17 COMPUTER MODELS AND SOFTWARE

17.1 INTRODUCTION

Many new computational software have been developed world-wide based on the intensive research effort in urban hydrology, hydraulics and stormwater quality. An engineer with access to computer facilities should normally choose one of these tools, according to his design objectives and the available resources. However, it should be borne in mind that proper use of such a new method or tool requires a good knowledge of the detailed operations that the method or tool can perform. In other words, the engineer should have knowledge of the hydrological, hydraulic and water quality processes simulated by the tool he is planning to use.

This Chapter discusses modelling, the process of setting up and running a computer model, and provides an overview of some of the modelling software currently available.

17.2 APPLICATIONS OF COMPUTER MODELLING

In the broadest context, a model can be defined as any organised procedure for the analysis of a problem. With such a definition, almost any traditional technique could be included for discussion, from the Rational Method to unit hydrographs. However, this Chapter treats a model in the popular sense of a computer program (software) designed to analyse one or many problems encountered in storm drainage systems.

The US EPA defines models as processes which are " used to increase the level of understanding of (natural or man-made) systems and the way in which they react to varying conditions". By varying the input conditions, the user can examine the effects of, for example, increased urban development on a drainage system.

Computer models use the computational power of computers to automate the tedious and time-consuming manual calculations. Most models also include extensive routines for data management, including input and output procedures, and possibly including graphics and statistical capabilities.

Computer modelling became an integral part of storm drainage planning and design in the mid-1970s. Several agencies overseas undertook major software developments and these were soon supplemented by a plethora of proprietary models, many of which were simply variants on the originals. The proliferation of personal computers in the 1990s has made it possible for virtually every engineer to use state-of-the-art analytical technology for purposes ranging from analysis of individual pipes to comprehensive stormwater management plans for entire cities.

In addition to the simulation of hydrologic and hydraulic processes, computer models can have other uses. They can provide a quantitative means to test alternatives and controls before implementation of expensive measures in the field. If a model has been calibrated and verified at a minimum one site, it may be used to simulate non-monitored conditions and to extrapolate results to similar ungauged sites. Models may be used to extend time series of flows, stages and quality parameters beyond the duration of measurements, from which statistical performance measures then may be derived. They may also be used for design optimisation and real-time control.

17.2.1 Advantages and Disadvantages

The analytical power of computer methods gives them major advantages over manual techniques. This is likely to result in more accurate designs, with cost savings by avoiding over- or under-sizing. A very important factor is that almost all computer models can fully account for storage in all stages of the hydrologic/ hydraulic routing. Recent work by Goyen & O'Loughlin (1999) has demonstrated the importance of storage at all stages of the stormwater process, even for individual houses.

Computer models allow some types of simulations to be performed that could rarely be performed otherwise, since periods of runoff or quality measurements in urban areas are seldom very long. It should always be borne in mind, however, that use of measured data is usually preferable to the use of simulated data. Modelling is not a good substitute for data collection, especially for water quality parameters. Although modelling is generally cheaper than data collection, the uncertainties involved, especially in water quality simulation, mandate the collection of data for model calibration and verification.

17.2.2 Basic Principles

The following basic principles apply to all forms of computer modelling:

1. All computer models require site-specific information to be supplied by the user. This may range from relatively simple data such as rainfall or drainage system data, through to detailed parameters for physical, chemical and biological water quality processes.
2. While modelling generally yields more information, simpler methods may provide sufficient information for developing a control strategy. *In general, the simplest method that provides the desired analysis should be used.* The risk of using a more complex (and presumably "better") model is that it requires more expertise, data, support, etc. to use and understand, with a consequent higher probability of misapplication.
3. If water quality problems are being considered, it still may not be necessary to simulate quality processes since most control strategies are based on hydrologic or hydraulic considerations. Quality processes are

very difficult to simulate accurately and they generally incorporate many heuristic procedures that require extensive calibration (Huber, 1985). If abatement strategies can be developed without the simulation of water quality parameters, the overall modelling program will be greatly simplified.

Models sometimes may be used to extrapolate beyond the measured data record. It is important to recognise, however, that models do not extend data, but rather generate simulated numbers that should never be assumed to be the same as data collected in the field.

Careful consideration should be given when using models to provide input to receiving water quality analyses. The quality response of most receiving waters is relatively insensitive to such short-term variations. In many instances, the total storm load will suffice to determine the receiving water response. Simulation of short time increment changes in concentrations and loads is generally necessary only for analysis of control options, such as storage or high-rate treatment, whose efficiency may depend on the transient behaviour of the quality constituents.

17.2.3 Training Needs

An often-quoted adage with computer applications is *'garbage in, garbage out'.* It is essential to understand that incorrect application of a computer model, can lead to totally misleading results.

All computer models require some skill and knowledge, although the depth of training required varies considerably.

Chapter 11 of this Manual noted the large gap between current drainage design practice in Malaysia, which mostly relies on a Modified Rational Method, and techniques in other countries which increasingly use detailed computer modelling. Wisner and Conic (1996) made similar comments, in regard to the situation in both Malaysia and Indonesia, and suggested that an intermediate step such as adoption of a unit hydrograph method, would be useful in raising the understanding of local drainage engineers.

17.2.4 Problem Identification

Studies and projects involving urban stormwater runoff quality can relate to many problems. In a narrower sense, a water quality study may address a particular issue, such as bacterial contamination of a beach, release of oxygen demanding material into a stream or river, unacceptable aesthetics of an open channel receiving urban runoff, eutrophication of a lake, contamination of basements from surcharged drains due to wet-weather flooding, etc.

Simulation of stormwater impacts on receiving water quality involves modelling of both quantity and quality. Superimposed on almost any water quality modelling effort is the need to analyse controls and abatement strategies. The considerable uncertainty inherent in quality modelling makes the effort especially difficult.

17.2.5 Modelling Objectives

If a problem does require modelling, the corresponding modelling objectives should be clearly defined. Models may be used for objectives such as the following:

1. To characterise the urban runoff for temporal and spatial flow distributions, pollutant ranges, etc.
2. To provide input to a receiving water quality analysis, e.g. to drive a receiving water quality model.
3. To determine effects, magnitudes, locations, combinations, etc. of control options.
4. To perform frequency analysis on hydrologic or quality parameters, e.g. to determine return periods of concentration/loads.
5. To provide input to economic analyses.

17.2.6 Modelling Procedures

According to the requirements of the software used, the designer will first assemble and carefully check all the required data on design rainfall, drainage geometry, hydraulic roughness, runoff coefficients, and rainfall abstraction parameters.

In many cases, some of the desired data will not be available and the designer will have to make assumptions and/or use default values given in the user's manual of the chosen software. If these default values seem unsuitable for the design conditions, the designer should test the model sensitivity to these values, using their probable range. If the model is too sensitive to such parameters, it should not be used and the designer should select another model of a similar complexity, or even a simpler one (e.g. as simple as the Rational Method).

The first review and analysis of the required and available data is very important and should not be attempted without a detailed user's manual. From a general point of view, the designer should not operate any comprehensive software without careful inspection of its detailed user's manual describing, with a sufficient detail, the operations, which are performed.

After the preliminary analysis, and according to the design objectives, drainage network complexity, available data, computer facilities, and other factors, the designer should be able to select an appropriate modelling procedure and software to suit the desired purpose.

(a) Data Requirements

Before a model is even considered, some data will be available to indicate that there is a problem. Such observations constitute a data set in and of themselves, and usually indicate the direction for subsequent data collection. At every stage of the preliminary analysis, one must ask if measured data can solve the problem. If so, there is no need to model.

If modelling is required, there are three types of required data; model input data, calibration data, and verification data. Input data consist simply of the required parameters to run the model, and typically include rainfall information, area, imperviousness, runoff coefficient and other quantity prediction parameters, plus quality prediction parameters such as constituent concentration (median value and coefficient of variation, CV), regression relationships, build-up and washoff parameters, etc. Calibration is the process of parameter adjustment to obtain a match between predicted and measured output. Verification holds the parameters constant and tests the calibration on an independent data set. Calibration is used to estimate the value of these parameters, and verification is used to test the validity of the estimate.

Data sets that can be used for calibration and verification may not exist for the site of interest. If the project objectives absolutely require such data (e.g., if a model must be calibrated to derive a receiving water quality model), then extensive local monitoring may be necessary.

(b) Basic Input Data

All models require the user to enter some form of input data. For quantity simulation, these data include catchment areas, imperviousness, slopes, roughness, etc.; channel and conduit linkages, shapes, sizes, slopes, roughnesses, invert and round elevations; characteristics of hydraulic structures or controls such as weirs, orifices and pumps; depth-area-volume-outflow relationships for storage units; information on downstream hydraulic controls, such as river stages or tidal elevations. Since the overall system is driven by rainfall, suitable rainfall hyetographs must be found (see below), as well as baseflow, if any, in the receiving waters.

Rainfall is the driving force for all hydrologic simulation models. If adequate measured rainfall is not available, a good calibration between measured and predicted hydrograph cannot be expected. For calibration purposes, measured rainfall must be input to produce output for comparison with measured hydrographs. However for design purposes, synthetic design storms are used (see Chapter 13).

Continuous simulation or statistical methods offer alternatives to the use of pre-defined design rainfalls. For example, a selection of historic storms can be made from a continuous simulation on the basis of the return period of the runoff or quality parameter of interest, e.g., peak flow, maximum runoff volume, maximum stage, peak runoff load, peak runoff concentration. These events, with their antecedent conditions for runoff and quality, can then be analysed in more detail in a single-event mode. Rainfall is variable in space as well as in time; models that accept multiple hyetographs can simulate storm motion and spatial variation that can strongly affect runoff.

A critical factor in successful hydraulic modelling of existing drainage systems is an accurate survey to determine invert elevations and conduit or channel condition. These are seldom the same as shown on as-built plans because of settlement, deterioration, and modifications to the system.

For water quality simulation, measured or estimated concentrations are generally used to simulate the mix of stormwater and baseflow that occurs during a storm, as well as the characteristics of solids scour and deposition that are to be simulated.

(c) Solution Methods

Methods of various types have been developed for the numerical solution of the equations describing unsteady and varied flow: these have included characteristic methods, finite-difference methods and finite-element methods.

At the present time, finite-difference methods form the basis of the most commonly used procedures/models for the solution of the equations: the partial differential equations are discretised and replaced by the corresponding finite-difference expressions, and values of water level and velocity are derived at discrete locations and at discrete values of time. The progress of the calculation can be visualised as a progression across a plane defined by x and t coordinate axes, x denoting position and t denoting time. The calculation starts from a set of initial conditions specified (for each member of a set of discrete values of x) at an initial value of time, and solutions (for stage and velocity) are obtained at discrete values of x at successive values of time – that is, solutions are obtained at discrete points on an x-t grid, on which the grid spacings are denoted by Δx (the incremental distance along the channel) and Δt (the time increment). It is not necessary that Δx and Δt have constant values over the entire x-t grid, although a constant value is usually specified for the time increment Δt.

Finite difference methods can be classified as

- explicit methods, or
- implicit methods

In an explicit method, the determination of the flow parameters at a given value of x (position) and t (time) is carried out without reference to the parameter values at other values of x at the same value of t – that is, the advancement of the solution through a time step is carried out at one grid point at a time. An implicit method, on the other hand, involves the setting-up and solution of a set of simultaneous equations involving the unknown parameter values at all values of x (together with the boundary conditions) at a given value of time. Some methods incorporate features of both classes, and hybrid implicit-explicit methods exist.

(d) Numerical Stability

If a numerical model is to yield useful results, it is essential that the scheme of computation on which the model is based should cause errors in calculated parameter values to decay rather than to propagate with increasing amplitude as the calculation proceeds forward in time. A computation scheme having this attribute is said to be stable. In practice, stability requirements impose upper limits on the spacing (Δx) of values of x and on the time increment Δt used in the calculation.

The conditions for stability in computation schemes of the explicit type are generally defined by the relation known as the *Courant Criterion*.

Computation schemes of the implicit type are inherently more stable than explicit schemes, as a result of the interaction amongst the simultaneous equations which are solved at each time step in an implicit scheme. Hausler and Apelt (1981) discuss the stability of implicit computational schemes.

(e) Initial and Boundary Conditions

The calculation starts with a prescribed set of initial conditions and must incorporate, as it progresses through time, the appropriate boundary conditions. Zoppou and O'Neill (1981) discuss some aspects of initial and boundary conditions.

In the interests of efficiency, it is desirable that the prescribed initial conditions should be as realistic as possible. Uniform flow conditions, or a steady-state water surface profile, may provide a suitable set of initial conditions. In general, the effects of the initial conditions will decay as the calculation progresses; Zoppou and O’Neill (1981) have drawn attention to certain cases in which errors in the initial conditions may not decay.

The boundary conditions which may exist at the extremities of a numerical model include a specification of discharge as a function of time (for example, a flood hydrograph), a specification of stage as a function of discharge (a rating curve) and a specification of stage as a function of time (for example, a tide curve).

(f) Calibration and Verification

The process of calibration of the model involves the adjustment (“tuning”) of the model to cause it to reproduce, with an acceptable degree of precision, known prototype behaviour. Adjustment (usually on a trial-and-error basis) of the following features may be undertaken:

- details of the computation scheme itself;
- the grid spacing, the distance Δx and the time step Δt;
- the definition in the model of the channel/storage geometry;
- values of the roughness parameter for various parts of the boundary;
- boundary conditions;
- values of discharge coefficients in “cell” models.

Failure to reproduce prototype behaviour may be due to errors in geometry: such errors may arise either from actual errors in survey information or from erroneous entry of data into the model. Where the form of a channel reach of irregular shape has been “schematised” and approximated by a regular geometric shape, adjustment of the schematised shape may be required.

Initial estimates of values of the Manning roughness parameter will usually be derived by application of recognised procedures, on the basis of the recognisable physical characteristics of the boundary surfaces. It is to be expected that calibration of the model should be possible without gross variations of the roughness parameter values from these initial estimates, although the effects of flow unsteadiness may necessitate some variation, particularly in cases involving tidal flows (with reversals of direction) in alluvial channels. Any necessity to adopt roughness parameter values which are grossly inconsistent with the physical characteristics of the channel boundaries should be a cause for concern, and must dictate caution in the use of the model for the prediction of flow parameters under conditions which are substantially different from the conditions applying in the calibration of the model.

Verification of the model involves further confirmation, after the process of calibration has been completed, of the model’s ability to reproduce known prototype behaviour. The prototype data used in verification of the model should obviously be independent of the data used as the basis for calibration of the model.

Only in exceptional circumstances will a completely adequate body of appropriate and reliable prototype data be available for the calibration and verification of the model. The probable limitations applying to the reliability and precision of the available data should be kept in mind. It is necessary to assess, in each individual case, the precision with which agreement between model results and prototype data must be achieved in order to establish that calibration and verification of the model have been effected; this assessment must take into account all the circumstances associated with the particular investigation.

(g) Accuracy

On the assumption that a given computation scheme is stable, as discussed in the preceding section, consideration of the accuracy of the scheme involves assessment of the "correctness" of the results yielded by the scheme – that is, of the extent to which the calculated parameter values are in agreement with the "true" physical values. In the case of free-surface flow in irregular channels, the "true" values are rarely known. Thus, in general it is not possible to assess the absolute accuracy of a computation scheme.

The inherent accuracy of a computation scheme will depend upon the extent to which higher-order terms are included in the finite-difference expressions derived from the basic differential equations or use of higher order elements in finite element method. In principle, the accuracy of a scheme can be improved by the inclusion of higher-order terms. The accuracy of the results derived from a given finite difference model can also be improved by decreasing Δx and Δt. Improvements in accuracy gained in either of these ways will involve increases in the run-time and costs of operating the model.

Recent improvements in computing power have allowed most of these problems to be overcome. In general it can be stated that with most present-day models, errors arising from the inherent characteristics of the computation scheme will probably not be significant, in comparison with the much greater uncertainties associated with the definition of rainfall inputs, losses, system geometry and hydraulic roughness.

(h) Sensitivity Analysis

Before attempting to calibrate and verify a model, the user should be familiar with its capabilities and nuances. Some models have very few parameters to adjust, simplifying the calibration process, but others may have more. The user should perform a sensitivity analysis (with hypothetical data if necessary), varying key parameters by known percentages and inspecting the change in output. In this way, it will be far easier to know which parameters should be changed during the calibration process.

For example, in urban areas, most models are highly sensitive to imperviousness but only slightly sensitive to soil infiltration parameters. First runs with any model should deal with a very simple configuration for which the result is known, e.g., steady rain on an impervious surface and build up gradually to more complex and realistic systems. In this way, the user can exercise good judgement regarding the validity and reasonableness of the results.

(i) Calibration

Model calibration consists of adjusting model parameters (e.g. imperviousness, roughness) until the predicted output agrees with measured observations. For example, the predicted hydrograph or pollutograph may be adjusted to agree with the measured hydrograph or pollutograph. For most models, calibration will be performed using observed storm events. How many storms are required cannot be answered exactly, but 3-6 events are desirable. The calibration process should be performed simultaneously for all available storms in order to produce a robust calibration. In this instance, the single set calibration parameters will result in less-than-perfect fits for any single storm but better for all storms together, and presumably better for further predictions.

Calibration tends to be subjective. When several storms are used, it is customary to plot predicted versus measured peaks and predicted versus measured volumes, seeking to produce points that fall on the 45-degree line indicating perfect agreement. Deviations from the line of perfect fit are one measure of the goodness of fit. Hydrographs should also be compared visually for shape and peak.

During the calibration process, care must be taken to make sure that the physical parameters are not adjusted outside their reasonable range to achieve a "calibration". For example, if the Manning roughness coefficient for a concrete pipe has to be set at 0.10 to achieve calibration, most likely there is an error in the input data of some other variable such as channel/pipe slope or model conceptualisation.

Calibration usually provides the only means for determining values for input parameters related to water quality, such as build-up rates and washoff coefficients. Although limited measurements of surface constituents have been conducted (Terstriep et al, 1982), such data are generally useful only for a first parameter estimate. Quality concentrations and loads are so difficult to predict that calibration data provide almost the only practical means for parameter estimation.

(j) Verification

Verification is the process of testing whether a calibrated model can reproduce observations in an independent set of model events. Ideally, an equal number of storms should be used for verification as for calibration; however, 1-3 events often seems to be the pragmatic limit of the number of storms that can be afforded for this purpose. Goodness of fit may be assessed similarly to the method used for calibration. In the more unlikely event that the verification is poor, an improved calibration can be attempted. This is sometimes performed using a different grouping of storms for calibration and verification than was used during the first attempt.

(k) Uncertainty Analysis

Uncertainty analysis is rapidly becoming part of accepted modelling practice. It involves varying the model-input parameters and examining the effect on the output, as described above under *Sensitivity Analysis*.

Uncertainty analysis can be used to compute expected output variability as a function of ill-defined input parameters. This technique can serve as a means of quantifying the model's acceptability.

Uncertainty analysis can also be useful in evaluating the relationship between field data sampling and modelling. Hypothetical sampling scenarios can be tested to understand the expected uncertainty in model output. If the level of output variability is too large, the sampling strategy can be improved until an acceptable level of model output uncertainty is achieved. Finally, uncertainty analysis can also be used to quantify model acceptability (expansion of goodness-of-fit testing).

(l) Production Runs

Following the successful calibration and verification processes, the model is ready for application to the practical problem. During this phase, just as in earlier phases, all model parameters and results should be double-checked for reasonableness. Continuity checks built into a model often aid in checking results so that an unrealistic gain or loss of water or pollutants can be noticed. Violations of continuity sometimes indicate numerical problems, but more likely they may indicate an error in model schematisation.

17.3. OVERVIEW OF AVAILABLE SOFTWARE

17.3.1 Classification Schemes

Several classification schemes can be developed for models and software, to differentiate the type and versatility of various models, e.g., deterministic versus stochastic, transient versus steady state, lumped versus distributed, number of dimensions, quality and/or simulation, etc.

One way of looking at modelling is to consider that there are several levels of the process/application – from planning, analysis and design to operation that can be used for classifying software.

(a) Planning Level

Planning involves a comparison of general design and/or mitigation strategies and may include optimisation and risk assessment. At the planning level, the relative effectiveness of alternative drainage and flood control practices may be assessed and economic trade-offs evaluated. Modelling is likely to be somewhat less detailed in an effort to screen several alternative strategies. Continuous simulation can be useful at this level to determine relative flooding frequency as affected by alternative stormwater management programs, selection of hydrologic events for detailed design and assessment of the reliability of a proposed design, and economic optimisation.

(b) Analysis and Design Level

At the analysis/design level, the detailed analysis of an existing system, proposed system, or system improvements is investigated. Examples include analysis of alternative surface drainage patterns, location of detention storage facilities, and alternative runoff transport systems (e.g. swales vs. pipes). Design models must be capable of performing realistic simulation of hydrologic, hydraulic and possibly, water quality phenomena.

(c) Operation Level

Operational control facilities/structures are devices that function during a storm such as variable weirs, pumps and gates. The operational rules and performance of these devices can be simulated using an appropriate computer software in order to optimise their operation rules and design. A further development is application of real-time control of pumps, diversions, weirs and storages to optimise the performance of the drainage system.

Another important division of models is into *deterministic* and *stochastic* types. Deterministic models attempt to reproduce physical, chemical and even biological processes (to the extent that such processes can be understood scientifically) to produce outputs, while stochastic models represent the outcomes of processes by statistical analysis.

In practice many models use a mixture of the two techniques. Processes that are too complex or poorly understood to be modelled deterministically, may be represented by statistical characteristics; while many statistical models also employ simple process-type mechanisms.

A third useful classification is into *hydrologic*, *hydraulic* and *water quality* model types. The usage of these three terms is the same as elsewhere in this Manual. Some models are only of one type, but others include two or all three of the above types. A fourth type of model, of *receiving waters*, is used in environmental assessments. Receiving water models are outside the scope of this Manual and therefore, they are only briefly mentioned.

Quantity modelling is relatively well understood. Many models can convert rainfall into runoff and perform flow routing; the user can make a selection on the basis of method used, computer supported options included, etc. A reasonably accurate prediction of a runoff hydrograph will result if the modeller knows just three input parameters: the catchment imperviousness (or directly connected or hydraulically effective imperviousness), the catchment area and the rainfall hyetograph. Given these three parameters, hydrograph volumes and peaks may be predicted within reasonable accuracy even before calibration.

Quality modelling is quite different. In a review of quality modelling methodologies, Huber (1985) concluded that prediction of absolute values of concentrations of quality parameters was not possible without calibration and verification data. That is, first-cut modelling attempts may differ from "true" values by orders of magnitude for concentrations and loads. The general conclusion is that modelling of quality parameters should be performed only when necessary, and only when requisite calibration and verification data are available. Nevertheless, modelling without measured calibration and verification data can still be used to assess the *relative* effect of control strategies. This can be a valuable planning tool.

Subsequent sections discuss each type of model. A summary of some of the currently available modelling software is given in Appendix 17.A.

17.3.2 Software Selection

The brief abstracts in subsequent sections, information in Appendix 17.A, and the comparative reviews referenced previously may help in selection of modelling software, but the choice is often made on much more pragmatic grounds. For instance, a Government agency may specify that certain software be used for reasons of standardisation; or local support may be available for a particular software.

Probably the most important factor is familiarity of the potential user with techniques employed by the software. Inferior techniques applied by a knowledgeable engineer will often produce much more reliable results than a sophisticated model that the user does not understand and therefore treats as a "black box".

Data availability is another important consideration. For instance, complex flow routing cannot be performed in a stormwater system without extensive data, which may lead the engineer to a simpler technique that is not so data intensive. The need for data should not be ignored, however. If the problem is sufficiently complex, there may be no alternative to the use of a sophisticated model and its attendant data collection requirements.

The number of modelling options is very large; the reviews provided here are representative of the best known operational models, but are not all-inclusive. The potential modeller should consult current publications for information on availability of new models. All of the listed models use metric units.

This Chapter discusses only those models that are "operational", i.e. defined as satisfying the following three criteria:

1. An operational model must have documentation. This must include a user's manual that describes input data requirements, outputs to be expected, and computer requirements. In addition, the theory and numerical procedures used in the model predictions should be stated. Documentation is the characteristic that most often distinguishes a model that can be accessed and used by others from the other computerised procedures described in the literature.
2. An operational model must have support. Normally this is provided on commercial terms by the original software developer. Support means that the user can obtain answers, by telephone or written correspondence, to problems that arise during model implementation and use.
3. An operational software program should have been widely used by other than just the software developer. Regardless of its technical virtues, a procedure described in a single journal article or report with no experience or "review" by the engineering community is a poor candidate for use by a third party. Furthermore, user feedback is an invaluable means for identifying software limitations and "bugs," and initiating improvements and corrections to a software. Of course, no model will meet this third criterion initially, and the prospective user must decide on the relative merits of new options versus older ones.

17.3.3 Public-Domain or Commercial Software

Modelling software may be provided either in the public domain, or by commercial suppliers. A few well-known models, such as SWMM, have versions in both domains and it is important that the user considers the choice.

Public-domain software usually is produced by either government agencies, particularly in the USA, or academic institutions. It is available either free or at a nominal cost (usually less than US $100) to cover the cost of distribution. Many public-domain models are available for download from the Internet and these have been noted, where possible, in Appendix 17.A. Public-domain software generally has only limited user support and documentation. In some cases volunteer user groups can provide support. Training courses may be available from commercial operators.

Commercial software, on the other hand, has a higher cost but contain more useful features. Value-added features such as graphical interfaces or linkages to Geographic Information Systems (GIS) and CADD are usually only available in commercial software. On-line documentation is now accepted practice and it should be provided with the software. Almost all commercial software suppliers offer training, support and more regular upgrades and all of these features would involve additional costs. The cost of these features should be compared with their value to the user.

An important consideration with either type of software is the reliability of the supplier. Problems will be caused if either a public-domain or commercial software ceases to be supported. Because of incompatible data formats it is difficult to transfer data from one model to another.

17.3.4 Computer Aided Design and Drafting (CADD)

Computer Aided Design and Drafting (CADD) has become synonymous with microcomputer workstations and high quality graphics or drawings transferable from the computer to mylar, and then to blueprints. It is possible to computerise standard design details, such as manholes, catch basins, headwall and piping, and to store them in the computer for later recall and insertion on a detail sheet. Many manufacturers of drainage products have developed design drawings that can be modified on the user's computer to customise them for an individual project.

Computer Aided Design (CAD) in the field of urban development, usually involves the creation of a Digital Terrain Model or DTM. This is a three-dimensional model of the existing and finished land surfaces by coordinates and graphical representations. Several CAD programs are able to directly generate a DTM from survey data obtained by means of a Total Station instrument. Once a DTM has been set up it facilitates many of the routine design calculations, and it also allows rapid checking of a number of design alternatives.

In hydrology and hydraulics, computer simulation has been significantly enhanced by the use of graphic displays to aid in data entry and editing, for instance to follow graphically changes in the hydraulic gradient as the simulation progresses. Moreover, these capabilities have been expanded and merged with surveying and drafting packages to provide even greater flexibility. For example, after digitising topographic data into the computer, a detention basin can be graphically designed on the computer screen. The basin's volume then can be calculated from the drawings and interactively input into the hydraulic model (in the model's required format).

Other programs are available that can combine standard input data with data supplied for the individual design by the user and calculate times of concentration, travel times, inflow/outflow hydrographs, stage/storage/ outflow curves, etc. The rapid improvements in both software and computer hardware mean that, in the future, the possibilities will be limited only by the imagination and skill of the user.

17.3.5 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) enable the user to incorporate a wide range of spatial information about the physical system into a computer database. This can include not only information about the ground surface, but details of the urban infrastructure (water, wastewater, streets, electric, gas, etc).

Rapid developments are occurring in the GIS field in order to integrate all the elements described above into a complete mapping and hydrology/hydraulic analysis and design package that can:

1. Provide watershed physical feature mapping
2. Compute hydrologic model input parameters such as catchment areas.
3. Model the rainfall/runoff process to determine design flows
4. Provide the capability for on-screen design of the system, including conveyance structures and appurtenances
5. Optimise the final design
6. Map or draw the system as designed, including plan and profile drawings of all structural components.

These developments can eliminate many of the repetitive calculations in drainage design. Opportunities for linkage to GIS systems are an important factor in the selection of computer models.

It should be noted that the requirements for checking and verification of designs so developed will still be necessary (or perhaps even more important).

17.4 HYDROLOGIC MODELS

17.4.1 Description

Most hydrologic models attempt to simulate the rainfall-runoff process. This ensures that the effects of rainfall, the single most important hydrologic variable, are properly taken into account.

17.4.2 Rational Method Models

The Rational Method is quite simple to program into a spreadsheet and therefore few efforts have been made to produce it in computer model form. One such model which is used for small sub-divisions in Australia and elsewhere is **RatHGL**. This software combines the Rational Method hydrology with HGL calculations in an iterative manner.

17.4.3 Hydrograph Method Models

(a) Time-Area Method

The Illinois Urban Drainage Area Simulator (**ILLUDAS**) (Terstriep and Stall, 1974) evolved from the British Road Research Laboratory Model (Watkins, 1962; Stall and Terstriep, 1972). The model uses time-area methods to generate hydrographs from the directly connected impervious area and from the pervious area. For pervious areas, the Horton infiltration equation is used to generate typical infiltration rates based on input of the soil's SCS hydrologic group. A design routine is included that will re-size pipes of insufficient hydraulic capacity. User-provided stage/discharge/ storage relationships are used to provide detention facilities anywhere in the system. Plots of calculated and observed hydrographs may be produced. Its simplicity and metric option have given ILLUDAS widespread use. Although quality is not formally included in the model, it has been added for special applications (Noel and Terstriep, 1982).

The **ILSAX** program (O'Loughlin, 1993) is a widely used Time-Area model in Australia. It is a general-purpose hydrologic and hydraulic model. ILSAX is a MS-DOS program developed from the South African ILLUDAS-SA program, which was itself a development of the American ILLUDAS program and the British Transport and Road Research Laboratory Method (known as the TRRL or RRL model). In 1998 an enhanced version of ILSAX, known as **DRAINS** was released commercially in Australia. Within a single package, it integrates several types of procedure (design, analysis, hydrology and hydraulics) and various scales of operation (property drainage, street drainage, trunk drainage and river flooding analysis). Its design and analysis procedures lie between relatively simple methods (such as the Rational Method and a water surface profile for maximum flows) and rigorous, complex procedures (such as hydrological physical process models and full hydrodynamic, unsteady flow models), providing a good compromise between simplicity, ease of use and accuracy.

DRAINS/ILSAX and the Transport and Road Research Laboratory (**TRRL**) Model, both use the Hydrograph Method. These models require the user to divide the catchment into sub-areas and enter the following general types of input: catchment characteristics, travel times, and characteristics of the assumed concentrated storage at the sub-area outlet. DRAINS/ILSAX allows for separate routing of three distinct areas:

- directly-connected impervious area
- supplementary area
- pervious area

Separate routing is recommended in urban areas in order to adequately represent the catchment response.

Other similar hydrograph models/Software include MIDUSS and StormCAD (Appendix 17.A).

(b) SCS Method

The original Soil Conservation Service (**SCS**) methodology developed for general application (USDA, 1971) was later adapted specifically to urban areas, and the latter procedure has come to be known as **TR55** (USDA, 1975). An updated user's manual is available (USDA, 1986a), along with a microcomputer version (USDA, 1986b).

Unit hydrographs are used to convert rainfall into runoff. Flow routing in channels can be performed separately by another model such as by the companion TR20 program (USDA, 1983). SCS methods are widely used in the United States due to the wealth of soil information provided by the agency. Additional background on the method is provided by Viessman et al (1989) and McCuen (1982). Information on application is usually available from local SCS offices as well.

17.4.4 Rainfall-Runoff Routing Models

Rainfall-runoff models are so called because they use various mathematical representations of the rainfall-runoff process. A generalised depiction of this process is shown in Figure 17.1. The different formulations vary in complexity and suitability for different applications.

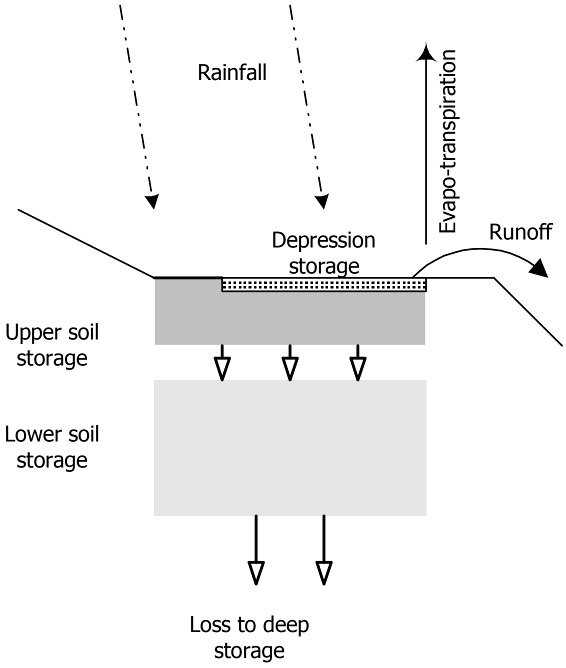

Figure 17.1 Rainfall- Runoff Processes

In urban drainage applications, separate routing of the impervious and pervious catchment area components is recommended in order to adequately represent the catchment response.

RORB (Laurenson and Mein, 1990) and **RAFTS** (Goyen et al, 1991) are Australian examples of rainfall-runoff and streamflow routing models. Both are suitable for systems ranging from urban drains to large river catchments. They include optional channel routing and optional storage routing for dams or ponds. Alternatively, they can be used in combination with a detailed hydraulic model such as those in Section17.5. Other overseas programs with similar capabilities include **HEC-1** or its latest version **HEC-HMS**.

The HEC-1 model developed by the U.S. Corps of Engineers Hydrologic Engineering Centre is designed to simulate the surface runoff response of a river catchment to precipitation by representing the catchment as an interconnected system of hydrologic and hydraulic components. Each component models, an aspect of the precipitation-runoff process within a portion of the catchment, commonly referred to as a sub-catchment. A component may represent a surface runoff entity, a stream channel, or a reservoir. The result of the modelling process is the computation of streamflow hydrographs at desired locations in the river catchment. Multiplan-multiflood analysis allows the simulations of up to nine multiples (ratios) of a design flood for up to five different plans (or characterisations) of a stream network in a single computer run. Dam-break simulation provides the capability to analyse the consequences of dam overtopping and structural failures.

The original version of the Storm Water Management Model **(SWMM)** was developed for EPA as single-event model specifically for the analysis of combined sewer overflows (Metcalf and Eddy Inc., 1971). Through continuous maintenance and support, the software now is well suited to all types of storm water management from urban drainage to flood routing and floodplain analysis. Version 4 (Huber and Dickinson, 1988; Roesner et al, 1988) performs both continuous and single-event simulations.

SWMM is segmented into the Runoff, Transport, Extran, Storage/Treatment and Statistics blocks for rainfall-runoff, routing and statistical computations. The Runoff block provides five alternative hydrograph methods: the Runoff Non-linear Method, Kinematic Wave, Laurenson Routing, SCS Unit Hydrograph, and Time-Area Methods. Water quality may be simulated in all blocks except EXTRANS, and metric units are optional. Ex-proprietary portions have been adapted for various specific purposes and locale by individual consultants and other federal agencies, e.g., FHWA. Mainframe and microcomputer versions are available from EPA in Athens, Georgia. Several proprietary versions are available (see list in Appendix 17.A).

17.4.5 Hydrologic Models for Other Purposes

All of the methods listed in the preceding sections can be successfully used in urban drainage calculations. These calculations are primarily concerned with flow peaks during intense rainfall. Under these conditions, impervious area response dominates and the influence of soil type and loss rate is relatively insignificant.

Different problems arise in the modelling of large catchment areas and river systems. The influence of pervious areas, soil loses and evapo-transpiration becomes significant. Rainfall-runoff models can be used in this situation with careful calibration. The issues involved in modelling the hydrology of large river systems are outside the scope of this Manual.

Many of the well-known hydraulic models listed in the next section have optional input hydrograph generation procedures. For example, SWMM has a range of options in its RUNOFF module, ranging from simple Rational Method type calculations to rainfall-runoff routing. Some of the widely-used hydrologic software in Europe and the US are designed for calculating inflows to combined sewer systems. As such they have only limited application to drainage problems in Malaysia. Also, it should be borne in mind that different parts of the world have very different climate and hydrologic responses. More research is needed to identify the most suitable hydrologic models for Malaysian conditions.

17.5 HYDRAULIC MODELS

17.5.1 Description

All hydraulic models are deterministic. The basic hydraulic and hydrodynamic equations are well known and described in Chapter 12, and in numerous theoretical texts. Different hydraulic models take various approaches to solving these equations within the bounds of user friendliness, reasonable computing requirements, and stability.

Unlike the situation with hydrologic models, the basic hydraulic principles are common throughout the world and therefore there is no difficulty associated with adopting models developed in other countries.

17.5.2 Free Surface Hydraulics

(a) Steady-state Models

By far the most widely used steady-state one-dimensional hydraulic model for open channels is **HEC-RAS** or its predecessor, **HEC-2**. This program, which was developed by the U.S. Corps of Engineers Hydrologic Engineering Centre, is intended for calculating water surface profiles for steady, gradually varied flow in natural or man-made channels. Both subcritical and supercritical flow profiles can be calculated. The effects of various obstructions such as bridges, culverts, weirs and structures in the floodplain may be considered in the computations.

The computational procedure is based on the solution of the one-dimensional energy equation with energy loss due to friction evaluated with Manning's equation. The computational procedure is generally known as the standard-step method. The program is also designed for application in floodplain management and flood insurance studies to evaluate floodway encroachments and to designate flood hazard zones. It is also capable of assessing the effects of channel improvements and levees on water surface profiles.

HEC-RAS was developed from HEC-2 to provide better capability with modern personal and microcomputers. The current Version 2.2 released in 1998, has user-friendly data entry and graphical output and a comprehensive online help function. HEC-RAS is available both in the public domain and commercially.

(b) One-dimensional Hydrodynamic Models

Among the best-known and widely used one-dimensional open channel hydrodynamic models are **MIKE-11** and **EXTRAN**. MIKE-11 is mainly suitable for rivers. Both models use a link-node approach where the channel is divided into sections, of uniform cross-section and flow. Flow hydrographs and other boundary conditions are applied at nodes.

EXTRAN, a component of SWMM is a one-dimensional model, which is particularly applicable to urban drainage channels, where it is necessary to be able to also model structures such as weirs, culverts, drops and super-critical flow.

Hydrodynamic models are recommended for situations where storage behaviour and other time-dependent effects such as varying tailwater, are being considered. Steady-state models such as HEC-RAS can give misleading results in such situations.

Up to this point, the discussion has been limited to consideration of a one-dimensional model of flow in a single channel. An extension of the concept permits the investigation of flow in a channel system which consists of (or may be schematised into the form of) a network, of greater or less complexity, of one-dimensional channels by constructing a branched link-node system (Phillips et al, 1991).

Examples of such systems include channels with junctions (of tributary channels) or branches, or where the flow is divided around one or more islands. Such a configuration may also be used to represent flow in a channel of compound cross section where the interaction between the main channel flow and the overbank flow is of such complexity that the traditional one-dimensional approach, is considered inadequate.

The simplest type of network model is that in which the channel system consists of a main channel and tributary streams only – that is, the system includes junctions but does not include branches or flow divisions. When channel systems of greater complexity are considered, two particular types of network model may be recognised – the link-node type and the cell type.

In a link-node model, the channel system is schematised (in plan) in the form of a system of storage elements, each of which is centred on a node of the model, and a system of conveyance elements (channels) connecting the nodes. The storage elements and the conveyance elements are not physically separate the storage elements collectively occupy the entire volume of the channel system, as also (in general) do the conveyance elements. Accordingly, a given element of space within the channel system will usually form part of a storage element and also part of a conveyance element. Operation of the model involves the application, at each time step, of the one-dimensional equation of motion to the flow in each conveyance element and of the continuity equation at each storage element.

(c) Two-dimensional Hydrodynamic Models

In a narrow river channel, the predominant direction of flow in the channel is parallel to the boundaries. In a pond, the boundaries dictate the flow pattern only in the immediate vicinity of the boundaries.

The investigation of flow in ponds requires the use of a two-dimensional model. With the x and y co-ordinate directions in the horizontal plane, the governing equations are:

- the Equation of Motion for the x co-ordinate direction;
- the Equation of Motion for the y co-ordinate direction;
- the Equation of Continuity, in a form appropriate to two-dimensional flow.

Starting from a prescribed set of initial conditions, the calculation is advanced through time in a manner analogous to that outlined above of a one-dimensional model.

two-dimensional models may also be used for wide rivers, floodplains and estuaries. Such applications are generally outside the scope of this Manual.

17.5.3 Pipe Hydraulics

(a) Steady-State Models

In contrast to the widespread use of HEC-RAS for open channels, steady-state pipe hydraulic models are not widely used. Essentially they perform the same calculations as in the manual Hydraulic Grade Line computation, described in Chapter 25. The hydraulic grade line component of **RatHGL** is one example of such a model. In practice, since very little more effort is required to set up or run a hydrodynamic pipe model than a steady-state pipe model, the former is more widely used.

(b) Hydrodynamic Models

A number of hydrodynamic models of pipe systems exist. Their development has tended to focus on the combined sewer systems in the USA and Europe, but they are equally suitable for stormwater pipes.

17.5.4 Hydraulics of Drainage Networks

Many of the newer models can handle both pipe and open channel hydraulics. This allows modelling of complex drainage networks including a range of different conveyance systems.

The hydraulic component of **DRAINS/ILSAX** can model pit entry capacities, bypass flows, and overflows from inlets, and route them from one entry pit to another. It can also simulate the behaviour of detention basins, non-circular conduits, and open channels.

SWMM can simulate backwater, surcharging, pressure flow and looped connections (by solving the complete dynamic wave equations in its Extran Block); and has a variety of options for quality simulation, including traditional build-up and washoff formulations as well as rating curves and regression techniques. Subsurface flow routing (constant quality) may be performed in the Runoff Block in addition to surface quantity and quality routing, and treatment devices may be simulated in the Storage/Treatment Block using removal functions and sedimentation theory. A hydraulic design routine is included for sizing of pipes, and a variety of regulator devices may be simulated, including orifices (fixed and variable), weirs, pumps, etc. A bibliography of SWMM usage is available (Huber, 1986) that contains many references to case studies. Other software with similar capabilities includes **MOUSE**.

17.6 WATER QUALITY MODELS

17.6.1 Description

Only the deterministic type of water quality model is really useful for urban stormwater studies. Because this type of model allows the inputs to be varied, the effects of various alternative stormwater management actions can be tested (at least in principle). Stochastic models exist but are not discussed here.

All water quality models of the deterministic type have a hydrodynamic model as their base. It is obviously necessary to have an adequate understanding of the quantities of stormwater and its movement, before any attempt can be made to investigate its quality. It is equally essential to *calibrate* the hydrodynamic base as accurately as possible, before investigating water quality.

Various water quality modules are then applied to the basic hydrodynamic model. Often there is a facility for the user to select which of the different water quality modules are required for a particular application.

17.6.2 Water Quality Load Models

AQUALM-XP is a relatively simple model for calculating pollutant loads over long periods. It also includes some types of structural control measures such as ponds or GPTs.

AQUALM-XP uses the modified Boughton rainfall/ runoff model, which is especially suitable for long-period simulation. It uses a daily time step. The model is not intended for flood simulation as it does not accurately represent flood peaks. Pollutant loads are generated using either export rates or EMCs.

It is strongly recommended that the AQUALM-XP model should only be used if flow calibration data is available, or if hydrology model parameters can be transposed from a nearby catchment for which model calibration has been performed. Use of the model without flow calibration can give very misleading answers.

17.6.3 Water Quality Process Models

Much of the recent and ongoing development in water quality models is directed at the modelling of water quality processes.

SWMM is an example of a general-purpose model capable of being used in a wide variety of water quality studies. Processes, which can optionally be simulated within the software, include pollutant build-up, wash-off during rainfall, transport, advection, sedimentation, and bio-chemical processes. In all cases the user will need to choose suitable values for the process parameters. Limited guidance is available within the program, or from documentation. However in the current state of knowledge these models are best used only by those with adequate expertise and in situations where calibration to local conditions is possible.

Other software with similar capabilities includes the water quality components of MOUSE.

17.7 RECEIVING WATER MODELS

To complete the full cycle of network analysis, it is necessary to consider the impact of the quantity and quality of urban stormwater that is discharged to a *receiving water* such as a river, lake or estuary. A range of receiving water models exists for this purpose.

In principle, receiving water modelling could be used to assess whether, in the face of loads generated from urban development or other activities, the receiving waters meet or are likely to meet the target water quality standards. In practice, this is a major task, which is outside the scope of this Manual. These models are generally very demanding in the amount of data entry required for initial set up, and in the computing power and run time required for an accurate simulation. Many users of this Manual would have little or no need to use such models. They are therefore only described briefly.

As well as the inputs of quantity and quality of urban stormwater, receiving water models typically require input of natural river flows, tidal boundary conditions, currents, wind, temperature, solar radiation, and any point source loads such as from a wastewater treatment plant. Ignoring any of these inputs will result in an invalid model. Therefore, by their very nature these models require an interdisciplinary approach.

(a) Types of Receiving Water Models

All receiving water models use a hydrodynamic model as their base. Various water quality modules are then applied to the basic water movements. Often there is a facility for the user to select which of the different water quality modules are required for a particular application.

Receiving water modelling software can be classified as one-, two- or three-dimensional according to its representation of the basic flow hydrodynamics. Not surprisingly, the complexity increases greatly as the number of dimensions increases.

One-dimensional models are suitable for analysing stormwater or other impacts in many well-mixed river systems. The assumption involved is that river flow is completely mixed due to turbulence and therefore it is not necessary to consider variations across the river, nor variations with depth.

A useful variation of the one-dimensional model is the *one-dimensional layered* model. In essence this consists of two or more one-dimensional models, one above the other representing layered or stratified flow. Special routines handle the hydraulic interaction and pollutant mixing between the model layers. Stratified flow is often encountered in estuaries/reservoirs, where freshwater runoff passes relatively unmixed over deep, saline water, and these models are useful in that application.

Two-dimensional models are used in situations where the effects of flow in the horizontal direction need to be considered, but the flow can be considered to be uniform in a vertical direction. They are therefore, typically used for shallow lakes, wide rivers and estuaries where stratification is not likely to occur.

Three-dimensional models solve the full hydrodynamic equations in three dimensions. Because of their complexity and computing power requirements their application is generally only warranted in the most detailed and sophisticated analyses.

17.8 CURRENT STATE-OF-THE-ART

The "state-of-the-art" of computer modelling for stormwater drainage, at the time this Manual published (2000), can be summarised as follows:

(a) Routine Applications

Use of computer methods for these applications is widespread among government agencies and consultants in the developed world, e.g. Europe, North America, Japan, Australia and New Zealand; and increasingly in Malaysia. These include:

- use of standard design rainfall inputs, derived by statistical analysis of local data;
- use of geometric data and real-world coordinates, directly transferred from DTMs in CAD or GIS systems;
- computer-assisted sizing of drainage system designs prepared at the sub-division level;
- HGL calculations (pipes) or water surface profile calculations (open channels) for design;
- analyses of the behaviour of existing drainage systems in order to identify deficiencies;
- hydrodynamic analysis of detention storage systems; and
- sizing of water quality control devices based on nominated performance criteria.

(b) Specialised Applications

Use of computer methods for these applications is more limited because of the specialised nature of the software, cost and skill requirements.

- modelling of internal circulation and processes in lakes and ponds;
- modelling of water quality loadings at a catchment scale;
- modelling of the impacts of point and non-point source loads on receiving waters.

It is the aim of this Manual to encourage the adoption in Malaysia of similar practices to those listed above.

17.9 REVISIONS

While it is as up to date as possible, it is inevitable that the information herein will rapidly be superseded by new technological developments.

Users interested in updating their knowledge should regularly review the technical literature. Technical conference papers, in particular, often contain reviews of the latest 'state-of-the-art' of computer modelling.

APPENDIX 17.A LIST OF COMPUTER MODELLING SOFTWARE

This list contains a summary and information on the computer modelling software referred to in this Chapter. The list does not include all available software. Inclusion of a program on this list does not imply endorsement by DID. Other programs that are not listed may be equally or more suitable for particular applications.

Table 17.A1 List of Computer Software and Suppliers

Program Group & Software Name	Description (see text for details)	Hydrology	Hydraulics				Water Quality		Planning		Suppliers (see List)
		Flood Routing	Open Channels, Waterways	Pipe Systems	Culverts, Bridges, Structures	Storage Routing	Pollutant Estimation	Water Quality Controls	BMP Evaluation	GIS/ CAD Integration	
<u>Hydrology only</u>											
RORB	Conceptual Model	Event				√					
HEC-1/HMS	Conceptual Model	Event				√				L	3, 4, 7, 10
XP-RAFTS	Conceptual Model	Event				√				L	11
<u>Hydraulics only</u>											
HEC-RAS	One-dimensional open channel steady-state hydraulics		√		√					√	3, 4, 5, 7, 10
<u>Hydrology and Hydraulics</u>											
XP-RatHGL	Rational Method hydrology, steady-state hydraulics	Event		√						√	11
DRAINS (ILSAX)	Time-Area hydrology, storage, pipe or open channel hydraulics	Event	√	√		√				L	9
MIDUSS	Time-Area hydrology, storage, pipe or open channel hydraulics	Event		√		√					4
StormCAD	Time-Area hydrology, storage, pipe hydraulics	Event		√		√				√	7

(continued)		Hydrology	Hydraulics				Water Quality		Planning		Suppliers (see List)
Program Group & Software Name	Description (see text for details)	Flood Routing	Open Channels, Waterways	Pipe Systems	Culverts, Bridges, Structures	Storage Routing	Pollutant Estimation	Water Quality Controls	BMP Evaluation	GIS/ CAD Integration	
<u>Water quality</u>											
XP-AQUALM	Hydrology, water quality, BMPs	Continuous				(daily)	√	√	√	L	11
<u>Hydraulics and water quality</u>											
HYDROWORKS	Pipe hydraulics and water quality *	Event or continuous		√			√	√			8
<u>Hydrology, hydraulics and water quality</u>											
SWMM	Integrated hydrology, pipe and open channel hydraulics, pumps, water quality, BMPs	Event or continuous	√	√		√	√	√	√	L	2, 4
XP-SWMM	Integrated hydrology, pipe and open channel hydraulics, pumps, water quality, BMPs	Event or continuous	√	√		√	√	√	√	L	11
MOUSE	Pipe hydrodynamics, water quality *	Event or continuous	L	√	√					L	6
<u>Special purpose</u>											
XP-CULVERT	Culvert hydraulics				√	√					11
CULVERTMASTER	Culvert hydraulics				√						7
PDMOD	Pond water quality							√			1
WMOD	Wetland water quality							√			1

NOTES: The user is responsible for selecting modelling software to suit the project requirements.

* Software so marked includes optional, simplified hydrology modules predominantly intended for sewer modelling.

L Limited capability (at time of writing)

Receiving water models are not listed. For a brief discussion on receiving water models see Section 17.7 of the text.

List of Software Suppliers in Table 17.A1.

Public Domain

1. CRCFE, University of Canberra, Canberra ACT 2601 Australia. Tel: +61 (2) 6201-5371. Website: http://lake.canberra.edu.au

2. EPA, USA. Website: http://www.epa.gov

3. Hydrologic Engineering Centre, US Army Corps of Engineers, USA. Website: http://www.hec.usace.army.mil

Commercial

4. Alan A. Smith Inc., 17 Lynndale Dr, Dundas Ont, Canada L9H 3L4. Tel: +1 (905) 628-4682. Website: http://www.alanasmith.com

5. BOSS International, 6300 University Avenue Madison, Wisconsin USA 53562. Website: http://www.bossintl.com

6. Danish Hydraulic Institute (DHI), Agern Allé 5, DK 2970 Hørsholm Denmark. Tel: +45 (45) 179 333. Website: http://www.dhi.dk/general/dhisoft.htm
   Distributors: DHI Malaysia, Suite 10, 8th floor, Wisma Perindustrian, Jalan Istiadat, Likas 88400 Kota Kinabalu. Tel: (88) 260-780. E-mail: dhikk@tm.net.my
   Dr Nik & Associates, No. 20-2 Jalan 10/55A, Taman Setiawangsa, 54200 Kuala Lumpur. Tel. (3) 451-8866

7. Haestad Methods, 37 Brookside Rd, Waterbury CT 06708 USA. Tel: +1 (203) 755-1666. Website: http://www.haestad.com/software

8. Wallingford Software, Howbery Park, Wallingford, Oxfordshire OX10 8BA UK. Tel: +44 (0) 1491 826392. Website: http://www.wallingfordsoftware.com
   Agent: HWRA Sdn Bhd, 52 Jalan Negara, Phase 1, Taman Melawati, 53100 Kuala Lumpur. Tel: (03) 405 3167. E-mail: andjb@pc.jaring.my

9. Watercom, Australia. Tel: +61 (2) 9587-5384. Website: http://www.watercom.com.au

10. WRCS, 1390 Market St Ste. 2115, San Francisco, CA 94102 USA. Tel +1 (707) 447-6724. Website : http://waterengr.com

11. XP Software, 8-10 Purdue St Belconnen ACT 2616 Australia. Tel +61 (2) 6253-1844.
    and 2000 42nd Ave #214 Portland, Oregon 97213 USA. Tel +1 (888) 554-5022. Website: http://www.xpsoftware.com
    Distributor: Abadi Land & Environment Sdn. Bhd., 17, Jalan Daud, 50300 Kuala Lumpur. Tel (03) 291-3007. E-mail: wmnawan@tm.net.my