Appendix B

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CH2MHILL

TECHNICAL MEMORANDUM

Task 8.4 WW COLLECTION SYSTEM HYDRAULIC MODEL REVIEW

DATE:	September 27, 2006	Project No.: 513-01-06-12
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SUBJECT:	Sanitary Sewer Master Plan Updates	

SUMMARY

CH2M HILL has reviewed and compared the leading software packages for wastewater collection system simulation including consideration of hydraulic methods, user-interface amenities, database/geographic information system (GIS) compatibility, software developer, vendor support, project scope, and price. On the basis of our review, we recommend that the City of McMinnville (City) select the XP SWMM package as their software platform for simulation of its wastewater collection system. This platform will best meet the City's needs for the model, including ease of use and cross-application for stormwater system modeling. If the City agrees with this recommendation, we intend to perform modeling work in that package, including presentation of results, either within the model itself or using a GIS interface. Model files can also be provided to the City in EPA SWMM 5 format, a public domain platform that allows for low-cost data transfer and storage.

INTRODUCTION

This technical memorandum (TM) documents the evaluation of wastewater collection system hydraulic models for the City. Six models were identified as candidates for simulating existing conditions and for evaluating future conditions and capital improvement alternatives.

The primary purpose of a hydraulic simulation model is to provide the City with a tool that can be used to gain a better understanding of the hydraulics of the wastewater collection system. The tool can be used to evaluate and potentially improve existing operations and to assess and plan for accommodating future conditions, including master planning, facility planning (capital improvement), and wet-weather flow management.

To be considered by the City, models must have basic capability and functionality, including the following:

- Acceptable hydraulic methods
- Dynamic routing
- Computational speed
- Easy-to-learn and use through an advanced Graphical User Interface (GUI)
- GIS and database (ODBC) interface
- Accurate and reasonably precise computational results
- Adequate results presentation capabilities
- Supported by experienced vendor who has been in the business for at least 5 years

MODEL SELECTION PROCESS

The selection process usually consists of identifying available hydraulic models that generally meet the City's needs. The models are then subjected to an initial screening, and a few are selected for further evaluation. The capabilities of the short-listed models (below) are then evaluated in more detail.

The model selection process should attempt to balance the City's need for a usable tool that meets the general model capabilities listed above against the City's resources. The resources (most importantly staff, but also hardware and software) available to the City for the maintenance of the system database and upkeep of a comprehensive model should be considered in the selection process. The models included in this evaluation are commonly used. The review was based on available model documentation, published literature, and CH2M HILL experience on previous projects.

RECOMMENDATION

Of the models described in detail in the attached appendix, four use computational methods that are appropriate for today's standard of wastewater collection system hydraulic simulation accuracy and precision: MOUSE, Infoworks, SWMM EXTRAN (including XP-SWMM and MIKE SWMM), and SEWERCAT. Of these four, three use the implicit method to solve the fully dynamic equations of motion (St. Venant equations) for all pipe segments simultaneously at each time step: MOUSE, Infoworks, and SEWERCAT.

XP-SWMM was selected as the package of choice. The software is available at modest cost relative other options, has an intuitive user interface, and can present results graphically on-screen. The software can also model stormwater events, which may be useful to the City for future planning efforts. CH2M HILL has extensive experience with the model and has current licenses that can be used to develop the City's system model at no additional cost.

Appendix

Overview of Hydraulic Model Capabilities

Hydraulic models simulate flow, velocity, and hydraulic grade in wastewater collection systems. In most cases, they include methods to generate base wastewater flows (sanitary sewage from residential, commercial, and industrial sources and non-storm period groundwater infiltration), infiltration and inflow (I/I) response to rainfall and snowmelt, and the routing of the combined base and I/I flows through the collection system. The model must be able to accurately simulate routing, backwater, surcharge, flow diversions, looping, boundary conditions, and pump operations that occur in wastewater collection systems. The general goal of the model is to support an understanding of how the collection system responds to a variety of precipitation events and to provide a tool to plan for managing the system over time as development and re-development occurs.

Hydraulic models usually are differentiated as steady state or dynamic, depending on the capabilities of the model to simulate complex hydraulic situations. Steady-state models have been applied in studies where complex hydraulics such as surcharging, flow splits, and system travel time are not significant. Steady state models were more pervasive several years ago when computer speed was a limiting factor. Computer run times for a given system are very dependent on how changeable the flow regime becomes during a storm and the amount of surcharging and backwater effects within the system. Dynamic models can simulate all the complexities of a wastewater collection system and are the standard of practice in today's computer environment. Most dynamic models are based on the equations for one-dimensional unsteady flow for open channels known as the Saint-Venant equations. The numerical stability of models is a function of the algorithms used to solve the equations for each pipe in the wastewater collection network.

The dynamic models available today range from stand-alone Fortran-code models to enhanced model software packages that work in a Windows/XP operating environment and include data pre-processors, model results graphic post-processors, and GIS interface capabilities of varying degrees. Some models have evolved to a pure Windows environment, whereas others use Windows as a launching tool for their program. The level of integration to Windows can be highly variable between the models.

Models capable of directly interfacing with GIS will reduce the amount of effort required to set up the model and the effort to maintain it in the future. A one-way link will allow the GIS to supply the model with input data describing the wastewater collection facilities and their service areas. A two-way link will allow the GIS to access model results if the output format is compatible with the GIS system selected for use. Features that may vary from one model to another include the following:

- Pump curves—The number of points on the curve that can be added to the model will allow better simulation of pump operations. Models with real-time controls can sequence pumps as well as gates, weirs, and orifices. The term "pump curve" relates to how pumps are modeled by discharge/head (Q/H) relationships or differential head from upstream/discharge nodes versus discharge (Q/dH), not true pump curves that find operating points based on system head and pump head.

- Conduit loss factors—Models vary in the number of options for pipe friction loss factors. These should be compared against the actual losses expected within the City's system. All models have at least Manning's "n" factors, but some have more extensive "k" factors for such items as entrances/exits, contraction/expansion, and manhole losses. As long as the model has a Manning's "n" factor, an equivalent head loss Manning's "n" factor can be used to represent minor losses in addition to roughness.

- Results file format—Some models save the file that is created in binary format that is easier to read for graphics. These can be exported back to an external ASCII file to update an external database.

- Inflow hydrographs—Some models access the hydrographic data as needed. Other models attach the file to each node, which ties up the computer storage space and slows down the simulation. Alternative interface files could be set up to speed up this process if needed to speed up computer simulation.

- Real-time controls—Many models have real time control (RTC) modules available for their programs at an additional cost. RTC essentially involves optimizing the use of available capacity in the sewerage system during a rain event. If one portion of the system is experiencing heavy rainfall and consequent high sewer flow response, hydraulic structures (usually gates and weirs) can be invoked to restrict and store flows in an area not experiencing heavy rain and high flows. RTC can be completely automated, where sensors at strategic locations throughout the system control automated gates and weirs to control flow and use available storage capacity, or it can be more reliant on operator intervention. Modeling tools are available to work in conjunction with existing hydrodynamic simulation to plan and evaluate RTC options and strategies.

- On-line help—The online help varies in complexity for each model. If the end user is very familiar with the model and its operations, this may not be critical. If the user is not that familiar with the model, the online help and the ease of use may make a difference in how quickly a novice user will successfully use the model.

- Error checks—Each model is different in how it finds and shows errors in the data. Some models will find them, but not display the error graphically. Some will do both.

- Graphic displays—Some models have graphic displays that are linked to the data files, so that the user can change between them very easily. Some graphic output is not as clean as others.

Commercially Available Hydraulic Models

Numerous features must be considered when evaluating a hydraulic model. The more complex the models, the more features there are to evaluate. Currently, many different computer models are available to analyze wastewater collection systems. Most of these do not meet the minimum requirements needed for the City's use because they are not dynamic models, do not interface with GIS, do not calculate hydraulic grade lines, are no longer supported, or are not easy to learn and use. The models that were selected for evaluation provide the basic features necessary to effectively model the City's wastewater collection system.

The available models selected for evaluation are listed in Table 1, along with the name of the company that publishes the model and the contact information.

Table 1
Summary of Models Selected for Evaluation

Name of Model	Vendor	Contact Information
MOUSE	DHI (Danish Hydraulic Institute)	DHI Inc. 301 S. State Street Newtown, PA 18940 215/504-8497 FAX 215/504-8498 www.dhisoftware.com
MIKESWMM	DHI (Danish Hydraulic Institute)	DHI Inc. 301 S. State Street Newtown, PA 18940 215/504-8497 FAX 215/504-8498 www.dhisoftware.com
INFOWORKS CS	Wallingford Software Inc.	6015 Harris Parkway, Suite 120, Fort Worth, Texas 76132 817 /370 2425 FAX 817 370 1981 www.wallingfordsoftware.com
USEPA SWMM EXTRAN	U.S. Environmental Protection Agency	Model Distribution Coordinator U.S. Environmental Protection Agency 960 College Station Road Athens, Georgia 30605-2720 706/355-8400 www.ccee.orst.edu/swmm/
XP-SWMM	XP-Software	2000 42nd Ave #214 Portland, OR 97213-1305 888/554-5022 FAX 1-888-554-5122 www.xpsoftware.com
SEWERCAT	Earthtech	300 Oceangate, Suite 700 Long Beach, CA 90802 562/951-2000 563/951-2100 www.sewermodel.com
HYDRA	Pizer	4422 Meridian Avenue N. Seattle, WA 98103 800/222-5332 Toll Free 206/634-2808 206/634-0624 FAX www.pizer.com/hydra.htm

A brief summary of the main features of each of the models is provided below.

MOUSE is a state-of-the-art hydraulic modeling software package designed to simulate unsteady flows in pipe networks. It was developed by the DHI in the 1970s, but introduced to the United States in the early 1990s. It is the most widely used, commercially available, fully dynamic wastewater collection system simulation software in the world.

Its hydraulic computations are comprehensive, using an implicit, finite difference, numerical solution of the governing flow equations (St. Venant) and sparse matrix methods to perform the solution of simultaneous equations. The MOUSE package provides efficient and accurate solutions in multiple-connected, branched, and looped pipe networks and can readily transition between subcritical and supercritical flow regimes. It precisely simulates flow features, such as backwater and surcharging.

In addition to its computational features, the MOUSE package has advanced capabilities for displaying simulation results. Results can be presented using color coding and symbols in plan view, as well as with static and dynamic graphs and profiles. Also, the DHI suite of products provides advanced add-on modules if the user should need to augment hydraulic analysis capabilities in the future. These features include a GIS liaison, real-time control, advanced surface runoff, sediment transport, water quality simulation, and receiving water simulation modules.

DHI recently developed an interface software program known as "MIKE URBAN." MIKEURBAN has the capability of interfacing with three different hydraulic engines: MOUSE, SWMM 5.0, and MIKENET (a DHI water distribution model). Recent experience with this interface has been mixed. Certain elements, such as a scenario manager for evaluating different modeling conditions, and the GIS interface have been found to be relatively cumbersome in the current release.

The MOUSE hydraulic modeling package contains all of the features necessary to set up and build a representation of a wastewater collection system, to run simulations for varying flow scenarios, and to view results.

MIKE SWMM is an interface between EPA's SWMM hydraulic engine and the modeler's computer Data can be digitized and viewed with background images and edited with similar graphical editors as DHI's MOUSE system. The primary difference between MOUSE and MIKESWMM is the hydraulic engine. The MOUSE hydraulic model tends to be more stable and have greater processing speed. The current MIKE SWMM uses the SWMM 5.0 engine. Another difference is that the only add-on module available to MIKESWMM is a GIS module. DHI is moving away from the MIKE SWMM application in favor of the MIKE URBAN system.

Infoworks CS, first released in August 1994, was developed by Wallingford Software, which is a wholly owned subsidiary of the H. R. Wallingford Group that was privatized from a British government agency 15 years ago. Infoworks is widely used in Britain and Belgium and is being used increasingly in the United States. The model is fully dynamic and uses an implicit scheme to solve the St. Venant equations. Infoworks features a Windows interface and has additional modules available for water quality, real-time controls, sediment transport, and design. Infoworks has an extensive user interface that allows easy editing of system data and includes online help. A comprehensive graphics interface allows the user to animate model results in plan or profile views. InfoWorks is the upgraded version that incorporates GIS interfaces, real-time controls, more stable simulations for large data sets, return period and time series analyses, and other features. Although one of the better tools available, the cost of the system is quite high as described in the table below.

EPA Storm Water Management Model (SWMM) version 5.0 is the model originally developed in the early 1970s by the U.S. Environmental Protection Agency (EPA) for analysis of quantity and quality problems associated with urban runoff. This latest re-write of SWMM was produced by the Water Supply and Water Resources Division of the U.S. Environmental Protection Agency's National Risk Management Research Laboratory in a joint development effort with CDM, Inc. EXTRAN is the fully dynamic routing module within SWMM that uses an explicit finite-difference solution to the equations of motion. EXTRAN solves the complete dynamic flow routing equations (St. Venant equations) for simulation of backwater, looped connections, surcharging, and pressure flow. This method imposes the Courant time-increment restraint. Numerical instabilities often arise during the computations that may be corrected by reducing the computational time-step. No formal technical support exists, but as a freeware application, there is a large and active users group where solutions to common problems are shared. SWMM 5.0 now includes a graphical user interface. CAD and GIS interface is more limited than proprietary platforms.

XP-SWMM 10.0 is XP-Software's newest version of the SWMM model built around EPA's SWMM. XP-Software has repackaged the model with a new graphics interface and Microsoft ACCESS database capability. XP-SWMM is a 32-bit Windows application. The package includes extensive online help and error checking capabilities. XP-SWMM also has the capability to use data imported from GIS, computer-aided drafting (CAD), and database software. Additional modules purchased separately include tools for direct GIS interface and flood mapping, among others. The hydraulic solution technique used in XP-SWMM is the explicit method based on the EPA SWMM EXTRAN Version 4.4 model, with some improvements. The modeling engine is relatively stable and technical support is available.

SEWERCAT (Sewer Computer Analysis Tools) was developed by Reid Crowther Consulting in England as a value-added tool for its clients. This model was developed for the Seattle Metro in the late 1980s and includes a dynamic wave analysis based on the implicit algorithms obtained from Colorado State University. The algorithm solves the St. Venant equations and is capable of simulating complex hydraulics. The Windows version includes modules for water quality, real-time control, and includes a GIS-like map interface. In 1997, the model was made available to the open market after refinement.

HYDRA was developed by Al Pizer, of Pizer Incorporated, approximately 20 years ago. The hydraulic methods used in the program are typically considered too simplistic for complex collection systems. HYDRA performs time-delay hydrograph routing, often referred to as the Cincinnati method, rather than using the St. Venant equations that account for continuity and momentum in describing fluid flow. This model does not have the capability to account for complex hydraulics, such as backwater, surcharging, or looped flow conditions. The computation of the hydraulic grade line is not integrated with the flow routing computations, which means that overflows and hydraulically controlled flow diversions cannot be simulated accurately. HYDRA 6, which was released in August 1998, is a full 32-bit Windows application. The model includes a graphical user interface, which displays results in plan and profile views. Additional features include graphic interfaces for AutoCAD.

Price

Table 2 lists approximate base prices of the six software packages considered suitable for use by the City, along with comparative information.

Table 2
Approximate Pricing of Software Packages (2004 prices shown)

Name of Model	Base Price	Discussion
MOUSE	• $9,900 without additional modules. • $11,300 - Level 1 Combo includes one module (RDI/I).	• 15,000 Node Base Model (Unlimited) • Software maintenance cost will be approximately $3,000 - $4,000 per year. Annual software maintenance includes online and telephone tech support, and at least one version upgrade. • Extra cost for additional modules Real Time Control, Sediment Transport • Free upgrade to MIKE URBAN • Free 2 hour webinar training course • All cost includes 30% Discount (10% to CH2M HILL +20% to public agencies)
INFOWORKS	• $38,000 (INFORWORKS/Collection System(CS)) with RTC	• 100,000 Node Base Model • 50 pipe version of WS • 25 Nodes version of Rivers • Additional $5,700 annual service maintenance cost • Extra cost for additional modules such as GIS, Real Time Control, Sediment Transport
MIKE SWMM	• $3,200 (without GIS model) • $6,300 (with GIS model)	• Unlimited Node Base Model • Additional $480 annual service maintenance cost • Additional $9,600 for upgrade to MIKE URBAN (accomplished by upgrading to MOUSE within a limited time offer to receive the MIKE URBAN. No guarantee that offer will be extended indefinitely.) • Additional $1,800 for 6 months lease to GIS model if not purchased with MIKE SWMM • All cost includes 30% Discount (10% to CH2M HILL +20% to public agencies)
USEPA SWMM EXTRAN	Free	• Graphical user-interface • No vendor support • ASCII file based input and output
XP-SWMM	• $9,600	• 5,000 Node Base Model • 1-year of full service, technical support program upgrade • Additional $1,800 annual service maintenance cost • Cost includes 25% Discount to public agencies
SEWERCAT	Free	• Cannot purchase software without consulting agreement with Reid-Crowther, Inc.

Hydraulic Methods

Wastewater collection simulation software packages generally are structured so that a link node network can be developed to represent system features, such as manholes, pipes, pumps, diversion structures, storage facilities, and outfalls. Various methods may be included to support the generation and/or import of flow hydrographs assigned to nodes in the modeled system. The major difference between packages is the methods used to solve the governing hydraulic equations to calculate the routing of flow through the system and corresponding hydraulic grades. Most software packages use one of four computational methods, as described below:

Cincinnati Method: This is a time-lag method of hydrograph routing. An average velocity is computed for a pipe segment, and a hydrograph presented at the upstream end of the pipe is translated downstream, with its shape unchanged and hydrograph ordinates shifted on the time axis by an amount equal to the pipe's length divided by its average velocity. This method is sometimes referred to as the "roller-skate method" because of the analogy of loading a hydrograph onto a pair of roller skates and skating it to the downstream end of the pipe–the hydrograph shape being unmodified. Such a method had some merit 30 years ago when computer speed and memory were limited, but with today's computing capabilities, this method should never be used. It does not accurately simulate the physics of fluid flow. The marginally popular, commercially available computer program HYDRA still uses this method.

Kinematic Wave Method: This method uses the governing hydraulic (St. Venant) equations with some terms eliminated to speed and simplify computations. Terms that are discarded limit the ability to solve a pipe network, because the finite-difference approximation to the solution of the resulting equations does not use elements from the next downstream pipe. Thus, routed flow cannot "feel" any backwater influences. This limitation restricts the application of the kinematic wave method to dendritic systems; i.e., systems that have tree-like structures with no looping.

With the Kinematic Wave method, diversions in pipe networks can only be accommodated using rating curves. Typically, rating curves at diversion structures provide only rough approximations of flow splits, because flows are influenced by downstream conditions in both the main line and the branch, and at the time the flow split computations are performed, downstream conditions are unknown (they have not been computed yet). After kinematic wave routing is performed, surcharge computations can be carried out, beginning at the downstream end of the system, using flows computed with the kinematic wave equations. Because of huge advances in computing power during the past 20 years, the kinematic wave method generally should not be used. Many commercially available wastewater collection system models include an option to route flows using the Kinematic Wave method. EPA's SWMM TRANSPORT module and CH2M HILL's Wastewater Collection Analysis Model (SAM) developed in the late 1970s use the kinematic wave method.

Fully Dynamic Equations of Motion, Explicit Formulation: This method solves the fully dynamic equations of motion (St. Venant equations) for all pipe segments simultaneously at each time step. Depths and velocities are computed for the current pipe segment presuming that information in neighboring pipe segments is known. Once a solution is obtained for one pipe, computations proceed to the next neighboring pipe, using updated information from previous calculations. A limitation of this method is a stability criterion, called the Courant condition, which limits the computational time step based on the system's shortest pipe segment. As a result, instabilities occur frequently, often limiting the accuracy of results. This methodology is used in EPA's SWMM EXTRAN module.

Fully Dynamic Equations of Motion, Implicit Formulation: This method also solves the fully dynamic equations of motion (St. Venant equations) for all pipe segments simultaneously at each time step. However, with this method, the Courant stability criterion is eliminated (although rapid changes in flow rate still require short time increments to capture sufficient flow and depth information to describe the event). Another advantage is increased computational stability when compared to the explicit method. With a gigabyte of memory and the 733 MHz computing speed currently available on desk-top computers, the implicit formulation is clearly the method of choice. MOUSE, Infoworks and SEWERCAT use this method.

The disadvantage of the method compared to the explicit method is its potential for greater computational time and computer memory requirements, caused by the need to solve a large matrix. However, the matrix contains mostly zero elements, and sparse-matrix methods greatly speed matrix operations and reduce computer memory requirements, because only non-zero elements of the matrix are stored. In fact, the implicit scheme usually requires less run time than explicit methods because explicit methods require numerous iterations when instabilities occur.