Chapter 2

Integration of US Army Corps of Engineers' Time-Series Data Management System with Continuous SWMM Modeling.

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Of the computer applications currently widely used in civil engineering, hydrological modeling has been mostly restricted to discrete events. However, with improved affordability of powerful computing, long-term continuous modeling has now become much more attractive. At the same time, long-term urban impacts on water quality have also become an important design concern in recent years. Continuous simulation is known to be a fundamental and reliable method for modeling nonpoint source pollution and its long-term effects on aquatic habitat. In the past, the main argument against using continuous modeling has been the difficulty of managing large amounts of input and output data. A very large portion of this data is time-series (TS) in nature and requires special time series management (TSM) software. Different data formats and software also cause difficulties for continuous modeling of stormwater management. Our purpose in this effort is to provide code that mitigates these arguments against continuous modeling.

A survey of modelers was conducted to confirm the necessity and importance of developing easy-to-use software that assists long-term continuous modeling. A graphical user-interface called CASCADE2 was designed and developed to integrate the Hydrologic Engineering Center Data Storage System (HECDSS) with the Storm Water Management Model (SWMM). Our purpose at this stage is not to integrate HEC application programs with SWMM, but merely to facilitate the easy export and import of datasets from HECDSS to SWMM.

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CASCADE2 automatically manages and processes hourly and 15-minutely TS data for use with continuous SWMM. It allows the user to export or import any amount data from HECDSS by creating a dynamic macro, which overcomes the limitation in HECDSS of export or import of only monthly data. Storm-event statistics can also be computed by CASCADE2 automatically, and a summary file which includes station information, the total depth of rain, and the top ranked storm events is given at the end. Both SWMM and HECDSS program are run within CASCADE2, which thus acts like a shell, designed for application in typical, busy design offices.

A performance assessment of CASCADE2 in terms of computational speed and storage space is provided. A panel of professional engineers tested CASCADE2 and the results are summarized. Long-term TS data can now be collected, stored, and retrieved in minutes not days, as compared to conventional efforts.

2.1 Introduction

In this section, the result of survey of experts in stormwater management is presented: a literature review related to current data management systems is given; and the HECDSS data management system is introduced.

2.1.1 Survey of Experts in Stormwater Management

A survey of experts in stormwater management for research purposes is important and useful, because it helps identify current needs in urban stormwater management.

Eight survey questions were designed for the following purpose:

1. to obtain opinions on using continuous or event modeling in stormwater management;
2. to obtain a practical perspective on how many professionals are familiar with the existing TS data management systems and have real experience with the basic needs of linking models with these data management systems;
3. to ascertain the need for software tools for managing long-term TS data.

Copies of the questionnaire were distributed to 75 attendees at the workshops on the USEPA SWMM4 model with PCSWMM and other shells and the annual Toronto conference on Stormwater and Water Quality Management Modeling, February 19-23, 1996, Toronto, Canada. Attendees included private consultants, government representatives and education professionals, who were diversified in their experience and professional background, most of them having experience with computer modeling techniques.

Of these, 35 surveys were completed and returned. Three prominent categories were identified from the set of responses: environmental and water resources engineers (68%), professors and students (15%), and related professionals (29%). Related professionals include planners, software developers, and civil engineers.

The survey results showed that 60% of the respondents believed that continuous modeling is necessary in stormwater management. 100% of the respondents believed that a software tool for managing long-term TS data is needed. Also:

1. some stormwater modelers would prefer to use continuous modeling instead of event modeling if long-term TS data were easy to access;
2. the main difficulties when using continuous modeling are: obtaining relevant rainfall data, input and output files manipulation and storage, data collection and data entry, too many data formats which can't be accepted by SWMM, the high cost of calibration, and the time required;
3. sources of TS data include: Environment Canada, Atmospheric Environment Services (AES), National Weather Service (NWS), EARTHINFO, the National Oceanic and Atmospheric Administration (NOAA), and local governments; and
4. the two TS data management systems HECDSS and ANNIE are not well known by the stormwater management modelers.

2.1.2 Evolving Data Environment for Hydrology

Credible modeling requires reliable data. A computational hydrology work group often receives hydrological data from external data gathering agencies. Digital data comes in many formats, from many sources.

Canadian Information Agencies

Various data providers in the Canadian system of data acquisition are:

1. Inland Waters Directorate of Environment Canada, who recently introduced a Monitoring and Information Branch for the Ontario Region, responsible for collecting and disseminating water data from over six hundred sites across Ontario.
2. Water Survey of Canada (WSC), who handle hydrometric and sediment data. Data Management and Client Services are responsible for managing the data, providing client and administrative services, as well as ensuring quality control.

3. Atmospheric Environment Service (AES), who have a large network of observation stations in its weather and climate programs. All the collected meteorological data are managed by AES, a branch of Environment Canada, responsible for acquiring and archiving sufficient data to define the climate of Canada (Allsopp, 1987).
4. National Water Quality Data Base (NAQUADAT), who serve as a storage and retrieval system for field and laboratory measurements from 8,500 sampling sites across Canada. A variety of computer software has been developed for retrieval functions. Additionally, graphical and statistical functions were available to the user (Environment Canada, 1990).

United States Information Agencies

The US Geological Survey, the US Environmental Protection Agency, and the National Oceanic and Atmospheric Administration are the three most prominent agencies in the United States responsible for collecting, managing, or otherwise manipulating information that relates to water and earth sciences.

1. US Geological Survey produce and distribute information on a wide variety of earth-science specialties such as geology, hydrology, cartography, geography, and remote sensing, as well as information on land use and energy, mineral and water resources. This information is available in many forms, and in various data formats. It is the largest water resources research and information agency in the United States, and has taken a lead role in maintaining water databases (USGS, 1994). The USGS National Centre operated and maintained two systems: the National Water Data Exchange (NAWDEX) and the National Water Data Storage and Retrieval System (WATSTORE) (USGS, 1993). The Water Resources Division began the National Water Information System (NWIS) in 1983, which was designed to integrate and replace both WATSTORE and NAWDEX, and represented the first endeavor to construct a distributed database management system specifically for water data (Edwards et al., 1987).
2. USEPA water resources data collection programs are not as extensive as the USGS, but they have developed a large-scale database utility similar to WATSTORE, for the storage and retrieval of water quality data: Storage And Retrieval System (STORET).
3. National Oceanic and Atmospheric Administration (NOAA) has two notable data archival centers. (i) The National Weather Service (NWS) is responsible for the meteorological and hydrological services of NOAA, and operates hundreds of facilities across the

United States. (ii) 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).

2.1.3 Storm Water Management Model (SWMM)

The Storm Water Management Model (SWMM) was originally developed for the Environmental Protection Agency in 1969 by Metcalf and Eddy Inc., Water Resources Engineers Inc., and the University of Florida. In addition to the computational modules of SWMM (RUNOFF, TRANSPORT, EXTRAN, and STORAGE/TREATMENT), there are several TS management modules (Huber and Dickinson, 1988): RAIN, TEMP, STATISTICS, and COMBINE. Both RAIN and STATISTICS modules are used in CASCADE2. The purpose of the RAIN block is to read long time series of precipitation records, perform an optional storm event analysis, and generate a precipitation interface file for input into RUNOFF. The STATISTICS module is used to separate the continuous hydrograph record and pollutographs (concentration as a function of time) into independent storm events; it also calculates statistics and performs frequency analysis.

2.1.4 Hydrological TS Data Management System

Continuous simulation of hydrographs for long periods at many locations in a study area requires the management of large volumes of TS data. It has been found that SWMM has inefficient data processing techniques for continuous modeling. Modeling for urban impacts on water quality often requires the linking of several hydrological and hydraulic models, and incompatible datafile formats often give difficulties to modelers for this application. Thus, it becomes increasingly important to use external TS management systems that are independent of the hydrology models (Lumb, 1995).

The two most widely-used systems developed specifically for managing hydrological TS data are ANNIE (from USGS) and HECDSS (from HEC). Since CASCAD2 (Gregory, 1995) links ANNIE with SWMM, CASCAD2 was written to link HECDSS with SWMM.

HECDSS

The Hydrologic Engineering Centre (HEC, of the US Army Corps of Engineers) developed the data storage system (DSS - *note: .dss in this chapter refers to a file-extension*) to meet needs for data storage and retrieval for water resources studies. The system, which has been under development since 1979,

enables efficient storage and retrieval of TS and other data-types for which storage in blocks of contiguous data elements is most appropriate.

Like ANNIE, HECDSS is nonproprietary and written in the FORTRAN language. 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, TS type, starting date, timestep, and an additional user-defined descriptor (US Army Corps of Engineers, 1990). Four data “types” are recognized by HECDSS: flow, incremental precipitation, stages, and precipitation mass curve. Data blocks are labeled with a six-part pathname. Several DSS utility programs will generate a list of the pathnames in a DSS file and store that list in a “catalog” file. Figure 2.1 shows a sample HECDSS catalog file that describes an hourly rainfall dataset for Oregon.

```
HECDSS Complete Catalog of Record Pathnames in File OREGONP.DSS
Catalog Created on May 29, 1995 at 16:26   File Created on May 9, 1995
Number of Records: 252                   DSS Version 6-FO
Sort Order: ABCFED
```

Ref. Number	Tag	Record Pathname
1	T277	/OREGON/MISSOURI/PRECIP-INC/01JAN1974/1HOUR/OBS/
2	T278	/OREGON/MISSOURI/PRECIP-INC/01FEB1974/1HOUR/OBS/
3	T279	/OREGON/MISSOURI/PRECIP-INC/01MAR1974/1HOUR/OBS/
4	T280	/OREGON/MISSOURI/PRECIP-INC/01APR1974/1HOUR/OBS/
5	T281	/OREGON/MISSOURI/PRECIP-INC/01MAY1974/1HOUR/OBS/
6	T282	/OREGON/MISSOURI/PRECIP-INC/01JUN1974/1HOUR/OBS/
7	T283	/OREGON/MISSOURI/PRECIP-INC/01JUL1974/1HOUR/OBS/
8	T284	/OREGON/MISSOURI/PRECIP-INC/01AUG1974/1HOUR/OBS/
9	T285	/OREGON/MISSOURI/PRECIP-INC/01SEP1974/1HOUR/OBS/
10	T286	/OREGON/MISSOURI/PRECIP-INC/01OCT1974/1HOUR/OBS/
11	T287	/OREGON/MISSOURI/PRECIP-INC/01NOV1974/1HOUR/OBS/
12	T288	/OREGON/MISSOURI/PRECIP-INC/01DEC1974/1HOUR/OBS/
13	T289	/OREGON/MISSOURI/PRECIP-INC/01JAN1975/1HOUR/OBS/
14	T290	/OREGON/MISSOURI/PRECIP-INC/01FEB1975/1HOUR/OBS/
15	T291	/OREGON/MISSOURI/PRECIP-INC/01MAR1975/1HOUR/OBS/
16	T292	/OREGON/MISSOURI/PRECIP-INC/01APR1975/1HOUR/OBS/
17	T293	/OREGON/MISSOURI/PRECIP-INC/01MAY1975/1HOUR/OBS/
18	T294	/OREGON/MISSOURI/PRECIP-INC/01JUN1975/1HOUR/OBS/
19	T295	/OREGON/MISSOURI/PRECIP-INC/01JUL1975/1HOUR/OBS/
20	T296	/OREGON/MISSOURI/PRECIP-INC/01AUG1975/1HOUR/OBS/

Figure 2.1 Sample HECDSS catalog file.

Utility programs have been developed to manipulate or display data stored in a DSS file. Several of these programs are described briefly below (US Army Corps of Engineers, 1990). HECDSS is depicted in Figure 2.2.

- **DSSUTL - General Utility Program**
- 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.
- **DSPLAY - Graphical Display Program**
- enables users to graphically display or tabulate TS data. Users can enlarge or reduce plots, and edit data directly on-screen.
- **MATHPK - Mathematical Manipulation of DSS Data**
- provides utilities for mathematically manipulating TS data, or for computing statistics.
- **Data Entry Programs**

A variety of utility programs are available for entering data into a DSS database file. Some are designed to enter data from another data base, WATDSS which reads data from a file retrieved from the USGS WATSTORE system, or a WATSTORE format file from a Compact Disk, and enters it into a DSS file. Other programs are designed to enter data “manually” or in a generic form. DSSTS is a prompt-driven program for entering regular-interval TS data.

Figure 2.2 HECDSS data storage system.

2.2 Time-Series Manager Development

In this section, the data storage system utility program (DSSUTL) in HECDSS is introduced; the development of TS manager CASCADE2 (co-evolving assistant software for changing computational and data environments) is described; and the graphical user-interface is presented.

2.2.1 Software Structure

In this study, three utilities were considered important to meet the continuous modeling needs of typical engineering design offices:

1. retrieving TS data;
2. archiving TS data; and
3. data analysis operations.

Microsoft Windows was used to develop CASCADE2 and Visual Basic was selected as the programming language. The total program requires 9MB of disk space. CASCADE2 will run on any system capable of running Windows, requiring a personal computer using a 386SX or higher processor and running Microsoft Windows version 3.1 and MS-DOS version 5.0 or later. Problems may occur with Windows NT. Processing time can be much shorter if CASCADE2 is installed on a 486DX2-66 or higher processor. At least 4MB of RAM is required, 12MB of RAM or more is recommended. Hard disk with 50MB should be available, 100MB is recommended. Approximately 570K of free memory is required for running SWMM.

2.2.2 Data Storage System Utility Program (DSSUTL) in HECDSS

The previous section describes several utility programs in HECDSS, of which DSSUTL is the only one used in CASCADE2, as it provides a means of performing utility functions on data stored in HECDSS. These functions include tabulating, editing, copying, renaming, and deleting data. The program can also format and copy data into an ASCII sequential file for transfer to another computer, or for use by a program without DSS capabilities. The DSS file is a binary file.

A capability of DSSUTL is the exportation or importation of TS data for exchange between DSS and an MS-DOS spreadsheet. This is accomplished by the user defining data sets to be exchanged and an exchange format. When exporting data from DSS, the data is written to an ASCII (text) file with the defined format. The user then exits DSSUTL and executes the PC program and imports that ASCII file. Importing data to DSS essentially follows the reverse procedure. Exporting or importing data with DSSUTL requires the use of several commands to perform one function. The "exchange format" command is inherently more complex than any other command. Because of this, users typically write these commands in an input file or in the PREAD macro file.

Once the exchange format and exchange variables have been entered, data may be exported with the EXPORT command or imported with the IMPORT command. A time window must be used when exporting data, and may be used when importing (if the import file does not contain the date and time of the data). The file name to export to, or import from, follows the command name. Figure 2.3 shows an example of export and import macro.

Example 1. Export one month 1h interval time series data

```
MACRO EXPORT
TIME 01JAN1992 0100 31JAN1992 2400
EV PRECIP=/OREGON/MISSOURI/PRECIP-INC/01JAN1992/1HOUR/OBS/
EF 61533009      [DATE:YY] [DATE:MM] [DATE:DD] [TIME:HH] [TIME:MM]
//[PRECIP]
EX EXDATA.DSX
ENDMACRO
```

Example 2. Import one month 1h interval time series data

```
MACRO IMPORT
TIME 01JAN1992 0100 31JAN1992 2400
EV PRECIP=/GREEN RIVER/GLENFIR/PRECIP-INC/01JAN1992/1HOUR/OBS///
U=INCHES T=PRE-CUM
EF [SKIP] [SKIP] [SKIP] [SKIP] [SKIP] [SKIP] [PRECIP]
IMP IMPORT.IMP
ENDMACRO
```

Figure 2.3 Example export and import macro.

The PREAD macro file can contain many sets of commands that are identified by a macro name. DSSUTL will automatically connect to the macro file in the same directory. To execute those commands, the user enters “!RUN macro-name” at the DSSUTL prompt (where macro-name is the name of the macro to execute).

The export and import macros in Figure 2.3 have been used in the CASCADE2 source code with the following changes:

- DSSUTL allows export of at most five months TS data at a time, but by using repeated lines of EX and TIME step through the time window, in 5-month increments, this method can be repeated as many times as required. In the following example macro, exdata1.dsx and exdata2.dsx are two export files, each including five months data (exdata1.dsx includes Jan., 1992 -May, 1992; exdata2.dsx includes June, 1992 - Oct., 1992):

```
MACRO EXPORT
TIME 01JAN1992 0100 31MAY1992 2400
EV PRECIP=/OREGON/MISSOURI/PRECIP-INC/01JAN1992/1HOUR/OBS/
EF 61533009      [DATE:YY] [DATE:MM] [DATE:DD] [TIME:HH] //
[TIME:MM] [PRECIP]
EX EXDATA1.DSX
TIME +5M +5M
EX EXDATA2.DSX
ENDMACRO
```

- Each export macro cannot be longer than 50 lines, so it is tough and boring work to export say 75 years TS data. CASCADE2 solved this problem by chaining macros as shown in Figure 2.4.

```
macro example
line 1
.
line 45
!r chain1
endmacro
macro chain1
line 46
line 47
.
line 90
!r chain2
endmacro
macro chain2
line 91
line 92
.
endmacro
```

Figure 2.4 Example chain macros.

2.2.3 Overview of the TS Manager Utilities

CASCADE2 is intended to be an easy-to-use, graphical interface that links HECDSS with SWMM. Two types of TS data are utilized by CASCADE2, hourly and 15-minutely rainfall data. Rainfall datafiles are directly exported from HECDSS, and the resulting sequential file is then converted to a format recognizable by SWMM. Once retrieved, the appropriate SWMM format can easily be determined, by noting the location (starting and ending character positions) of the station ID string or other identifiers. With CASCADE2, the sequential file may be processed by the RAIN module of SWMM, which creates an interface file to be used by the RUNOFF module, and may also be used to calculate storm event statistics using the STATS module of SWMM.

The utilities of CASCADE2 are classified into three components, namely: retrieving TS data; archiving TS data; and data analysis operations, described in detail in subsequent sections. Figure 2.5 shows the layout of CASCADE2.

Figure 2.5 Layout of CASCADE2.

2.2.4 Retrieving Time-Series Data

After selecting the “Retrieve From HECDSS” menu option, CASCADE2 displays all the .dss files in the user’s computer. Figure 2.6 shows the dialog box. If there is no catalog file of the selected .dss file, CASCADE2 will ask the user to create a catalog file for further use. This message box is shown in Figure 2.7.

Figure 2.6 Export file selection dialog box.

Figure 2.7 Create catalog file message box.

Then the HECDSS Retrieve user interface, which is displayed in Figure 2.8, will be shown on the screen. The user is prompted for the start and end year to be exported (CASCADE2 allows the user to export yearly data), and the name under which the export file will be saved. CASCADE2 then starts the HECDSS program and writes a dynamic macro file that automatically extracts the selected HECDSS datasets into a sequential export file. The HECDSS run will commence in a separate window, independent of CASCADE2.

Figure 2.8 HECDSS export option in CASCADE2.

After the HECDSS run is completed, the export file will then be converted into SWMM format (IFORM 3) and compressed in order to save space, and an extension name .if3 will be added automatically. This file will be processed to run a statistics analysis by running the two SWMM modules RAIN and STATS.

2.2.5 Archiving TS Data

After selecting the “Archive To HECDSS” menu option, the HECDSS Archive user interface will be displayed on the screen. Figure 2.9 shows this form. The user is prompted to enter the import filename, and a HECDSS database filename. This file can be a new .dss file or an existing .dss file.

The figure shows a dialog box titled "Import Datasets To HECDSS". It has two text input fields. The first is labeled "Enter Import Data Filename:" and contains the text "exdata". Below it is a note: "Note: *.imp extension will be added automatically". The second is labeled "Enter HECDSS File Name:" and contains the text "newdss". Below it is a note: "Note: *.dss extension will be added automatically". At the bottom of the dialog are two buttons: "OK" and "Cancel".

Figure 2.9 HECDSS import option in CASCADE2.

Then the DSSUTL run will commence in a separate window, independent of CASCADE2. A dynamic macro file in CASCADE2 will automatically create a catalog file that describes dataset attributes.

2.2.6 Data Analysis Operations

After selecting the “Time-series Data Analysis” menu option, all SWMM format rainfall datafiles on the user’s computer will be displayed. Figure 2.10 shows the form. CASCADE2 can manage five SWMM formats so far: NWS (Fixed, .if0); NWS (Variable, .if1); Old NWS (.if2); User-Defined (.if3); Old AES Rain (.if5). CASCADE2 reads and displays file information in the top of the user interface, and recommends default parameters for a SWMM input datafile in the bottom of the user interface (the user can change these default parameters), including file name, comment lines, minimum interevent time, 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 user interface. Figure 2.11 shows the form. The SWMM run will also commence in a separate window. The SWMM engine is a separate application, running independently of CASCADE2.

Figure 2.10 Rainfall datafile selection dialog box.

After the SWMM run is completed, it automatically goes back to the user interface. Finally, a message asks the user if a storm event summary file is desired. CASCADE2 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.

Figure 2.11 Storm event analysis option in CASCADE2.

2.3 Time-Series Data Manager Evaluation

The aim of CASCADE2 is to automatically process file transactions between SWMM and HECDSS in a Windows environment. CASCADE2 provides a visually- appealing, easy-to-use interface that 1. integrates the TS management functions of HECDSS with the continuous modeling applications of SWMM, 2. reduces the model learning time and 3. allows modelers to take more time to conduct sensitivity, calibration, error, and uncertainty analysis.

The performance and utility of CASCADE2 was assessed by the authors, using hourly and 15-minutely rainfall datafiles, and by a panel of professional engineers.

2.3.1 Overall CASCADE2 Features

Data management, storage and retrieval are essential for typical engineering design offices, especially for such long-term data. In general, CASCADE2 provides the user with the following features:

- Long-term continuous modeling requires that large amounts of TS data be manipulated for the most part externally and individually by the user. Lack of available data and inability to manage the large input datasets and output datasets are two major arguments against using continuous modeling. CASCADE2 retrieves data from a large data management system HECDSS, and then converts the data to one standard format. A graphical, easy-to-use software tool has been developed to assist this task.
- Large hydrometeorological datasets are required as input in continuous modeling, which needs large storage space in the computer. CASCADE2 solved this problem by processing the sequential file using the RAIN module of SWMM to create an interface file, which can then also be used by other modules in SWMM.
- An informative description of the rainfall TS is often needed by modelers. With CASCADE2, the user may also choose to calculate storm event statistics using the STATS module of SWMM, which gives a table of ranked events. The table includes time of day that each event began, total rainfall volumes during each event, duration of each event and a rank order table of magnitude of the event being analyzed, return period of that magnitude, and frequency. Figure 2.12 shows the storm event statistics produced by STATS. Figure 2.13 displays the storm event statistics summary file created by CASCADE2.

2.3.2 Processing Time

Managing TS data for long periods is a critical and time-consuming task. As an important performance parameter therefore, processing times were measured using eight .dss files which include 1, 2, 3, 5, 10, 13, and 21 years of hourly and 15-minutely rainfall data on a 486DX-66 computer. The average processing time to export one year hourly data is 67 seconds. The average processing time to run the statistics analysis on the exported datasets is about 60 seconds. The average processing time to export one year of 15-minutely data is 267 seconds. The average processing time to run the statistics analysis on it is about 120 seconds.

Table of Magnitude, Return period and Frequency
Constituent analyzed: Rain (inches) Hourly rainfall data 1974.out
Event parameter analyzed: Rain Volume

Date	Time (Hour)	Magnitude (inches)	Return Period (Years)	Percent < or=
740518	1.00	0.770	2.000	100.00
740518	2.00	0.600	1.000	96.55
740517	4.00	0.600	0.667	93.10
740517	23.00	0.510	0.500	89.66
740518	4.00	0.400	0.400	86.21
740517	2.00	0.370	0.333	82.76
740517	3.00	0.320	0.200	79.31
740516	23.00	0.320	0.182	75.86
740304	0.00	0.320	0.167	72.41
740517	0.00	0.300	0.105	68.97
740420	13.00	0.220	0.100	65.52
740928	4.00	0.200	0.095	62.07
740420	15.00	0.190	0.065	58.62
740420	16.00	0.180	0.063	55.17
740420	12.00	0.180	0.061	51.72
740421	0.00	0.180	0.043	48.28
740518	6.00	0.170	0.043	44.83
740510	23.00	0.160	0.042	41.38

Figure 2.12 Storm Event Statistics File.

Hourly Rainfall Data (1974-1990) Created on December 11, 1995
Minimum Intervent Time : 1 hours Rainfall Depth Threshold Value : .1 inches
Total depth of rainfall : 245.69 inches Number of storm events analyzed : 591.

Rank	Time of Occurrence (Year/MM/DD/Hour)	Value (inches)
1	1987 04 23 11:00	6.43
2	1987 05 28 7:00	5.23
3	1989 05 10 15:00	2.50
4	1986 05 17 23:00	2.50
5	1989 05 09 14:00	2.12
6	1986 05 16 22:00	2.12
7	1987 08 13 3:00	2.06
8	1987 12 13 17:00	2.05
9	1987 09 04 2:00	1.92
10	1987 06 08 19:00	1.91
11	1983 06 18 1:00	1.75
12	1983 03 26 3:00	1.58
13	1987 06 10 16:00	1.44
14	1989 07 26 5:00	1.37
15	1988 04 20 3:00	1.28
16	1985 09 01 1:00	1.27
17	1984 09 01 1:00	1.27
18	1986 04 20 8:00	1.19

Figure 2.13 Storm event statistics summary file.

Figure 2.14 Processing time to export hourly datasets from HECDSS and STATS analysis.

Figure 2.15 Processing time to export 15-minutely datasets from HECDSS and STATS analysis.

Figures 2.14 and 2.15 show the plots of processing times versus period of record for hourly rainfall data with best fit lines and their equations. From the equation, it can be inferred that to export 75 years hourly rainfall data needs about 80 minutes if using a 486DX-66 computer, and then needs 11 minutes to run the statistics analysis; to export 75 years of 15-minutely rainfall data needs about 300 minutes if using 486DX-66, and 33 minutes to run the statistics analysis.

Compared to the same work in a typical design office, it may take days to create the 75-year input datasets for continuous modeling.

2.3.3 File Size

As mentioned at the beginning of this section, storage of long-term TS rainfall data will occupy a large amount of computer space. The HECDSS sequential export files and various SWMM format rainfall datafiles are all ASCII text files, which are easy to visualize, but difficult to store. CASCADE2 creates binary interface files instead of the ASCII text files by using SWMM.

For the hourly rainfall data, the average size of one year .dss file is approximate 50KB; the export text file is 341KB, which is about seven times the size of the .dss file; but the binary SWMM interface file of one-year datasets is only about 2KB, which is 4% of the original .dss file. Figure 2.16 displays the plots of file size versus period of record with best fit lines and their equations.

For the 15-minutely rainfall data, the average size of one-year .dss file is approximate 155KB; the export text file is 1,360KB, which is about eight times

Figure 2.16 File size comparison (hourly data).

the size of the .dss file; but the SWMM binary interface file of one-year datasets is only about 60KB, which is about 40% of the original .dss file. Figure 2.17 displays the plots of file size versus period of record for 15-minute data with best fit lines and their equations.

Figure 2.17 File size comparison (15-minutely data).

2.3.4 Test by Panel of Engineers

A panel of professional engineers, experienced in stormwater management modeling, were invited to test CASCADE2. They provided an unbiased review of the tool, using their own experiences to determine whether CASCADE2 is helpful, and also checked that the information presented by CASCADE2 was correct.

The User’s Guide for the test version of CASCADE2 and the evaluation questionnaire were provided. Eleven evaluation questionnaires were completed and returned, a 70% response rate. Three prominent categories were identified from the set of responses, namely: researchers and developers; professors and students; and consultants.

The summary of the panel findings showed that 50% of the respondents were familiar with HECDSS. The majority had experience with SWMM and HEC models. Generally, it took a CASCADE2 user 20 minutes to read the User’s Guide, 20 minutes to learn how to use the program, and 40 minutes to test CASCADE2, about one hour and 20 minutes in total. Nearly 100% had no difficulty using CASCADE2 and were all basically satisfied with the user interface, nearly 80% of the respondents found that two utilities in CASCADE2

(data retrieval and data archival) were most important in their practice. All the tests showed that the results of the statistics analysis were correct, and the summary table created by CASCADE2 is simpler and clearer than the SWMM output datafile.

The following is a summary of improvements recommended by the panel:

1. Include another utility program in HECDSS called DSPLAY as an option to view DSS data and create a catalog file of DSS file; include a simple text viewer so the user does not have to exit CASCADE2 to see the results.
2. Make it possible to export other data such as hydrographs stored in DSS into a SWMM readable format; import SWMM results into DSS format so that results can be plotted using DSPLAY program.
3. When running DOS applications, have them run in the 'Window' mode instead of full screen, then have a message with instructions on the file-name or whatever in the background and visible with DOS in the active window.

Based on tests with this representative panel of users, it may be concluded that:

1. CASCADE2 provides effective software to manage and process TS data;
2. a single TS manager is very useful in the organization and analysis of datasets used in stormwater management;
3. as a tool, CASCADE2 is easy to learn and use because of its user interface; and
4. CASCADE2 saves modeling time, since different agencies prefer different models for stormwater management and switching models should be easier with this program.

2.4 Conclusions

The result of the survey of experts in stormwater management has shown that the majority believe that continuous modeling is necessary in stormwater management. The main difficulties when using continuous modeling are: input and output file manipulation and storage, data collection and data entry, the different data formats and software tools. Stormwater modelers feel that a TS data manager (which can retrieve long-term continuous rain data from data management systems automatically on the user's computer) is necessary and useful. Furthermore, the two TS data management systems HECDSS and ANNIE are not well known by stormwater management modelers.

HECDSS was developed to meet needs for data storage and retrieval for water resources studies. Several utility programs have been developed to

manipulate or display data stored in a DSS file. Exporting or importing datasets requires the use of several commands to perform one function. These commands are quite complex, often taking the user a few days to learn, and also, in HECDSS, the datasets are stored monthly, each dataset comprising one month data - at most five months data can be exported at a time. It is time-consuming to export several years data. CASCADE2 overcomes this limitation by writing a dynamic macro, allowing any amount of data to be exported at a time.

Our purpose at this stage is not to integrate HEC application programs with SWMM, but merely to facilitate the easy export and import of datasets from HECDSS to SWMM. At present, CASCADE2 is limited to manipulating both hourly and 15-minutely rainfall data. It includes a user-interface integrating HECDSS with SWMM and its TS data routines (STATS).

Performance of CASCADE2 was tested on both 486-DX33 and 486-DX2 personal computer using 70 years of rainfall data. The performance was measured in terms of both file size and processing time. The average processing time to export one year hourly data is around 1 minute when using 486-DX2, and another 1 minute is needed to run a statistical analysis. To export 1 year of 15-minutely data needs 4.5 minutes, and 2 minutes to run the statistical analysis.

The original and sequential file formats are not storage-space-efficient, and therefore not practical for storage or transmission of very long-term datasets. Binary files are more efficient. The performance assessment results show that SWMM can store hourly rainfall data in interface files about 6% the size of HECDSS, and 15-minutely data about 40%.

A panel of professional engineers, experienced in stormwater management modeling, were invited to test CASCADE2. The purpose of these tests was simply to gather feedback on the simplicity of the interface: how the interface could be made simpler in order to be made more efficient. Findings of the test panel indicated that CASCADE2 is robust and suitable for professional applications.

This study provided code that mitigates arguments against continuous modeling, and also revealed both the feasibility and practicality of linking continuous stormwater modeling with a TS-data management system. CASCADE2 automatically manages and processes TS data for use with a continuous stormwater model. It was shown that long-term TS data can now be collected, stored, and retrieved in minutes rather than days.

CASCADE2's utility could benefit from further enhancements: it should be elaborated to manage other types of TS data, such as streamflow data, water quality data; and other time-step data, for example 5-minutely rainfall data, which is widely used in forecasting flooding caused by individual cells within a storm. Creating a package that includes several widely-used databases, able to exchange data information, and combine the functions and features of all databases, fills a real need in stormwater modeling.

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