CHAPTER 6

SIMULATION PROGRAMS

ADVANTAGES OF COMPUTER MODELLING

A variety of methods has been described enabling the engineer to estimate runoff and design a drainage system accordingly. In all cases the runoff process has been simplified to some extent in order to enable design parameters to be established. In some cases there is oversimplification with the result that the effect of some variables is ommitted. Simplification is invariably demanded in order to achieve a design. Once a preliminary design is achieved, however, there is no reason why the design cannot be improved by reworking and sensitivity studies. It is in the refinement of the design that computer simulation is useful.

It must be borne in mind that simulation is an analytical tool in the design process. It is also of use in management studies, and in research, but as far as the design engineer is concerned, it is a means of analyzing a system designed by some other means. Many of the urban drainage simulation programs available require data input in the form of drainage network layout, conduit sizes and grades and a complete design storm hyetograph. These features are seldom available to the design engineer, and hence analytical and simulation programs are to him a second stage in the design. There are direct design programs available based on a given layout. There are also least-cost optimization programs as outlined in Chapter 11. But these require some simplification again and the final design could be improved with more sophisticated programs.

Simulation programs are justified by the improvement they achieve with repetitive analysis. Not only do they enable discharges to be calculated with greater accuracy than the simplistic methods outlined, but they also permit sensitivity studies.

By manipulating the variables, eg. pipe diameters, the analyst is able to optimize the system to an extent. The effect of detention storage, network layout, grades and diameters and gutter capacity interact to complicate the computations and these effects justify some form of numerical computation before the design is finalized.

In cases of multiple objectives, simulation programs are valuable. Thus the concentration of flow in large conduits may reduce overall construction costs but inconvenience some ratepayers. The effect of construction of a stormwater drainage system on the catchment may be of importance. More rapid concentration of runoff due to pavings and canalization will create higher flows downstream, possibly resulting in erosion or flooding hitherto unexperienced. Natural infiltration will be reduced, resulting in lowering of the water table. These effects can most readily be studied by modelling.

The simulation and analysis of stormwater drainage systems is therefore invariably both informative and cost effective. This does not mean that all new drainage schemes are analyzed by computer. To gain access to computer modelling facilities the designers must commit themselves to a fairly substantial outlay. The following steps indicate what is involved in modelling.

1. Programming and debugging a new model
2. Study of various models available and selection of an available computer package.
3. Selection of computer hardware and operators.
4. Mounting program on computer, debugging and adaptation to local conditions.
5. Training staff in the use of the model.
6. Study of user's manuals and familiarity with program.
7. Collection of data for modelling from records and field.
8. Interpretation of data, discretization, coding and punching.
9. Trial runs of program for calibration purposes.
10. Verification of model against existing runoff data.
11. Sensitivity analysis using alternative designs and storm input.
12. Refinement of the initial design and possibly repeat of previous steps.
13. Report back on conclusions.

There are many objectives in modelling and it would be wise to define these before committing expenditure in that subject:

1. Basic research e.g. familiarity with models and their capabilities.
2. Planning location and scale of outfalls, diversion and treatment facilities.
3. Design of conduits, diversion works and treatment facilities.
4. Refinement of designs by successive trials.
5. Catchment impact assessment i.e. the effect of drainage on the environment.
6. Selection of management and operational alternatives such as diversion rates, treatment levels.
7. Cost estimates.
8. Identification of point source pollutants.

9. Hydrological analysis of stream flooding.
10. Prediction of water quality in reservoirs and streams.

BASIS OF FLOW MODELS

Most models require data to a fairly high level of detail. Thus pipe diameters, gutter dimensions, friction factors, grades and lengths are specified to a number of significant digits. Overland flow planes can be lumped or discretized to a certain extent to the discretion of the analyst. In fact some experience in defining flow planes is useful as it affects concentration times and runoff quite markedly. Storm data (precipitation versus time) again is required to some degree of accuracy.

It is therefore important that the analyst is aware of the limitations in the programs. This may in turn influence the attention he pays to data preparation. The British Transport and Roads Research Laboratory Model (RRL) and its USA version the Illinois Urban Drainage Area Simulator (ILLUDAS) are based on isochronal methods i.e. flow velocities are independent of runoff intensity and based on full pipe conditions. Travel times are therefore only correct at design flows and dynamic effects plus the rising and falling limbs of the hydrograph are incorrectly predicted.

Unsteady flow analysis in drains is performed most efficiently by the kinematic method (e.g. the E.P.A. Stormwater Management Model, SWMM). Depth-discharge relationships are thus based on the steady flow discharge formulae such as that of Manning. Time variation in depth is also accounted for but rapidly varied flow is not correctly analysed.

Some programs are orientated towards single events whereas others perform continuous simulation i.e. they cater for the effect of previous events on the groundwater and storage state. Most simulation models are dynamic i.e. they reproduce changes with time. Optimization models on the other hand are usually static i.e. on account of the complexity of dynamic optimization they consider only one point in time. Generally the models discussed simulate flows with some theoretical basis, however simplified. Some catchment water resource models, however, and some quality models use an empirical base i.e. equations are based on limited measurement and not proven.

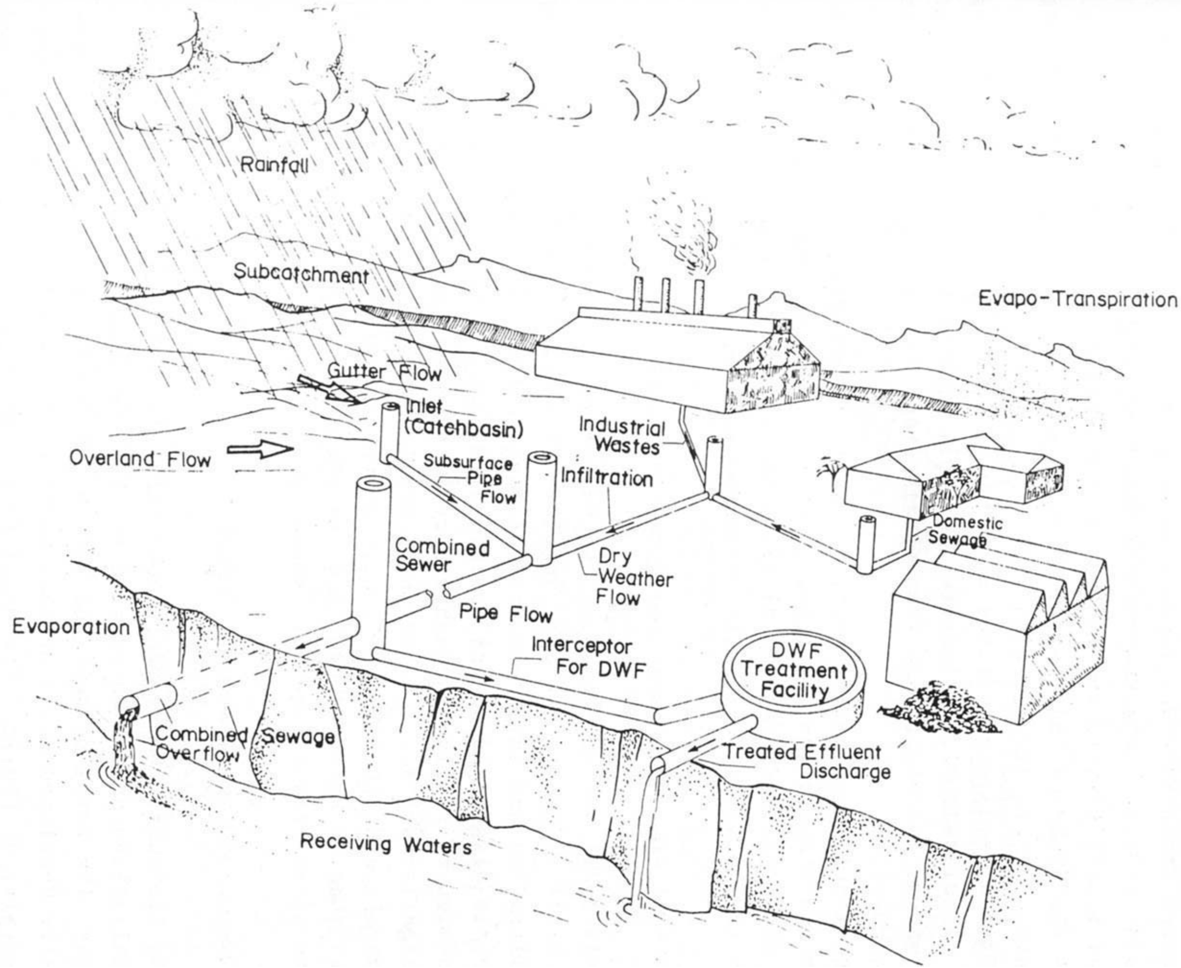

Fig. 6.1 Typical Urban Drainage System Model for SWMM - Diagrammatic

SOME MODELS

Road Research Laboratory Model (RRL)

Time-area methods have remained popular in England, and the Road Research Laboratory developed a program on the lines described by Watkins (1962). The assumption of specific isochrones, or lines of equal travel time to the mouth, is made regardless of storm intensity. Thus the dynamics and storage in the system are not simulated and single events only are studied with it.

After hydraulic properties of conduits such as cross sectional areas are calculated, flow velocities for full pipe flow and travel times are estimated. Isochrones are thus obtained and plotted to establish a time-area curve.

The model also ignores pervious areas. Interception, depression storage and evaporation are likewise omitted. Gutter flow and surcharge are not permitted. Water quality is not considered despite the fact that the model was originally intended for combined sewers.

Illinois Urban Drainage Area Simulator (ILLUDAS)

This model was developed at the University of Illinois (Terstriep and Stall, 1974) to overcome some of the shortcomings of the RRL model. Infiltration and interconnected drainage areas are permitted, but the model is also based on the isochronal method. Storage effects are simulated by routing through reservoir-type storage. Data input is straightforward and running costs are low. Quality is not considered.

The RRL and ILLUDAS models have proved satisfactory for small areas (less than 10 km^2) and provided the storm is not an extreme event (with a recurrence interval exceeding 20 years).

Stormwater Management Model (SWMM)

The Stormwater Management Model (EPA, 1971) was developed by three organizations under contract to the U.S. Environmental Protection Agency. The firms Metcalf and Eddy and Water Resources Engineers originally developed parts of this model which is now maintained by the University of Florida. The model is for the study of the quantity and quality of runoff from urban catchments. It is divided into a number of blocks, some of which may be run on their own or in series with others. The blocks are described below:

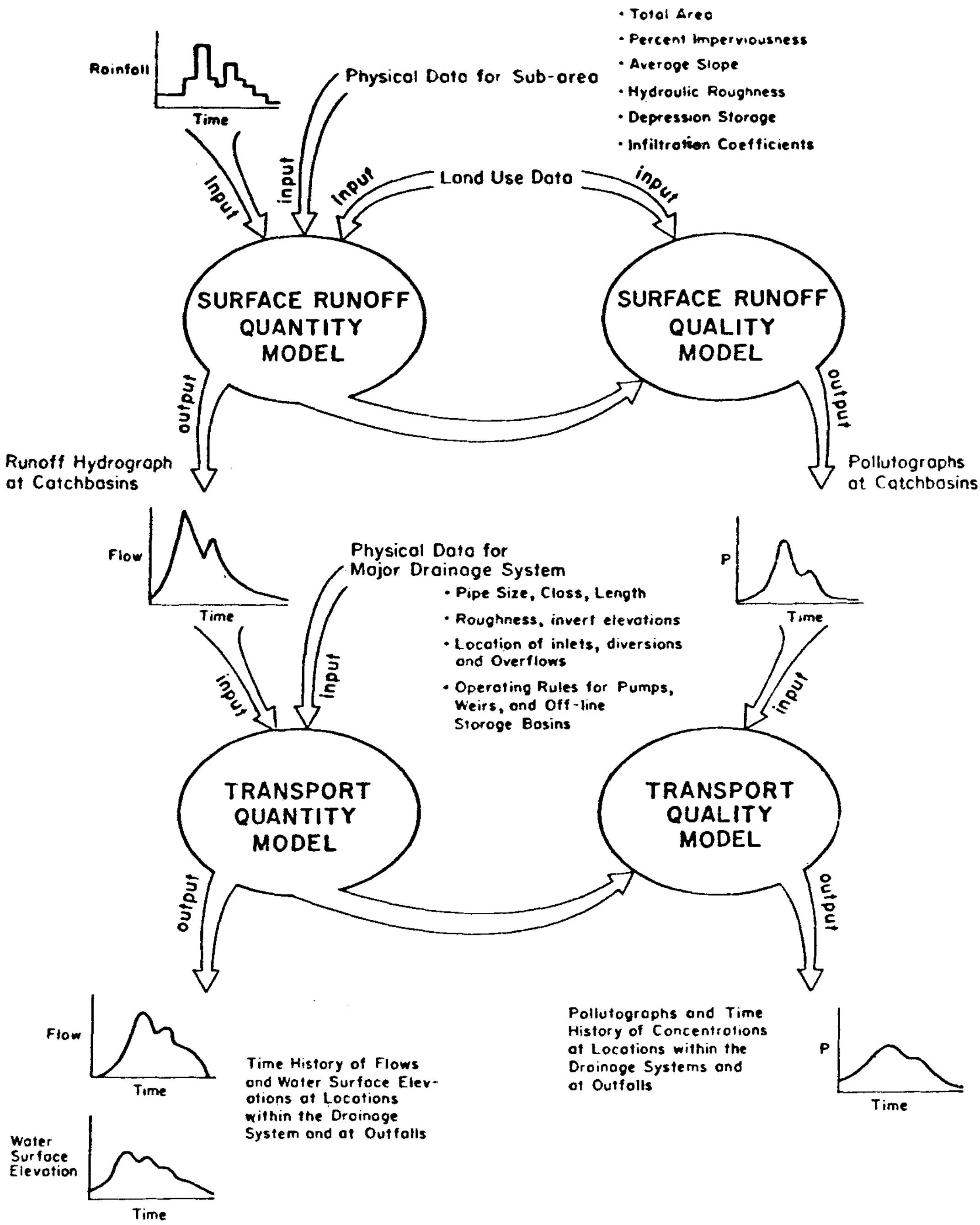

Fig. 6.2 Structure of SWMM Surface Runoff and Transport Models

1. *Executive Block*, which controls the running and links other blocks.
2. *Runoff Block*, which models flood flows off pervious or impervious ground, in gutters, drains and channels. It is based on a numerical solution of the kinematic equations so does not allow for backwater or weir storage effects. Quantity and quality may be simulated and hydrographs at any point in the system may be displayed.
3. *Transport Block*. This is a more refined routing subroutine and allows for overflowing manholes, backwatering and flow in non-uniform channels and rivers.
4. *Storage and Treatment*. The waters may be stored to alleviate floods, and treated to reduce pollutants. A sophisticated biological treatment process and solids removal system is permitted, but the number of pollutants removable is limited.
5. *Receiving Waters Block*. The circulation in lakes may be studied considering hydraulic gradients, wind effects, overflows, and numerous sources of inflow. Pollution, water levels and flows may be listed over a period of time at selected nodes.

Stormwater Runoff Model (STORM)

The U.S. Corps of Engineers (1974) developed STORM for the purpose of studying urban stormwater runoff erosion and treatment. Pollutants such as suspended solids, BOD, nitrogen and phosphorous are assumed to be conservative.

Hydrocomp Simulation Model (HYDROSIM)

The U.S. firm Hydrocomp developed a program originally for runoff simulation in non-urban areas and modified it for sewered areas. It is essentially a catchment routing model with an empirical and theoretical basis. Continuous routing on any selected time scale is possible. The program is not available to the public.

University of Cincinnati Urban Runoff Model (UCURM)

The University of Cincinnati Urban Runoff Model is not based on time-area methods, (Papadakis, 1972). It routes the flows overland and through gutters and pipes using continuity and Manning's resistance equation.

Infiltration is accounted for using Horton's equation, and surface retention is related to depression storage using an exponential equation. The drainage area is divided into subcatchments. Starting with overland flow, excess rainfall is routed through successive components of the drainage system.

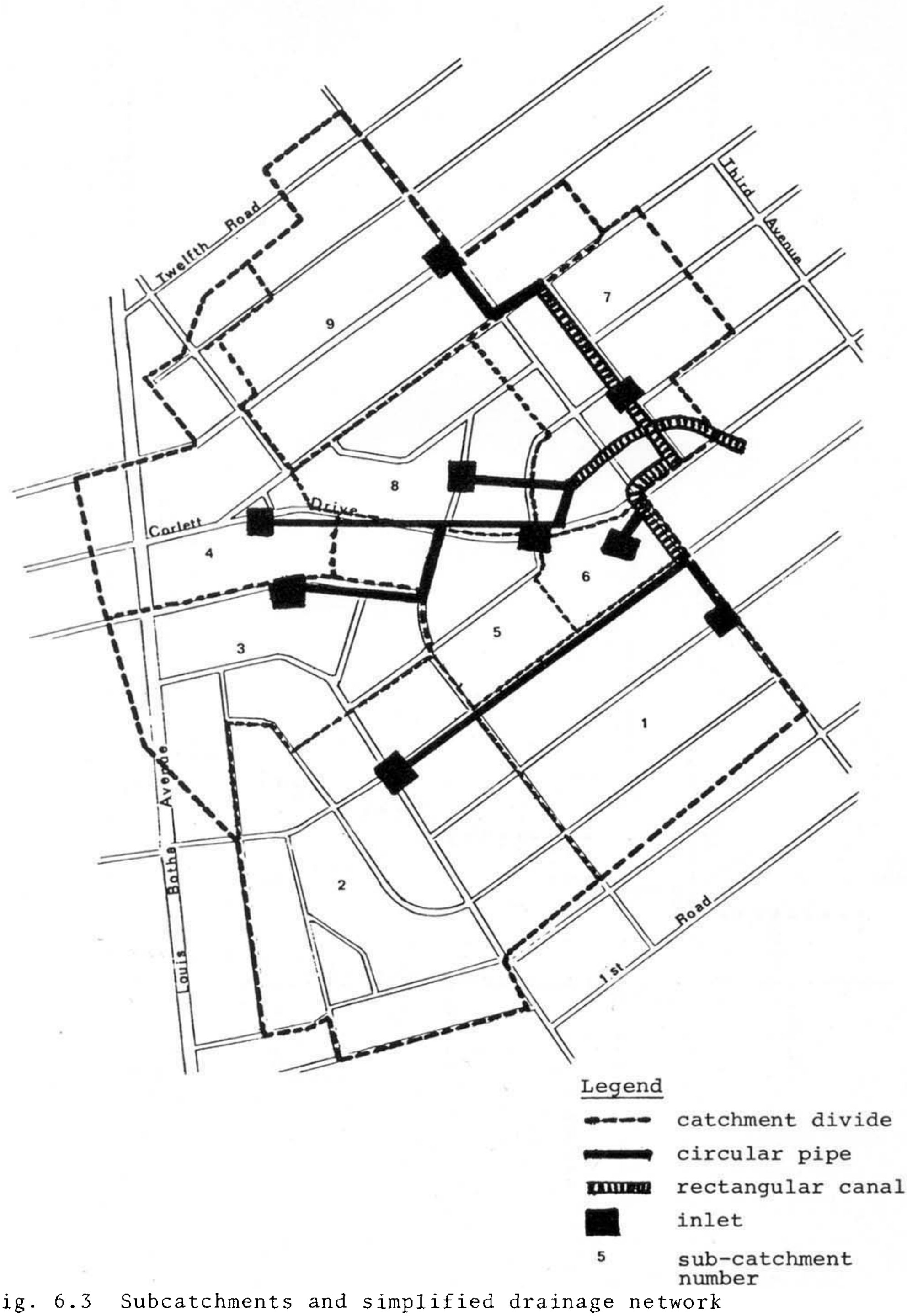

Fig. 6.3 Subcatchments and simplified drainage network

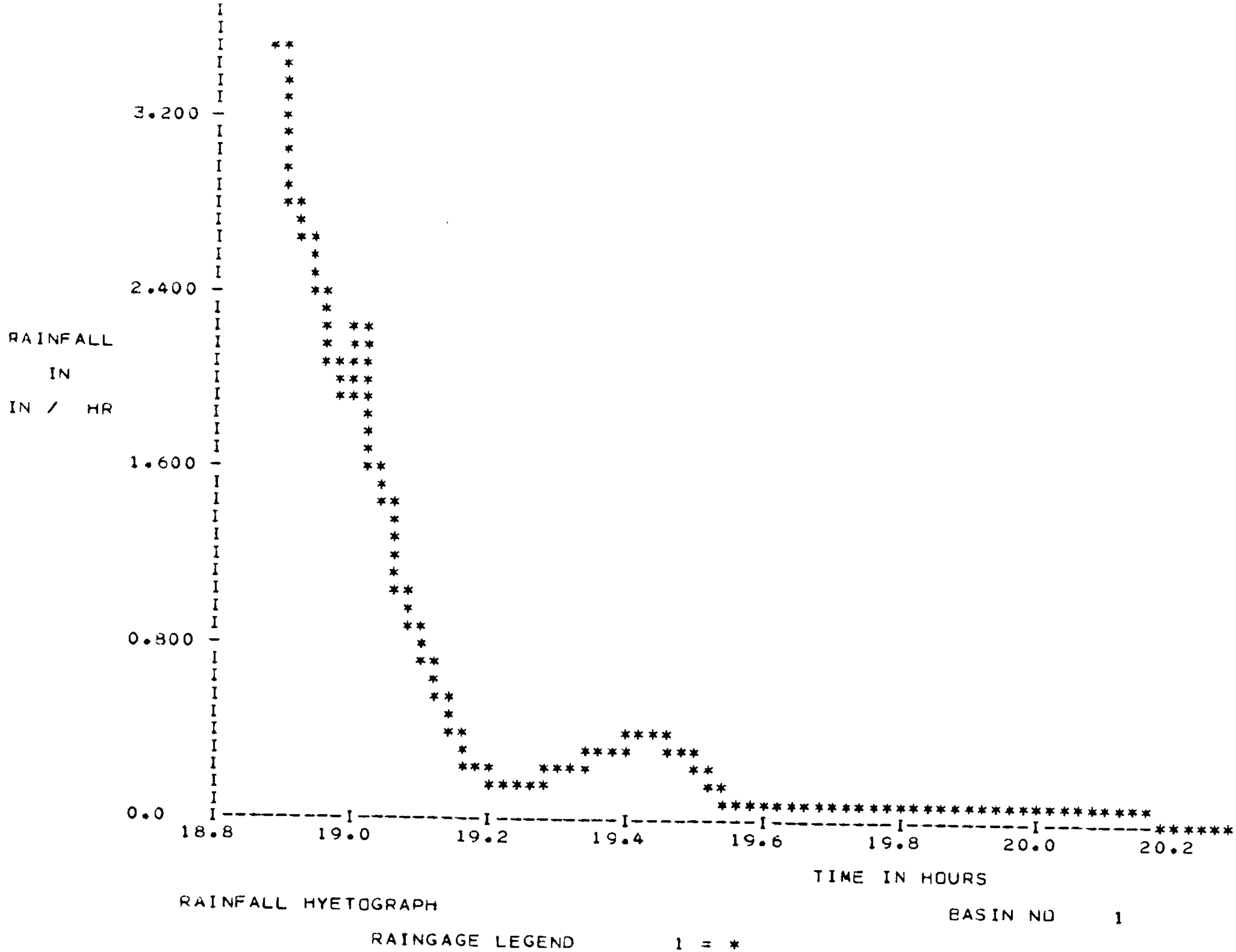

Fig. 6.4 Hyetograph plot by SWMM

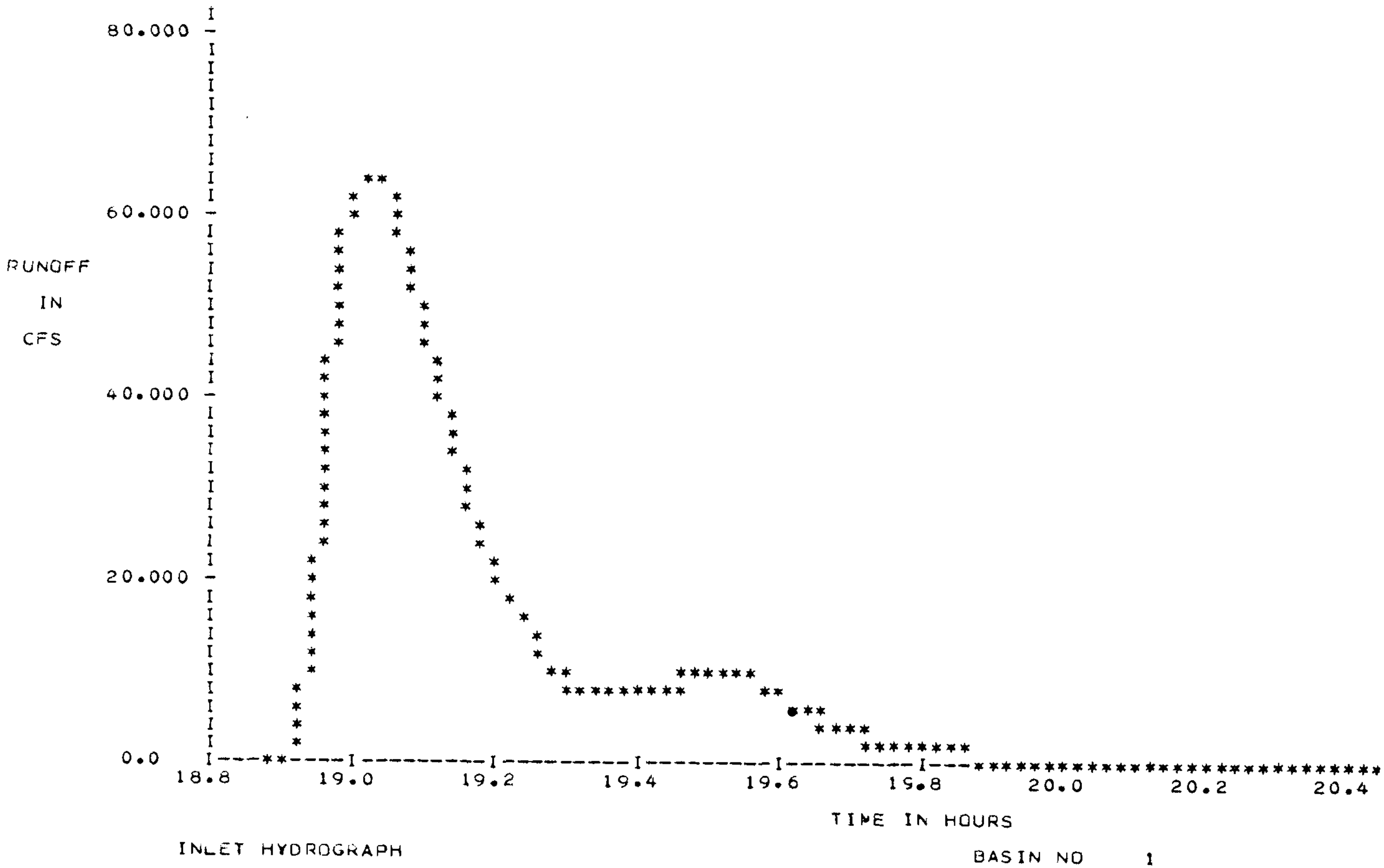

Fig. 6.5 Hydrograph plot by SWMM

Other models.

The University of Cincinnati (1970) also developed a simulation model for pollution washoff. A decay function is included but sediment transport is also permitted. Solluble pollutants are assumed to travel with the water.

Models of reservoirs include that of Chen and Orlob (1971). Their model is based on a multi-layered system, each layer which is assumed to be completely mixed.

The Texas Water Development Board (1970) developed DOSAG-1 to simulate BOD and DO in streams. QUAL-1 was developed by them to simulate temperature, BOD, DO and conservative minerals in streams, but requires more data than DOSAG-1. They are one-dimensional models but branches and a variety of options are possible. Another program, the Texas Water Yield (TWY) model, is based on the SCS curve number procedure and is primarily to estimate runoff. The Massachussets Institute of Technology developed a program called MITCAT (MIT catchment model).

A number of comparisons of alternative models have been made (Heeps and Mein, 1974; Marsalek et al, 1975). Viessman et al (1977) list some of the urban drainage simulation programs in use and their capabilities. Their shortcomings or advantages also are set out. Wanielista (1978) concentrates on a comparison of quality simulation programs. In particular his Best Management Practices Model (BMP) evaluates the effect of diversion of stormwater for treatment. Cost effectiveness of diversion, retention and treatment are given. Runoff is calculated on the SCS curve number method.

WATER QUALITY MODELS

An in-depth study of pollution, catchment management and water purification is beyond the scope of this section, but because many simulation models handle quality as well as quantity a brief discussion of this aspect is justified. The drainage engineer is in fact just as concerned with pollution as with flooding. The protection of the environment against water problems involves a simultaneous study of both aspects. In fact as urban or industrial development grows, the pollution problem expands more rapidly than the flood problem. Pollution is difficult to prevent or control. Whereas one can predict (statistically at least) the flow off the catchment, the quality of the river may be unknown at the time of design. Illegal dumping, diffuse washoff, connections from wastewater treatment works, runoff from dirty industries

TABLE 6.1

Summary of some Runoff Simulation Programs.

Program	Prime feature	Hydraulic routing	Quality capabilities	Comprehensiveness	Ease of Use	Computer required
RRL	Combined sewers	Impervious area only. Single events	None	Limited	Reasonable	IBM
ILLUDAS	Stormwater routing	Isochronal	None	Limited	Simple	IBM
STORM	Runoff quality	Secondary	Good, conservatives	Quality balance	Reasonable	IBM,CDC, Univac.
SWMM	Routing in drains	Kinematic, continuous	Secondary	Very	Big input	IBM, CDC, Univac.
HYDROSIM	Non urban	Modified for sewers	Many	Extensive	Not available to public	IBM
UCURM	Storm sewer flow	None	None	Simple	Easy	IBM
MITCAT	Least cost simulator	Yes	None	Limited	Not available to public	
TWY	Runoff quality	SCS method	Regression	Limited	Requires calibration	IBM
BMP	Diversion and treatment	SCS	Good	Limited	Reasonable	

and from streets, all contribute to the deterioration in the quality of water in streams, rivers, lakes and even the seas.

Fortunately the pollution load is usually most severe when runoff is highest. Dilution of the pollutants may therefore render them innocuous or undetectable. On the other hand the pollution during dry periods may be severe. There may result deterioration of the ecology of rivers and lakes, killing of fish or vegetation, and even a danger to humans and animals from toxic wastes.

Water quality variations can most easily be studied with mathematical models. The analysis of pollutants in streams (Velz, 1970) has been modelled analytically (Thomann, 1972) and numerically (Rinaldi et al, 1978). Planning and optimization models have also been developed (Deininger, 1973). Reactions and circulation in large water bodies is more difficult to predict but considerable research on the modelling of water quality in reservoirs or lakes is proceeding (IIASA, 1978).

The procedures in simulating quality of runoff are very similar to those for quantity. Instead of developing hydrographs, one develops "polutographs" (Overton and Meadows, 1976). Mass balance equations are established at nodes or between reaches. The mixing, dispersion and reactions within the system are simulated. The output is in the form of pollution load and concentration over time at various points. Although some older models were empirical (black box type, requiring calibration for each situation) the modern preference is for some theoretical basis for the equations controlling reactions.

Pollutants can be categorized as organic e.g. silt, inorganic (dissolved salts affect conductivity, pH and hardness), biological (e.g. sewage), thermal (temperature) or radioactive. These classifications doe not facilitate analysis and a breakdown into chemical elements is preferred. Parameters which have received most study are BOD (biochemical oxygen demand) and the coupled DO (dissolved oxygen). Nitrogen, phosphorous, TOC (total organic carbon) and silica,the constitutes of algae,are suspected to be the cause of eutrophication of lakes in subtropical climates. Whereas dissolved salts and organics are usually conservative parameters requiring a mass balance only at each node, BOD and nutrients are non-conservative as they are subject to reactions and decay.

The biological reactions of even the most common pollutants are not yet thoroughly understood, so modelling techniques can only approximately predict water quality. The transport of pollutants, whether in solution or in suspension is more easily modelled. Even dispersion (turbulent mixing and molecular diffusion) can be modelled. Temperature and density gradients, resulting in upward or downward transport and wind movements can also be accounted for. Groundwater movement in non-homogeneous and anisotropic aquifers has received considerable attention (Fried, 1975).

Models for predicting pollutant washoff used in the United States are generally of the form

$$P = M\ (i - e^{-kR\Delta t}) \qquad (6.1)$$

where P is the mass of pollutant washed off the catchment in a time increment Δt, M is the available pollutant mass at the start of the time step, k is a washoff decay coefficient and R is the runoff rate per unit area. The equation is used in a step-wise manner to simulate the pollutant washoff rate.

Available pollutant accumulation between streams depends on the pollutant, winds, and type of ground cover. Jewell et al (1980) quote 10 pounds per acre per day (10kg/ha/d) total buildup in US cities, and k about 1 per inch (40 per m). A frequently used figure for k is 4.6 per inch, based on a runoff of 0.5 inches per hour removing 90% of the constituent.

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