# Chapter 22

# Taking Hydraulic Models for a Test Drive - Side by Side Comparison

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Hydraulic modeling is often a very important part of the sewer system analysis process and the simulation results are used for planning, design, or operational purposes. Several numerical models are currently

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available to engineers, but little data is available to allow direct comparison between their performance.

This paper will provide some benchmark results for three numerical dynamic hydraulic models - SPIDA, EXTRAN, and RUNSTDY. Of these, only EXTRAN is non-proprietary; and RUNSTDYwas developed and is marketed by the authors. The focus of this paper will be on the application of these models to large-scale urban sewer systems, and examples will be provided for two different sewerage systems. The comparison of performance will focus on measurable parameters such as speed of execution and accuracy of results.

In addition to purely computational aspects of the models, issues related to the data management and ease of use will be addressed. Special emphasis will be placed on the analysis tools required for real-time-control design and implementation.

## 22.1 Introduction

The goal of numerical mathematical modeling is to produce an accurate description of a system in the form of a computer program. Mathematical modeling may be conducted for different reasons and the requirements for the model differ depending on its intended use. The possible uses for numerical models include the following:

1. In **design**, models can be used to automate the computations necessary to determine the design requirements for new facilities. The main users for these models are engineers.
2. **Operation and maintenance** staff often encounter problems where models can be of great assistance. Examples of questions that may be raised by the Operations and Maintenance departments, and answered through modeling, are as follows:
   - What are the effects of the current siltation levels on the operation of the system? What improvements in capacity would be obtained by cleaning the sewer?
   - Would raising the weir level in an outfall structure reduce CSO's and improve the operation of the system? How far can the weir be raised before surcharge is experienced?
3. **Operator training** is often crucial in maintaining efficient operational practices. If the programs are capable of

representing operator intervention in simulated real time, models can be used to assist in preparing the operators for supervisory control.

4. **Planning** includes consideration and assessment of a wide range of design and operational options, often on a system-wide basis. Through the use of models, a number of different scenarios can be assessed quickly and efficiently. Planning models are most useful when they are able to communicate with other planning systems and databases, such as GIS systems or SCADA/data archival systems.
5. **Real time control** is being considered by a number of agencies as a cost-effective option to CSO abatement. Simulations are an essential part of both design and implementation of real-time-control strategies for sewer systems. In order for the model to be useful in the design of the control systems, it needs to provide the user with full control over program execution, including pausing, restarting, and changing of the simulation parameters "on the fly."

If the models are to be used for operation or real time control, it is important to consider the level of control that the user can have over program execution. An important aspect of RUNSTDY is that it provides flexibility and control over its execution.

## 22.2 Brief Description of Models

All of the models presented in this paper contain solutions to the Saint Venant equations, which describe the dynamics of flow through two basic equations for conservation of flow and momentum:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \qquad (22.1)$$

$$\frac{1}{gA}\frac{\partial Q}{\partial t}+\frac{1}{gA}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+\frac{\partial h}{\partial x}-\left(S_o-S_f\right)=0 \qquad (22.2)$$

where:

$Q$ = discharge
$A$ = flow cross-sectional area
$h$ = depth
$S_0$ = sewer slope
$S_f$ = friction slope
$x$ = distance
$t$ = time

The above set of partial differential equations has to be solved numerically since there are no general analytical solutions available. The basic characteristics of three commonly-used models (SPIDA, EXTRAN, and RUNSTDY) are briefly summarized in this paper. The applications of the models to large-scale urban sewer systems are compared in terms of simulation time and accuracy.

## 22.3 SWMM4 EXTRAN model

EXTRAN is a dynamic flow routing model that includes computation of backwater profiles in open channel and/or closed conduit systems that are experiencing unsteady flow. EXTRAN is the part of the SWMM model that includes hydraulic computation for surcharging sewer systems and is endorsed by the U.S. Environmental Protection Agency (EPA). It is in the public domain, and available from Dr. Wayne Huber, Civil Engineering Department, Oregon State University, Corvallis, OR, 97331.

EXTRAN uses a link-node description of the sewer system to discretize the gradually-varied unsteady flow equations. The conduit system is idealized as a series of links or pipes which are connected at nodes or junctions. The program includes a variety of control structures. The equations are solved based on the idealized and discretized governing equations which formulate simple solutions for discharge in all the links. The heads are computed at maintenance hatches or pipe junctions subject to sets of boundary conditions at the inlets and outlets of the system.

In EXTRAN, the Saint Venant equations are solved numerically using a modified Euler method which yields a completely explicit finite difference scheme. This scheme requires a relatively short time step to maintain stability of the solution as restricted by Courant criterion defined as $\Delta t \leq \Delta x / u$, where $u$ is wave celerity. Details of EXTRAN model can be found in EXTRAN User's Manual (Roesner et al., 1989).

The advantages of the explicit scheme used by EXTRAN are its simplicity in formulating the scheme and small memory requirements. The drawback of the explicit solution is that short time steps are required during the simulation, which means long computer processing time for long-term simulations of large-scale sewer systems.

## 22.4 SPIDA model

SPIDA is an unsteady routing model of the hydrological and hydraulic processes for highly looped storm drainage networks. It is proprietary, and was developed by Wallingford Software and is widely used in the U.K. It is available from the address in the list of references (Wixcey et al, 1985).

The full Saint Venant equations are solved numerically for gradually varying flow. The sewage system is conceptualized as links and nodes that include storage. The equations are discretized over links based on a 4-point scheme in which the variables and their derivatives are replaced by weighted averages over the four corners of the box in x-t computational domain.

Storage nodes are modeled for computation of normal and overload conditions of the system, including flooding. The continuity equation to be satisfied at each storage node is added into the governing equations.

The 4-point scheme makes the discretized equations implicit. This removes the restriction on the time step by Courant Criterion for numerical stability of the solution. The time derivative of depth in continuity equations over storage nodes are discretized by Euler's Method. Head-discharge relationships for a variety of control structures are included in the model.

The linearized matrix system is solved using a commercially available package associated with the recurrence relationships. The stability of the calculations, particularly in the transition between pressurized and free surface flow, is ensured using the iterative Newton-Raphson Method.

## 22.5 RUNSTDY model

RUNSTDY is a proprietary, dynamic wave routing model for the analysis of complex sewer systems. An implicit numerical method is used to solve the full Saint Venant equations of unsteady, gradually varied flow for looped systems. It is marketed by the authors of this chapter.

The model is based on a link-node approach. Flows at nodes due to lateral inflow and street flooding are considered by adding corresponding terms at the right hand side of the continuity equation. Both discharge and head are determined at nodes by using a weighted 4-point implicit numerical solution scheme. The discretization of the differential equations can be applied to subcritical and supercritical flow conditions. In addition, various flow equations are utilized to simulate flow through control structures and junctions (RUNSTDY User's Manual, Reid Crowther and Partners Ltd., 1993).

The time step for the calculations is not restricted by the Courant criterion due to the implicit scheme. This allows the user to choose relatively large time steps for long-term simulation. However, in order to maintain stability and accuracy of the simulation results, smaller time steps should be used during periods of higher flow conditions, rapid changes in boundary conditions, and the period of transition between pressurized and free surface flow. Therefore a variable time step is incorporated into the model to allow the use of large time steps to be used during dry weather conditions and smaller time steps to be used during storm conditions. The advantage of the variable step feature of the model is to reduce the computing time for continuous simulations while providing an appropriate level of accuracy.

Another feature distinguishing RUNSTDY from other models is the solver for the discretized system. The linearized set of equations generated from the Saint Venant equations form a sparse-matrix system. In this model, a commercial sparse-matrix solver (Harwell MA28) is used for the solution of the looped system. This method allows for a time-efficient solution for the system.

## 22.6 Test Description

Most computer models consist of several components - user interface, data base, and the computational "engine" that includes algorithms for solving the model equations. The model engine is supported by components that allow the user to interact with algorithms and data. An example of the model architecture is shown in Figure 22.1 below.

The focus of this paper will be mostly on the overall performance of the computational engine for three models - SPIDA, RUNSTDY, and EXTRAN. The data for comparisons will come from simulations performed

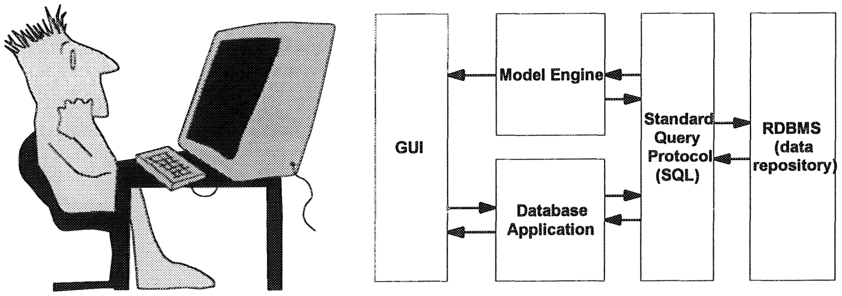

**Figure 22.1**
**Typical model structure.**

by Reid Crowther staff. These simulations were performed on projects for two sewer systems - Crossness system operated by Thames Water in the United Kingdom, and Marion /Despins Combined Sewer District in Winnipeg.

Although the ease of use (or "user friendliness") can be a major factor affecting the value that the model brings into the analysis process, this chapter will not address the comparison of the user interfaces for the following reasons:

- There are several graphical interfaces for EXTRAN today, and none of them represents a clear standard that could be tested.
- Within this chapter, emphasis was placed on three simple measurable aspects of the models - accuracy of results, speed of execution, and control of execution.

All simulations were performed on a 486 dx2/66 personal computer with 16 MB of RAM.

## 22.7 RUNSTDY vs. SPIDA

Both RUNSTDY and SPIDA were applied to several catchments within a large urban drainage system. The primary focus of the project was to develop a numerical model that would be used as a tool for planning of CSO and flood reduction strategies. The catchment description summary is as follows:

- 307 km of drainage trunk systems
- 9 pump stations
- 27 outfalls

- one centralized sewage treatment works
- area of 245 km$^2$
- 198 flow control structures:
  - 24 orifice controls
  - 7 operating sluice gates
  - 28 flap gates
  - 145 overflow weirs

The sewer system asset database consisted of roughly 5,000 nodes. For the purpose of the study, this system was modeled as a network of roughly 1000 nodes. A summary of RUNSTDY execution times for the three basic scenarios is shown in Table 22.1.

The dry weather flow hydrograph is generated based on the population and area in each catchment. SWMM RUNOFF model was used to compute the storm flow hydrograph based on the rain fall data

SPIDA simulations were performed for one of the basic scenarios - the event with hydraulic loads equivalent to three times dry weather flow (test 1). The execution summary of this simulation is shown in Table 22.2.

The results of simulations (flows and heads throughout the system) with the same network data and the same inflow hydrographs were in close agreement between SPIDA and RUNSTDY.

**Table 22.1**
**RUNSTDY execution times for test 1**

| | **Dry weather flows (cycled)** | **Jan 5, 1989 inflows** | **3 times Dry weather flow** |
|---|---|---|---|
| Simulation event duration (hrs) | 72 | 72 | 72 |
| maximum time step () | 20 minutes | 6 minutes | 10 minutes |
| minimum time step (minutes) | 2 minutes | 1 minute | 2 minutes |
| number of simulation steps | 218 | 1185 | 1115 |

| **Run times:** | | | |
|---|---|---|---|
| File reading (in minutes) | 1 minute | 1 minute | 1 minute |
| Initialisation (in minutes) | 5 minutes | 5 minutes | 5 minutes |
| Simulation (in minutes) | 6 minutes | 24 minutes | 22 minutes |
| Total run time (in minutes) | 12 minutes | 30 minutes | 28 minutes |

**Table 22.2**
**SPIDA execution times for test 1.**

| | **3 times dry weather flow** |
|---|---|
| Simulation event duration (hours) | 72 |
| maximum time step | 15 seconds |
| minimum time step | determined internally within program |

| **Run times:** | |
|---|---|
| Initialisation (in minutes) | 1 hour 9 mintes |
| Simulation (in minutes) | 73 hours 26 minutes |
| Total run time (in minutes) | 74 hours 35 minutes |

Due to time constraints SPIDA simulations were not tested for other scenarios but the general experience with SPIDA was that the execution times were significantly longer.

It is important to re-emphasize that there are additional important factors of the model's performance that were not tested or discussed within the context of this paper. On this particular study there was some concern about the level of expertise required to use RUNSTDY versus the expertise necessary to execute SPIDA. Some users felt that SPIDA was a more "forgiving" model in terms of the set up and data preparation.

## 22.8 RUNSTDY vs. EXTRAN

Comparison between RUNSTDY and EXTRAN was performed on a subset of a larger sewer network in Winnipeg, Manitoba. The larger network included the 350 hectare total Marion and Despins Combined Sewer Districts, which are located near central Winnipeg and are bounded on the west and south by the Red River and on the east by the Seine River. The two districts are interconnected along their boundary, but each has its own outfall and flood pumping station to the Red River. Development of the Marion district began in the early 1900's and consists of mostly single family residential with multi-family units and commercial buildings restricted to two or three major streets. The Despins district is a little older and contains a variety of land uses such as industrial, commercial, institutional and residential. The trunk sewers are egg-shaped except near

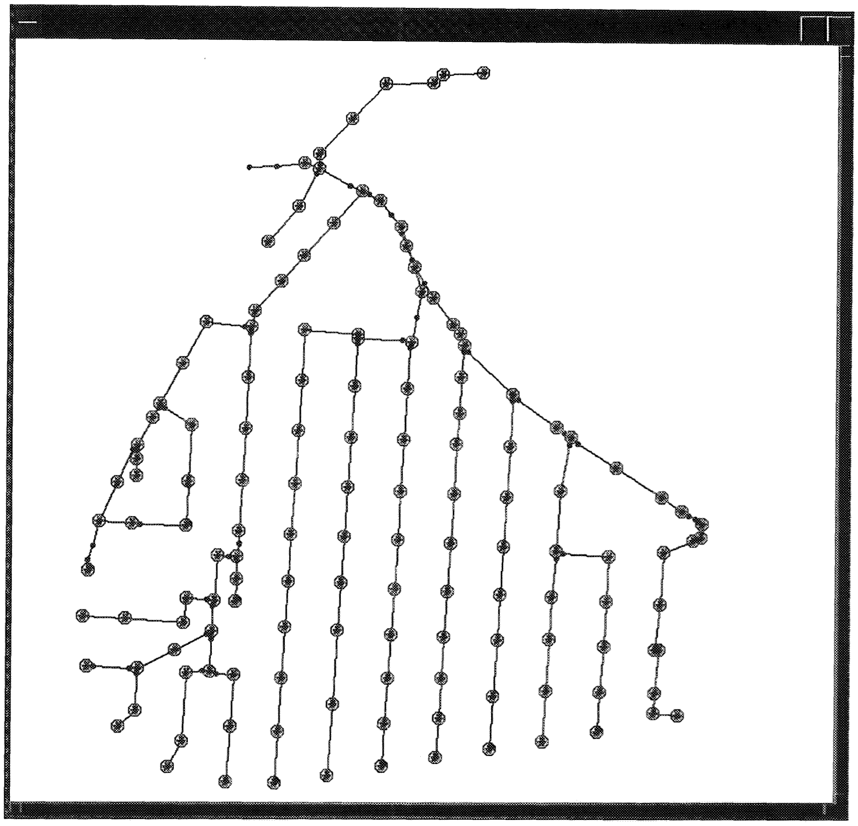

**Figure 22.2**
**Schematic of the system simulated using RUNSTDY and EXTRAN.**

their outlets, where relatively recent system improvements have been carried out using circular pipe. Needless to say, some of the existing sewers are rather old.

For the purpose of the test, a part of the system serviced by the Marion pump station was simulated using both RUNSTDY and EXTRAN. The system tested had 122 catchments over 223 acres, and included 143 links. The schematic for the system used in the test is shown in Figure 22.2.

The inflow hydrographs for both EXTRAN and RUNSTDY tests were generated by SWMM RUNOFF Model, based on a rainfall event.

The simulation was executed for a 24-hour period that included the storm event. The simulation results for flows and levels were fairly close, as shown in Figure 22.3.

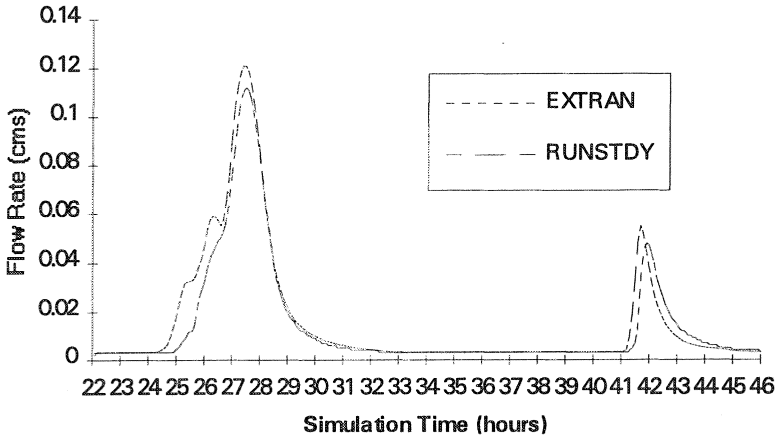

**Figure 22.3**
**Flow out of the system - simulation results for EXTRAN and RUNSTDY.**

The minor difference in computed flows between EXTRAN and RUNSTDY is at least partly because the pump station was modeled differently. The summary for the simulation times is presented in Table 22.3.

It is important to note that the results presented in Table 22.3 reflect execution time for a storm event applied to a fairly small system. If continuous simulations were performed, they would include periods of dry weather flow. During periods of dry weather flow, the difference in time step for RUNSTDY (10 min) and EXTRAN (60 seconds is maximum according to EXTRAN manual) may result in significantly better execution speed for RUNSTDY. Long term simulations were not conducted for the purpose of this paper.

**Table 22.3**
**Execution times for 24 hour simulations.**

| | **max. time step** | **min time step** | **time step** | **simulation time** |
|---|---|---|---|---|
| EXTRAN | | | 30 sec | 135 sec |
| RUNSTDY | 10 min | 1 min | | 31 sec |

## 22.9 Summary and Conclusions

For the systems tested in this paper, simulations using RUNSTDY, SPIDA and EXTRAN produced very similar results in terms of computed flow rates and heads. Significant differences were observed in execution speed, with RUNSTDY showing an edge over SPIDA and EXTRAN.

This paper is not meant to imply superiority of one model over the others, but merely to point out some measurable differences in performance. Final decisions regarding choice of hydraulic models for each person or organization should consider a number of factors, speed of execution being just one.

## References

Reid Crowther and Partners, (1993). RUNSTDY User's Manual. Available from: Reid Crowther and Partners Ltd. #300, Atrium VII, 340 Midpark Way S.E., Calgary, AB, T2X 1P1, Canada, 1993.

Roesner, L.A., Aldrich, J.A., and Dickinsion, R.E. (1988) Storm Water Management Model User's Manual Version 4: EXTRAN Addendum I. EXTRAN Cooperative Agreement CR-811607, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Wixcey, J.R., M. Lewy, and R.K. Price (1985) Computational Modeling of Highly Looped Networks of Storm Sewers, Wallingford Software, Howbery Park, Wallingford, Oxfordshire, OX10 8BA, U.K.