manager (CASCCADE) Utilities

CASCCADE was written for this study as a standalone program, intended as an easy-to-use, graphical interface that links time-series data management

Summary Table of Data Attributes
 Attributes of ANNIE file "TEXAS.WDM", 27-Jul-95, MAG.

DSN	PERIOD OF RECORD	STANAM	STAID
	BEGIN	END	

41	1947/11/30 1992/4/29	Hourly Rainfall Data: Port Arthur, TX (2)	417174

Daily Summary Table

Station number 417174
 Table of daily values for the 12-month period ending December 1949
 Rainfall, accumulated (inches)
 Hourly Rainfall Data: Port Arthur, TX (2)

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
---	---	---	---	---	---	---	---	---	---	---	---	---
1	0.00	0.00	0.32	0.27	0.00	0.00	0.02	0.00	0.56	0.00	0.00	0.00
2	1.02	0.04	0.17	0.14	0.00	0.00	0.03	0.00	0.00	1.11	0.00	0.00
3	0.02	0.04	0.00	0.00	0.00	0.00	0.03	0.05	0.00	6.89	0.00	2.48
4	0.11	0.44	0.00	0.46	0.00	0.00	1.94	0.05	0.00	2.15	0.00	0.00
5	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00
6	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	1.60	0.00	0.00
8	0.00	1.20	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.69	0.00	0.00
9	0.00	0.31	0.27	0.00	0.00	1.38	0.02	0.00	0.34	0.00	0.00	0.53
10	0.00	0.00	0.00	1.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
11	0.00	0.00	0.00	0.00	0.00	1.31	0.81	0.94	0.20	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.83	0.09	0.86	0.38
13	0.00	0.00	3.08	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.50
14	0.00	0.00	1.63	0.00	0.00	0.13	0.22	0.00	0.00	0.01	0.00	0.62
15	0.01	0.25	0.00	0.00	0.00	0.34	0.24	0.00	0.00	0.14	0.00	0.01
16	1.14	0.00	0.00	0.00	0.07	0.00	1.73	0.00	0.43	0.00	0.00	0.00

Figure 8.3 Sample ANNIE/SWSTAT output files (continued below).

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
---	----	----	----	----	----	----	----	----	----	----	----	----
17	0.08	0.31	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	4.01
18	0.73	1.15	0.04	0.00	0.00	0.06	0.04	0.00	0.43	0.00	0.00	0.00
19	0.00	0.00	0.00	0.12	0.00	0.02	0.04	0.00	0.19	0.17	0.00	0.00
20	0.00	0.25	0.00	1.64	0.00	0.00	0.27	0.08	0.02	0.30	0.00	0.00
21	1.10	0.00	1.64	0.04	0.00	0.00	0.45	0.00	0.03	0.00	0.00	0.03
22	0.01	1.33	0.00	0.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.02	0.00	0.00	0.46	0.00	0.32	0.09	0.00	0.00	0.01	0.00	0.00
24	0.00	0.09	0.00	0.00	0.56	0.12	1.23	0.00	0.00	0.71	0.00	0.00
25	0.01	2.11	0.00	0.10	0.00	0.00	0.96	0.00	0.00	0.05	0.00	0.00
26	0.02	0.10	1.08	0.00	0.00	0.76	0.96	1.12	0.00	0.00	0.00	0.01
27	0.22	0.00	1.33	1.01	0.68	0.00	0.40	0.00	0.00	0.00	0.00	0.66
28	0.00	0.00	0.00	0.07	0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00
29	0.01		0.56	0.10	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	0.39		0.09	0.00	0.00	0.00	0.00	0.30	0.00	0.50	0.00	0.00
31	0.00		0.00		0.00		0.65	0.00		0.19		0.07
	----	----	----	----	----	----	----	----	----	----	----	----
Total	4.89	7.82	10.21	6.72	1.36	4.88	10.58	3.37	3.03	14.63	0.86	9.40
Mean	0.16	0.28	0.33	0.22	0.04	0.16	0.34	0.11	0.10	0.47	0.03	0.30
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.14	2.11	3.08	1.64	0.68	1.38	1.94	1.12	0.83	6.89	0.86	4.01

Basic Statistics Table
Computation of Basic statistics.

DATA- SET	NUMBER		STANDARD		NUMBER		NON-ZERO
NUMBER	MINIMUM	MAXIMUM	MEAN	DEVIATION	OF DATA	VALUES	RETURNS
					USED	UNUSED	CODE NO.
---	-----	-----	-----	-----	-----	-----	-----
41	0.000	4.570	0.006	0.058	389328	0	

Figure 8.3 (continued) Sample ANNIE/SWSTAT output files.

utilities to a continuous hydrological model. Visual Basic was selected as the programming language for CASCCADE, due to its ease of use and ability in developing Microsoft Windows applications.

By implementing standardized data formats, the transfer of data between modeling applications is not constrained by the limitations imposed by hydrology models. In this way, a variety of continuous hydrological models other than SWMM can be added to the interface. It is further anticipated that, by essentially removing the internal data management utilities of modeling programs, model learning times will be reduced and practitioners more likely to apply a variety of specialized models in their analysis. Ideally, stormwater modelers should be provided with more time to conduct sensitivity, calibration, error and uncertainty analyses.

CASCCADE development proceeded with the strict aim of automatically processing file transactions between SWMM and ANNIE in a Windows environment. As a result, CASCCADE provides an interface that integrates the time-series management functions of ANNIE with the continuous modeling applications of SWMM. Development was intended to automate data management utilities for the SWMM user, as opposed to adding ANNIE file handlers directly in the SWMM source code. By automating file management between ANNIE and SWMM, compatibility can be maintained throughout enhancements and new releases of the two programs.

The utilities of CASCCADE are classified into three components: file retrieval, file archival, and data analysis operations.

File Retrieval Operations

Hourly rainfall data are the only time-series utilized by CASCCADE, although other resolutions and even irregular timesteps can be implemented. Before proceeding with other time-series manager operations, the user must select rainfall data. Upon selecting the "Retrieve From ANNIE" menu option, the user is prompted for the ANNIE database file name, dataset number to be exported, and the name for which the export file will be saved. CASCCADE then starts the ANNIE program and writes a macro file that automatically extracts the selected ANNIE dataset into a sequential export file. Experienced users may also use ANNIE on its own, if desired.

Figure 8.4 shows the form that is displayed immediately after CASCCADE has extracted the export file from ANNIE. CASCCADE first reads the export file ("PORTART.EXP"), displaying descriptive information including the station identification number (No. 417174), station name ("Hourly Rainfall Data: pa2", representing the datafile for Port Arthur, TX that has been illustrated in Figures 8.2 and 8.3), and the starting and ending dates (four-digit year followed by the month, day, and hour. Note: ANNIE treats midnight as the 24th hour of the previous day).

Convert Rain Data To SWMM Format

Export File

File Name: pa2 EXP

File Format: ANNIE Export File Start Date: 1947 11 30 24

Station ID: 417174 End Date: 1992 04 29 24

Station Name: Hourly Rainfall Data: pa2

SWMM Rainfall Datafile

Enter File Name: Note: *IF3 file extension will be added.

OK Cancel

Figure 8.4 ANNIE Export option in CASCADE.

The lower part of the form prompts the user for the file name into which the ANNIE export file will be converted into SWMM format. An extension (.IF3) is automatically added to the file name, denoting a rainfall datafile with the IFORM =3 format. After the data has been converted to SWMM format, CASCADE informs the user of the conversion, lists the name of the file that was converted, starting and ending dates of the rain data, and reports the total depth of rain for the entire period of record.

CD-ROM data archives are often sold with their own accessing software, and so these were not considered in the development of this interface. Direct retrieval of data archives from Internet sources, especially through anonymous FTP procedures, was originally proposed to be included in this research, but postponed for a number of reasons. Even though a number of commercial and shareware Internet tools are available to Visual Basic programmers, it was felt that an Internet access utility would merely be a novelty at this time. Such Internet tools for Visual Basic were developed for a version of Windows which does not support Internet protocols. Windows95 will feature a true underlying software stack known as Transmission Control Protocol/Internet Protocol (TCP/IP). Therefore, it was felt that a time-series manager with an Internet access utility will become obsolete immediately upon release of Windows95. (*written in August 1995 - editor's note*)

It is worth re-emphasizing that our survey results were probably biased in favour of Internet, as a result of artificially-stimulated interest by the media. The Internet is becoming an indispensable tool for locating information and finding addresses of data archives and, in this regard, it is well-suited as a research or help utility for meta-data (data that describes a larger dataset), rather than as a source of hydrological time-series data. Furthermore, liability issues are very tangible in stormwater designs that involve risk to property or human life. Quality assurance of modeling data is a key issue, and it was felt that the Internet is not yet an appropriate medium for such data. Transmission of stormwater modeling data through the Internet may prove to be advantageous in real-time control systems, where time-series data needs to be managed during a rainfall event.

In spite of the survey results, it is speculated that a more attractive alternative for storing and retrieving time-series data is offered by CD-ROM. CD-ROM offers cost-effective and personal access to information of interest to stormwater modelers, where quality control can be guaranteed by the data observer.

File Archival Operations

With CASCCADE, hourly rainfall datafiles can be archived in an ANNIE database file once they are in a recognizable SWMM format. Upon selecting the "Archive To ANNIE" menu option, CASCCADE displays all SWMM format rainfall datafiles on the user's computer (grouped by file extension: .IF0 files for IFORM = 0 formats, .IF1, .IF2, .IF3, and .IF5 file formats).

Figure 8.5 shows the form that is displayed after a rain datafile has been selected. CASCCADE reads and displays file information including the directory and name of the file ("C:\MGTHESIS\NWSD.IF1"), the format (NWS Variable-Length Records, or IFORM = 1), the station identification number (No. 417174) and the period of record. The lower portion of the form is used to prompt the user for an ANNIE database file name, a geographic location for the rainfall measurement station (which is stored in ANNIE for future reference), and a dataset number that can either be assigned by default or set by the user, if desired.

Before datafiles are converted into ANNIE import files, CASCCADE first converts them from their original IFORM format into a standard, user-defined format (IFORM = 3). The file name and dataset number are reported before ANNIE import files are saved.

After saving each import file, CASCCADE asks the user if another datafile is to be imported. If the user chooses yes, the above steps are repeated. Otherwise, CASCCADE prompts the user for an ANNIE database file name, initiates the ANNIE program, and writes a macro file that will automatically import all of the selected datafiles into a single ANNIE database file and create a catalogue file that describes dataset attributes.

Convert Rain Data To ANNIE Import Format

Source File

File Name: C:\MGTHESIS\NWSD\IF1

File Format: NWS (Variable)Start Date: 1947 12 01 00

Station ID: 417174End Date: 1992 04 23 16

ANNIE Archive

Enter File Name: NWSD

Station Location: Port Arthur, TX

☒ Change ANNIE Dataset Number (DSN) Enter New DSN: 41

☒ Delete Intermediate Files (*.if3) When Completed

☒ Delete ANNIE Import Files (*.imp) When Completed

Note: Enter seven character filename. File extensions will be added.

Note: Enter geographic location of rain measurements.

OK

Cancel

Figure 8.5 ANNIE Import option in CASCADE.

Data Analysis Operations

When the user selects the “Analyze Storm Event Statistics” menu option, CASCCADE again displays all SWMM-format rainfall datafiles on the user’s computer. Figure 8.6 shows the form that is displayed after a rain datafile has been selected. CASCCADE reads and displays file information in the top of the form, and recommends default parameters for a SWMM input datafile in the bottom of the form, including file name, comment lines, minimum interevent time (the duration of time which distinguishes discrete rainfall events in a continuous time-series), storm event threshold (the minimum depth of hourly rain for which events will be analyzed), and the number of storm events to be ranked in descending order of depth. SWMM interface file names are also specified in this form.

CASCCADE then writes the input datafile for an application of the RAIN and STATS module of SWMM. Before initiating the SWMM program, CASCCADE informs the user of the input file name and specifies the SWMM output file name to be used.

Create SWMM Input Datafile

Source File

File Name: C:\MGTHESIS\NWSD.IF1

File Format: NWS (Variable) Start Date: 1947 12 01 00

Station ID: 417174 End Date: 1992 04 29 16

SWMM Input Datafile

Enter File Name: **NWSD** Note: *.DAT extension will be added.

Enter First Comment Line: **Hourly Rainfall Data For Port Arthur, TX**

Second Comment Line: **Created on August 23, 1995**

Minimum Interevent Time: **2** (hours)

Storm Event Threshold: **.25** (inches)

Ranked Events Desired: **18**

Enter File Name For Rainfall Time-Series Interface File: **RAIND1**
NOTE: *.INT extension will be added.

Enter File Name For Statistical Interface File: **STATD1**
NOTE: *.INT extension will be added.

OK **Cancel**

Figure 8.6 Storm Event Analysis option in CASCADE.

Finally, CASCCADE asks if the user desires a storm event summary . If yes, CASCCADE reads the SWMM output file and creates a summary table that includes descriptive station information, the total depth of rain, and the top ranked storm events, according to the parameters entered in the bottom part of the form in Figure 8.6. Figure 8.7 shows the storm event summary table created by CASCCADE, in which storm events (as computed by the STATS module of SWMM) are ranked in order of rainfall depth. The first two lines are comments entered by the user, including the date that the summary file was created. Figure 8.7 also echoes the station ID number, the user's choice of minimum interevent time, and the threshold rainfall depth. Total rainfall depth is listed, as well as the number of storm events (above the threshold value) that were analyzed.

Hourly Rainfall Data For Port Arthur, TX
Created on September 06, 1995

Storm Event Summary For Station 417174
Minimum Intervent Time : 0 hours
Rainfall Depth Threshold Value : .5 inches
Total depth of rainfall : 2401.30 inches
Number of storm events analyzed : 1070.

Rank	Time of Occurrence		Value
	(Year/MM/DD/Hour)		(inches)
1	1985 08 20	15:00	4.57
2	1968 04 08	23:00	4.22
3	1960 08 14	5:00	3.77
4	1966 08 11	7:00	3.30
5	1973 04 17	5:00	3.06
6	1969 07 15	16:00	2.73
7	1957 09 22	14:00	2.69
8	1983 08 06	16:00	2.66
9	1983 05 20	14:00	2.63
10	1961 10 01	14:00	2.54
11	1959 07 09	18:00	2.54
12	1987 09 12	13:00	2.53
13	1980 09 05	22:00	2.53
14	1976 05 31	10:00	2.50
15	1980 09 05	21:00	2.42
16	1958 07 18	15:00	2.39
17	1985 05 08	13:00	2.35
18	1969 12 06	3:00	2.32

Figure 8.7 Storm event statistics summary file.

8.4.2 Performance Assessment

The performance of CASCCADE was assessed using a variety of hourly rainfall datafiles: four files from southern US, two from central US, and two from eastern Canada, as shown in Figure 8.8. These files use a variety of popular formats: one file for each of the NWS Fixed-Length and Old NWS formats, four files in the NWS Variable-Length format, and two files in the Old AES format. Additionally, a wide range in the period of record is featured: from less than 2 years to more than 44 years, totaling just over 140 years for the eight datafiles.

Although not directly output by CASCCADE, statistics computed by the SWSTAT module of ANNIE and by the STATS module of SWMM, matched for all eight datafiles. This is the first time, to the writers' knowledge, that such a direct comparison has been made.

The top-ranked events for each station were identical, and the total rainfall depths were computed precisely (to the nearest 0.01 inch) by both SWSTAT and STATS for all six NWS weather stations. The totals for the two AES stations differed slightly (the SWSTAT total was 1.0% higher than the actual total for the

unknown station, and 0.3% higher for the Hamilton station) due to both round-off error and the loss of one significant digit when converting from units of 0.1 millimetres to 0.01 inches.

Dataset Number	Type Of Hourly Rainfall File	Location	Station ID	Period Of Record		
				Start Date	End Date	Total (yr)
11	NWS, IFORM = 0	Apalachicola, FL	080211	27-Apr-64	5-Jun-76	12.1
21	NWS, IFORM = 1	Indianapolis, IN	124259	1-Jan-87	28-Aug-88	1.7
31	NWS, IFORM = 1	Port Arthur, TX	417173	6-Jan-40	25-Feb-53	13.1
41	NWS, IFORM = 1	Port Arthur, TX	417174	1-Dec-47	29-Apr-92	44.4
51	NWS, IFORM = 1	Jacksonville, FL	084358	1-Aug-48	30-Dec-92	44.4
61	Old NWS, IFORM = 2	Minneapolis, MN	215435	1-Jan-60	28-Dec-61	2.0
71	Old AES, IFORM = 5	(unknown), ON	61060009	1-Nov-78	31-Dec-81	3.2
81	Old AES, IFORM = 5	Hamilton, ON	61533009	1-May-70	31-Jul-89	19.3
Total Or Average						140.1

Figure 8.8 Rainfall data files tested.

File Sizes

Figure 8.9 plots file size versus period of record for various files. Original NWS/AES rainfall datafile sizes are plotted, along with a “best fit” line that minimizes the sum of the square of differences. For the eight files, the best linear fit passes through the origin up to 600 kilobytes for the two 44 year datasets. File sizes of ANNIE database files are also plotted in Figure 8.9, representing the same NWS/AES data in binary WDM format. The best fit line does not pass through the origin, since ANNIE assigns datasets in multiple blocks of 40 kilobytes.

ANNIE database files showed some variability in the amount of data stored on an annual basis; the original datafiles showed considerably more variability, reflecting the wide variety in data formats.

A comparison of file sizes confirms that, although the original datafiles offer a visually appealing format (ASCII text), they are not efficient in terms of storage space. Furthermore, the size of NWS/AES datafiles precludes efficient transmission across the Internet. Rainfall data are more effectively stored as binary files than as ASCII text.

It was found that, on average, ANNIE database files were 31% the size of their original format. In comparison, binary SWMM interface files were, on average, 55% the size of their original format. This finding provides justification for implementing ANNIE in CASCADE, rather than using the internal data management system in SWMM.

By extrapolating the best fit lines in Figure 8.9 to a 75 year hourly datafile, an indication of CASCADE’s performance over three-generation stormwater

Figure 8.9 File size comparison.

modeling can be made. The original 75 year datafile would occupy over one megabyte of disk space, but could be stored in a binary ANNIE database file 0.28 megabytes in size. At this rate, a single CD-ROM could store between 150,000 and 200,000 years of hourly rainfall data. Recognizing the high variability in Internet transmission rates, it would take about two minutes to transmit this ANNIE file during a heavy demand period (for example, when average transmission rates drop to only 2.5 kilobytes per second). In contrast, conventional data

retrieval methods, which include such tasks as submitting a request to the archiving agency, and then waiting to receive the diskettes by mail or courier, could take at least two days, probably about one week.

Survey results suggest that stormwater modelers would be willing to retrieve modeling data through the Internet during low demand periods, perhaps using an overnight batch run. During an overnight (twelve-hour) period, between 150,000 and 200,000 years of hourly rainfall data could be collected, assuming an average retrieval rate of 14.4 KB per second, which also happens to be the capacity of typical computer modems.

Processing Times

Elapsed processing times were measured on a 486 DX2 personal computer, operating at 33 MHz, with 8 MB of RAM. It was felt that this represents the lower bound of typical engineering design office computers; performance results will be better for newer computers. Processing times include the time that elapsed from the initial selection of the menu option until the task was completed. In addition to CPU time, the elapsed processing time includes the time for the user to react to various prompts and messages.

Figure 8.10 shows the processing time required to create archive files, that is, to read each hourly rainfall datafile and convert the data into an ANNIE import file format. The best fit line passes through the origin and a time of nearly 9 minutes for the two 44 year datasets. Also plotted is the time required to unarchive datasets, that is, to export each datafile from ANNIE and convert the data into a SWMM file format. The best fit line begins at two minutes and ends at a time of nearly 8 minutes for the largest files. The line does not pass through the origin, since the time to load ANNIE into memory is included. Processing times were presented this way, because CASCCADE is able to load multiple datafiles into a single ANNIE database at one time, but can only export one dataset from an ANNIE file at a time.

Not only does the time required to load DOS programs (such as ANNIE, SWMM, or HECDSS) into memory depend on the computer specifications, but it is also highly dependent on the FORTRAN compiler. To improve the performance of these programs in a Windows environment, the FORTRAN source code should be compiled as a dynamic-link library file, rather than as a DOS executable file. The USACE has already developed a working dynamic-link library version of HECDSS (Nicolini, 1995). No FORTRAN compilations were made as part of this present study.

The total time to import datafiles into ANNIE is the sum of the time it takes to generate the import files and the time it takes to load the import files into ANNIE. For all eight datafiles (140.1 years), it took an average of just under 32 minutes to import data into ANNIE, or 13.6 seconds per year of record. Exporting datafiles from ANNIE averaged just under 38 minutes, or about 16.2 seconds per year of record.

Figure 8.10 Processing time comparison.

By extrapolating these rates to a 75 year hourly datafile, it would take 17 minutes to archive the file, and only 12 minutes to unarchive. Conventional data archival times are not as easily estimated, and, most likely, rarely measured in practice. However, the automatic storage and retrieval of long-term rainfall data in minutes rather than days, ought to offer an attractive alternative. Because ANNIE treats all hydrological data as generic time-series, similar results are expected for other modeling data, such as observed and simulated streamflow, and pollutant concentrations.

8.5 Conclusions

Only long-term hydrological simulation can be used to address the long-term environmental impacts caused by nonpoint source pollution; event-based methods are both irrational and unethical for such considerations (James, 1994). The alleged unmanageability of long-term time-series data has often been cited as the primary motive for rejecting continuous modeling methods. Benefiting from recent technological advances in information exchange, computing speed, and data management methods, this study revealed the practicality of long-term simulation.

Many agencies collect and manage water resources throughout North America. However, there are no universal standards to ensure consistency in data format and content, nor are coordinated collection efforts prevalent. This means that existing databases may be overlooked or duplicated, which is unfortunate, since data collection programs often require great time and money commitments, and so the information collected is an important and valuable asset.

As data is transferred between computer applications, improved management techniques have been encouraged (Kittle et al., 1989; Lumb et al., 1990). Ideally, a solution would aim for an integrated, multi-media database with equal access available to all users. Information should be shared and promoted across disciplines, including government, universities, private industry, public interest groups, and any other interested individuals.

A survey of stormwater modelers was conducted to ascertain their continuous modeling needs. Practitioners generally agree that continuous modeling is necessary, contrary to numerous planning and design manuals that proclaim continuous modeling is neither desirable nor feasible for stormwater modeling. Furthermore, many favour software tools that aid in their data collection and modeling exercises.

Recognizing that a need exists “for a straightforward, consistent methodology for building interactive interfaces for available and developing environmental models and data bases” (Kittle et al., 1989), a graphical user interface, CASCCADE, was written in Visual Basic for the Windows operating system environment. CASCCADE automatically manages and processes time-series data for use with a continuous stormwater model.

Over 140 years of hourly rainfall data were used to test CASCCADE, and significant improvements in efficiency were demonstrated. In comparison to conventional efforts, it was shown that (a) 75 years of hourly time-series data can be collected, archived, and then unarchived in only half an hour rather than two days or more; (b) the Internet and CD-ROM offer very attractive alternatives to conventional transmission and storage media for digital data; and (c) that between 150,000 and 200,000 station-years of hourly rainfall data could be stored on a single CD-ROM, or transmitted via the Internet in only 12 hours during a low-demand period.

While data storage and retrieval are critical processes in the analysis of urban drainage system impacts upon the environment, the typical engineering design office is not capable of managing this data. Modeling for aquatic habitat often requires the application of several different programs (for example, linking a surface water hydrology model with a receiving channel model), each featuring unique data management utilities and file formats. This imposes difficulty on the modeler, who must contend with the transfer of data between applications. Either the modeler must become proficient in several different data management systems, or separate modeling tasks will be divided among several experts. Regardless of the outcome, it is likely that large datafiles will be inefficiently managed in this fashion.

It is essential that engineers promote cost-effective, computer-efficient techniques and strategies in their studies. In the past, the computational economy of hydrological simulation was based on fast computing speed. Applying models to larger drainage systems and for longer periods of time, a further constraint has been added: the computer's ability to manage large volumes of data. This means that the efficiency of long-term, continuous modeling should be measured in terms of optimizing data processing and transfer speed, as well as data storage space.

Although it was not within the scope of this study to develop novel or efficient computer programming techniques, the necessity and feasibility of linking time-series data management utilities with a variety of hydrological modeling applications was demonstrated. Further enhancements could be added that provide stormwater modelers with a flexible means for exchanging data, and accessing widely-distributed data sources and information systems that have been invisible to engineers to date.

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Appendix

Table 8.1 Directory Of Internet Services

Services listed are World-Wide Web home pages, unless noted otherwise.

Consortium For International Earth Science Information Network	
CIESIN, URL is http://www.ciesin.org	
Environment Canada	
Atmospheric Environment Service, URL is http://www.dow.on.doe.ca	
Environment Canada, URL is http://www.doe.ca	
Great Lakes Information Mgmt Resource, URL is http://www.cciw.ca/glimr/intro.html	
Great Lakes Information Network	
GLIN, URL is http://www.great-lakes.net:2200/0/glinhome.html	
National Centre for Atmospheric Research	
Meteorological Data Support Section, URL is http://www.ucar.edu/dss/index.html	
National Oceanic and Atmospheric Administration	
NOAA, URL is http://www.noaa.gov	
NCDC, URL is http://www.ncdc.noaa.gov	
OASIS, URL is http://www.ncdc.noaa.gov/oasis/oasis.html	
Universities Council on Water Resources	
Universities Water Information Network, URL is http://www.uwin.siu.edu/	
University of California, Davis	
WATER-ON-LINE Mailing List, Server is listproc@ucdavis.edu .	
University of Guelph	
SWMM-USERS Mailing List, Server is listserv@uoguelph.ca .	
US Army Corps of Engineers	
Hydrologic Engineering Centre, URL is http://www.wrc-hec.usace.army.mil/	
US Department of Agriculture	
National Agricultural Library, Water Quality Information Centre, URL is http://www.inform.umd.edu:8080/EdRes/Topic/AgrEnv/Water	
US Environmental Protection Agency	
USEPA, URL is http://www.epa.gov	
CEAM Anonymous FTP Server, URL is ftp://earth1.epa.gov	
US Geological Survey	
Water Resources Information, URL is http://h2o.usgs.gov	
NAWDEx, URL is http://h2o.usgs.gov/public/nawdex/nawdex.html	

Links to information sources for hydrology and related environmental sciences can be found at the following locations:

<http://www.us.net/adept/links.html>
<http://wwwdaac.msfc.nasa.gov>
<http://ingis.acn.purdue.edu:9999/wetnet.html>
<http://www.fsl.orst.edu/hydrology.html>
<http://etd.pnl.gov:2080/hydroweb.html>