THE USE OF
SWMM SIMULATION MODEL IN
URBAN STORM WATER MANAGEMENT

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by
Süleyman Sırrı ÖNER

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İZMİR

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We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as thesis for the degree of Master of Science.

Prof. Dr. Ertuğrul Benzeden
(Advisor)

Prof. Dr. Nilgün Harmancıoğlu
(Committee Member)

Yrd. Doç. Dr. Türkay BARAN
(Committee Member)

Approved for the
Graduate School of Natural and Applied Sciences

Prof. Dr. Macit Toksoy
Director
Graduate School of Natural and Applied Sciences

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The present study of SWMM (Storm Water Management Model) aims to introduce the model with its theoretical and technical background. It is intended here to install and run the model, and further to apply it on a case study comprising a small watershed.

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S. Sırrı Öner
Civil Engineer
January, 1997

ABSTRACT

In recent times, rapid population growth and urbanization have led to serious problems to be solved and managed by scientists and engineers. One of the most significant problems relates to management of urban drainage systems.

Recent advances in both modeling techniques and computer technology have resulted in the development of sophisticated computer-based mathematical simulation models. These models serve to simulate both water quantity and quality problems encountered in urban watersheds. One of these models is the SWMM (Storm Water Management Models) that has found a wide area of application in developed countries.

The objective of the presented study is to investigate capabilities and properties of SWMM in simulating urban drainage and to apply it in simple hypothetical basins so that basic requirements for a real case study can be identified. To this end, the model software is studied to identify its basic characteristics and requirements. Next, hypothetical data are used to test the operation of the model.

The results of the study have shown that the basic problems that may be encountered in SWMM applications are related to data limitations. Provided that data required by the model are obtained, the SWMM model can be effectively used in the planning and design of urban drainage systems of major cities in Turkey. The presented study points out to capabilities of the model in this respect. It is expected that SWMM will be employed by urban planners and managers in our country. On this respect, the presented study serves the delineate model requirements and data needs for effective applications of SWMM. Having noted the characteristics and data requirements of the model at this stage, it is intended to run the model on the case of a real urban watershed as part of future studies.

ÖZET

Günümüzde, şehirlerdeki hızlı nüfüs artışı ve çarpık kentleşme gibi kontrolsüz gelişen olaylar, bilimadamlarını ve mühendisleri temel problemler ile karşı karşıya bırakmaktadır. Bu problemlerin en önemlilerinden biri kentsel drenaj sistemleridir.

20. yy son çeyreğinde, özellikle bilgisayar teknolojisindeki hızlı gelişim, birçok alanda olduğu gibi kentsel bölge drenaj sistemlerinin simulasyonunda kullanılan matematiksel modellerin de bilgisayar teknolojisi ile birleştirilip daha karmaşık yapıdaki geniş kapsamlı hidrolik-hidrolojik ve su kalitesi modellerinin kurulmasını sağlamıştır.

Sunulan çalışmada kentsel bölge drenaj sistemlerinin simulasyonu amacıyla geliştirilen bilgisayar destekli matematiksel modeller incelenmiş; özellikle, yurt dışında yaygın bir kullanıma sahip, kentsel akışları kalite ve kantite acısından inceleyen SWMM (Storm Water Management Model) modeli açıklanmıştır. Çalışmada, SWMM modelinin temel özelliklerinin belirlenmesine çalışılmış; bu özellikler örnek bir uygulama üzerinde araştırılmıştır. Bu çalışmalar sonunda, etkin bir model uygulaması için modele uygun ve yeterli miktarda veri toplanmasının zorunlu olduğu görülmüştür. Bu tür model gereksinimleri karşılanabildiği takdirde SWMM, ülkemizdeki kentsel drenaj sistemlerinin planlama, tasarım ve yönetim problemlerinin çözümü açısından oldukça etkili bir araç olabilecektir. Yapılan çalışmada, yakın gelecekte Türkiye'de de kullanılması umulan SWMM ve benzeri modellerin gerektirdiği veri tabanının şimdiden hazırlanması için yol gösterilmektedir.

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CHAPTER ONE
INTRODUCTION

In recent years, the management of water resources has become highly complex as current problems encountered have become varied both in content and in scale. In the past, the basic problem in management was to determine where and how much water was available for specific uses. Nowadays, the quality of water has also become a significant factor along with all other factors that affect water quality and quantity. Thus, water resources are now considered as a part of the environmental continuum which includes air, soil, and water as the vital components for sustaining life on earth. Since these components are interactive and their interactions are complex, environment must be managed and protected as a cohesive whole . This can be accomplished through an integrated approach to environmental management.

An integrated approach to basin management requires better tools to aid in the decision-making process. Among these tools are mathematical models which have found a wide area of application in resource management studies. Mathematical models developed for watershed studies have two basic objectives:

a) identification of the watershed system with respect to basic processes and interactions involved;
b) assessment of alternative management strategies (scenarios) to arrive at the most appropriate basin management scheme.

Another development in the past few years has been the revolution in computer technology along with that in information technology. In addition to current management needs, the development of the new watershed models has been shaped by the state of scientific understanding and the availability of data and computational/programming resources. With increased scientific understanding, models' ability to represent physical process has improved. More and better data have allowed modelers to more effectively calibrate and validate their models, which in turn has resulted in increasing confidence in both model results and in the use of models to evaluate alternative management strategies. Faster, more powerful, and less expensive computers have allowed the use of models by a larger community of modelers, and for more complex applications.

Currently a large number of computer-based watershed models are available for use in water resources management. These are highly comprehensive models, and some of them have found a wide area of application. Among these SWMM (Storm Water Maagement Model) has been extensively used in recent years for simulation of urban drainage systems. The Storm Water Management Model, SWMM, is one of the most important complex models of storm water developed by U.S EPA (Environmental Protection Agency), which is widely used today in developed countries. This model is a comprehensive, relatively sophisticated hydrologic, hydraulic and water quality simulation model for analysis of quantity and quality problems associated with urban runoff.

The SWMM model may be used for both planning and design of urban storm water drainage systems. The planning mode is used for an overall assessment of the urban runoff problem and proposed abatement options. It can be used to study the impact of waste loads on instream water quality and to identify the magnitude and quality characteristics of nonpoint waste loads as part of a field sampling program. The SWMM model has the following major capabilities:

(a) conversion of any rainfall hyetograph or hyetographs into a runoff hydrograph for each watershed that is modeled,
(b) production of pollutographs, runoff water quality graphs, based on land use, management, rainfall, and other data,
(c) computation of hydrographs and pollutographs for dry weather flow,
(d) flood routing through multiple channels and pipes,
(e) simulation of the impacts of optional water storage facilities,
(f) computation of storm water treatment impacts using an array of treatment technologies,
(g) computation of receiving water quantity and quality impacts,

(h) computation of capital and operating and maintenance costs for storage and treatment options,

The objective of the presented study is to investigate the capabilities and properties of SWMM in simulating urban drainage and to apply it in a simple hypothetical basin so that basic requirements for a real case study can be identified. To this end, the model software is studied to identify its basic characteristics and requirements. Next, hypothetical data are used to test the operation of the model.

The results of the above investigations have shown that the basic problems that may be encountered in SWMM applications are related to data limitations. Appropriate data are needed both to represent the physical properties of an urban drainage system and calibrate the model parameters. Otherwise, default values may have to be used, in which case the model does not represent the urban watershed in a realistic way. If sufficient and appropriate data available, SWMM can be effectively used to simulate water quantity and quality conditions in an urban catchment.

In the next section, the use of mathematical models in water resources management is emphasized, and types of models currently employed are described. The properties of the SWMM model package, together with known applications of the model, are considered in Chapter 3. Chapter 4 presents the theoretical backround for the model. The implementation of the model is detailed in Chapter 5 and an example run is presented. Finally, Chapter 6 summarizes basic solutions derived as a result of the above investigations.

CHAPTER TWO

THE USE OF MATHEMATICAL MODELS IN WATER RESOURCES MANAGEMENT

2.1 General Description of a Mathematical Model

The term "model" has come into widespread use in recent years. In fact, the term is used so much that sometimes one feels its meaning has become imprecise. Therefore, an attempt will be made to define precisely what is meant by the word "model" and how it is used in hydrologic design.

The complexity of both human and natural systems has led to the use of models. Basically, a model is a representation of some form of reality. Models can be developed in many forms. Physical models provide a physical analogy to the operation of a system. In most cases, physical representation of the physical system being modeled is not possible. Then, a mathematical model is generally used. In hydrologic design, one normally speaks of mathematical models rather than physical models. In this sense, emphasis will be directed on the category of models called mathematical equations which characterize the prototype system, giving relationships between variables enabling description, analysis, and prediction under the conditions to be modeled.

There are many classes of mathematical models. The underlying principle of all such models is to allow for the analysis of the operation of some system in order to evaluate system performance. The modeler then uses the model to determine whether or not the system will function at some desired level. The model necessarily limits the number of variables to be simulated for ease of use. On the other hand, some acceptable level of accuracy must be maintained if the model is to be acceptable for the application at hand (Gordon, 1985).

It may be helpful to think of a mathematical model as simply an equation representing a process. For example, the Manning's equation (2-1) is a hydraulic model for calculating the depth of flow in an open channel:

$$Q = (1/n) . A . R^{2/3} . S^{1/2} \quad \textbf{2.1}$$

where Q is the river flow, A, the cross-sectional area, R, hydraulics radius, S, the hydraulic gradient and n, the roughness coefficient.

The model simply predicts discharge as a function of roughness, depth, hydraulic geometry, and slope. It is not inaccurate to call this a model although some would call this an oversimplification. They regard models as more as complicated representations of physical phenomena. Certainly, Manning`s equation does not represent very well the complexities inherent in the hydraulic phenomena described; nevertheless, it is a model.

Another model is the familiar rational equation for calculating the runoff expected from a small watershed subjected to thunder storm rainfall:

$$Q= C . I . A \quad \textbf{2.2}$$

where Q is the discharge from a watershed, C, the runoff coefficient, I, the rainfall intensity, and A, the area of the watershed. Here, the model predicts the watershed discharge or yield as a function of runoff coefficient, rainfall intensity, and watershed area. Again, it is a very simplified version of a complicated physical phenomenon. The above simplified examples illustrate that a hydrologic model is really a method to predict the outcome of some physical process of interest.

In hydrologic design and decision-making for water resources management, planners have traditionally used simple models in the form of relatively simple calculations without consulting to computer models. However, this approach limits the complexity of the decision-making framework since it is not possible to intuitively analyze more than a few variables at one time. Computer modeling offers a relatively inexpensive and effective way to incorporate a large number of variables into the decision-making process (Gordon, 1985).

Complicated mathematical models, such as those which require large computer storage capabilities and sophisticated mathematics and programming, are generally more precise representations of the physical phenomena than are the simpler models such as the rational formula.

A mathematical model is simply a quantitative expression of a process or phenomenon one is observing, analyzing or predicting. Since no process can be completely observed, any mathematical expression of a process will involve some element of stochasticism or uncertainty. Hence, any mathematical model formulated to represent a process or a phenomenon will be conceptual to some extent, and the reliability of the model will be based upon the extent with which it can be or has been verified. Model verification is a function of the data available (time, manpower, and money) to perform the scientific tests. Since time, manpower and money always have finite limits, decisions must be made by the modelers as to the degree of complexity the model is to have and the extensiveness of the verification tests that are to be performed.

Then, the initial task of the modeler is to make a decision as to which model to use or build, how to verify it and how to determine its statistical reliability in application, e.g. feasibility, planning, design or management. This decision-making process is initiated by clearly formulating the objective of the modeling endeavor and placing it in the context of the available resources on the project for fulfilling the objective.

If the initial model form does not achieve the intended objective, then it simply becomes a matter of revising the model and repeating the experimental verifications until the project objective is met. Hence, mathematical modeling is by nature heuristic and iterative. The choice of model revisions as well as the initial model structure will also be heavily affected by the range of choice of modeling concepts available to the modeler and by the skill which the modeler has or can develop in applying them.

The distinction between linear and nonlinear systems is of paramount importance in understanding the mechanism of mathematical modeling. A linear system is defined mathematically by a linear differential equation, the principle of superposition applies and system response is only a function of the system itself. An example of a linear system representation is the unit hydrograph model. A nonlinear system is represented by nonlinear differential equations, and system response depends upon the system itself and the input intensity. An example of a nonlinear system representation is the equation of gradually varied open channel flow (kinematic wave theory). It is well known that real world systems are very nonlinear, but linear representations have often been made because of lack of knowledge of the system or because of the pressures exerted by the resource constraint.

Figure 2.1 is a schematic representation of the modeling process. The modeling process is not new; it is nothing more than a modern expression of the classical scientific thought process involved in the design of an experiment. What is very new is that today a very large number of concepts can be evaluated efficiently in a very small amount of time at a relatively small expense. The mechanism which permits these evaluations is the high speed digital computer and a body of analytical techniques called systems analysis. Therefore, to be effective, the modeler must be knowledgeable not only of the phenomenon itself but also of computer science and the discipline of systems analysis (Overton and Meadows, 1976).

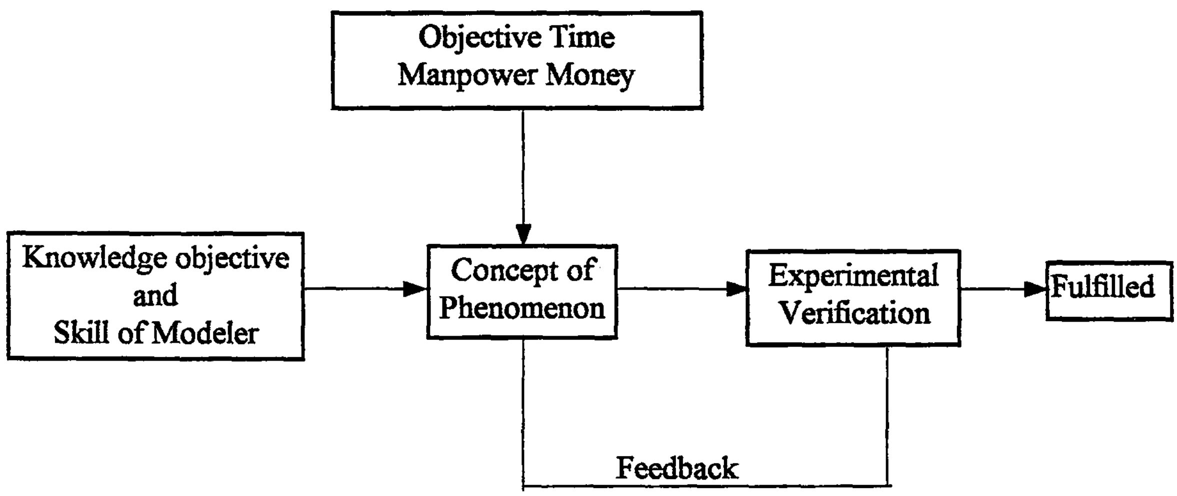


Figure 2.1 The Modeling process (Overton and Meadows, 1976)

2.2 Classification of Mathematical Models

Mathematical models must be employed in the planning process for water resources management. These models are needed to account for differences in site characteristics and to simulate the consequences of alternate development schemes (Overton and Meadows, 1976).

Mathematical models may be divided into two major categories: deterministic models and stochastic models. One might say that deterministic models are used to make forecast while stochastic models serve to make predictions. It is common in engineering to differentiate between prediction and forecasting (Loague and Freeze, 1985). Prediction refers to suites of simulated hydrographs that are to be used for the purposes of engineering design. On the other hand, forecasting refers to simulated hydrographs of specific future events to be used in making operational decisions. In prediction, it is acceptable to judge model performance in a statistical sense; in forecasting it is necessary to judge model performance on an event-by-event basis.

A deterministic mathematical model does not consider randomness; a given input always produces the same output (Chow et al., 1988). These models have a theoretical structure based upon physical laws and measures of initial and boundary conditions and input. When conditions are adequately described, the output from such a model should be known with a high degree of certainty.

Deterministic models are classified into lumped and distributed mathematical models. In a deterministic lumped model, the system is spatially averaged or regarded as a single point in space without dimensions. For example, many models of the rainfall-runoff process are considered as in Figure 2.2. This approach treats the precipitation input as uniform over the watershed and ignores the internal spatial variation of watershed flow. In contrast, a deterministic distributed model considers the hydrologic process taking place at various points in space and defines the model variables as functions of the space dimensions.

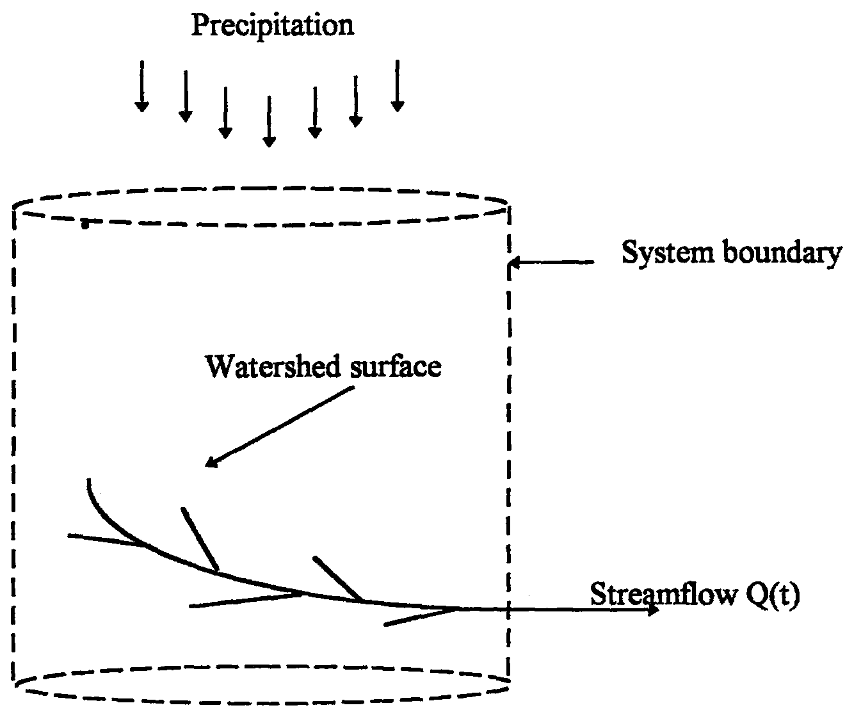


Figure 2.2 The watershed as a hydrologic system (Chow et al., 1988).

Both lumped and distributed models are classified as steady-flow (the flow rate not changing with time) or unsteady-flow models. Such a classification of deterministic models is shown in Figure 2.3.

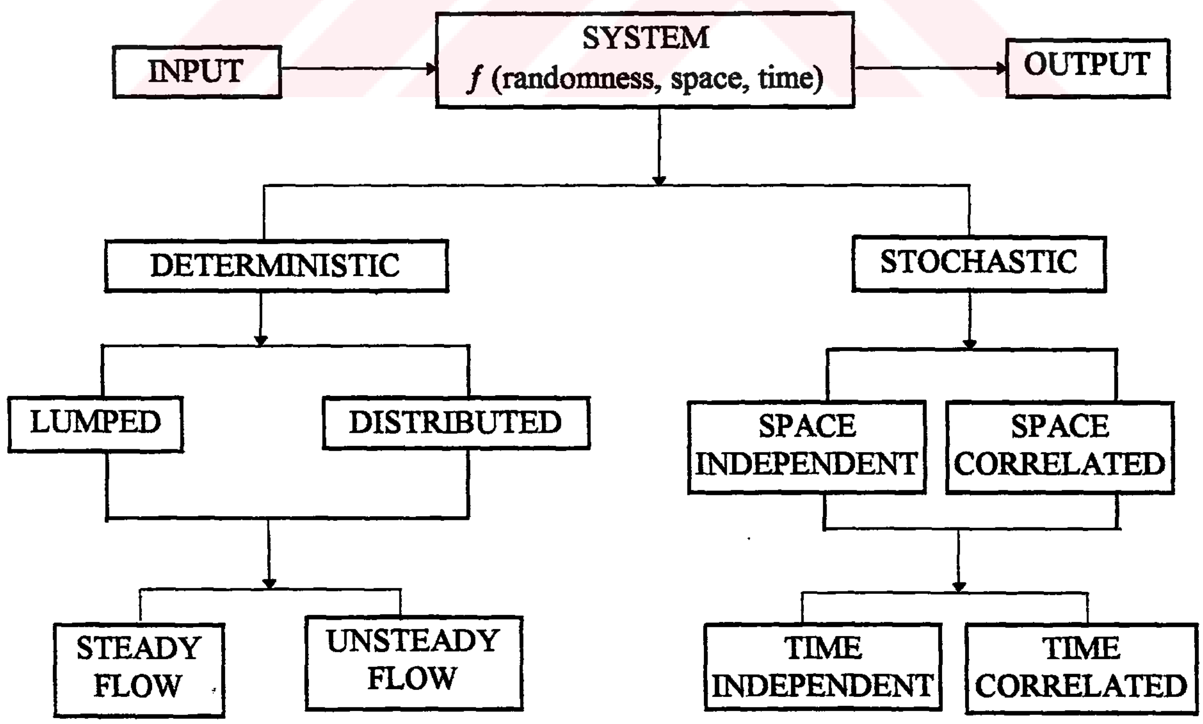


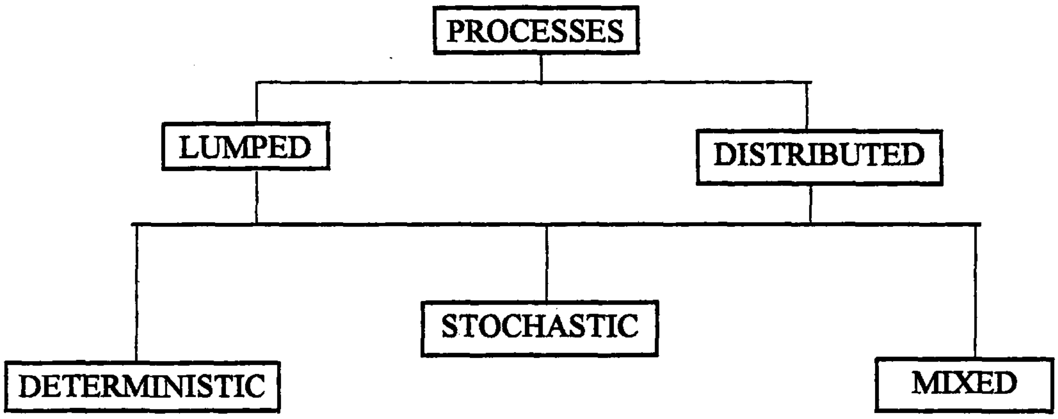
Figure 2.3 Classification of hydrologic models (Chow et al., 1988)

A stochastic model has outputs that are at least partially random. If the random variation is large, a stochastic model is more suitable, because the actual output could be quite different from the single value a deterministic model would produce. For example, reasonably good deterministic models of daily evaporation at a given location can be developed using energy supply and vapor transport data. But, such data cannot be used to make reliable models of daily precipitation at that location because precipitation is largely random. Consequently, most daily precipitation models are stochastic.

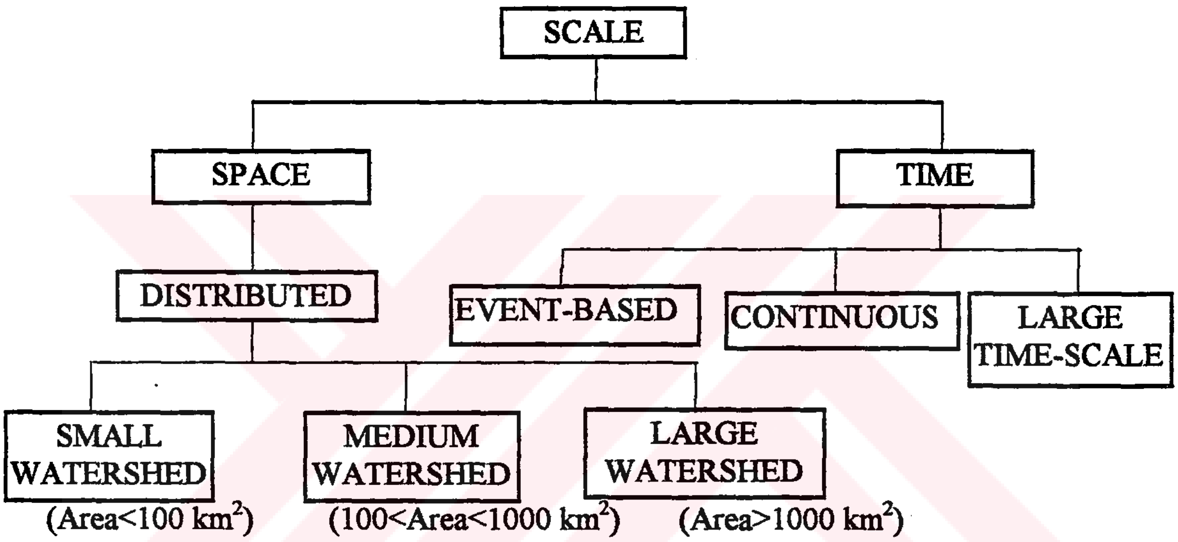
Stochastic models are classified as space-independent or space-correlated according to whether or not random variables at different points in space influence each other. We may also classify these models as time-independent or time-correlated. A time-independent model represents a sequence of events that do not influence each other. A time-correlated model represents a sequence in which the next event is partially influenced by the current one and possibly by others in the sequence.

All mathematical models are approximations of reality, so the output of the actual system can never be forecast with certainty. Likewise, a phenomenon varies in all three space dimensions, and in time. However, simultaneous considerations of all five sources of variation, such as randomness, three dimensions in space, and time, have been accomplished for only a few idealized cases. A practical mathematical model usually considers only one or two sources of variation.

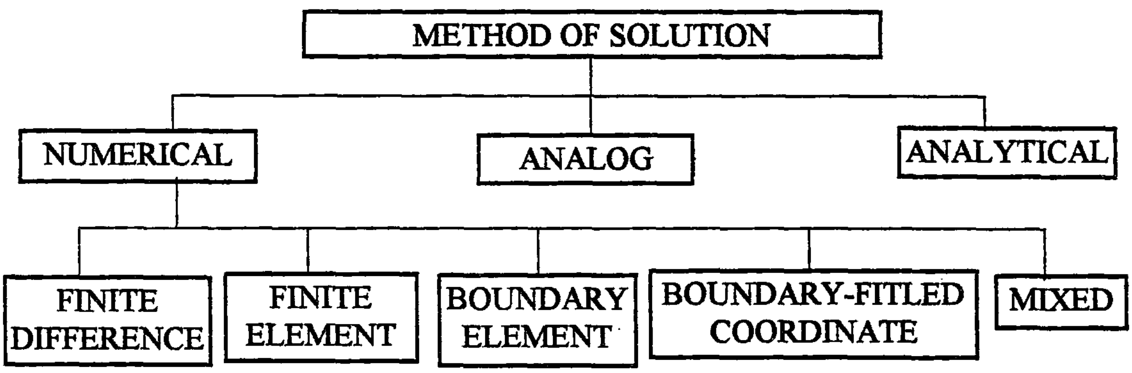
In general, models can be classified as in Figure 2.4 according to:
(a) process description;
(b) space and time-scales used; and
(c) solution technique (Singh, 1995).



a) Classification based on process description.



b)Classification based on space/time scales.



c) Classification based on solution technique.

Figure 2.4 A general classification of mathematical models (Singh, 1995)

2.3 Modeling Procedure

A model has five basic components as shown in Figure 2.5 (Singh, 1995):

a) system description (e.g. watershed geometry),

b) inputs,

c) governing laws,

d) initial and boundary conditions,

e) outputs.

The modeling procedure basically involves the determination of the above components.

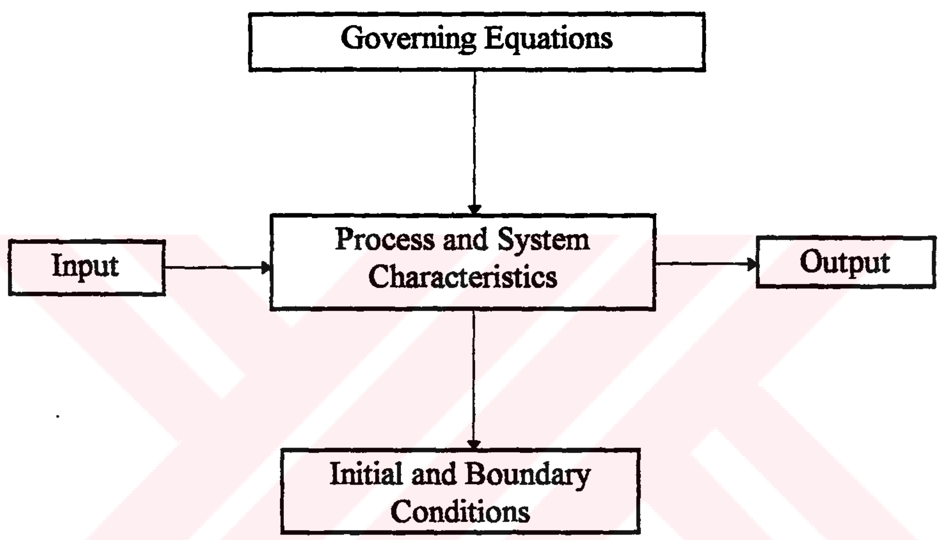


Figure 2.5 Components of a mathematical model (Singh, 1995).

In modeling, the solution technique to be used has an important role in effectiveness of the model. Solution methods begin with simple hand calculations and extend to graphical methods and simulation and optimization techniques supported by computers. The choice of the method depends on the complexity of the problem to be solved. The validity of a model depends on how it is developed, verified and calibrated.

In modeling, the most important step is to define the purpose and the basis of the model. This step involves the description of the system in a conceptual manner which is then converted into mathematical expressions. Figure 2.6 shows the basic steps of model development.

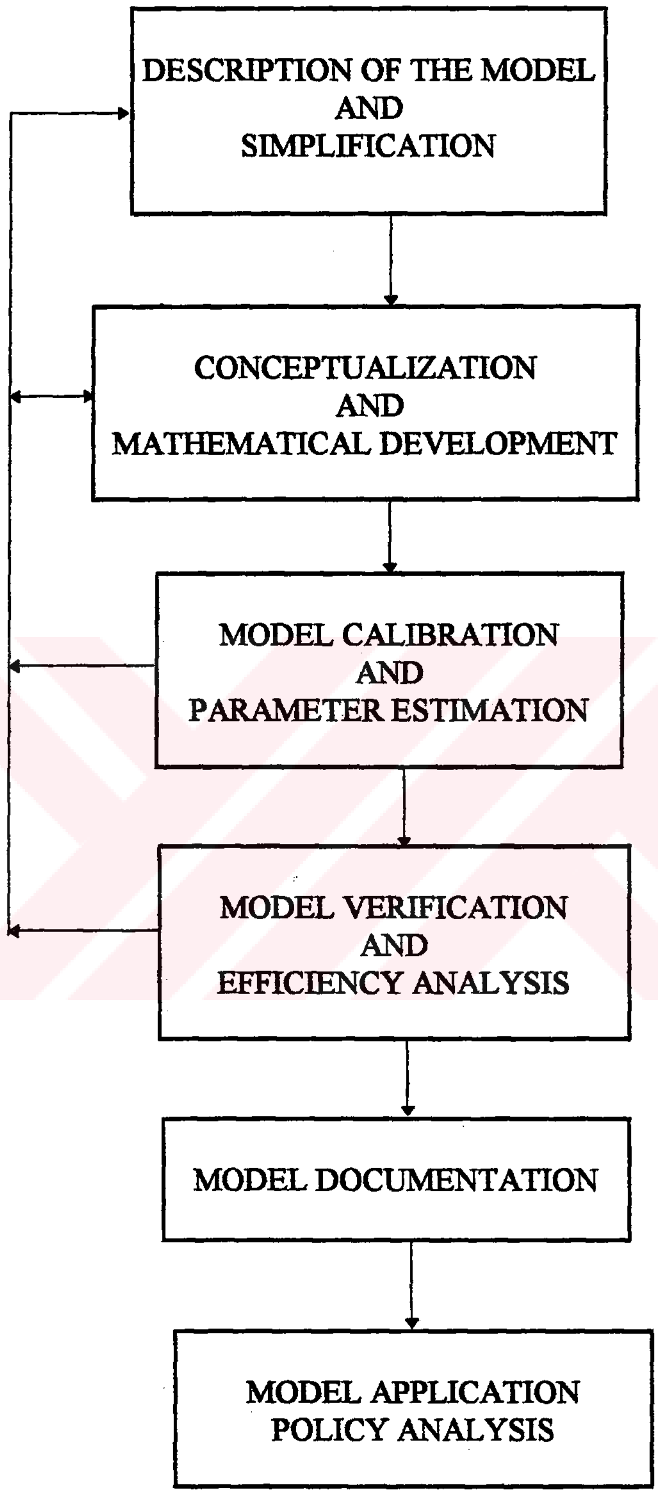


Figure 2.6 Basic steps of model development

The steps of the modeling procedure can be summarized as:

(a) conceptual identification of the problem;

(b) determination of the mathematical equations that describe the event;

(c) investigation of the method that gives stable and exact solutions;

(d) application of the model to a real event (calibration and verification);

(e) calibration and verification of the model;

(f) comparisons between model outputs and measured data and evaluation of model efficiency.

In general, mathematical expressions used in a model are very complex and involve partial differential equations which may be difficult to solve. Navier-Stokes equations are the best examples for basic hydrodynamic models. Analytical solution of these equations are possible for definite conditions after having made simplifications and assumptions. However, these solutions are not often used in simulation procedures.

In reality, numerical solution methods are based on iterative solution techniques which have to be used very carefully. First of all, the equations that are utilized should be clearly defined to provide stable and true solutions. Model development involves first a theoretical development where concepts are identified and expressed in mathematical terms. This is followed by a selection of the appropriate solution technique.

After developing the theoretical solutions, the model should be applied to a real phenomenon. Such an application requires calibration and verification so that the model represents the real case. These procedures are often time-consuming and tiresome.

To illustrate the modeling procedure, let's consider a small catchment with one raingage and one streamgage. Over a period of years, hyetographs for a set of rainfall events are observed as $P_1(t)$, $P_2(t)$,.........., $P_n(t)$, $P_{n+1}(t)$,..........,$P_m(t)$ and hydrographs for the corresponding streamflow events as $Q_1(t)$, $Q_2(t)$,.........., $Q_n(t)$, $Q_{n+1}(t)$,..........,$Q_m(t)$.

One such event is illustrated in Figure 2.7. As noted there, the full hyetograph P(t) may in some cases be represented by the summary variables { P_D, P_{mx}, t_{mx} } and the full hydrograph Q(t) may in some cases be represented by the summary variables { Q_D, Q_{pk}, t_{pk} } where :

P_D ⟶ total rainfall intensity [L/T];

P_{mx} ⟶ maximum 2-min rainfall intensity [L/T];

t_{mx} ⟶ time to end of P_{mx} from the beginning of the event [T]:

Q_D ⟶ by the total catchment area [L]:

Q_{pk} ⟶ peak stormflow rate [L3/T]:

t_{pk} ⟶ time to Q_{pk} from the beginning of the event [T].

Let us assume that the first n events [$P_1(t)$.....$P_n(t)$; $Q_1(t)$......$Q_n(t)$] have been selected as the calibration events and the remaining events are the verification events. A mathematical model for the prediction of a hydrograph $Q_{m+1}(t)$ given a hyetograph $P_{m+1}(t)$ would then take one of the forms;

$$Q_{m+1}(t) = f[\{P_{m+1}(t); a_1,a_2,......,a_n ; b_1,b_2,......,b_n \}] \qquad \textbf{2.3}$$

or

$$[\, Q_d, Q_{pk}, t_{pk} \,]_{m+1} = f[\{P_D, P_{mx}, t_{mx} \}_{m+1} ; a_1,a_2,......,a_n ; b_1,b_2,......,b_n \,] \qquad \textbf{2.4}$$

where f represents the functional form of the model, [a_1, a_2,....., a_n] represents a vector of calibration parameters, and [b_1, b_2,..., b_n] represents a vector of physically based parameters.

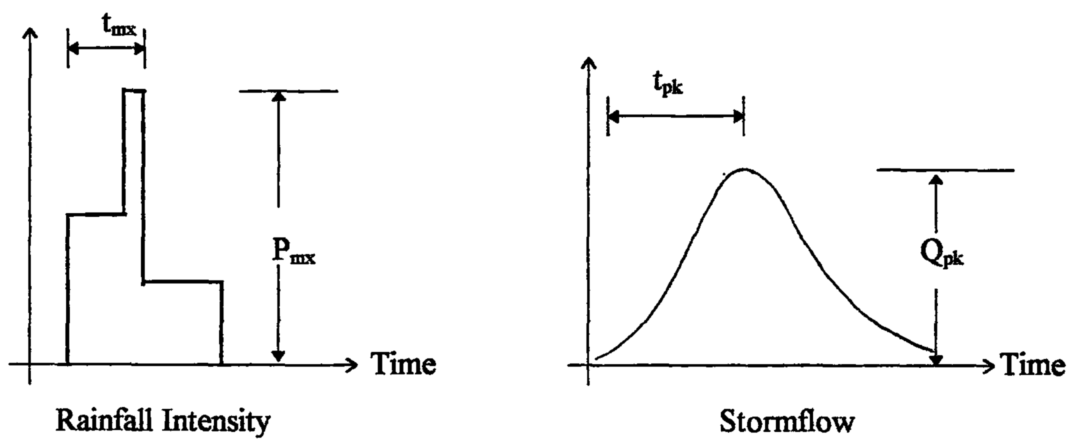


Figure 2.7 Hypothetical rainfall-runoff event showing event summary variables (Loague and Freeze, 1985)

The calibration parameters a_i are determined from the (n) calibration events for which the P(t) and Q(t) are known. The physically based parameters, b_i are distributed parameters such as soil hydraulic conductivity or channel slope that can be measured or estimated at various points on the catchment.

Model calibration is an important task to investigate the fit between model outputs and observed data. In this step, the modeler compares outputs with one or more observed sets of data. The data set used for calibration should be different from the data used for model development.

Model calibration is performed using one or more observed data sets of both inputs and outputs. The model parameters and the model itself are adjusted or modified so as to produce an output that is as close to the actual observed process as possible. The evaluation of model parameters is usually a subjective trial-and-error procedure but may be refined by least squares or quasilinerization methods. This step is called model or parameter identification (Loucks v.d., 1981; Gordon, 1985).

Model verification requires an independent set of input and output data to test the calibrated model. The verification data must be independent of that used to calibrate the model. A model is verified if the model's predictions compare favorably with observed field data. Here, again the criteria for deciding whether or not model output and observed field data are essentially the same, for the same input conditions, are largely subjective.

One last step before using the developed model for the solution of real problems is sensitivity analysis where the sensitivity of the model to variations in the basic parameter is tested. In this analysis, the modeler tries to answer the following questions (Gordon, 1985):

a) does the model demonstrate the real system behavior ?

b) does the model evaluate the extreme conditions that occur in the real system or does it exceed known limits beyond some point?

c) if the model is insensitive to parameter variation, is this an accurate representation of reality or only a mathematical error?

2.4 The Use of Computer-Based Mathematical Models in Water Resources Management

In recent years, the management of water resources has become highly complex as current problems encountered have become varied both in content and in scale. In the past, the basic problem in management was to determine where and how much water was available for specific uses. Nowadays, the quality of water has also become a significant factor along with all other factors that affect water quality and quantity. Thus, water resources are now considered as a part of the environmental continuum which includes air, soil, and water as the vital components for sustaining life on earth. These components are interactive and their interactions are complex. Thus, a management change applied on one component has effect on other components. This interactive nature requires that the environment is managed and protected as a cohesive whole . Furthermore, this can be accomplished through an integrated approach to environmental management. The basic tool for integrated management is now considered as watershed models, which are more comprehensive than the earlier mathematical models of hydrological processes (Ozkul & Harmancioglu, 1996).

On the other hand, water resources problems have also become varied with respect to scale. In the past, most problems were local, requiring local remedies. Currently, however, spatial distribution of problems has become highly significant so that water resources management is directed towards regional or further to basin-wide problems. This is essentially another reason why watershed models have been put in widespread use.

A model for integrated water management helps to develop implementable solutions to water resources problems by combining all the essential component models into an optimization scheme. The incorporates all of the interactive forces or influences. Therefore, it helps the decision-making process and keeps the policy results within the perspective of social goals and legal constraints (Singh, 1995)

Another development in the past few years has been the revolution in computer technology along with that in information technology. In addition to current management needs, the development of the new watershed models has been shaped by the state of scientific understanding and the availability of data and computational/programming resources. With increased scientific understanding, models' ability to represent physical process has improved. More and better data have allowed modelers to more effectively calibrate and validate their models, which in turn has resulted in increasing confidence in both model results and in the use of models to evaluate alternative management strategies. Faster, more powerful, and less expensive computers have allowed the use of models by a larger community of modelers, and for more complex applications. Improved computer software has facilitated interactions between data, the model, and the modeler.

Currently a large number of computer-based watershed models are available for use in water resources management. These are highly comprehensive models, and some of them have found a wide area of application. Among these are HSPF (Hydrological Simulation Program-Fortran), SWRRB (Simulator for Water Resources in Rural Basins), and SWMM (Storm Water Management Model) (Özkul & Harmancıoğlu, 1996). Such models have two basic objectives:

a) identification of the watershed system with respect to basic processes and interactions involved;

b) assessment of alternative management strategies (scenarios) to arrive at the most appropriate basin management scheme.

In general, the available watershed models are classified into three groups:

a) urban drainage models,

b) basin drainage models

c) receiveing media models.

The next section deals with urban drainage models, an example of which is the SWMM used in this study.

2.5 Urban Drainage Models

2.5.1 The Urban Drainage System

Population growth and urban development can create potentially severe problems in urban water management (Chow et al., 1988). One of the most important facilities in preserving and improving the urban water environment is an adequate and properly functioning storm water drainage system. Construction of houses, commercial buildings, parking lots, paved roads, and streets increase the impervious cover in a watershed and reduce infiltration. Also, with urbanization, the spatial pattern of flow in the watershed is changed and there is an increase in the hydraulic efficiency of flow through artificial channels, curbing, gutters, and storm drainage and collection systems. These factors increase the volume and velocity of runoff and produce larger peak flood discharges from urbanized watersheds than those occurred in the preurbanized condition. Many urban drainage systems constructed under one level of urbanization are now operating under a higher level of urbanization and have inadequate capacity.

One view of the typical urban drainage system is shown in Fig.2.8. The system can be considered as consisting of two major types of elements:

Location Elements :These elements are the places where the water stops and undergoes changes as a result of human controlled processes, e.g. water storage, water treatment, water use, and waste water treatment.

Transfer Elements :These elements connect the location elements; these elements include channels, pipelines, storm sewer, sanitary sewers, and streets.

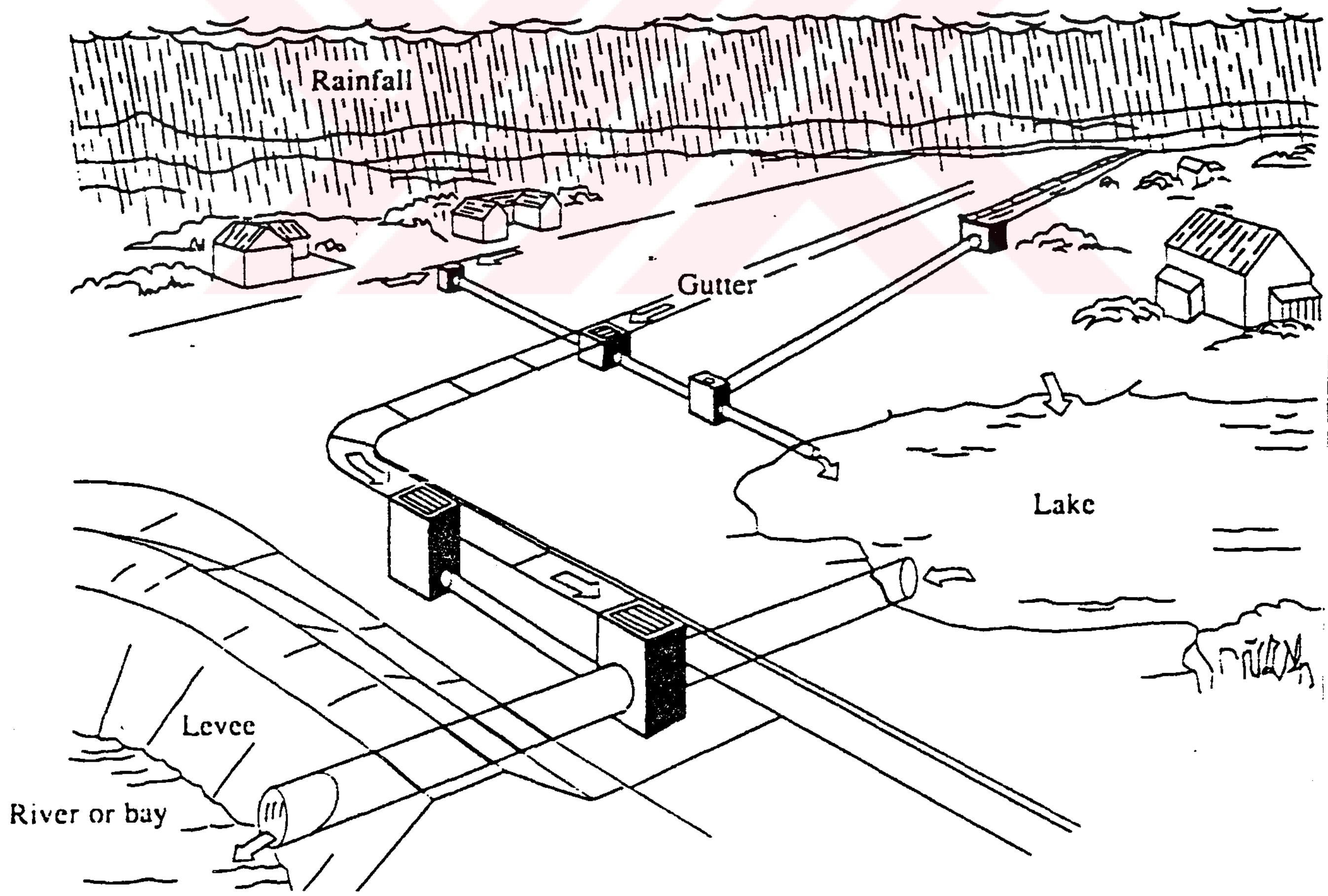


Figure 2.8 Typical Urban Drainage System (Chow et al., 1988)

The system is fed by rainfall, influent water from various sources, and imported water in the pipes or channels. Figure 2.8 shows a storm sewer system for collection of storm drainage in a pipe network and discharge to a receiving water body.

System concepts are increasingly being used as an aid in understanding and developing solutions to complex urban problems. These problems involve distributed systems, and must be analyzed to account for both spatial and temporal variations. Urban watersheds vary in space in that the ground surface slope and cover, and the soil type change from place to place in the watershed. They vary in time in that hydrologic characteristics change with the process of urbanization. The mathematical formulation of models for urban water systems distributed in both time and space is a complicated task. Consequently, spatial variation is sometimes ignored, and the systems are treated as being lumped. Some spatial variation can be introduced by dividing the watershed system into several subsystems that are each considered lumped, and then linking these lumped system models together to produce a model of the entire system.

Models can be used as tools for planning and management of the urban drainage system. In particular, a number of computerized watershed simulation models have been proposed. The determination of the runoff volume and peak discharge rate are important issues in urban storm water management.

2.5.2 Urban Storm Water Management Models

Urban runoff quality and quantity constitute problems of both a historical and current nature (Huber et al., 1988). Cities have long assumed the responsibility of control over storm water flooding and treatment of point sources (e.g., municipal sewage) of wastewater. In recent years, comprehensive urban storm water management models are developed by the advent of modern, high speed computers which have led to the development of new, complex, and sophisticated tools for analysis of both quantity and quality problems.

The first computerized models of urban storm water management were developed during the late 1960's. Since that time, a multitude of comprehensive models have been discussed in literature. The models applicable to design of urban storm water drainage can be classified as planning models, design models, flow prediction models, and screening models (Fig.2.9).

Planning models are used for broader planning studies of urban storm water management problems, usually for a relatively large space frame and over a relatively long period of time (Chow et al., 1988). The quantity and quality of storm water is treated in a gross manner, considering only the mass conservation of water and pollutants without considering the dynamics of their motion through the system. Planning models are employed for such tasks as studies of receiving water quality and treatment facilities. Typical examples of planning models are: (1)SWMM-Storm Water Management Model, developed by Metcalf and Eddy,Inc., the Univesity of Florida, and Water Resources Engineers, Inc.; (2)STORM-Storage, Treatment,

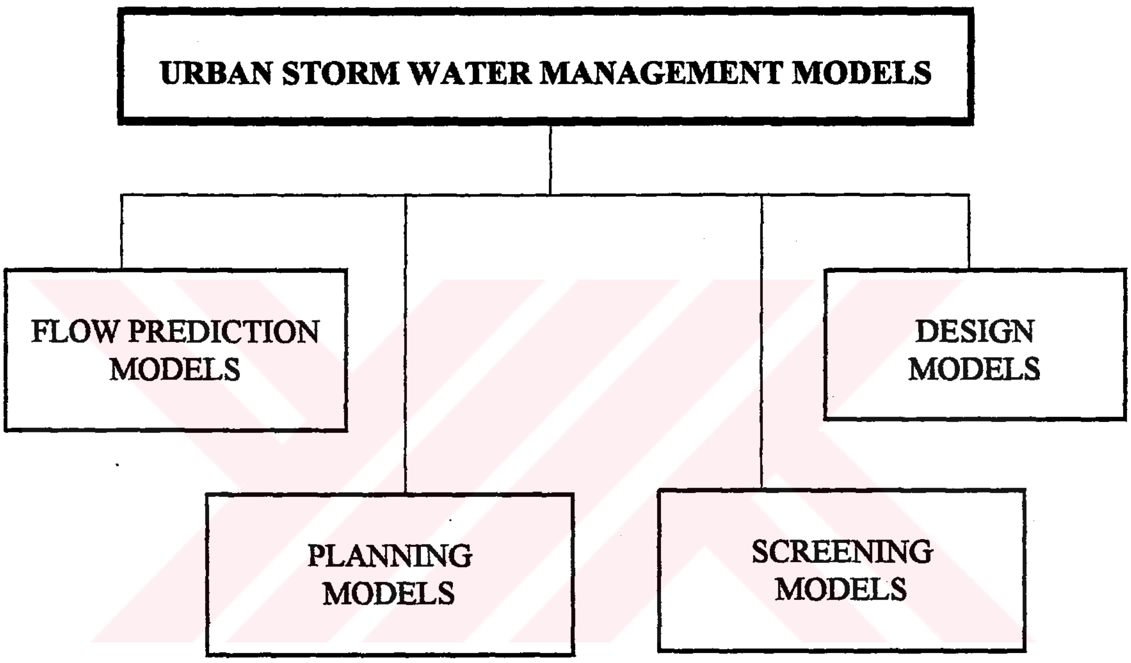


Figure 2.9 Classification of urban storm water management models

Overflow, Runoff Model, created by the U.S. Army Corps of Engineers; (3) RUNQUAL-Runoff Quality, which includes the hydraulic portion of the SWMM RUNOFF model and the stream water quality model QUAL-II (Roesner, Giguere, and Davis, 1977); (4) HSPF-Hydrological Simulation Program, which is a later version of the Stanford Watershed Model-SWM, developed by Johnson, et al.; (5) MITCAT-MIT Cathment Model, developed by Harley, Perkins, and Eagleson. A general comparison of urban planning models attributes are given in Table 2.1

Table 2.1 Comparision of Urban Model Attributes (Donigan et aL, 1995).

Attributes	DR3M-QUAL	HSPF	Model Statistical [a]	STORM	SWMM
Sponsoring agency	USGS	EPA	EPA	HEC	EPA
Simulation type [b]	C,SE	C, SE	N/A	C	C, SE
No Pollutants	4	10	Any	6	10
Rainfall/Runoff Analysis	Y	Y	Y [c]	Y	Y
Sewer System Flow Routing	Y	Y	N/A [j]	N	Y
Full, Dynamic Flow Routing Equations	N [j]	N	N/A	N	Y [d]
Surcharge	Y [e]	N	N/A	N	Y [d]
Regulators, Overflow, Structures e.g. Weirs, Orifices etc.	N	N	N/A	Y	Y
Special Solids Routines	Y	Y	N	N	Y
Storage Analysis	Y	Y	Y [f]	Y	Y
Treatment Analysis	Y	Y	Y [f]	Y	Y
Suitable for Screening (S)Design (D)	S,D	S,D	S	S	S, D
Available for Microcomputer	N	Y	Y [g]	N	Y
Data and Personnel Requirements [h]	Medium	High	Medium	Low	High
Overall Model Complexity [I]	Medium	High	Medium	Low	High

a EPA Procedure
b C = Continuous simülation, SE=Single event simulation
c Runoff coefficient used to obtain runoff volumes
d Full dynamic equations and surcharge calculations only in Extran Block of SWMM
e Surcharge simulated by storing excess inflow at upstream end of pipe.
f Pressure flow not simulated.
Storage and treatment anaylzed analytically
g FHWA study Driscoll et all (1989).
h General requirements for model installation, familiarization, data requirements, etc. To be interpreted only very generally.
I Reflection of general size and overall model capabilities. Note that complex models may still be used to simulate very simple systems with attandent minimal data requirements.
j Y = Yes , N=No

Design models are oriented towards the detailed simulation of a single storm event. They provide a complete description of flow and pollutant routing from the point of rainfall through the entire urban runoff system and often into the receiving water as well. Design models are generally used for simulation of a single storm event and are typified by short time steps (minutes) and short simulation times (hours). Data requirements may be moderate to very extensive depending upon the particular model employed.

Design models may be classified further into hydraulic design models and least-cost optimal design models. Hydraulic design models range from the simple rational method to much more sophisticated flow simulation models based upon solving the dynamic wave equations. One example of a hydraulic design model is ILLUDAS (Illinois Urban Drainage Area Simulator), developed by Terstriep and Stall (1974), which is popular both in the United States and abroad. This model is an extension of the British TRRL (Transportation and Road Research Labarotary) model (Watkins, 1962) to include both paved-area and grassed-area hydrographs (Claycomb et al., 1978).

Least-cost optimal design models are intended for determining the lowest-cost storm sewer layout and pipe diameters that will convey storm drainage adequately. These models are based on optimization techniques such as linear programming, dynamic programming, nonlinear programming, heuristic techniques, or a combination of these. The flow simulation for the sewer network is considered a part of the optimization. One of the more comprehensive models of this type is a dynamic programming model called ILDS (Illinois Sewer Design) developed by Yen.

Flow prediction models simulate the flow of storm water in existing systems of known geometric sizes or in proposed systems with predetermined geometric sizes. Most flow prediction models simulate the flow for a single rainfall event, but some can simulate the response to a sequence of events. The simulation might be for historical, real-time, or synthetically generated storm events. At least some simple hydraulics is considered in most models. A model may or may not include water quality simulation. The purpose of a flow simulation may be to check the adequacy and the performance of an existing or proposed system for flood mitigation and water pollution control, to provide information for storm water management, or to form part of a real-time operational control system (Chow et al., 1988).

An emerging design philosophy is to use either traditional (rational method) or more advanced optimization methods for designing a storm sewer system, then checking the final design by detailed hydraulics simulation and cost analysis. An example of this approach is a British design and analysis procedure called the Wallingford Storm Sewer Package - WASSP.

Screening models are preliminary, "first-cut" , desktop procedures that require no computer. They are intended to provide a first estimate of the magnitude of urban runoff quantity and quality problems, prior to an investment of time and resources into more complex computer based models. Examples of screening models include SWMM Level I by Heaney and Nix in 1977.

Finally, nowadays, lots of comprehensive urban storm water management models are used for urban hydrologic and hydraulic simulations that may be entirely suitable for a given problem.

2.6 Selection of a Model

The selection of a hydrologic model should foremost consider whether the model is applicable to conditions existing in the basin under study. For example, certain models were developed for use in urban areas. These models should not be used in rural areas without first evaluating whether the internal assumptions of the model are applicable in the rural basin. This requires that the user of a model becomes familiar with the process and internal operation of the model. For example, several of the models use Manning's formula to estimate overland flow. In natural basins of extreme slope, the Manning's formula is not directly applicable as it will forecast extreme supercritical velocities, while streams actually tend to cascade down the channel as a series of hydraulic jumps with flow velocities approximating critical velocity. Without knowledge of the method of streamflow computations, significant errors in the discharges would be overlooked (Claycom et al., 1978).

Once models have been chosen that are applicable to the basin under study, further considerations should include the budget for the project, the time available to prepare the hydrology, the availability of computer facilities, and the training of personnel. Budget considerations first apply to selection of the type of model, that is, whether a simple unit hydrograph program such as HEC-1 or TR-20 is to be used, or, a more complex kinematic wave model such as SWMM, MITCAT, or HYDROCOMP. A model that needs a large, detailed database when the project budget contains neither the time nor money to provide that data will almost certainly result in an unsatisfactory experience.

Ideally, the selection of a model should be based on a benefit-cost analysis. As in all engineering work, the identification and quantification of benefits and costs is difficult. But the fundamental concept will help immensely even if the analysis is more qualitative than quantitative. The more complex models will give more detailed results, however, their cost is generally several times greater than the cost of simple models. The unit hydrograph models also require less time and money to set up on computer systems, to train personnel in their use, and to collect the input data. The kinematic wave models have large computer storage requirements that only the larger computers can handle, sometimes necessitating that the user contacts with the program developer for normal program operation. These items also add to the cost. The cost of setting up a kinematic wave model to the point where it is functional is approximately double the cost of a unit hydrograph model. Actual costs depend on the availability of computer facilities and the knowledge of the computer operator.

Figure 2-10 presents the basic concept of a benefit-cost analysis. In general, the more complex a model, the more information is available, which rises rapidly due to increased input data and personnel requirements. More information is good, but as the model produces more information, the marginal benefit of that information is probably decreasing. What this means, of course, is that there exists an ideal point at which we can maximize the net gain or benefits (point A in Figure 2-10). In other words, there should be a model that maximizes the net gain.

In choosing between unit hydrograph model and a kinematic wave model, additional consideration should be given to the relationship between increased accuracy and decreased cost. Generally, the use of a kinematic wave model requires detailed input of infiltration, depression storage, basin slopes, basin roughness, channel slope, and channel roughness. The model performs a detailed analysis tracking the rainfall from its point of impact on the basin to a downstream point. The discharges obtained from this type of analysis are highly sensitive to changes in the above parameters and accurate values of these parameters are difficult to obtain without a costly, detailed field analysis. Arbitrary selection of program default values or average values for large basins will cause significant errors in discharge and defeats the purpose of the more detailed model. Unit hydrograph models use empirical coefficients to approximate the resulting hydrograph without considering in detail the process by which rainfall becomes runoff and reaches the design point. If gross approximations of the input parameters are made by the user of say MITCAT or SWMM, the results will be no better than the unit hydrograph methods at double the cost. Use of a kinematic wave model, therefore, when data does not exist, requires an extensive data collection program as a major part of the hydrologic project. The time and money for such an analysis should primarily depend on the economics of the hydraulic project characterization to predict outcomes in the form of quantity and quality values. Since study objectives may be directed toward both complete temporal and spatial detail as well as to gross effects such as total pounds of pollutant discharged in a given storm. It is essential to have both time series output, i.e., hydrographs and pollutographs and daily, monthly, annual and total simulation summaries available for review.

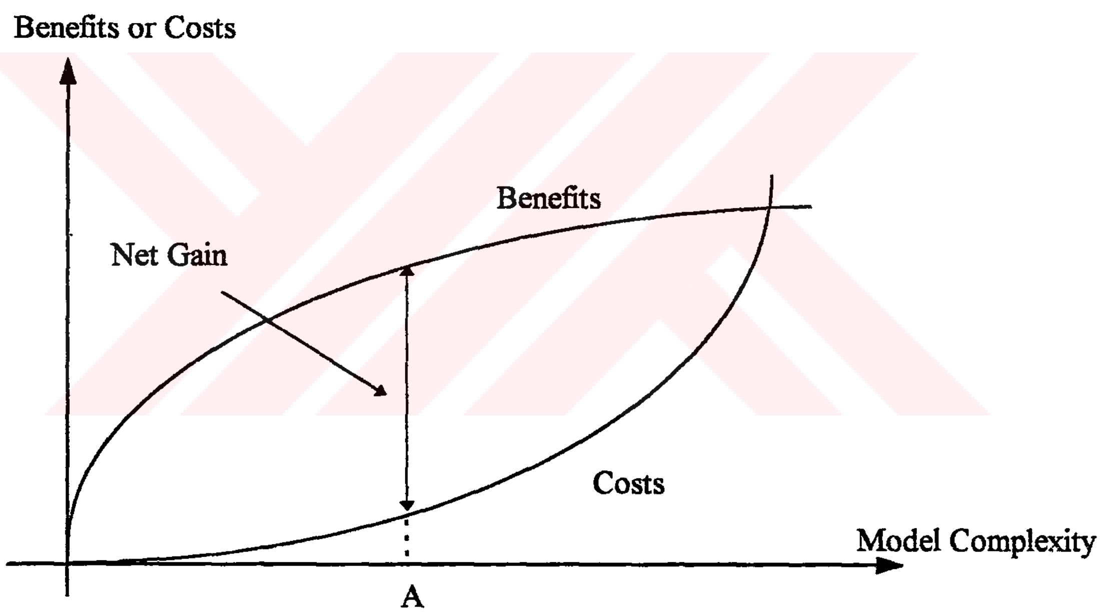


Figure 2.10 Benefits / Costs analysis for model selection (Nix et al., 1991).

CHAPTER THREE
THE STORM WATER MANAGEMENT MODEL (SWMM)

3.1 General Description of SWMM

The Storm Water Management Model, SWMM, is one of the most important complex models of storm water developed by U.S EPA (Environmental Protection Agency), which is widely used today. This model is a comprehensive, relatively sophisticated hydrologic, hydraulic and water quality simulation model for analysis of quantity and quality problems associated with urban runoff. The SWMM model has the following major capabilities (Huber et al., 1988):

(a) conversion of any rainfall hyetograph or hyetographs into a runoff hydrograph for each watershed that is modeled,
(b) production of pollutographs, runoff water quality graphs, based on land use, management, rainfall, and other data,
(c) computation of hydrographs and pollutographs for dry weather flow,
(d) flood routing through multiple channels and pipes,
(e) simulation of the impacts of optional water storage facilities,
(f) computation of storm water treatment impacts using an array of treatment technologies,
(g) computation of receiving water quantity and quality impacts,
(h) computation of capital and operating and maintenance costs for storage and treatment options,

The first SWMM model was developed in 1969 - 1971 by three groups: Metcalf and Eddy, Inc., the University of Florida, and Water Resources Engineers, Inc. (now Camp, Dresser and

McKee, Inc.) (Huber, 1995). Improvements to SWMM led to Version 2 in 1975 and to Version 3 in 1981. The first personal computer version, PCSWMM was distributed in 1984. Version 4 (3,4) the U.S EPA public domain personal computer version was developed in 1988 by Huber, Dickinson, and Roesner in 1988. The program was written in Fortran. In 1993 PCSWMM was transferred to the Windows environment. Finally, the latest version was developed as U.S EPA Windows SWMM for Total Maximum Daily Load, TMDL, analysis in 1994 (Lahlou et al., 1995).

The SWMM model may be used for both planning and design of urban storm water drainage systems. The planning mode is used for an overall assessment of the urban runoff problem and proposed abatement options. This mode is typified by continuous simulation for several years using long-term precipitation data. Catchment schematization is usually "coarse" in keeping with the planning level analysis. A design level event simulation may also be run using a detailed catchment schematization and shorter time steps for precipitation input. The SWMM is designed for use by engineers and scientists experienced in urban hydrology and water quality management. It can be used to study the impact of waste loads on instream water quality and to identify the magnitude and quality characteristics of nonpoint waste loads as part of a field sampling program.

As shown in Figure 3.1., the Storm Water Management Model, SWMM, simulates real storm events on the basis of rainfall (hyetograph) and other meteorological inputs and system (catchment, conveyance, storage/treatment) characterization to predict outcomes in the form of quantity and quality values. Study objectives may be directed towards both the complete temporal and spatial detail, as well as to gross effects such as total pounds of pollutant discharged in a given storm. It is essential to have both time series output, i.e., hydrographs and pollutographs, and daily, mothly, annual and total simulation summaries available for review.

The SWMM model is certainly formidable both in terms of its size and capabilities. Some criterias are given below for the usage of SWMM model:

(a) The engineer must be knowledgeable of the SWMM modeling techniques such as non-linear reservoirs, kinematic waves, St. Venant equations, and buildup-washoff equations. As a result, the engineer is assumed to be familiar with the problem to be solved and with customary techniques for handling it. A clear problem definition is a prerequisite to any solution methodology.

(b) By virtue of the problem size or complexity, a simpler technique or model will not work. It may be borne in mind, however, that if calibration/verification data are available, the SWMM model may also be used as a very simple "black box" model with minimal input data, at the expense of computer overhead to manage the program size and off-line files.

(c) Quality is to be simulated. Although there are other models that also simulate quality, the SWMM model is perhaps the most flexible of them. Of course, this model is often applied only to water quantity problems.

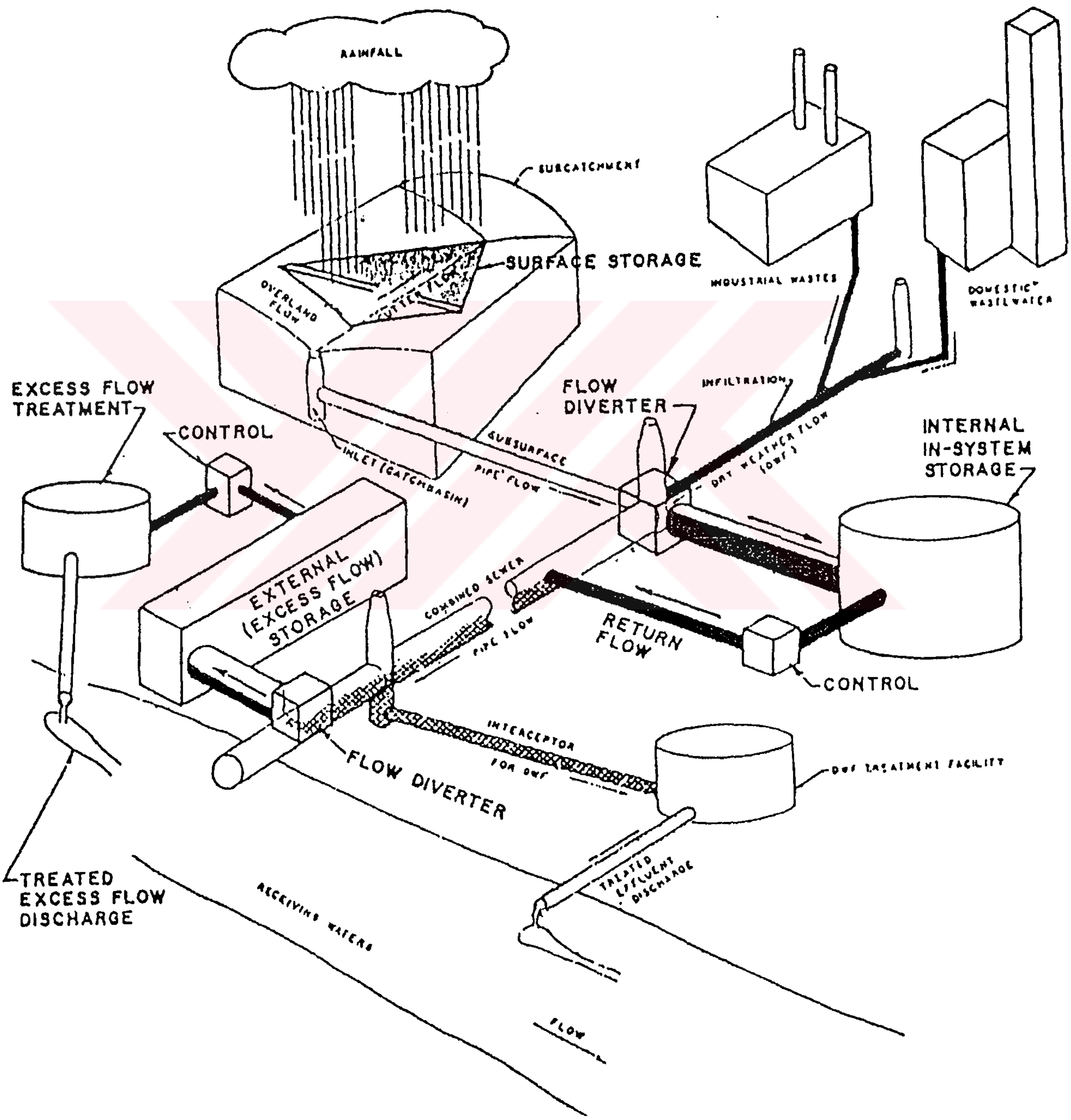


Figure 3.1 U.S EPA Storm Water Management Model (Overton and Meadows, 1976).

3.2 Previous Applications of SWMM

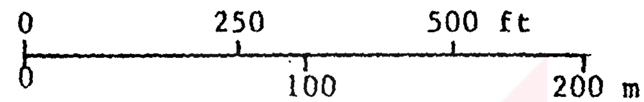
3.2.1 Modeling Studies Using SWMM

Models are very helpful in understanding, projecting, and abating combined sewer overflow problems. No model is perfect and each has its advantages and liabilities. The Storm Water Management Model, SWMM, is just one of several modeling options, but it has been used in hundreds of studies in the U.S., Canada, and as well as the other parts of the world, most often for analysis of complex drainage systems in highly urbanized areas. Several examples of SWMM applications may be found in readily available journals such as the American Society of Civil Engineers, ASCE, Journal of Hydraulic Engineering, Journal of Environmental Engineering, and Journal of Water Resources Planning and Management. SWMM also has been subject to numerous comments and critiques that have contributed to make it a very sophisticated simulation model.

The U.S Geological Survey (USGS) monitored the Kings Creek apartment complex in Miami, Florida for flow and quality in 1977-1978 and documented hydrologic properties of the catchment for modeling purposes (Huber et al. 1991). The 5.9 ha catchment had an overall imperviousness of 71% and a directly connected imperviousness of 44%. The most sensitive input parameters were subcatchment area, imperviousness and width. The catchment was subdivided into 13 subcatchments as shown in Fig.3.2. The drainage system of concrete pipes is shown in Fig.3.3.

Five storms were calibrated as a group, and another five were used to verify the calibration for peak flows and for runoff volume. Quality data for the Kings Creek apartment complex were not as plentiful as the flow data but nonetheless could be used for model testing. The flow prediction was not calibrated, but the quality parameters represented from six to eleven trial calibrations of buildup-washoff parameters, with varying degrees of success.

Comparison of measured and predicted hydrographs were good and not significantly different from an uncalibrated run. Also, comparisons of detailed pollutographs (concentration vs. time) were considered to be seldom necessary in application, because only the total storm event load is usually of interest (Huber, 1995).



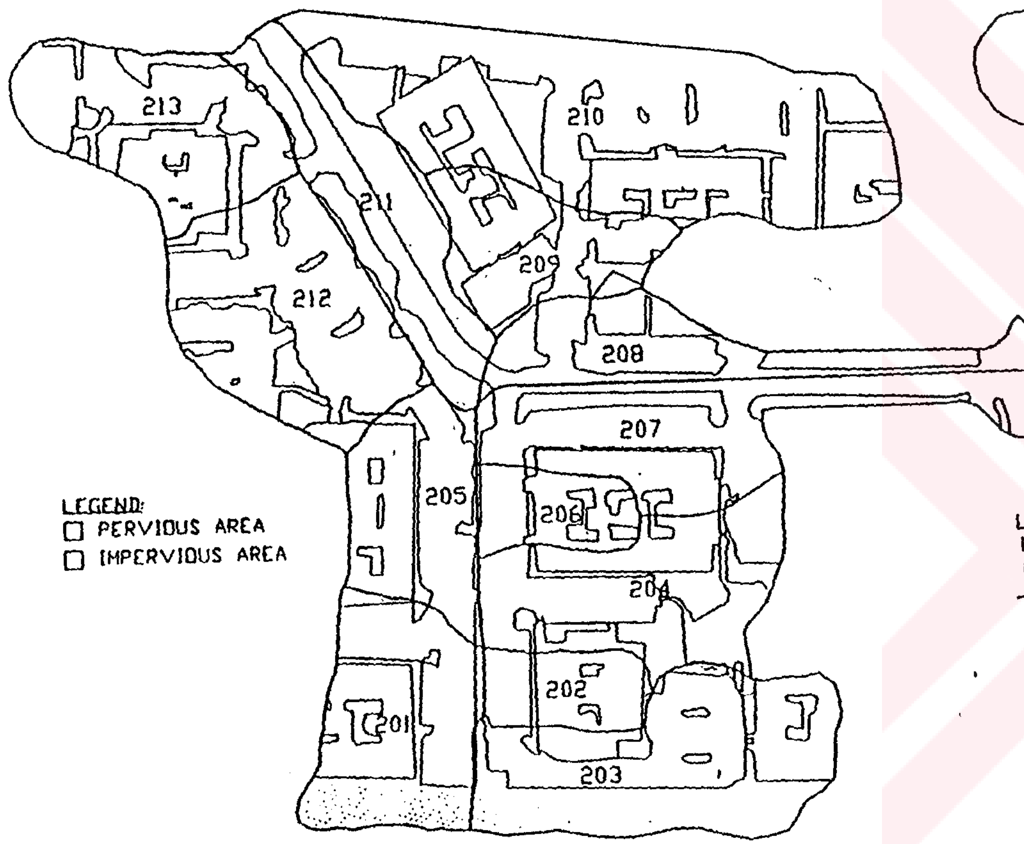


Figure 3.2 Kings Creek Apartment catchment subcatchment and imperviousness (Huber, 1995).

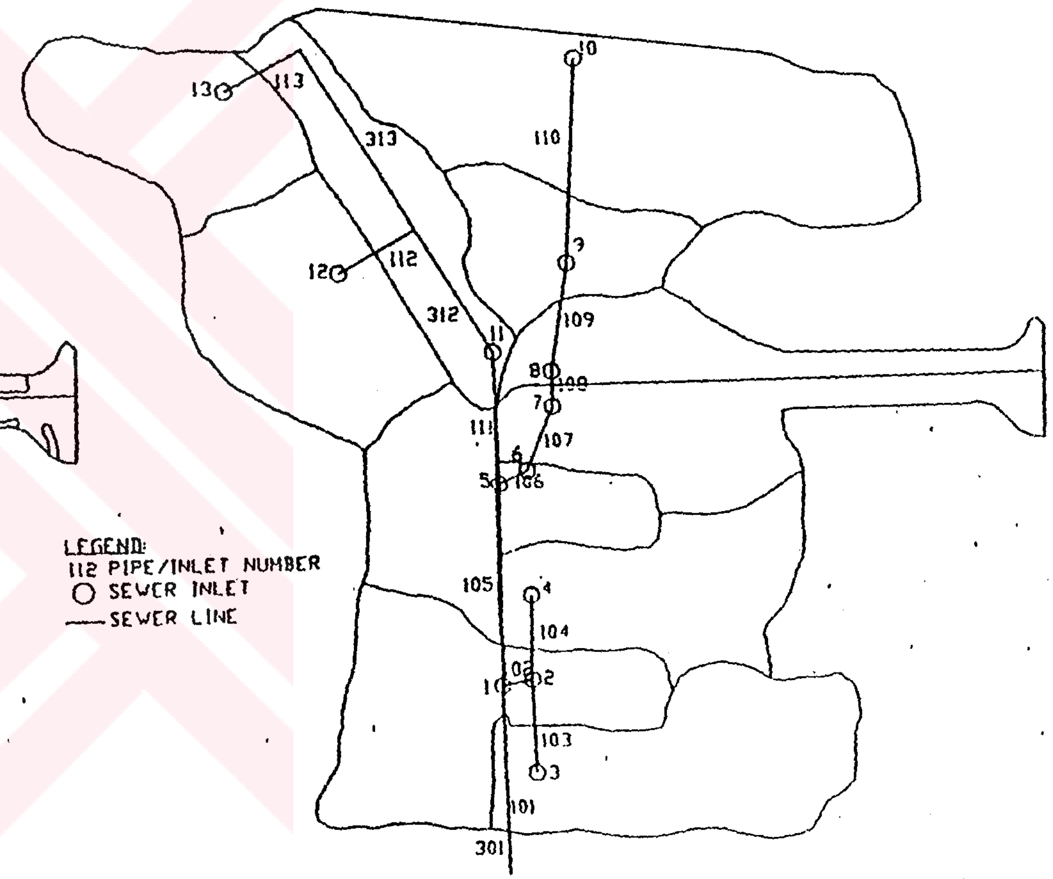


Figure 3.3 Kings Creek Apartment catchment pipe system (Huber, 1995).

The SWMM model was successfully applied to a urbanized residential watershed the Bachman Branch area in Dallas, Texas (Warwick et. al., 1991). Bachman Branch drains a 10 sq-mil urban, residental community with a low structural density. Thirty percent of the subarea is impervious. The terrain consists of 2-5% slopes with moderately tight soils. Precipitation and runoff were monitored by the U.S. Geological Survey (USGS) from 1963 to 1978. Figure.3.4 presents the Bachman Branch area in Dallas, Texas.

This area was analyzed in an earlier work in which the U.S. Army Corps of Engineers' storage, treatment, overflow, and runoff model (STORM) was applied to predict outflow hydrographs and associated water quality. The SWMM application is intentionally constrained to a rather gross spatial scale (no modeling of storm sewer transport) in order to mimic anticipated regional modeling efforts. Three different levels of watershed spatial abstraction are investigated in relation to the impact of using two different parameters for model calibration (pervious depression storage and percent imperviousness) along with three separate calibration events.

The calibrated SWMM model performed quite well at predicting both the total runoff volume and the peak flow rate. This successful application was most sensitive to calibration event selection, with the smallest event resulting in the worst overall performance. The importance of watershed conceptualization level was less significant, with no noticeable difference between the two highest abstraction levels. They use of percent imperviousness, as the single moawl calibration parameter, was generally more successful than adjustment of pervious depression storage.

Results are also compared with an earlier study performed on the same watershed and data set, which used the U.S. Army Corps of Engineers storage, treatment, overflow, and runoff model (STORM). At the end, SWMM water-quality simulation was also quite acceptable, but with a consistent underestimation of in-stream total suspended solids concentrations (Warwick et. al., 1991).

The SWMM was used to establish the sewer system of Rutland, Vermont (Nix et al. 1991). The city of Rutland comprises an area of approximately 7 sq-mil. Initial construction of the sewer system as it is today is shown in Fig.3.5. Before construction of a primary sewage treatment plant in 1963, sanitary sewage and urban runoff discharges were released directly to Otter Creek and its tributary, East Creek.

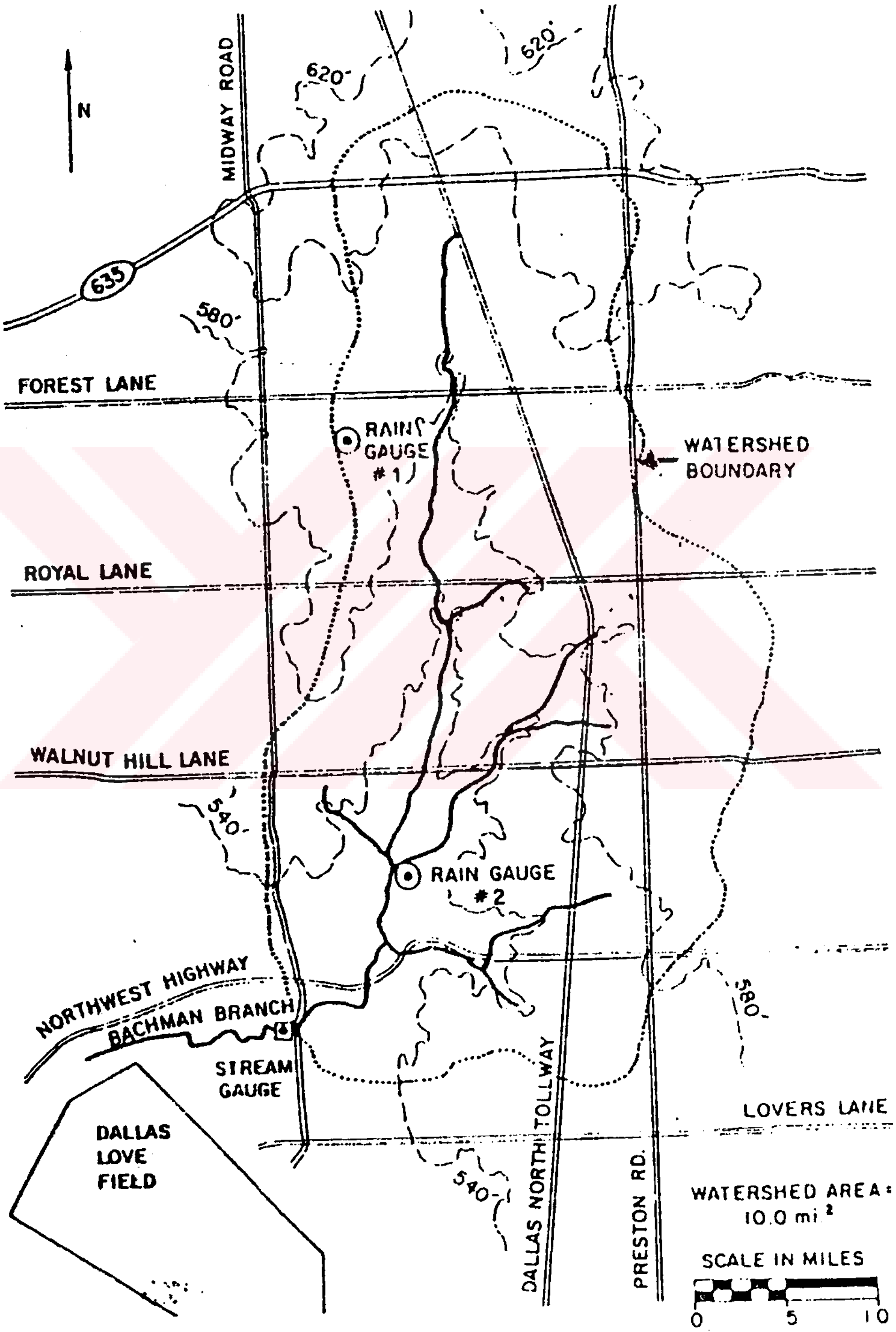


Figure 3.4 Bachman branch study area (Warwick et al., 1991).

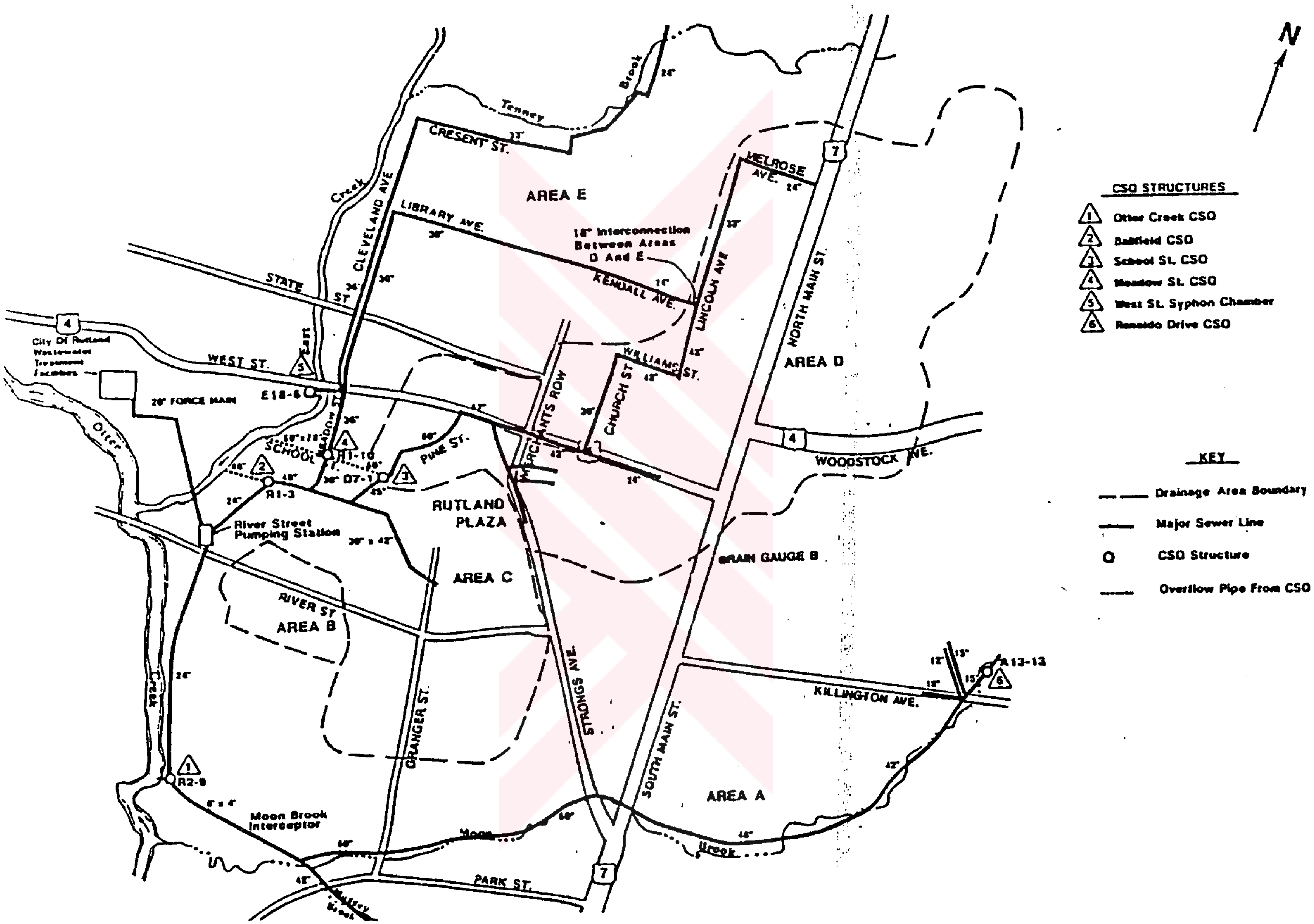


Figure 3.5 Schematic of the Rutland, Vermant combined sewer system (Nix et al., 1991).

The sewage system is divided into five drainage areas : Areas A,B,C,D, and E. Areas B,C,D, and E comprise what is also known as the East Creek Drainage Area (as all combined sewer overflows are discharged to East Creek). This area is dominated by older combined sewers. Area B is a very small area contributing only sanitary sewage to the River Street Pumping Station. Area C contains shopping and residential districts and includes about 5 percent of the City's area. Area D contains the downtown commercial and residential district and includes about 15 percent of the City's acreage. Area E comprises about one quarter of the city.

The areas contributing surface runoff to the sewer system were characterized by 22 subcatchments for use in the RUNOFF Block of the SWMM model (eight were located in area A, one in area C, six in area D, and seven in area E). Aerial photographs and 7.5-minute USGS topographic maps were used to provide the physical characteristics of the subcatchments. The RUNOFF Block was executed with a time step of five minutes. This value produced very small continuity errors and a smaller time step was considered unnecessary. A 15-seconds time step was used to execute the EXTRAN Block, which is one of the modules of the SWMM. These values represented a good compromise between stability considerations and run times.

The Rutland system model has been used to predict the peak carrying capacity of the sewer system, a ranking of the relative frequency and quantity of combined sewer overflows, locations of potential street flooding, and pollutant loadings based on flow projections and water quality data. This information has been used to evaluate various abatement alternatives. The Rutland case is an example of a reasonably well-structured, but also fairly typical modeling study. The system model was successfully validated and played an important role in the development of an abatement strategy (Nix et. al., 1991).

The SWMM model was applied to urban areas of Yarmouk, Kuwait (Zaghoul & Al-Shurbaji, 1990). Yarmouk is a flat area situated 3 km south of the downtown area and 7 km north of Kuwait International Airport . The catchment has an area of 48 ha of which approximately 25 percent is occupied by villas and 45 percent is open space. Streets cover approximately 22 percent, while other paved areas constitute 8 percent of the area. The roofs of buildings are not connected to the drainage system, and the buildings are surrounded by gardens and fences. All streets are surfaced with asphalt and bordered with concrete curbs; gutter inlets are distributed along the sides of the streets. The drainage system is of the separate type and comprises of circular concrete pipes in which water flows entirely by gravity to the outlet.

The topographic map of the catchment, land use, and storm drainage system maps are superimposed on each other to define the boundary of the catchment and the probable subcatchments. The catchment was divided into 82 subcatchments of regular shape, with each subcatchment leading to one manhole (Fig.3.6). This level of discretization was applied to all of the subcatchments. However, in order to reduce the time and effort required for simulation, a coarser level was also implemented to estimate the outflow discharge from the entire cathchment over four subcatchments (Fig.3.7). In this case, the width of each subcatchment was calculated as the summation of widths of the constituent small subcatchments. The other characteristics of the subcatchment (i.e., percent imperviousness, slope, and roughness) were calculated on the basis of a weighted average.

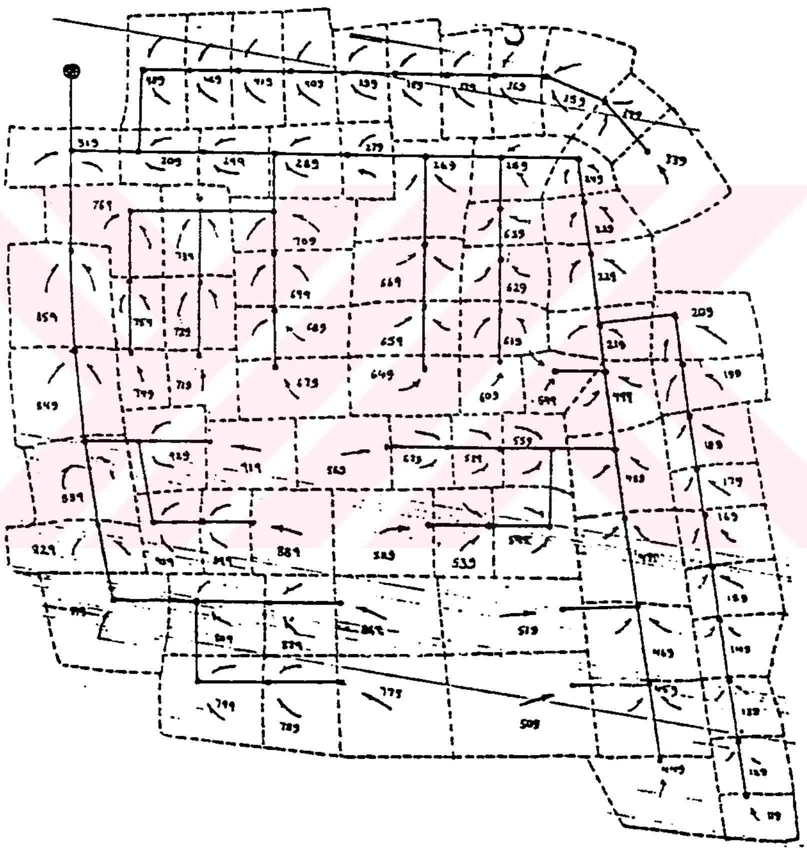


Figure 3.6 "Fine" discretization of the catchment (Zaghloul et al., 1990).

The nearest raingage (7 km) is located at the airport meterological station. Daily accumulated rainfall charts were available from the airport station. These charts were stored in a computer file, and a digitizer adapted with AUTOCAD (graphics package) is used to read the charts and to prepare hyetographs with three-minute intervals. Another raingage station is located close to the cathchment area is at Omariya, which is 1.5 km away. Unfortunately, daily charts were not available at this station; only the total daily rainfall by a standard gage was available. The Omariya Station was used to check the validity of the airport data and to determine the spatial variation in rainfall between the airport station and the selected study area.

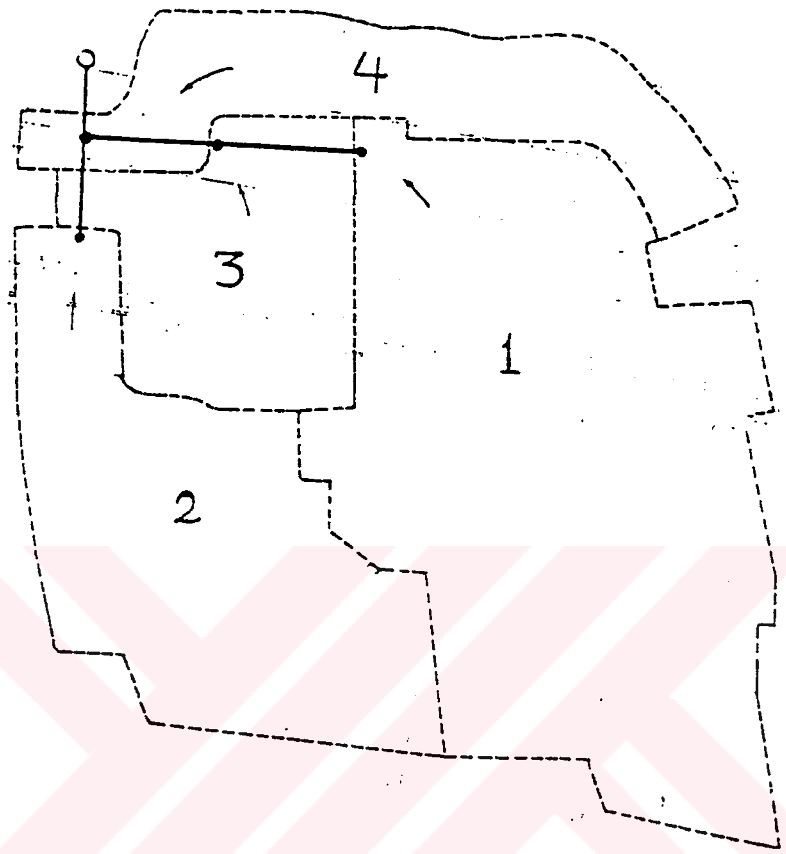


Figure 3.7 "Coarse" discretization of the catchment (Zaghloul et al., 1990).

The evaporation data were supplied by the airport meterological station in a tabulated from showing the daily amounts. The measurements of evaporation were based on class A Pan and Piche methods. As input to the RUNOFF Block, which is another module of the SWMM, the average daily rate of evaporation was calculated for each month.

Kuwait is a coastal, yet arid, country with no rivers or fresh lakes. The country relies heavily on desalinization for its water supply. Groundwater resources are limited and mostly brackish. Also, the high infiltration capacity of the prevailing sand soil indicates that there is no contribution by the pervious areas to runoff, especially during low rainfall intensities.

Off-street and paved areas that are not directly connected to the drainage system drain runoff water to the surrounding pervious areas and do not contribute to runoff. In Kuwait, only the streets and paved areas that are directly connected to the drainage system contribute to runoff. Hence, all model parameters that are related to pervious areas were not needed not to be accurately represented in the model.

The SWMM model was used to estimate the storm water runoff volume collected from all urbanized areas in Kuwait City. The annual expected harvested runoff water was found to be significant. The spatial variation of the rainfall depth over urban areas in Kuwait was large. Therefore, the choice of rainfall input in the SWMM simulation was very important. This could result in a significant difference between simulated and measured hydrographs. However, on the average, good model calibration and verification was achieved. For more accurate modeling, a raingage must be installed within the catchment area. An electronic flow measuring device should be installed at the outfall to continuously measure the runoff hydrograph (Zaghloul and Al-Shurbaji, 1990).

3.2.2 Studies That Integrate SWMM and GIS

Black & Veatch is completing stormwater master planning for three watersheds in Kansas City, Missouri using Storm Water Management Model (SWMM) (Black & Veatch, 1996). The scope of the work included field surveying to collect conveyance system data; mailing storm water surveys to watershed residents; modeling the watershed using the Runoff and Transport Blocks of SWMM; identifying existing and potential future inadequacies of the system; developing practical improvements, including cost projections; and integrating the SWMM model with GIS.

Detailed information about each watershed basin and conveyance structure is essential to ensure development of adequate datafiles needed for execution of the model. The SWMM model provides important and necessary information on the present and future adequacy of the system. The tedious and time-consuming task of developing the SWMM datafiles can be simplified by integrating the SWMM model with a Geographic Information System (GIS). A GIS is a user defined system of hardware, software, data, and procedures designed to present analysis, management, manipulation, and display of spatially referenced data in an accessible and user-friendly format.

Black & Veatch developed the integration of SWMM and GIS for storm water master planning for Kansas City, Missouri with three goals in mind. First, the aim was to organize the input data describing the drainage basin into a database. This was accomplished by creating a logical database format and user-friendly forms with an Oracle database to input, store, and display the runoff and transport block information. The second goal was to create the SWMM model datafiles. A Microstation Development Language (MDL) application was developed by Black & Veatch to integrate the information from the GIS, creating the datafiles necessary to perform the hydrologic and hydraulic analyses of SWMM. The third goal was to display the SWMM model results graphically within the GIS. Conveyance system capacities, design flows, and inadequacies were displayed on the drainage system.

The integration of GIS with the SWMM model for Kansas City, Missouri, resulted in a more efficient and effective way of gathering and storing data, creating datafiles, and displaying modeling results. The overall process of creating the datafiles was simplified with the use of the Microstation Development Language (MDL) application. As a result, efforts could be focused on the analysis of the drainage system and more possibilities could be identified within the GIS graphic format. The graphical display of the modeling results also provided an easy and effective means of analyzing the drainage system and identifying flooding locations and system inadequacies. Finally, with the City maintaining the modeling information within their GIS, future master plans will benefit from the up-to-date information (Black & Veatch, 1996).

3.2.3 Studies That Integrate SWMM with Expert Systems

Expert system technology is a relatively new tool that has been used with success in water resources. Several of these expert systems are built to assist the user in preparing data input and selecting parameters. In these systems, first, the program is run using the information from several well understood watersheds in order to assess the overall performance of the expert system and to identify any major problem associated with the model. After that, the program is asked to find the parameter values for watersheds that were studied previously by experts. Finally, parameter values are compared to the calibrated values (Baffaut and Delleur, 1989).

HYDRO developed at SRI, is a front end to the simulation model HSPF. The extended version of this expert system was written in the programming language PROLOG. The current version was developed using an expert system shell Knowledge Engineering System, KES, written in C and developed by Software Arhitecture and Engineering, Inc (Baffaut and Delleur, 1989).

Four watersheds of Florida with different characteristics have been calibrated for the Runoff Block of SWMM by Cunningham and Huber (1987):

(a) A residential sandy area with very little effective impervious area;

(b) A highway basin that consist of the intersection of two highways with some residential zones around;

(c) A shopping center with its parking lot, very flat with no pervious area;

(d) A high density residential basin.

SWMM model was calibrated for these four watersheds using the expert system with the same calibration and verification events that had been used previously.

The two calibration procedures were compared in two ways: a comparison of the quantitative calibration criteria (e.g., of the values of time, volume and peak difference and of the weighted error) and a comparison of the more qualitative criteria (e.g., the number of storm events with over- and underpredicted volumes and peaks). In addition, the final parameter values were compared to see if large differences result from the two calibrations.

The values of the quantitative criteria are very similar for the calibration events. The expert system seems to yield slightly better values for the verification events. The comparison of final parameters values showed little difference between them. The final values of the slope obtained by the expert system were lower and closer to the physical values of the watershed. These differences were compensated by the human experts who used lower values for the characteristics widths.

In conclusion, this study indicates that the expert system yields similar calibration results which are comparable with and sometimes superior to the results obtained by a human expert. The implication is that the expert system may prove to be a valuable aid to hydrologists and engineers who are faced with the task of calibrating SWMM for runoff simulation (Baffaut and Delleur, 1989).

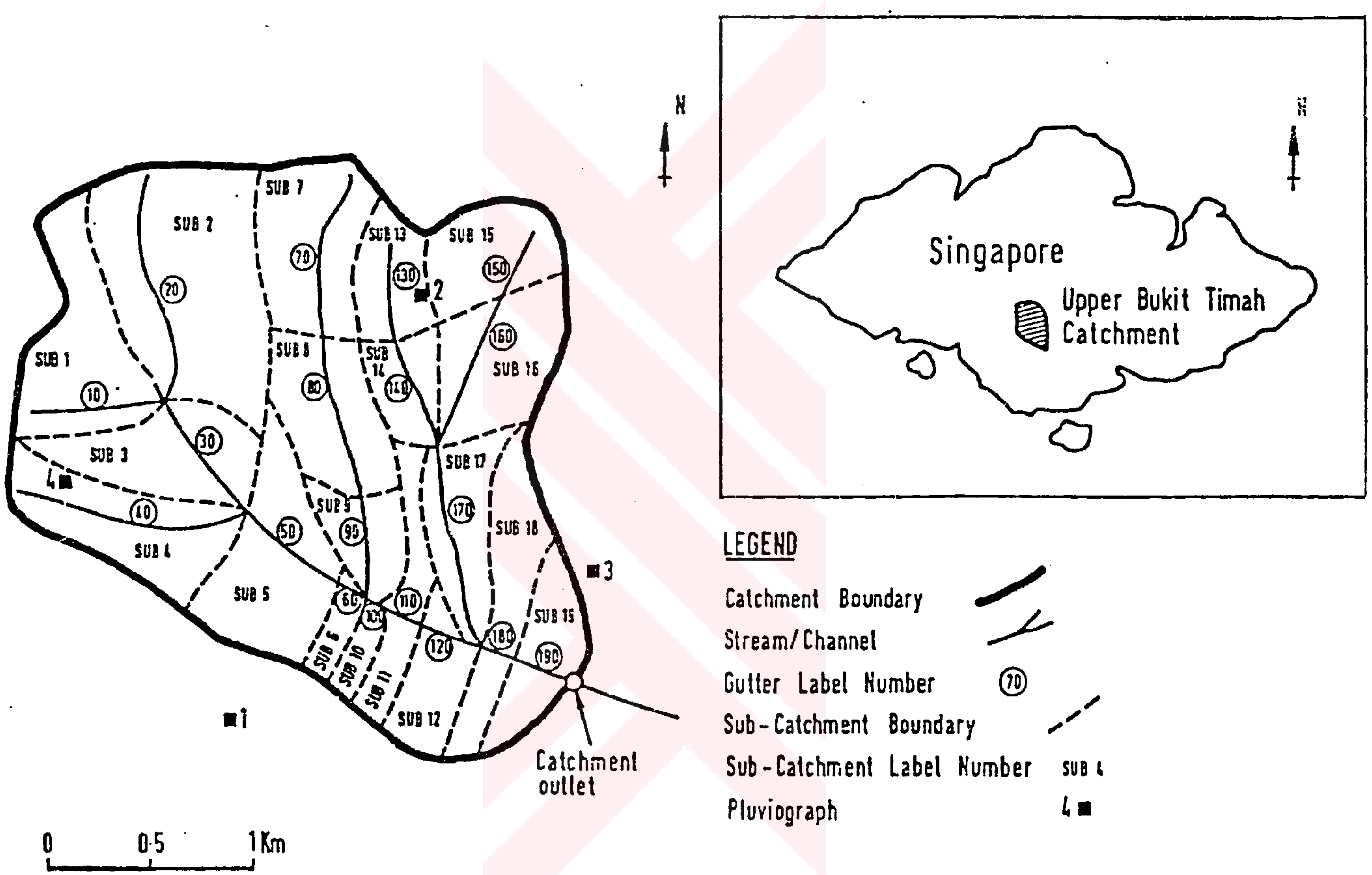
Another application is the Denver watershed which is located on the eastbound lane of the four-lane Notrh Avenue, a major access to the Denver Federal Center in Lakewood, Colorado (Baffaut and Delleur, 1989). The data collected characterize the runoff quantity for different rainfall intensities after one , two, three, four, and five dry days. To collect these data, simulated rainfall was applied to each plot with sprinklers. Runoff was measured at the outlet of each plot with flume. Discrete samples were collected by hand at the outflow of the expert system was tested on four pollutants: total phosphorus, suspended solids, lead, and zinc. Rainfall, runoff, and concentrations were obtained from the U.S. Geological Survey tape.

The goal of the expert system was to obtain a set of parameters for which the predicted pollutant loads were close to the measured loads. Also, the expert system proved a useful tool for the calibration of the model. The quantity calibration was performed using another expert system. The calibration was straightforward, and results were very good. The quality calibration was performed using this expert system (Baffaut and Delleur, 1990).

Liong et al. (1991) proposed a knowledge-based system for automating the calibration of the runoff model of Storm Water Management Model, SWMM. The automation and methodical approach of the knowledge-based SWMM in performing the calibration not only require less time and experience of the user, but also may achieve, in some cases, better results than the traditional approach to calibrate SWMM. The key components of the knowledge-based SWMM system focuses on:

(a) the results of a sensitivity study of calibration parameters;
(b) the strategy used for parameter selection and value assignment so as to match simulated and measured hydrographs;
(c) the knowledge representation scheme used to implement the calibration strategies.

An example of the application of the knowledge-based SWMM system is that on a catchment in Singapore (Liong et al., 1991). The catchment considered is the Upper Bukit Timah catchment (UBT), Singapore. The UBT catchment, Fig.3.8, has a drainage area of 6.11 km2, a fraction of imperviousness of about 19%, four rainfall stations within or just outside the catchment, and a gaging station at the catchment outlet. Only about 0.2 km2 of land is protected as a nature forest reserve while the rest of the catchment is occupied predominantly by factories and housing estates. The main channel is lined and straight, while the tributary canals are excavated and well alinged. The UBT catchment is subdivided into 19 subcatchments to represent the cathchment's spatially distributed characteristics.



Fgure 3.8 Upper Bukit Timah catchment (Liong et al., 1991).

Knowledge-based SWMM model has been applied specifically to the UBT catchment and includes knowledge specific to that catchment. However, the calibration strategies encoded in its rule base may be applied to any catchment since they are formulated in terms of achieving the best matches between predicted and measured hydrographs. The general strategies perform better with the inclusion of catchment specific knowledge in the form of a sensitivity study of the catchment parameters (Liong et. al., 1991).

3.2.4 Evaluation of the Previous Applications on SWMM

The Storm Water Management Model, SWMM is a large, complex model capable of simulating the movement of precipitation and pollutants from the ground surface through pipe and channel networks. This model has been used to predict the peak carrying capacity of the sewer system, a ranking of the relative frequency and quantity of combined sewer overflows, locations of potential street flooding, and pollutant loadings based on flow projections and water quality data. The results obtained so far have been successful provided that sufficient data are available.

The SWMM model could integrate with GIS to give more effective and efficient datafiles which are necessary to perform the hydrologic and hydraulic analyses of SWMM. The graphical display of the modeling results provide an easy and effective means of analyzing the drainage system and identifying flooding locations and system inadequacies.

The Expert and Knowledge-Based systems can be used to compare calibration parameters of SWMM. The examples mentioned in section 3.2.1 and section 3.2.2 showed that SWMM predicted loads were close to the measured loads.

The SWMM model simulates all aspects of the urban hydrologic and quality cycles, including surface runoff, transport through the drainage network, storage and treatment, and receiving water effects, the model has proved to be an appropriate tool for city engineers, especially when the sewer network is large or complex, or when quality is to be simulated.

3.3 SWMM Model Structure

An overview of the SWMM model structure is shown in Figure 3.9, and Figure 3.10 indicates the major process performed within the model blocks. In simplest terms, the program is constructed in the form of blocks as follows (Huber, et al., 1988):

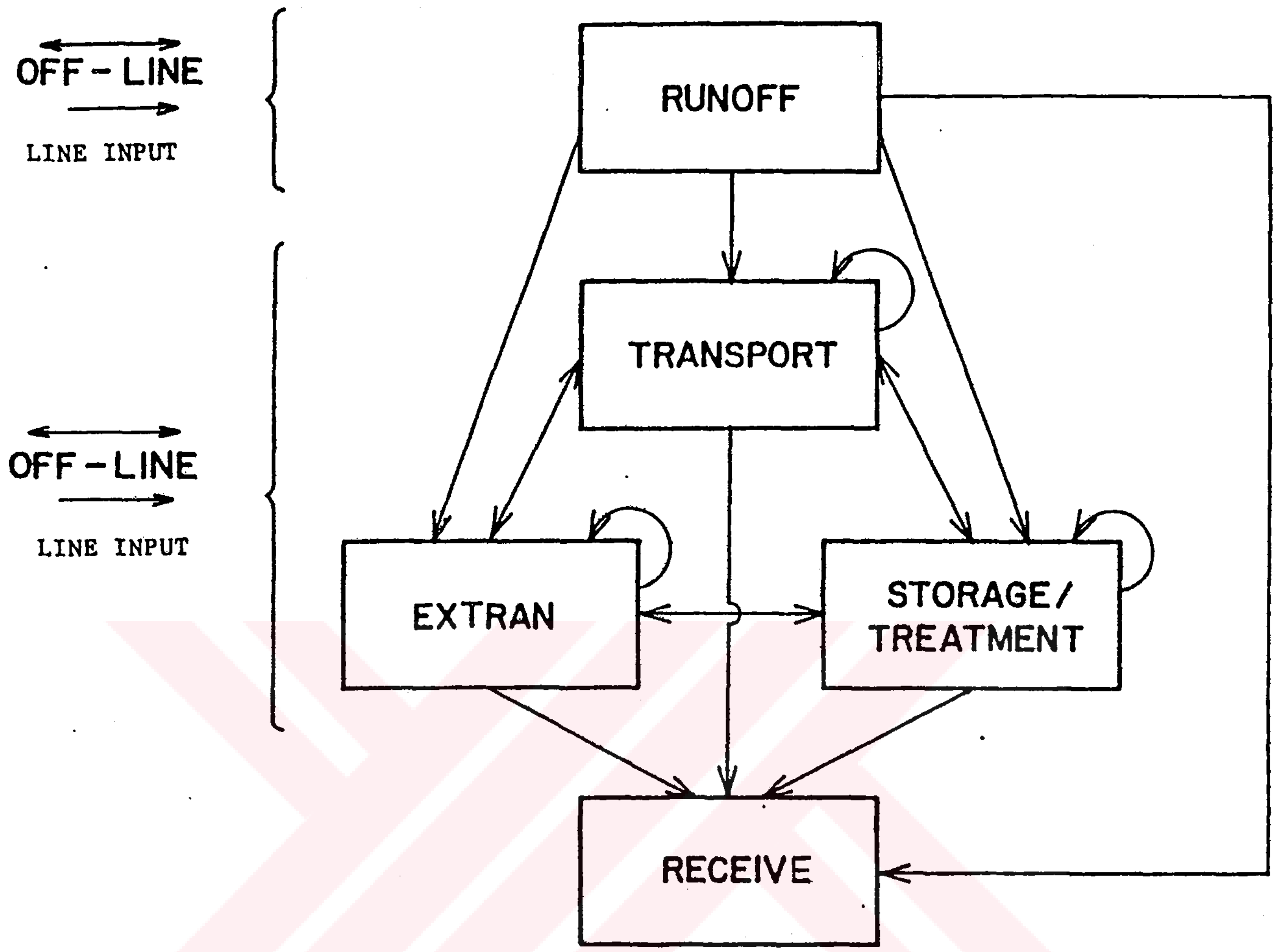


Figure 3.9 Overview of the SWMM model structure, indicating linkages among the computational blocks (Huber et al., 1988).

A)-The input sources:

The RUNOFF Block generates surface and subsurface runoff based on arbitrary rainfall (and/or snowmelt) hyetographs, antecedent conditions, land use, and topography. Dry-weather flow and infiltration into the sewer system may be optionally generated using the TRANSPORT Block.

B)-The central cores:

The RUNOFF, TRANSPORT and Extended Transport (EXTRAN) Blocks route flows and pollutants through the sewer or drainage system. Very sophisticated hydraulic routing may be performed with EXTRAN.

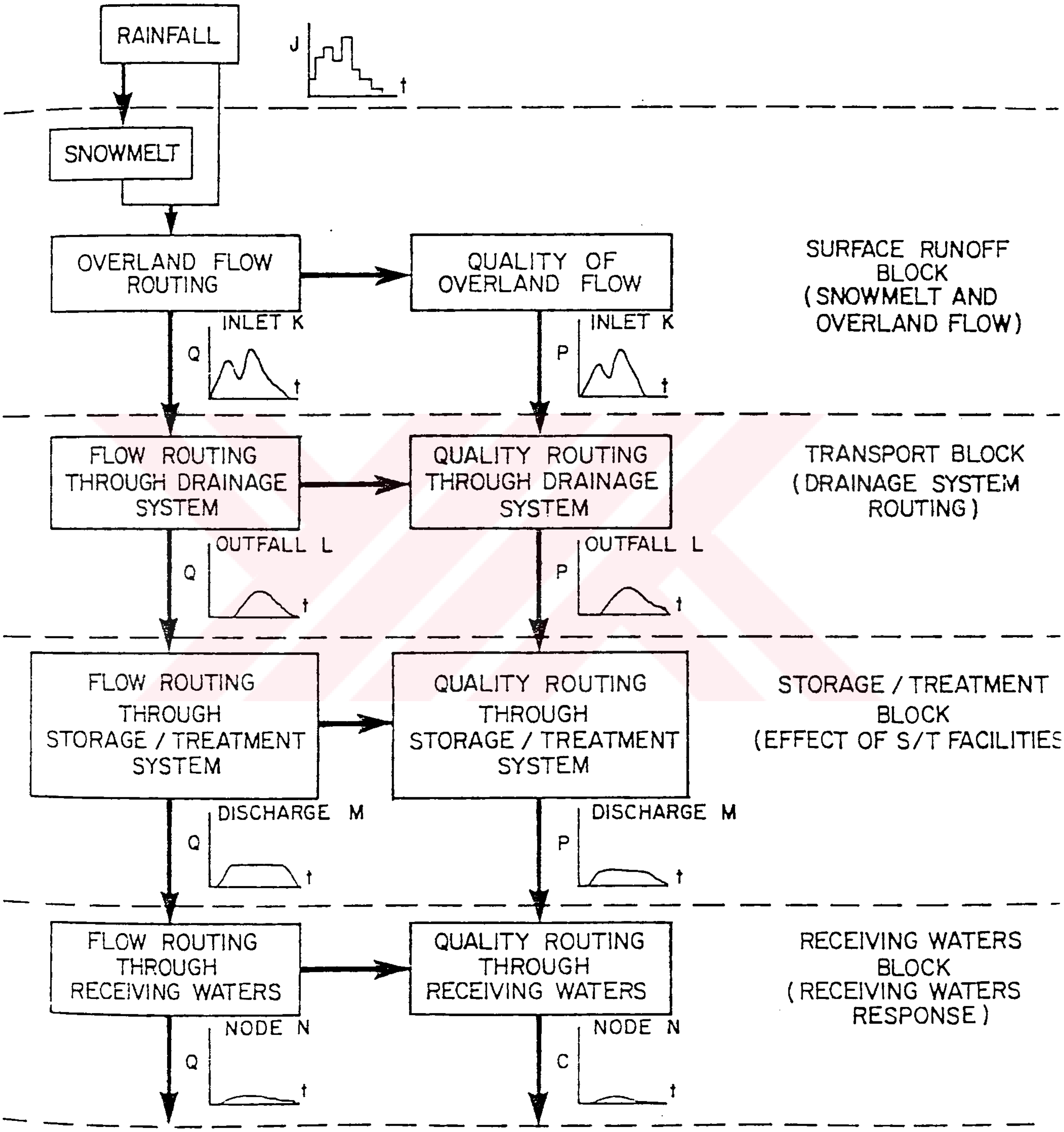


Figure 3.10 Overview of the SWMM model (Proctor and Redfern Ltd. et al., 1976).

C)-The correctional devices:

The Storage/Treatment Block characterizes the effects of control devices upon flow and quality. Elementary cost computations are also made.

D)-The effect (receiving waters):

The SWMM model doesn't include a receiving water model. The Receiving Water Block is no longer included within the SWMM model framework. However, a linkage is provided for the EPA WASP and DYNHYD models.

3.4Description of SWMM Model Blocks

3.4.1 Main Blocks

The Storm Water Management Model, SWMM, is divided into three main blocks as, Computational Blocks, Executive Blocks, Services Blocks. The relationship of the three main blocks and the other blocks is shown in Figure 3.11 (Huber, et al., 1988).

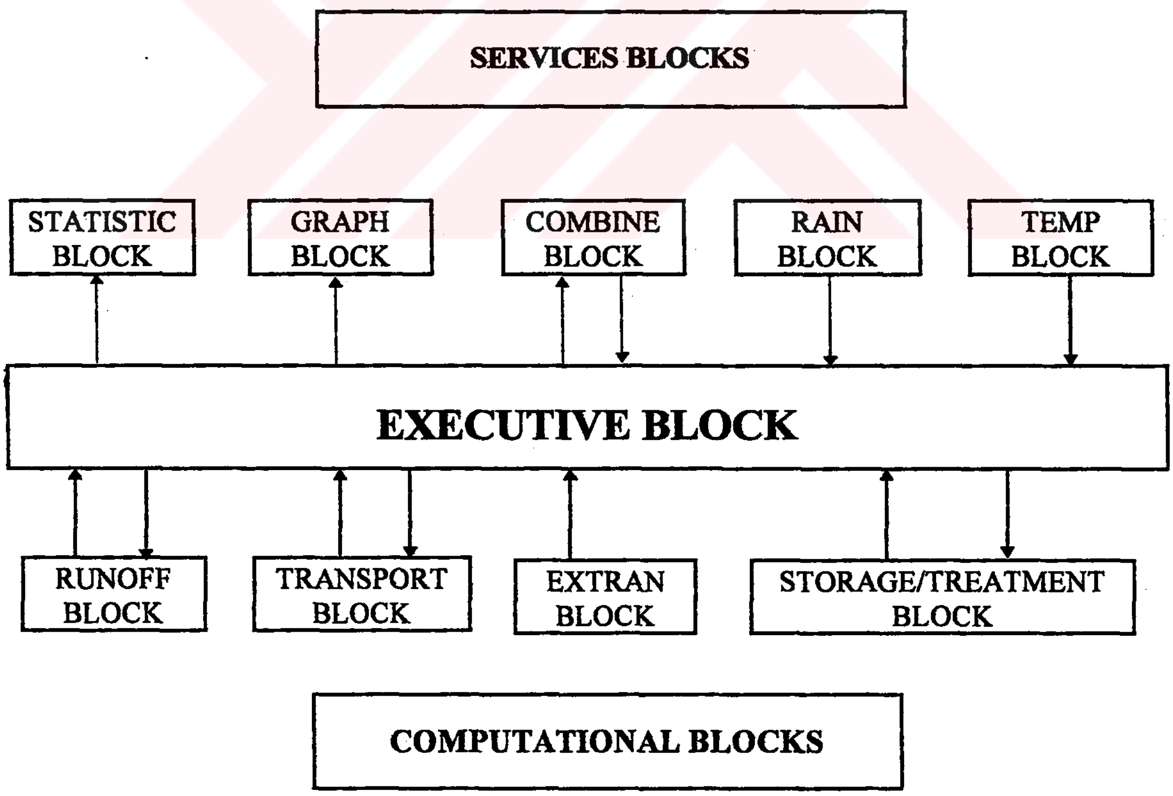


Figure 3.11 Blocks or modules of the SWMM program. Arrows indicate transfer of data by offline interface files (Huber et al., 1988).

Each block has a specific function, and the results of each block are entered on working storage devices to be used as part of the input to the other blocks.

3.4.2 Computational Blocks

The RUNOFF Block has been developed to simulate both the quantity and quality runoff phenomena of a drainage basin and routing of flows and contaminants to the major sewer lines. This block represents the basin by an aggregate of idealized subcatchments and gutter or pipes. The program accepts an arbitrary rainfall or snowfall hyetograph and makes a step by step accounting of snowmelt, infiltration losses in pervious areas, surface detention, overland flow, channel flow, and the constituents washed into inlets, leading to the calculation of a number of inlet hydrographs and pollutographs.

The RUNOFF Block is a critical block to the SWMM simulation. This block receives meteorological data from either Rain and/or Temp Blocks or user defined hyetographs (rainfall intensity vs. time) and then simulates the rainfall-runoff process using a nonlinear reservoir approach, with an option for snowmelt simulation. Groundwater and unsaturated zone flow and outflow are included using a simple lumped storage scheme. At the end, the RUNOFF Block produces hydrographs and pollutographs at inlet locations. This block may be run for periods ranging from minutes to years. Simulations less than a few weeks will henceforth be called single event mode, and longer simulations will be called continuous mode. With the slight exception of snowmelt, all computations are done identically for the two cases (Huber and Dickinson, 1988). Quality process in the RUNOFF Block include generation of surface runoff constituent loads through a variety of options :

(a) build-up of constituents during dry weather and wash-off during wet weather ;
(b) "rating curve" approach in which load is proportional to flow rate to a power ;
(c) constant concentration (including precipitation loads), and/or;
(d) Universal Soil Loss Equation, USLE (Donigan and Huber, 1991).

The overall catchment may be divided into a maximum of 200 subcatchments and 200 channel/pipes plus inlets. The RUNOFF Block transfers hydrographs and pollutographs for many as 200 inlets and 10 constituents through an assigned interface file to other SWMM blocks.

Routing through the sewer system may be accomplished in the SWMM model by the TRANSPORT Block. This block has the responsibility of coordinating not only routing of sewage quantities but also such functions as routing of quality parameters, estimating dry weather flow, infiltration and calling internal storage.

The Extended Transport (EXTRAN) Block provides the SWMM with dynamic wave simulation capability (Roesner, L.A. et al, 1988). The EXTRAN Block is the most comprehensive simulation program available in the public domain for a drainage system hydraulics. It simulates branched or looped networks; backwater resulting from tidal or nontidal conditions; free-surface flow; pressurized flow or surcharges; flow reversals; flow transferred by weirs, orifice; and pumping facilities; and storage at on-line or off-line facilities. EXTRAN uses a link-node description of the sewer system that facilitates the discrete representation of the physical prototype. The conduit system is idealized as a series of links and channels/conduits, which are connected as nodes or junctions. Links and nodes have well-defined properties which, taken together, permit representation of the entire pipe network. Links permit flow from node to node. Nodes are the storage elements of the system and correspond to manholes or pipe junctions in the physical system. Inflows, such as inlet hydrographs, and outflows, such as weir diversions, take place at the nodes of the idealized sewer system. EXTRAN capabilities are compared with those of Runoff and Transport in Table 3.1 (Huber, 1988).

In the TRANSPORT Block, flow routing is accomplished using the kinematic wave method, while quality processes include first order decay and simulation of scour and deposition within the sewer system based on Shield's criterion for initial of motion and generation of dry weather flow and quality. The TRANSPORT Block uses inlet hydrographs and pollutographs generated either from the Runoff Block via the interface file or from the user defined option as the input. It then determines the quality and quantity of dry weather flow, the system infiltration, pollutant loadings for each channel/pipe.

The Storage/Treatment Block, S/T, has been developed to simulate the routing of flows and pollutants through a dry or wet weather S/T plant containing up to five units or processes. The block will accept any number of time steps; therefore, a single-event or a continuous simulation is possible. Each unit may be modeled as having detention or non-detention characteristics. Various units may also be modeled using one or more units. Additionally, capital cost and operation and maintenance cost may be estimated for each unit.

Table 3.1 Flow routing characteristics of Runoff, Transport and Extended Transport Blocks (Huber et al., 1988).

	Runoff Block	Transport Block	Extran Block
1. Flow routing method	Non-linear reservoir, cascade of conduits	Kinematic wave cascade of conduits	Complete equations interactive conduit network
2. Relative computational expenses for identical network schematizations	Low	Moderate	High
3. Attenuation of hydrograph peaks	Yes	Yes	Yes
4. Time displacement of hydrographs peaks	Weak	Yes	Yes
5. In-conduit storage	Yes	Yes	Yes
6.Backwater and downstream control effects	No	No[a]	Yes
7. Flow reversal	No	No	Yes
8. Surcharge	Weak	Weak	Yes
9. Pressure flow	No	No	Yes
10.Branching tree network	Yes	Yes	Yes
11.Network with looped connections	No	No	Yes
12. Number of Pre-programmed	5	16	8
13.Alternative hydraulic elemants	WO	PWO	PWO
14. Dry weather flow and infiltration generation	Some	Yes	Yes
15. Pollutograph routing	Yes	Yes	No
16. Solids scour/deposition	No	Yes	No
17. Input of hydrographs pollutographs from external source	No	Yes	Yes

The Storage/Treatment (S/T) Block is a special type of element of the TRANSPORT Block. The S/T Block simulates the routing of flows and up to three pollutants through a dry- or wet-weather S/T tank containing up to five units or processes. It also simulates removal in S/T devices by:

(a) first-order decay coupled with complete mixing or plug flow;
(b) removal functions (e.g., solids deposition as a function of detention time), or;
(c) sedimentation dynamics.

These four Computational Blocks can be run either independently or in any sequence. The summary of the Computational Blocks such as model capability, solutions techniques using both flow routing characteristics and quality simulation parameters are summarized in Table 3.2. These solution techniques are described more comprehensively by for each block in section 4.

3.4.3 Services Blocks

In addition to the four Computational Blocks mentioned above, six Services Blocks are utilized (Huber, 1988). Line printer plots of hydrographs and other time series output may be obtained using the Graph Block. Measured as well as predicted time series may be plotted. Alternatively, the user may access the time series file for plots by other graphics software.

The Statistical Block performs simple statistical analyses on continuous event or single-event data. Both quantity and quality parameters may be analyzed. The options available include event separation with a table of magnitude, return period and frequency of events, a graph of magnitude versus return period, a graph of magnitude versus frequency, and the first three moments of the event data.

Statistical analyses are performed on data read from an interface file arranged in the standard SWMM format. This block may be called after any block that generates such a file. In addition, the user may create an interface file of rainfall or other data and, through an understanding and alteration of various conversion factors, may use the Statistics Block to analyze rainfall, rather than stormwater events.

Table 3.2 Summary of Computational Blocks in SWMM (Lahlou et al., 1995)

Block	Capability			Flow Routing Characteristics		Quality
	Description	Quantity (inlets)	Quality (pollutants)	Method	Backwater Effects	Method
Runoff	simulate quantity and quality runoff of a drainage basin, route flows and pollutants to major sewer lines, produce hydrographs and pollutographs at inlet locations	200	10	Non-linear reservoir, cascade of conduits	No	1) build-up/wash-off; 2) rating curve approach; 3) const. concentration; 4) USLE.
Transport	routes flow and pollutant through the sewer system, determine quantity and quality of dry-weather flow, calculate system infiltration, land, capital, operation and maintenance costs of two internal storage tanks	200	4	Kinematic wave, cascade of conduits	No	Shield's criterion for initiation of motion, and generation of simulation of dry-weather flow and quality.
Extran	routes flow through the sewer system, simulate backwater profiles (flows) in open channel and/or closed conduit systems, a drainage system can be represented as links and nodes, looped pipe networks, weirs, orifices, pumps, and system surcharges	200	0	Dynamic wave, complete equations, interactive conduit network	Yes	No water quality simulation
Storage/Treatment	characterize the effects of control devices upon flow and quality, simulate removal in S/T devices, calculate costs	5 units or processes	3	Storage routing		1) first order decay; 2) removal functions; 3) sedimentation dynamics.

Separation of the data into events depends on the unique series of zero and non-zero instantaneous flow values found at each location within the system being simulated. The results of the analyses would be expected to vary from location to location. Output from this block can thus be used to identify key events for further study and for many other screening and analytical purposes.

Precipitation is one of the principal driving forces in the SWMM model. The RUNOFF Block reads precipitation data and generates overland flows for input into the Transport Block or EXTRAN Block. The purposes of the Rain Block is to read long time series of precipitation records, perform an optional storm event analysis, and generate a precipitation interface file for input into Runoff.

Combine Block allows the manipulation of multiple interface files in order to aggregate results of multiple previous runs for input into subsequent blocks. In this manner large, complex drainage systems may be partitioned for simulation in smaller segments.

The purpose of the Temp Block is to input temperature, evaporation, and wind speed data and make a file accessible to the RUNOFF Block of SWMM model.

3.4.4 Executive Blocks

The Executive Blocks perform six main functions described below:

(a) assignment of logical units and files,
(b) control of the sequencing of computational blocks,
(c) graphing of data files by the line printer,
(d) control of the simulation time clock for all blocks,
(e) input error checking, and
(f) control and summarization of input and computational errors.

These six functions are summarized under subheadings Program Operation (a,b), SWMM Graphics (c), SWMM Time (d), Input Errors (e), and No-Fault Error Summary (f). This block operating "shell" of SWMM, and no hydrologic computations as such are performed in the Executive Blocks.

3.5 Implementation of the SWMM Model

3.5.1 Hardware Requirements

The system runs under Microsoft Windows. The minimum system requirements are described below:

- Windows Version 3.1
- 80386 Processor
- 4 Megabytes RAM
- 10 Megabytes hard disk space
- Numerical Coprocessor
- CONFIG.SYS statements :

  BREAK=ON
  BUFFERS=20 OR BUFFERS=32
  FILES=20
  DEVICE=C:\ANSI
  SYS DEVICE = extended memory manager
  SHELL=C:\COMMAND.COM C:\ /e:512 /p

NOTE: A math co-processor is recommended but not required.

3.5.2 Installation of the SWMM

STEP 1. Insert the SWMM Setup Disk (i.e., SWMM - DISK 1), into drive A: or B:

STEP 2. Start Windows and, at the Program Manager, choose File Run.

STEP 3. Type A:SETUP.EXE ("B:" if the disk is on the B: drive) and press ENTER.

STEP 4. The user will be asked to enter the path of the directory where he would like SWMM to be installed. When he accepts the default path or enters a new directory path, the installation will begin.

STEP 5. The SWMM model is then ready to use..

CHAPTER FOUR

TECHNICAL DESCRIPTION OF SWMM

4 General

For SWMM , the solution techniques used to compute both flow routing characteristics and quality simulation parameters were described in Table 3.2. In this section, these techniques are explained more comprehensively for each model block.

4.1Runoff Block

The Runoff Block forms the origin of flow generation within SWMM, and much of the emphasis in data preparation and user effort is aimed at successful execution of this block Runoff Block has been developed to simulate both quantity and quality runoff phenomena of a drainage basin and the routing of flows and contaminants to the major sewer lines (Huber et al., 1988). This subsection briefly describes the equations used for this purpose.

Many hydrologic models account for spatial variations by subdividing the overall catchment into subcatchments, predicting runoff from the subcatchments on the basis of their individual properties, and combining their outflows using a flow routing scheme. This procedure is followed in SWMM, in which subcatchments are idealized mathematically as spatially lumped, non-linear reservoirs, and their outflows are routed via the channel/pipe network.

The rainfall depth over each subcatchment is the basic input to the RUNOFF block. This block sequentially accounts for infiltration and depression storage to determine a net excess rainfall depth on the overland flow plane. The excess rain depth is used to compute an overland flow rate for each time step. SWMM uses a very simple algorithm for this RUNOFF block computation as shown in Figure 4.1 (Proctor and Redfern ltd., 1976).

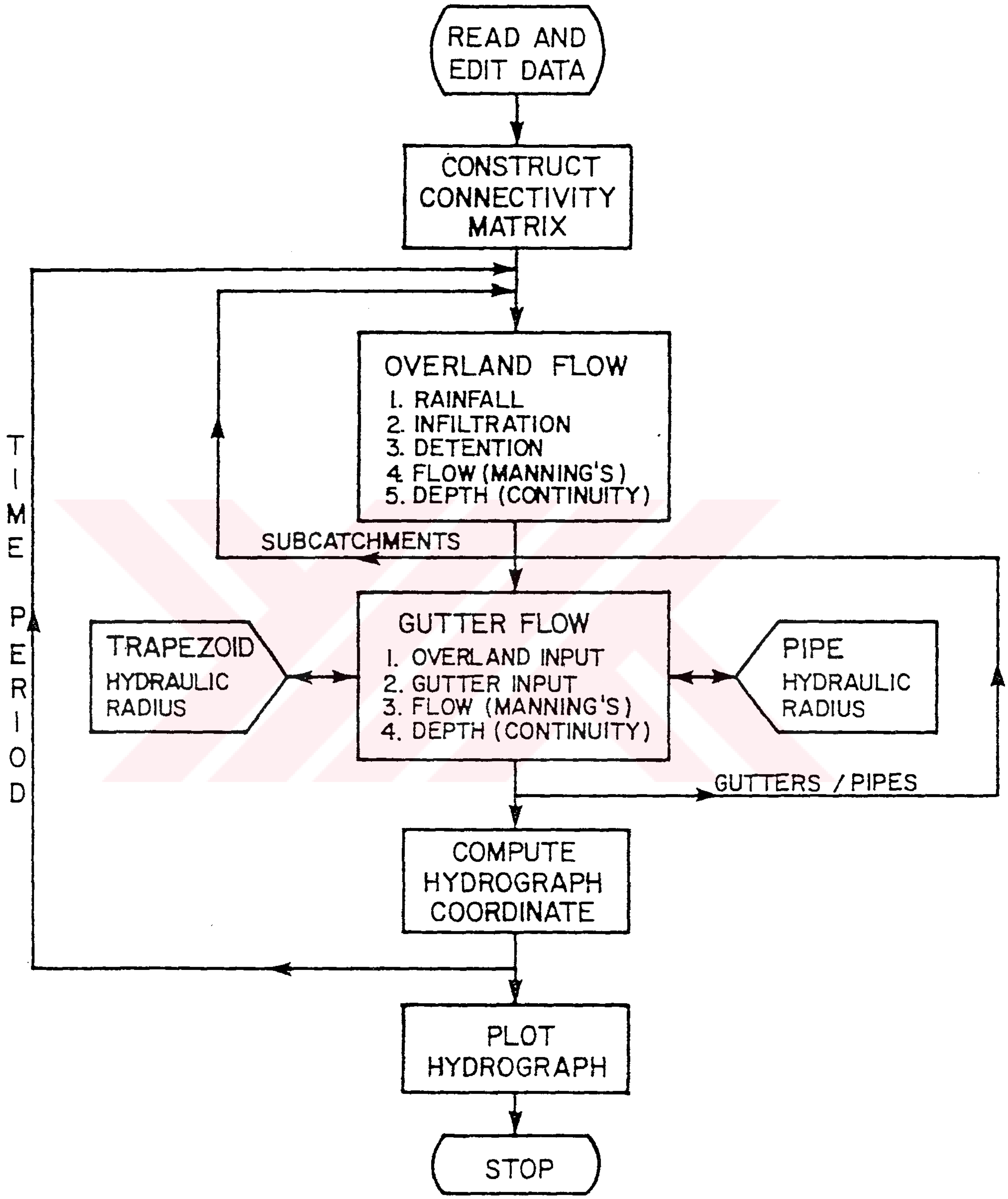


Figure 4.1 The flow chart of the Runoff Block (Proctor and Redfern et al., 1976).

Each subcatchment is schematized as in Figure 4.2, in which three or four subareas (depending upon on whether snowmelt is simulated) are used to represent different surface properties as described in Table 3.3. When snowmelt is not simulated, overland flow is generated from each of the three subareas by approximating them as non-linear reservoirs as shown in Figure 4.3.

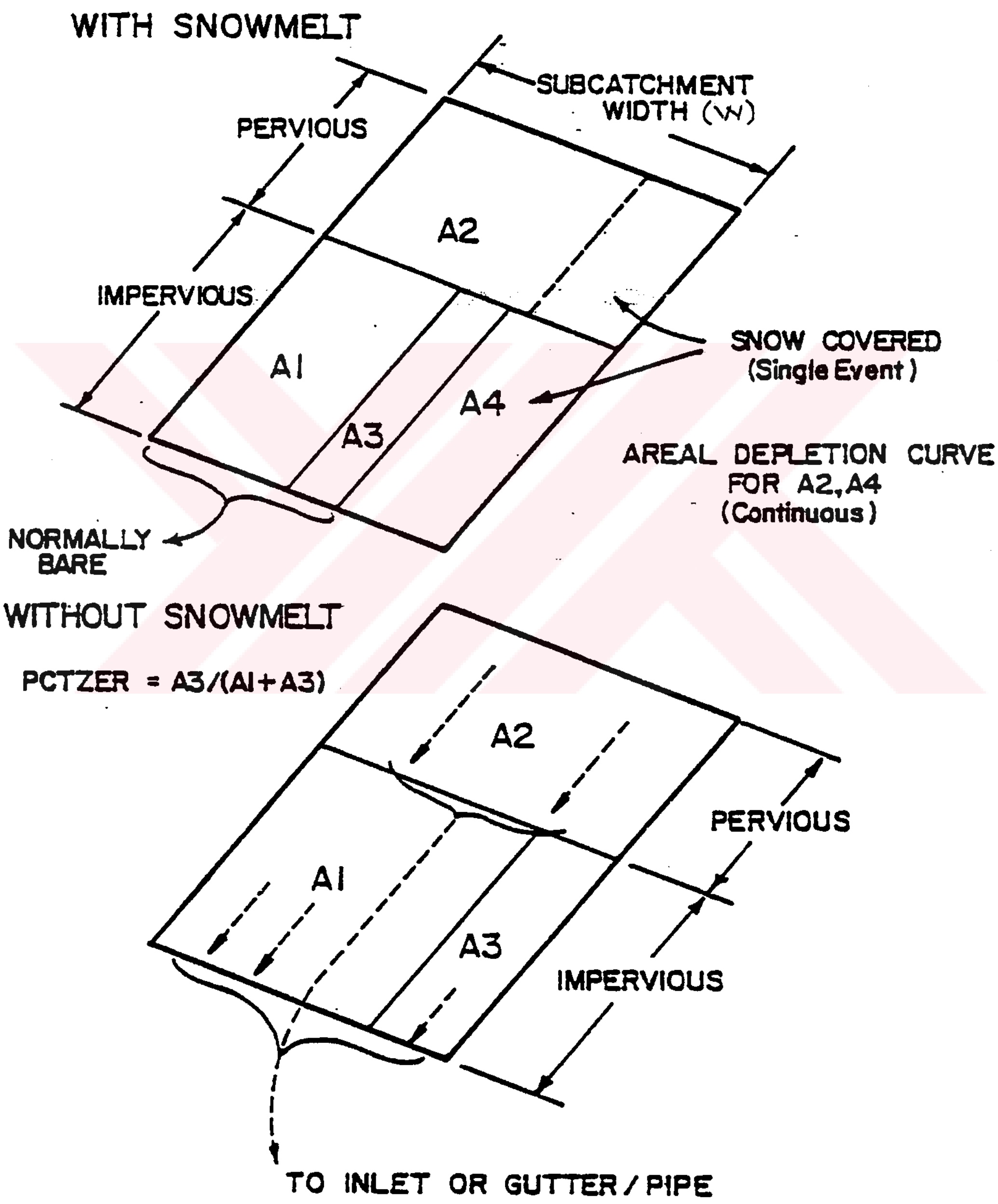


Figure 4.2 Subcatchment schematization. Flows from pervious and total impervious subareas go directly to gutter/pipe or inlet (Huber et al., 1988).

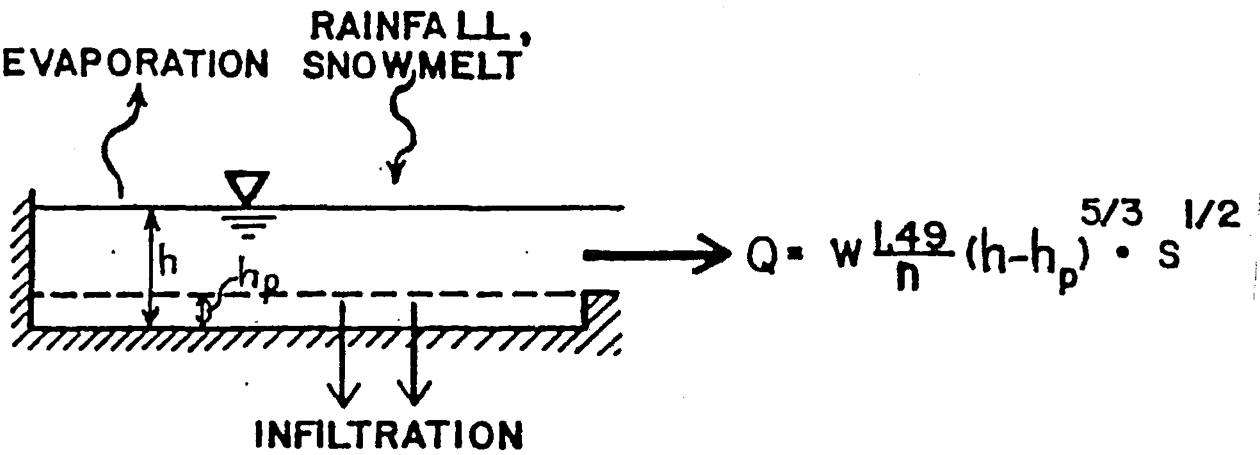


Figure 4.3 Non-linear reservoir model of subcatchment (Huber,1988).

The non-linear reservoir method is a spatially **lumped** configuration and really assumes no special subcatchment shape. However, if the subcatchment width, W, is assumed to represent a true prototype width of overland flow, then the reservoir will behave as a rectangular catchment, as sketched in Figure 4.4. Otherwise, the width (slope, roughness) may be considered calibration parameters and used to adjust predicted to measured hydrographs.

The non-linear reservoir is established by coupling the continuity equation with Manning's equation. Continuity may be written for a subarea as;

$$\frac{dV}{dt} = A.\frac{dh}{dt} = A.i_e - Q \qquad \textbf{4.1}$$

where ;

V→ volume of water on the subarea (ft),

h → water depth (ft),

t → time (sec),

A→ surface area of subarea (ft^2)

i_e→ rainfall excess (ft/sec),

Q → outflow rate (cfs)

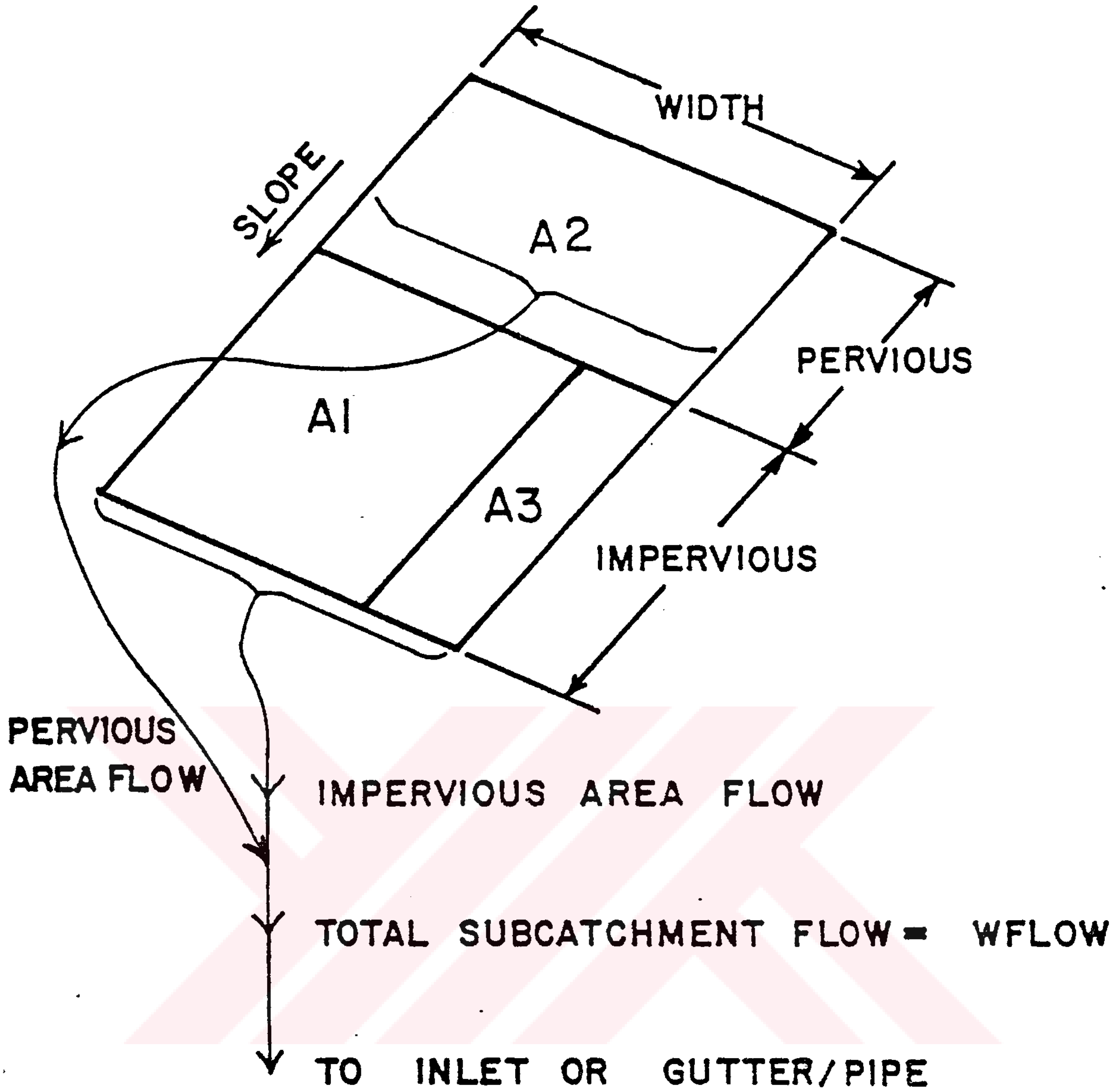


Figure 4.4 Subcatchment schematization for overland flow calculations. Flow from each subarea is directly to an inlet or gutter/pipe (Huber et al., 1988).

The outflow is generated using Manning's equation,

$$Q = W.\frac{1.49}{n}.(h - h_p)^{5/3}.S^{1/2} \qquad 4.2$$

where ;

W→ subcatchment width (ft),

n→ Manning's roughness coefficient,

$\mathbf{h_p}$→ depth of depression storage (ft),

S→ slope.

Equations 4.1 and 4.2 are combined into one non-linear differential equation that may be solved for one unknown, the depth, h. This produces the non-linear reservoir equation,

$$\frac{dh}{dt} = i_e - \frac{1.49.W}{A.n}(h - h_p)^{5/3}.S^{1/2} \qquad 4.3$$

$$= i_e + \mathbf{WCON}.(h\text{-}h_p)^{5/3}$$

$$\mathbf{WCON} = -\frac{1.49.W.}{A.n}S^{1/2} \qquad 4.4$$

where **WCON** is the routing parameter (ft/sec) used in subroutine watershed.

As a result, parameters such as the width, slope, and roughness are combined into one parameter, WCON. Thus, equivalent changes may be caused by appropriate alteration of any of the three parameters. Also, the width and slope parameters are the same for both pervious and impervious areas. The Manning's roughness and relative area are the only parameters available to the modeler to characterize the relative contributions of pervious and impervious areas to the outlet hydrograph. Equation 4.3 is solved at each time step by means of a simple finite difference scheme. For this purpose, the net inflow and outflow on the right hand side of the equation must be averages over the time step. The rainfall excess, i_e, is given in the program as a time step average i_*. The average outflow is approximated by computing it using the average between the old and new depths. That is, letting subscripts 1 and 2 denote the beginning and the end of a time step, respectively, Equation 4.3 is approximated by;

$$\frac{h_1 - h_2}{\Delta t} = i_e + \text{WCON}\,\{\, h_1 + \frac{1}{2}\,(h_2 - h_1) - h_p \,\}^{5/3} \qquad 4.5$$

Equation 4.5 is then solved for h_2 using a Newton-Raphson iteration.

Given h_2, the instantaneous outflow at the end of a time step, WFLOW (subcatchment outflow), is computed using equation 4.2. Parameter WFLOW is used in runoff quality calculations and is the flow value that is input to inlets gutter/pipes. The instantaneous outflow at a given time is also the flow value transfered to subsequent SWMM blocks.

Depression storage is a volume that must be filled prior to occurrence of runoff on both pervious and impervious areas, shown in Figure 4.3. In the Runoff Block, water stored as depression storage on pervious areas is subject to infiltration, so that it is continuously and rapidly replenished. Water stored in depression storage on impervious areas is depleted only by evaporation. The depression storage is generated as (Kidd, 1978);

$$h_p = 0.0303 \cdot S^{-0.49} \qquad \textbf{4.6}$$

where ;

h_p depression storage, inch

S catchment slope, percent.

In SWMM , depression storage may be treated as a calibration parameter, particularly to adjust runoff volumes. If so, extensive preliminary work to obtain an accurate a priori value may be pointless since the value will be changed during calibration anyway. If overland flow is shown in Figure 4.2 as running down-slope off an idealized, rectangular catchment, then the width of the subcatchment is the physical width of overland flow. But, real subcatchments will not be rectangular with properties of symmetry and uniformity. It is necessary to adopt other procedures to obtain the width for more general cases. This is of special importance, because if the slope and roughness are fixed (Equation 4.4), the width can be used to alter the hydrograph.

The kinematic wave model has been applied to describe flow over planes, as a model of the rainfall-runoff process (Chow et al., 1988). As shown in Figure 4.5, q_L is the lateral flow which is equal to the difference between the rates of rainfall and infiltration. The channel flow is taken to be flow per unit width of plane.

When inertia and pressure terms are not important, kinematic wave model governs the flow. The weight component is essentially balanced by the resistive force indicating that the fluid is not appreciably accelerating and the flow is nearly uniform. Generally, the kinematic wave approximation would be good, when the Froude number F > 1 with

$$F = V / c \qquad c = \sqrt{g.h} \qquad \textbf{4.7}$$

where ;

V→ stream velocity,

c→ wave velocity,

F→ Froude number.

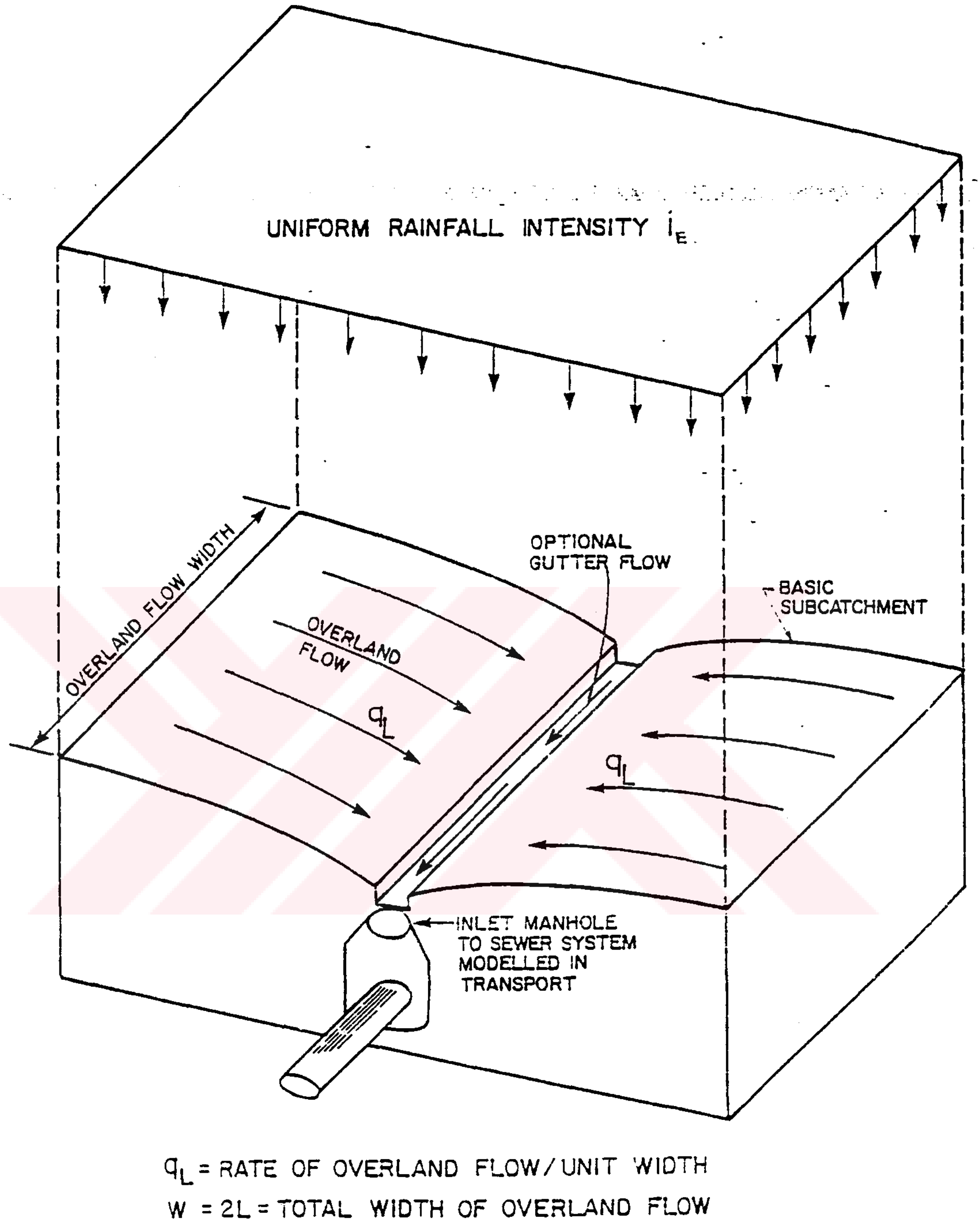


Figure 4.5 Schematic SWMM surface drainage arrangement (Proctor and Redfern Ltd. et al., 1976).

This situation is called supercritical flow, and the waves can not move upstream since V>c. Hence, kinematic flow could be defined as an unsteady uniform flow approximation.

The traditional formulation of the kinematic wave theory assumes the kinematic wave friction relationship parameter to be constant. The present study waives this assumption of parameter constancy, allows continuous spatial variability in the parameter and develops a more general formulation of the kinematic wave theory. This concept of parameter variability leads to a completely distributed model and might eliminate the necessity of utilizing a complex network model to present the watershed system. Furthermore, more general formulation will reduce the complexity of modeling watershed surface runoff and will greatly save computational time and effort (Singh, 1976).

The kinematic solution of overland flow for a plane of length L, width W, and slope S_0 can be derived assuming a relationship between the discharge and flow depth under uniform conditions as shown in Figure 4.6. Both continuity and momentum equations are used for this solution (Eagleson, 1970). The continuity equation is:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=i_e . w \qquad 4.8$$

We could also define the continuity equation for per unit width as:

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=i_e=i-f \qquad 4.9$$

where ;

h → local depth (ft),

t → time coordinate (sec),

q → rate of effective lateral inflow per unit area (ft/sec) (q = Q/W)

x → space coordinate (ft),

i → rainfall intensity (ft/sec),

f → infiltration rate (ft/sec).

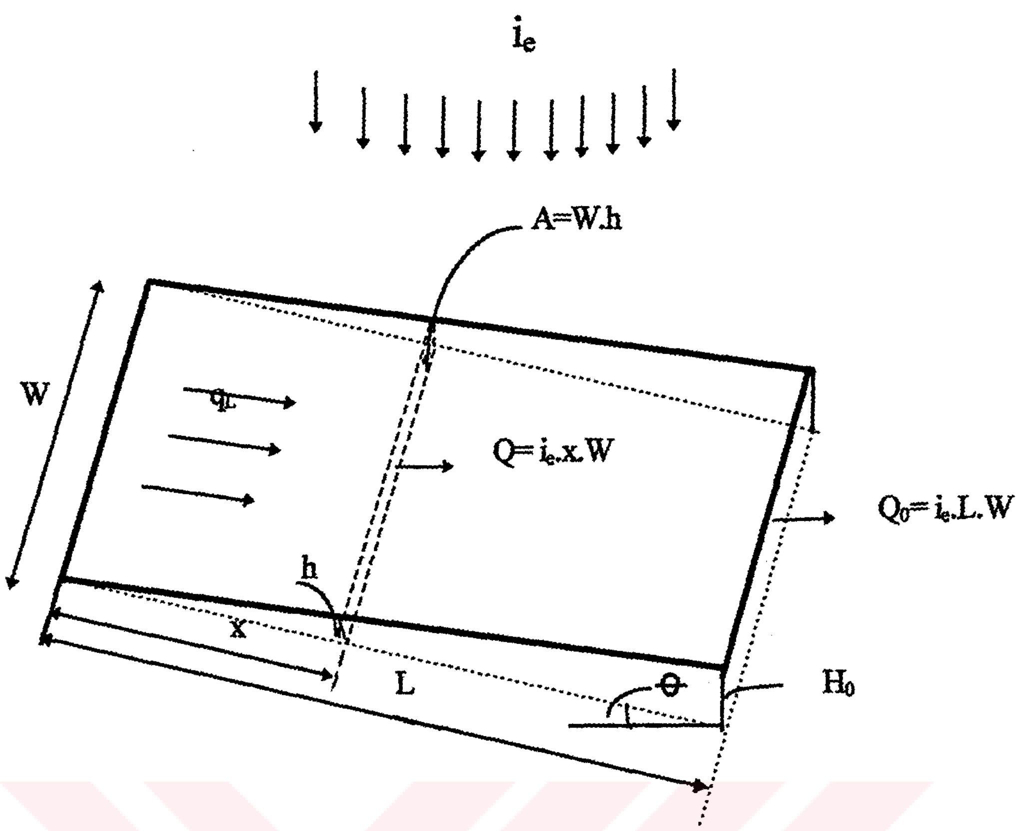


Figure 4.6 Rainfall-Runoff relationship on a plane

The momentum equation consists of terms for the physical processes that govern the flow momentum. These terms are: the local acceleration term, which describes the change in momentum due to the change in velocity over time; the convective acceleration term, which describes the change in momentum due to the change in velocity along the channel; the pressure force term, proportional to the change in the water depth along the channel, the gravity force term, proportional to the bed slope S_0, and the friction force term, proportional to the friction slope S_f. The local and convective acceleration terms (the first two terms in Eq. 4.10) represent the effect of inertial forces on the flow:

$$\frac{1}{A}\frac{\partial Q}{\partial t}+\frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)+g\frac{\partial h}{\partial x}-g(S_0-S_f)=0 \qquad \textbf{4.10}$$

As mentioned, the inertial and pressure terms are negligible in the kinematic wave model. Thus;

$$S_0 = S_f \qquad \textbf{4.11}$$

$$q = \alpha . h^m \qquad \textbf{4.12}$$

where ; α and m are the parameters of flow relationship assumed for kinematic wave solution, such as Manning's friction relationship.

Equations 4.9 and 4.12 are solved by the method of characteristics. The essence of the method, when applied to wave motions is to find the space-time locus of discontinuity in the partial derivatives of the important dependent variables. To find this locus in our case, we first operate on Equation 4.9 and 4.12 to write the pair of relations:

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=i_e=i-f \qquad 4.9$$

$$\frac{\partial q}{\partial x}=\alpha.m.h^{m-1}.\frac{\partial h}{\partial t} \qquad 4.13$$

Using the definition of a total differential, we can add the two equations;

$$dq=\frac{\partial q}{\partial x}dx+\frac{\partial q}{\partial t}dt \qquad 4.14$$

$$dh=\frac{\partial h}{\partial x}dx+\frac{\partial h}{\partial t}dt \qquad 4.15$$

Thus, Equations **4.9, 4.13, 4.14,** and **4.15** can be written in the matrix form as described below,

$$\begin{bmatrix} 1 & 0 & 0 & 1 \\ \alpha.mh^{m-1} & 0 & -1 & 0 \\ dt & dx & 0 & 0 \\ 0 & 0 & dt & dx \end{bmatrix} \begin{bmatrix} \partial h/\partial t \\ \partial h/\partial x \\ \partial q/\partial t \\ \partial q/\partial x \end{bmatrix} = \begin{bmatrix} i_e \\ 0 \\ dh \\ dq \end{bmatrix} \qquad 4.16$$

Discontinuity in the four derivatives will be indicated by indeterminacy in their solution. Indeterminacy, in turn, results from the vanishing of numerator and denominator in a solution of Eq. 4.16 by Cramer's rule of determinants. Setting the determinant of the coefficient matrix equal to zero, the ordinary differential equation;

$$\left(\frac{\partial x}{\partial t}\right)^2-\alpha.mh^{m-1}\frac{dx}{dt}=0 \qquad 4.17$$

is obtained, which has two positive roots that give the wave speed c;

$$\frac{dx}{dt}=c=\alpha.mh^{m-1}=m.V \qquad 4.18$$

$$\frac{dx}{dt}=c=0 \qquad 4.19$$

If we now replace, one at a time, the columns of the coefficient matrix by the column vector on the right hand side of Eq. 4.16, the resulting determinants must also vanish along the characteristic:

First column $$\frac{dq}{dx} = i_e$$ 4.20

Second column $$\frac{dh}{dt} = i_e$$ 4.21

Replacing the third column duplicates Eq. 4.19 and from the fourth column;

$$\frac{\partial q}{\partial t} = i_e.\alpha.mh^{m-1} \qquad 4.22$$

Finally, dividing Equations 4.21 and 4.18 gives the last derivative;

$$\frac{dh}{dx} = \frac{i_e}{\alpha.mh^{m-1}} \qquad 4.23$$

We begin our study of idealized overland flow by considering a uniform, plane catchment, in which overall length in the direction of flow is L. The surface roughness, slope, and flow regime will be assumed invariant in space and time. For further simplicty we can impose the initial and boundary conditions:

$$y=0 \quad \begin{cases} 0 \le x < L, t=0 \\ x=0, t>0 \end{cases} \qquad 4.24$$

and require that the rainfall excess i_e be spatially constant. From Equation 4.21:

$$dh = i_e.dt$$

$$\int_0^h dh = i_e \int_{t_0}^t dt \rightarrow h = i_e(t - t_0)$$

Inserting these into Eq. 4.23 and integrating with boundary and initial conditions give :

$$i_e \int_{x_0}^x dx = \alpha.m \int_{h_0}^h h^{m-1} dh$$

$$i_e(x - x_0) =.\alpha.m \int_{t_0}^t [i_e(t - t_0)]^{m-1} i_e dt$$

$$x - x_0 =.\alpha.m \int_{t_0}^t [i_e(t - t_0)]^{m-1} dt \qquad 4.25$$

where time variation in i_e has been permitted. In evaluating these integrals, the origin (x_0 , t_0) can be chosen from Eq.2.24, in which case h=0.

The discharge hydrograph as given by Eq. 4.12 is:

$$q(x,t) = \alpha h^{m}(x,t) \qquad 4.26$$

which becomes the catchment outflow hydrograph $q = q_L$ when $x = L$.

Let us further simply the problem now by requiring temporally constant rainfall excess such that:

$$i_0 = \begin{cases} i_e = \text{constant} & 0 \le t \le t_r\,,\ 0 \le x \\ 0 & t < 0,\ t > t_r,\ x < 0 \end{cases} \qquad 4.27$$

where t_r is the duration of rainfall excess. This amounts to assuming no infiltration after cessation of rainfall; thus t_r also is the storm duration.

Equation 4.25 can now be integrated to give the characteristic curves:

$$x - x_0 = \alpha . i_e^{m-1}(t - t_0)^m \qquad 4.28$$

If t_r is the infinite ($t_r = \infty$), we shall let the duration of rainfall excess be infinite. Let us focus our attention on what happens at some constant x.

Rain begins to fall at $t=t_0=0$, and the local depth will increase everywhere at the rate given by Eq. 4.21. Since $i_e=i=$constant, this rate will not change with time even though (for given x) we are operating on a different characteristic curve at each instant. Integrating the Eq. 4.21, we get

$$\int_0^h dh = i_e \int_{t_0}^t dt \rightarrow h = i_e(t - t_0) \qquad 4.29$$

which is an expression of the fact that water flows toward our x from upslope at the same rate that it leaves in the downslope direction. This is the case is everywhere initially except ($x=0$), where there is no inflow from upstream. A disturbance is created there by this flow deficit and will travel downstream along the limiting characteristic. Local depth continues to grow everywhere until the limiting characteristics reach the point in question, after which it remains constant. If we call this time t_w and recall that for the limiting characteristic ($x_0=0$), Eq. 4.24 gives ;

$$t_w = \left(\frac{x_w . i_e^{1-m}}{\alpha} \right)^{1/m} \qquad 4.30$$

x_w is the position reached by the limiting disturbance in time t_w. For the particular case (x_w=L), we define the maximum time during which growth of depth can occur on the surface. This time is usually referred to as the time of concentration (equilibrium) t_c and is given by;

$$t_c = \left(\frac{L . i_e^{1-m}}{\alpha} \right)^{1/m} \qquad 4.31$$

where ;

t_c→time of concentration (equilibrium) (sec),

L→ subcatchment length (ft),

i_e→ rainfall excess (ft/sec), and

α,m →kinematic wave parameters.

The kinematic wave formulation assumes that the runoff per unit width from the subcatchment is;

$$q_L = \alpha . h^m \qquad 4.32$$

where ;

q_L→flow per unit width (ft^2/sec),

h→depth of flow (ft).

Parameters α and m depend on the uniform flow equation used for normal flow. For Manning's equation, α and m are :

$$\alpha = \left(\frac{1.49}{n} \right) . S^{1/2} \quad \text{and} \quad m=5/3 \qquad 4.33$$

Finally, note that the dependence of time of concentration (equilibrium) upon the rainfall intensity. As i_e increase, t_c decrease. The calculation using Equation 4.24 is consistent with the definition of t_c given earlier. Time of concentration (equilibrium), t_c, is the time at which inflow equals to outflow. Equivalently, t_c is the time taken for most remote portion of the catchment to contribute to flow at the outlet, which is the time taken by a wave to travel from the remote point t_0 the outlet.

Infiltration is the process of water penetrating from the ground surface into the soil (Chow et al., 1988). Many factors influence the infiltration rate, including the condition of the soil surface and its vegetative cover, the properties of the soil, such as its porosity and hydraulic conductivity, and the current moisture content of the soil.

In SWMM, infiltration is computed by either **Horton or Green-Ampt infiltration model.** Horton's model is empirical and perhaps the best known of the infiltration equations. In its usual form, it is applicable only to events for which the rainfall intensity always exceeds the infiltration capacity, although the modified form used in SWMM is intended to overcome this deficiency.

SWMM and many other hydrologic techniques have used Horton's equation for prediction of the infiltration capacity into the soil as a function of time, as shown in Figure 4.7:

$$f_p = f_c + (f_o - f_c)e^{-kt} \qquad \textbf{4.34}$$

where ;

$f_p \rightarrow$ infiltration capacity (ft/sec), k decay coefficient (sec^{-1}),

$f_c \rightarrow$ minimum or ultimate value of f_p (ft/sec), t time from beginning of storm (sec).

$f_o \rightarrow$ maximum or ultimate value of f_p (ft/sec),

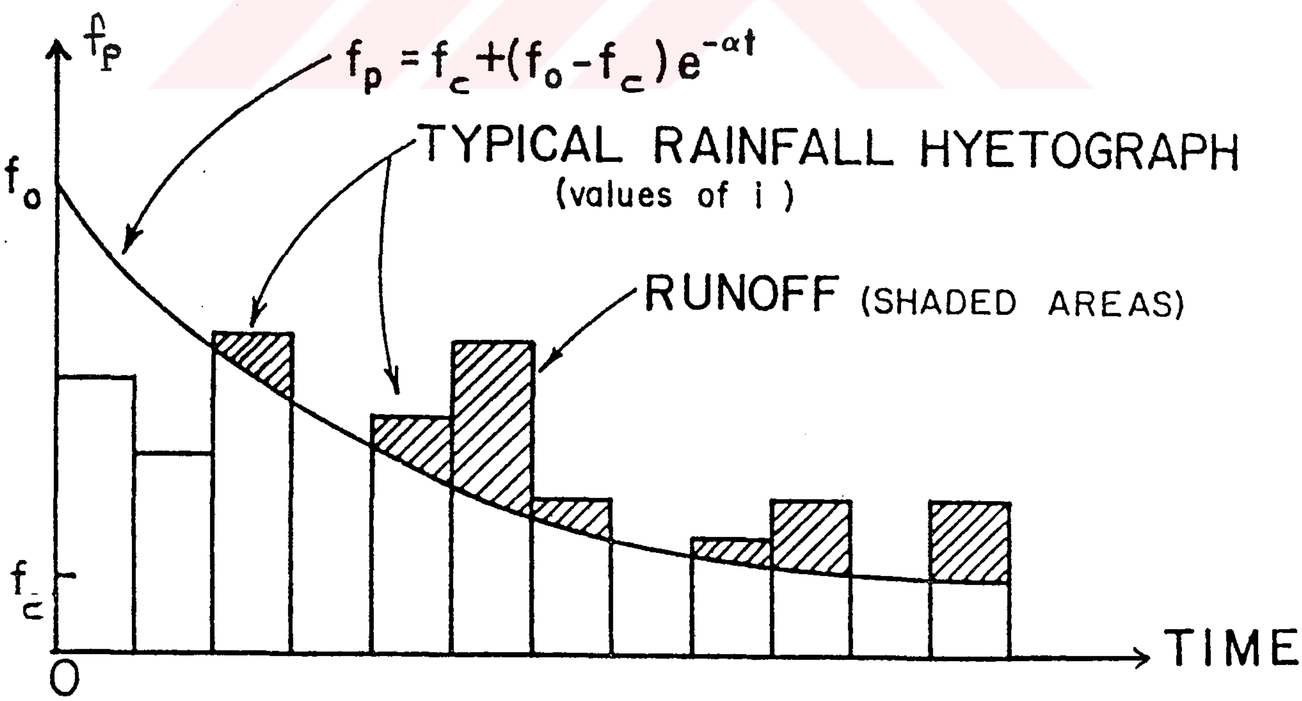


Figure 4.7 Horton infiltration curve and typical hyetograph for the case illustrated, runoff would be intermittent (Huber et al., 1988).

This equation describes the familiar exponential decay of infiltration capacity evident during heavy storms.

The Green-Ampt equation is a physically based model that can give a good description of the infiltration process. The Mein-Larson equation of it is applicable also for the case of rainfall intensity being less than the infiltration capacity at the beginning of the storm (Chow et al., 1988). This equation showed how The Green-Ampt equation could be adapted to a steady rainfall input and proposed a way in which the capillary suction parameters could be determined. The Mein-Larson equation is a two stage model. The first step predicts the volume of water, F_p, which will infiltrate before the surface becomes saturated. The infiltration capacity is predicted by the Green-Ampt equation as:

$$f = K_s\,(S.\,IMD\,/\,F + 1) \qquad \textbf{4.35}$$

where ;

f→ actual infiltration rate (ft/sec),

F→ cumulative infiltration depth (ft),

S→ average capillary suction at the wetting front, ft,

IMD→ initial moisture deficit (IMD = porosity - initial moisture content),

K_s→ saturated hydraulic conductivity of soil (ft/sec).

During a rainfall, water will pond on the surface only if the rainfall intensity is greater than the infiltration capacity, $i > f_p$. The "ponding time" t_p is the elapsed time between the time rainfall begins and the time water begins to pond on the soil surface.

As shown in Figure 4.8, at a time $t=t_p$ the soil surface is saturated. The saturated zone extends deeper into the soil and overland flow occurs from the ponded water when $i > f_p$, at times $t > t_p$. The cumulative actual infiltration at the ponding time t_p is $F_p = i.\ t_p$ and the infiltration rate by $f = f_p = i$. Substituting $f=i$ into Eq. 4.35 gives the volume of water infiltrated at ponding time under constant rainfall intensity as:

$$F_p = \frac{S.IMD}{\left(\frac{i}{K_s}\right) - 1}, \qquad i > K_s \qquad \textbf{4.36}$$

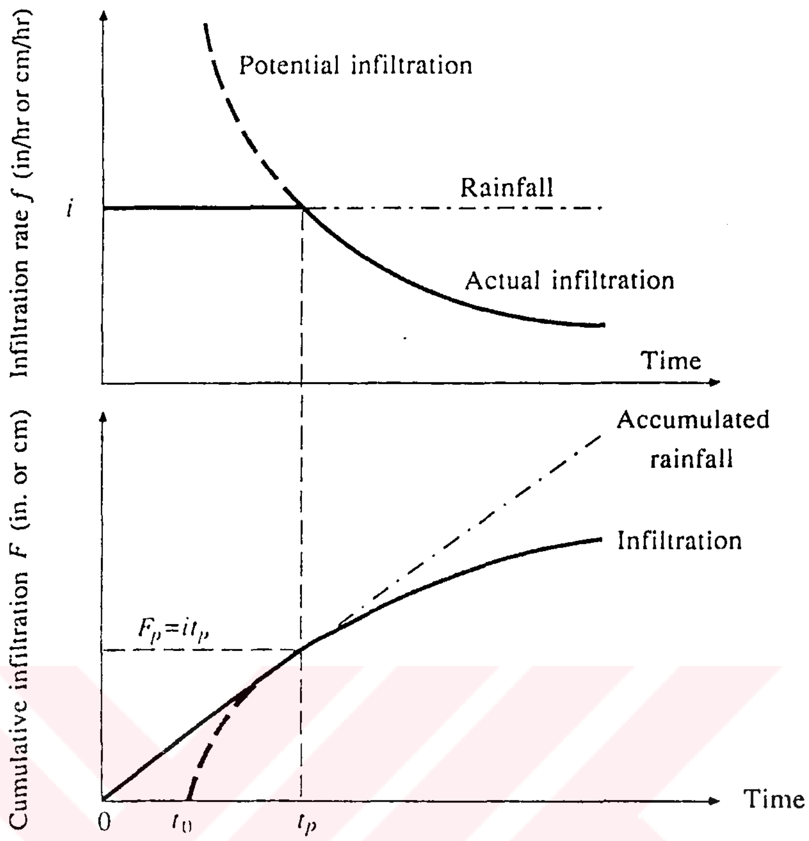


Figure 4.8 Infiltration rate and cumulative infiltration for ponding under constant intensity rainfall (Chow et al., 1988).

Equation 4.36 shows that the depth of rainfall required to saturate the surface depends on the current value of the rainfall intensity. Hence, at each time step for which $i > K_s$ is calculated and compared with the volume of rainfall already infiltrated for this event. Only if $F \geq F_s$ does the surface saturate, and calculations for this condition use Eq. 4.37.

The actual infiltration rate prior to ponding time t_p all are equal to the rainfall rate f=i, and no calculation is required for F_p since the actual cumulative infiltration F=i.t, $t < t_p$, is always less than F_p. The depth of actual infiltration after ponding can be computed by solving Eq. 4.37 for F by successive iterations, such as Newton's tangent methods

$$F = F_p + K_s(t - t_p) + S.IMD.\ln\left[\frac{S.IMD + F}{S.IMD + F_p}\right] \qquad 4.37$$

and then Eq. 4.35 can be used to obtain the infiltration rate f. Note that surface runoff exist only if $i > f$ after ponding. The equivalent time origin t_0 for potential infiltration after ponding, shown in Figure 4.8, is given by (Chow et al., 1988):

$$t_0 = t_p - \frac{1}{K_s}\left\{F_p - S.IMD.\ln\left[1+\frac{S.IMD}{F_p}\right]\right\} \qquad \textbf{4.38}$$

Simulation of urban runoff quality is a very inexact science. Very large uncertainties arise both in the representation of the physical, chemical and biological processes and acquisition of data and parameters for model algorithms. Such uncertainties can be dealt with in two ways. The first option is to collect enough calibration and verification data to be able to calibrate the model equations used for quality simulation. The second option is to abandon the notion of detailed quality simulation alltogether and either use a constant concentration applied to quantity predictions or use a statistical method.

For most several SWMM applications, the Runoff Block is the origin of water quality constituents. Although effects of dry weather flow and scour and deposition could be included in the Transport Block and Storage/Treatment Block, the generation of quality constituents in the storm water itself could only be included in the Runoff Block. Algorithm of the several Runoff Block quality computation is shown in Figure 4.9.

Several mechanisms constitute the genesis of storm water quality, most notably **buildup** and **washoff.** In an impervious urban area, it is usually assumed that a supply of constituents is built up on the land surface during dry weather proceeding a storm. Such a build up may or may not be a function of time and factors such as traffic flow, dry fallout and street sweeping. The material is then washed off into the drainage system. The washoff is the process of erosion or solution of constituents from a subcatchment surface during a period of runoff. If the water depth is more than a few milimeters , processes of erosion could be described by sediment transport theory. Such a mechanism should apply over pervious areas and in street gutters and larger channels. For thin overland flow, however, rainfall energy could also cause particle detachment and motion.

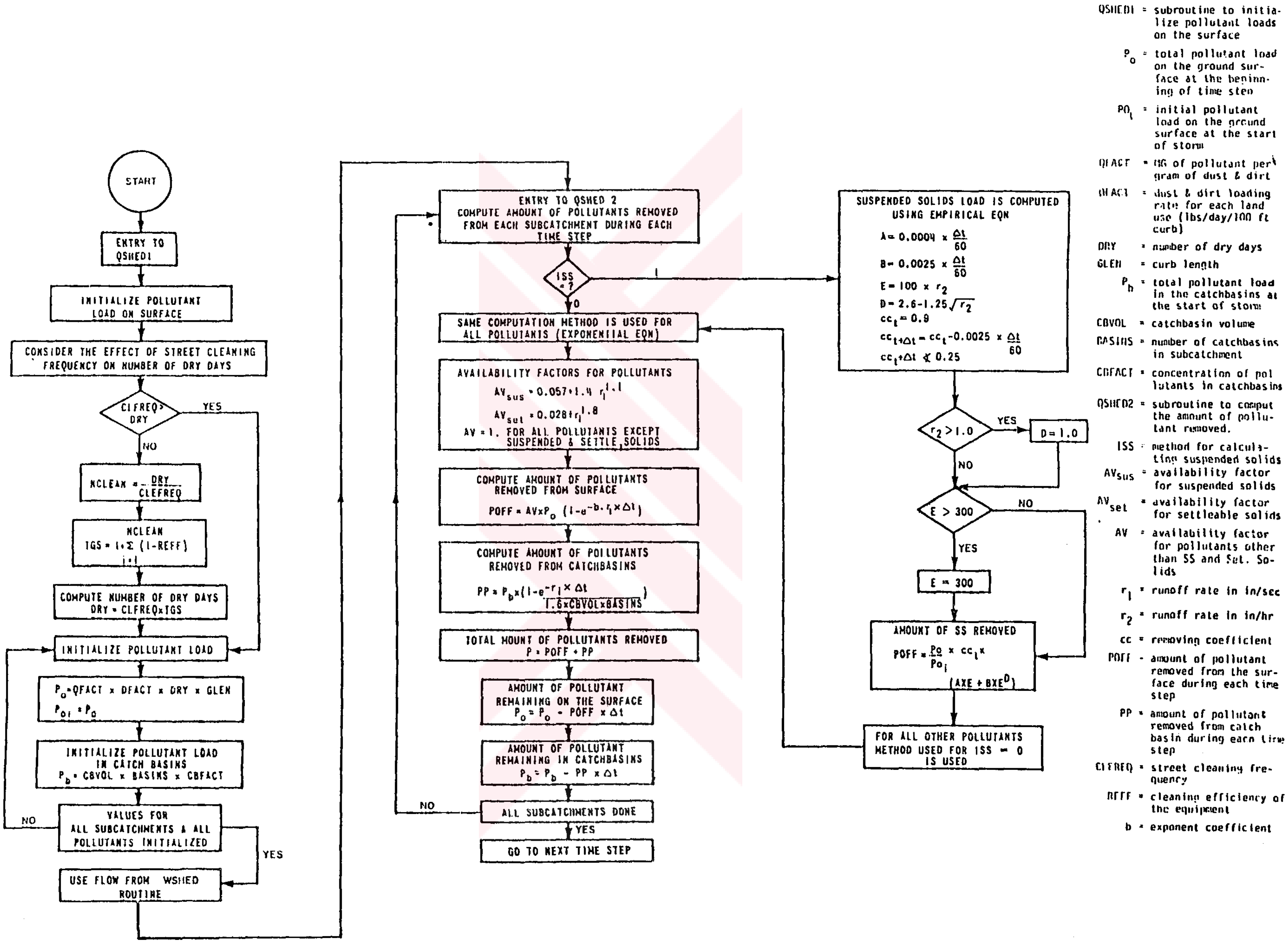


Figure 4.9 The algorithm of the SWMM Runoff Block quality computations (Proctor and Redfern et al., 1976).

As an alternative to the use of a buildup-washoff formulation, quality loads could be generated by a rating curve approach in which loads are proportional to flow raised to some power. Such an approach could also be justified physically and is often easier to calibrate using available data. Another quality source is catchbasins. These are treated in the SWMM model as a reservoir of constituents in each subcatchment available to be flushed out during the storm.

Erosion and sedimentation are often cited as a major problem related to urban runoff. They not only contribute to degradation of land surface and channels and sewer networks. Several ways exist to analyze erosion from the land surface, the most sophisticated of which include calculations of the shear stress exerted on soil particles by overland flow the influence of rainfall energy in dislodging them. In keeping with the widely used empirical approach, The Universal Soil Loss Equation, USLE, has been adapted for use in SWMM Runoff Block. Thus ;

$$L = R.\ K.\ LS.\ C.\ P \qquad \mathbf{4.39}$$

where;

R→ the rainfall factor,

K→ the soil erodibility factor,

LS→ the slope length gradient ratio,

C→ the cropping management factor or cover index factor,

P→ the erosion control practice factor.

L→ average annual soil loss per unit area (tons per acre per year).

Equation (4.33) represents a comprehensive attempt at relating the major factors in soil erosion. It is used in SWMM to predict the average soil loss for a given storm or time period.

A final source of constituents is the precipitation itself. Much more monitoring exists of precipitation quality at present than in the past, and precipitation could contain surprisingly high concentrations of many parameters. This is treated in SWMM by permitting a constant concentration of constituents in precipitation.

Many constituents could appear in either dissolved or solid forms and could be adsorbed onto other constituents and thus be generated as a portion of such other constituents. To treat this situation, any constituent could be computed as fraction of another. For instance, five percent of suspended solids load could be added to the BOD load. Up to ten quality constituents could be simulated in the Runoff Block. All are user supplied. Up to five user supplied land uses could be entered to characterize different subcatchments. Street sweeping is a function of land use and individual constituents.

Output consists of pollutographs at desired locations along with total loads, and flow-weighted concentration means and standard deviations. The pollutographs are plotted using the Graph Block.

4.2 Transport Block

Routing through the sewer system could be accomplished in SWMM by the Transport Block. This block has the responsibility of coordinating not only routing of sewage quantities but also of such functions as routing of quality parameters, estimating dry weather flow, infiltration, and calling internal storage (Huber et al., 1988).

To categorize a sewer system conveniently prior to flow routing, each component of the system is classified as a certain type of a element. All elements in combination form a conceptual representation of the system in a manner similar to that of links and nodes. Elements should be conduits, manholes, lift stations, overflow structures, or any other component of a real system. The solution procedure is the Kinematic Wave model. These techniques is described comprehensively in the Runoff Block section. As a consequence, backwater effects are not modeled beyond the real of a single conduit, and downstream conditions are assumed not to affect upstream computations.

Instructions for data preparation for the Transport Block have been divided along the lines of the major components for clarity of the presentation. These components are: Transport data, Quality, Internal Storage, Infiltration, and Dry-Weather flow. All data enter the Transport Block through one of those components.

Transport data describes the physical characteristics of the conveyance system. Use of the transport data involves three primary steps:

1) preparation of theoretical data for use by subroutines engaged in hydraulic calculations in the block,
2) generation of inlet hydrographs and pollutographs required as input the Transport Block and computational control,
3)preparation of physical data describing the sewer system.

Quality data identify pollutants to be routed and their characteristics. Up to four pollutants could be arbitrarily chosen for input and routing by the Transport Block. These would be chosen from the group which supplied by the Runoff Block. Each pollutant is subjected to a first order decay during the routing process by supplying a first order decay coefficient. Travel time through most sewer systems is short enough. Thus, decay is seldom important.

Routing quality parameters is performed by using the integral solution for the output from a completely mixed conduit volume. This tends to introduce artificial dispersion of concentration profiles. This is the most convenient way to introduce new loads at manholes along the system, as well as to facilitate scour and deposition. Each pollutant is assigned a specific gravity, particle size and particle size distribution, assumed to apply throughout the drainage system regardless of the sources of the pollutant. If the specific gravity is less than or equal to 1.0, the pollutant is considered to be entirely suspended (or dissolved) and not to be subjected to scour and deposition. If all calibration is to be performed using Runoff Block buildup-washoff parameters, for instance, it could be desirable to avoid the complexity of simulating scour, a second real but largely unknown source.

Use of the internal storage routine involves some basic steps A somewhat more detailed explanation should be found in the Storage/Treatment Block description in section 4.4.

The infiltration model has been developed to estimate infiltration into a given sewer system based upon existing information about the sewer, e.g. the surrounding soil and groundwater, and precipitation. The Transport Block's principal use has been mainly to simulate individual storms which cover a time period of less than a day. Average daily estimates from INFIL (Infiltration) are calculated only once prior to sewer flow routing (NINFIL is equal to 1).

The dry weather flow model describes the necessary drainage area characteristics to permit the computation of the respective inflow qualities and quantities. Three data categories are used to estimate sewage flow (quantity): drainage basin data, subarea data, and decision and adjustment parameters.

The purpose of the dry weather flow quality computation is to apportion waste characteristics (such as would be measured at a sewage treatment plant before treatment) among the various subareas in the drainage basin under study, or in the event no measured data are available to estimate and apportion usable average values. The apportionment is based upon the flow distribution, land use, measured or industrial flows, average family income, the use or absence of garbage grinders, and infiltration.

4.3 The Storage / Treatment Block

The Storage/Treatment Block, S/T, has been developed to simulate the routing of flows and pollutants through a dry-weather or wet-weather S/T plant. The primary objectives of the S/T Block are (Huber et al., 1988):

1) to provide the capability of modeling a larger number of processes in both the single event and continuous simulation,
2) to simulate the quality improvement provided by each process,
3) to simulate the handling of sludges,
4) to provide estimates of capital, operational and maintenance cost.

The Storage/Treatment units could be modeled as detention or non-detention units. Pollutants are characterized by their magnitude alone or by magnitude and their particle size specific gravity distribution. Any three of the pollutants available from other blocks are routed through the S/T Block. In summary, the S/T Block offers the user a flexible tool for modeling wet-weather and dry-weather facilities and evaluating their performance and costs.

4.4 Extended Transport Block (EXTRAN)

The Extended Transport Block, EXTRAN, analyzes the complex hydraulics of a system. This block solves the coupled complete St. Venant equations and accounts for phenomena such as backwater, looped connections, surcharging and pressure flow that were not considered or treated in a very simplified manner in the original Transport Model (Section 4.2). EXTRAN capabilities are compared with those of Runoff and Transport in Table 3.2.

EXTRAN originally contained both quantity and quality routines. However, the only use for the model has been for hydraulic analysis, and the quality routing has been formally removed from the program. The state of the art in urban runoff quality modeling is such that adequate simulation of pollutographs could be performed using the simpler hydraulics of the Runoff and Transport Blocks (Proctor and Redfern et al., 1976).

CHAPTER FIVE

THE SWMM IMPLEMENTATION IN WINDOWS

5.1 Accessing Data to SWMM

The SWMM has two main structures: "SWMM Windows Interface" and "Manual Run Option". When the Windows Interface option is selected, a flow-chart that is shown in Figure 5.1 appears. It shows the various interface blocks that are available and the sequence the user should follow in accessing them. All the interface blocks share certain characteristics since they are all in Windows. This section describes how to use the capabilities available in the various interface blocks in SWMM.

The SWMM Windows Interface is designed to be as user-friendly as possible. It consists of five interface blocks (Figure 5.1): METeorological data (MET), RUNOFF, USEr defined Hydrographs and Pollutographs (USEHP), TRANSPORT, and EXTRAN. Basically, the MET function acts as the Rain and Temp blocks. The RUNOFF, TRANSPORT, and EXTRAN interface blocks perform the same functions as the Runoff, Transport, and EXTRAN Blocks do in SWMM 4.3 (Fortran). The USEHP function allows the user to define time series of flows and concentrations at desired inlets (Lahlou et al., 1995).

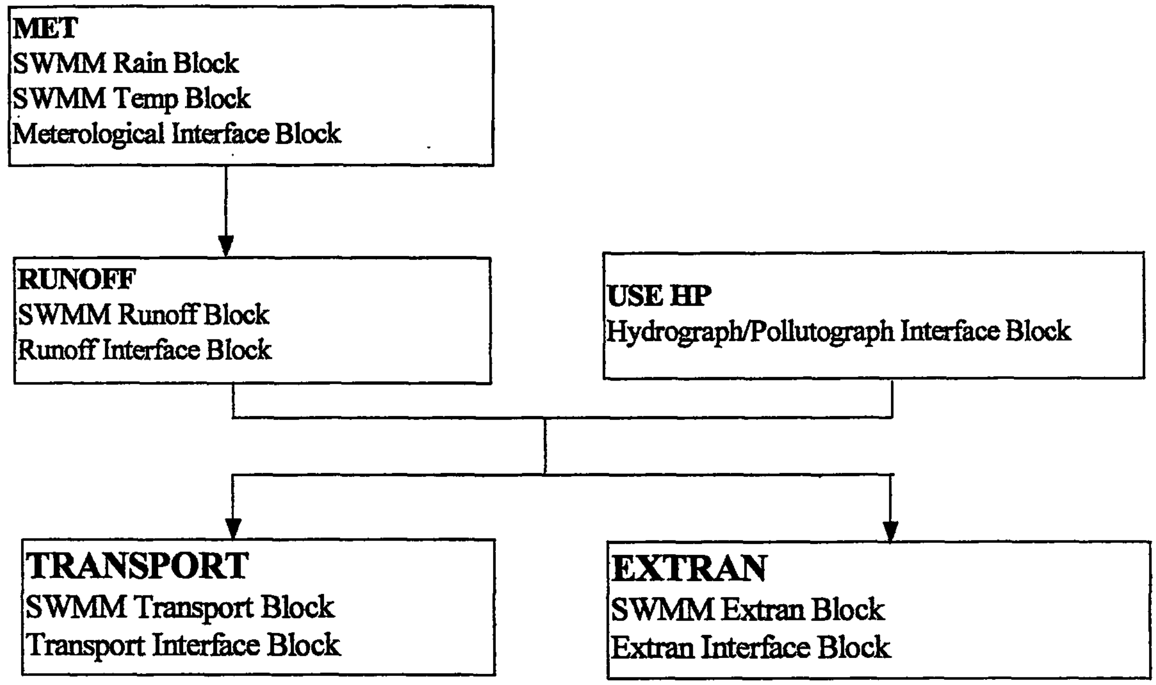


Figure 5.1 SWMM Windows interface functions (Lahlou et al., 1995)

A key feature of the design of a "Windows" user interface for SWMM 4.3 is the separation of meteorological data from the Runoff Block of user input. Users access the MET interface to create and edit meteorological data. Selection of meteorological data for use in a RUNOFF run occur as part of the RUNOFF function. The goal of this function is to consolidate user interaction and input of meteorological data in SWMM into one separate module. From a user's perspective, all meteorological data are accessed unambiguously by a single file name. This, therefore, eliminates meteorological data entry in the RUNOFF input file. Similar consideration made in the TRANSPORT and EXTRAN functions is the separation of user defined hydrographs and pollutographs from the TRANSPORT and EXTRAN user input. The USEHP function was developed to handle all user-supplied flows and concentrations.

The normal execution sequence for the SWMM Windows interface is indicated by an arrow symbol as shown in the screen in Figure 5.1. Usually, MET should be executed first to create interface files that are required input to the Runoff Block. Likewise, RUNOFF creates an interface file that is the required input to the Transport and EXTRAN Blocks. USEHP serves the same function for input to the Transport and EXTRAN Blocks as the runoff interface file does. TRANSPORT or EXTRAN can be executed independently when either a Runoff interface file or a USEHP file exists.

As mentioned earlier, MET allows the user to create and edit meteorological data. Input data in MET consists of three data components: general meteorological parameters, precipitation and evaporation, and snow data. Those three elements take a total of six screens (Table 5.1). The first screen describes the control variables in MET, such as the types of meteorological data and units associated with the MET data. The selections on the first screen determines which subsequent screens are accessible. The next two screens contain raingage stations and precipitation data. The fifth screen defines monthly average evaporation and/or wind speed. Air temperatures are stored on the fourth screen for continuous snowmelt simulation, and on the last screen for single event snow melt simulation. RAIN (precipitation) and evaporation data are always required in MET. Wind speed and temperature data are needed when the snowmelt is simulated.

Table 5.1 Data Category and Screen Input in MET interface (Lahlou et al., 1995)

Data Element	Category			Screen Title	Data Requirement	Screen No.
1	General Meteorological Parameters				Units, control variables	1
2	Precipitation			Station Table	Raingage station number (max=10)	2
				Rain Data Table	Hourly, daily, and any time step precip. values	3
	Evaporation			Avg. EVAP & WINDSPEED Table	Default evap. rates	1
					Monthly evap. rates	5
3	SNOW	Windspeed			Monthly windspeed rates	5
		Temp	Single Event	Single Event Snow Melt Air Temp. Table	Time interval, air temp values	6
			Continuous	TEMP Data Table	Daily Max & Min temp. data	4

Precipitation data are the single most important group of hydrologic data required by SWMM. SWMM requires a hyetograph of rainfall intensities versus time for the period of simulation. For single event simulation, this is usually a single storm, and data for up to ten raingages may be entered. For continuous simulation, hourly, daily or other continuous data from at least one gage are required. The RAIN data should be entered in the Rain Data Table on Screen No. 3.

Evaporation can be input either by entering monthly average rates or using default rates that are internally supplied in the SWMM model. Wind speed and temperature data are needed if snowmelt simulations are included. Similar to evaporation rates, a monthly average wind speed should be provided. When a daily NOAA (NOAA is a file that contains rain, temperature, etc. and it is supported by EPA) data file is selected, MET will automatically compute monthly values for evaporation and wind speed.

Air temperature can be entered on either Screen No.4 or Screen No. 6 based upon the types of snowmelt simulation. Continuous snowmelt simulation requires a complete time history of daily maximum and minimum temperatures on Screen No. 4. These maximum/minimum temperatures are supplied in the NOAA data file. A single event snowmelt simulation receives air temperatures from Screen No. 6 for a given time step entered on the first screen. The temperatures are constant over the time interval.

After all the data are entered, MET will generate four MET interface files: a RAIN data interface file, a TEMP data interface file, an evaporation and wind speed file (EVAWIND), and a single event snowmelt temperature file (SINAIR). The first two interface files are the SWMM scratch files processed during the execution of the Runoff block. The other two files would be processed into the Runoff Block input file. The evaporation and wind speed data from the EVAWIND file will be placed on F1 and C2 (SWMM ID in the Runoff Block) data group lines in the RUNOFF input file, respectively. The air temperature from the SINAIR file will be input to C5 data group line.

The RUNOFF interface block assists in creating the Runoff input file and calls the SWMM Runoff Block for execution. It is designed to closely follow the input representation order in the Runoff Block. Input data in RUNOFF are divided into five data elements: general control parameter, meteorological data, water quality, description of a drainage system, and print control. The general control parameter includes identification of a MET file, unit, simulation length, starting date, time step, and type of simulations. These selections determine whether subsequent screens or controls are accessible. The meteorological data include precipitation, evaporation, temperature, and wind speed, which should be generated through the MET function. Water quality simulation requires the user to specify up to ten pollutants and appropriate parameters to buildup and washoff mechanisms, and up to five land uses to characterize different subcatchments. Erosion and groundwater simulations are optional. A drainage system can be described as number of subcatchments (subwatersheds) connected with channels/pipes. Necessary inputs associated with subcatchment are surface area, width, ground slope, Manning's roughness coefficient, and infiltration rates. Channel descriptions are the length, Manning's roughness coefficient, invert slope, diameter for pipes, and cross-sectional dimensions of the channel.

There are total of twenty-three screens in the RUNOFF interface (Table 5.2). The screen input sequence reflects the overall structure of the Runoff Block. Screen numbers are assigned corresponding to the data elements and to cover all the input requirements. Table 5.2 also shows the relationship between the screen numbers in the Runoff Interface and SWMM ID (group identifiers) in a RUNOFF input file. The relationship between variables of SWMM 4.3 and controls of SWMM interface can be observed in **Appendix A.** Furthermore a spreadsheet is generated to identify the controls (variables) for each screen. This table defines the following for RUNOFF:

1) variable name in the Runoff Block,
2) the description of the variable,
3) SWMM ID in the Runoff Block (SID),
4) screen number (SCR),
5) control number (CS),
6) control type (CT), item, range, default, and unit.

The USEHP function is designed to create and edit user-defined inlet flows and concentrations. This option is preferable to the RUNOFF interface file option for those users who wish mainly to use the Transport Block or the EXTRAN Block. For EXTRAN, the user should provide only inlet hydrographs in USEHP since EXTRAN is not capable of simulating water quality. There are a total of five screens in the USEHP interface block and input requirements are listed briefly in Table 5.3. USEHP will generate four USEHP files as input to the Transport and Extran Blocks. As shown in Table 5.3, the values stored in USEHP correspond to the variables and data group lines in either a Transport Block input or an EXTRAN Block input.

Table 5.2. Screen Input Sequence in RUNOFF Interface (Lahlou et al., 1995)

Data El.	Category	Content			SWMM ID	Screen No.
1	General Control Parameter	Titles			A1	1
		Units			B1	2
		Simulation	Starting, ending time, time step		B1, B3	1
		Simulation Type: Groundwater Flow & Quality (J1)				2
2	Meteorologic Data (B1)	Precipitation (D1)	hyetographs (1-10)		E1-E3	2
			RAIN (database)			
		Evaporation	default rates		F1	
			monthly rates			
			TEMP (database)			
		Snow (B1)	no		C1-C5	2,3,4,5
			single event			
			continuous			
3	Water Quality	Pollutants (1-10)			J3	6 & 7
		Land uses & fractions			J2 & J4	8 & 9
		Groundwater Concentration			J5	10
4	Description of a Drainage System	Channel/Pipe	#,inlet #, length,slope, Manning's n		G1-G2	11
		Watershed/ Subcatchment	Surface Water	#, inlet	H1	12 & 13
				infiltration		
			Groundwater	physical	H2-H4	14
				empirical		
			Snow		I1-I2	15 & 16
			Erosion		K1	17
			Quality		L1-L2	18
5	Print control	SWMM output, Inlet hydrographs, pollutographs, inflows, outflows, channel depths.			B2, M1-M3	19-23

Table 5.3 Screen Input Sequence in USEHP Interface (Lahlou et al., 1995).

Data Element	Category	Data Requirement	Transport Block	Extran Block	Screen No.
1	General Control Parameters	Units, # of inlets, # of pollutants, # of data points	NINPUT NPOLL	NJSW	1
2	List of Inlet Numbers	Inlet number	I1	K2	2
	Pollutant Name Table	Pollutant name, input and output unit	F1	No	3
	Time of day	Time in hours	R1	K1,K3	4
	Hydrograph/Pollutograph Table	Time series of flows and concentrations			5

The Transport Block was implemented following the same procedure as used for the Runoff Block. Table 5.4 indicates the screen input sequence in the TRANSPORT interface as compared to in the SWMM model. The TRANSPORT interface is characterized into six data components, namely TRANSPORT simulation control, sewer system description, water quality, infiltration and dry-weather flow, study area description, and print control. TRANSPORT simulation control defines an inlet hydrograph and pollutograph file, computational parameters, units, and types of simulation. Sewer system description provides the physical characteristics of the conveyance system. Quality data identify pollutants to be routed and their characteristics. Infiltration and Dry-Weather Flow (DWF) data describe the necessary drainage area characteristics to permit the computation of the respective inflow quantities and qualities. Print control reports a time history of inlet hydrographs and pollutographs, and a time history of channel depths.

The TRANSPORT interface contains a total of seventeen screens. The data components associated with screen numbers in the interface and SWMM ID in SWMM 4.3 are presented in Table 5.4. This table is designed to assist in assembling data for implementing WINDOWS processes of SWMM and give a clear picture of identifying the variables used in TRANSPORT interface as compared to SWMM 4.3.

There are three data components included in the Extran Block: EXTRAN simulation control, sewer system description, and output print and plot. The EXTRAN simulation control defines the simulation, an inlet hydrograph file, computational control, and simulation methods. Like the TRANSPORT interface, EXTRAN gets inlet flows from either a RUNOFF interface file or a

Table 5.4 Screen Input Sequence in TRANSPORT Interface (Lahlou et al., 1995).

Data Element	Category	Content		SWMM ID	Screen No.
1	TRANSPORT Simulation Control	Title		A1	1
		Inlet Hydrographs and Pollutographs		B3	
		Computational Control		B1,B3	
		Simulation Type	Simulation Type	B3	2
			Unit	B1	
			# of Constituents	B1	
2	Sewer System Description	Sewer System Table		E1	3
		Special Types of Sewer Element	Storage Tank	G1-G5	
			New Shapes	C1,D1-D9	
			Natural Channel (HEC-2 format)	E2-E4	
3	Water Quality			F1	4
4	Infiltration and Dry-Weather Flow			K1,K2,L1-L3, M1-M4	5,6,7,8
5	Study Area Description	Study Area Parameters		N1,O1,O2	9 & 10
		Process Flow Characteristics		P1	11
		Categorized Study Area		Q1	12
6	Print Control	Printed non-conduit elements for hydrograph & pollutograph	Transferred to Graph Block	B1,C1,H1	13 & 14
			Input	J1	15
			Output	J2	16
		Printed conduit elements for depths		I2	17

USEHP file. Therefore, the user must run either RUNOFF or USEHP before proceeding with EXTRAN. The sewer system description is divided into two sections: identification of channels/conduits and junctions. The cross sections of channels/conduits can be regular or irregular. For regular channels, input data are relatively simple. For irregular channels, however, data are complex and a detailed description to define cross sections for each channel is needed. Junction data can be described as regular junctions and special flow devices that divert sanitary sewage out of a combined sewer system or relieve the storm load on sanitary interceptors. The five types of junctions are storage, orifice, weir, pump, and outfall. Like irregular channels, those special junctions may require detailed input describing a time-history curve for stage, volume, flow, etc. Output print and plot determine numbers of junctions and channels for printing and plotting of heads and flows. There are twenty-three screens for the EXTRAN interface, as shown in Table 5.5. Sixteen of these screens are for inputs for channels and junctions. Two looping screens are developed to handle large input depending upon the type of channel or junction.

The Manual Run options include the following items:

a) Accessing An Existing File or Opening a New File
b) SWMM File-Naming Conventions
c) Saving Input Files
d) Setting Up a Default Editor for Viewing Output Files
e) Submitting an Input File to the Model
f) SWMM Windows Interface Commands and Function Keys
g) Import File Option in SWMM
h) Export Function
i) Array Screen Capabilities
j) Using the Manual Run option

When the user first enters any of the Windows SWMM Blocks, he will be automatically assigned a new file. The new file name and number appear at the top of the screen in parentheses. To access an existing file, the user clicks on the **FILE** option on the very top line, selects the **OPEN** option and selects the file that he wants from the list that appears.

Table 5.5 Screen Input Sequence in EXTRAN Interface (Lahlou et al., 1995).

Data Element	Category	Content		SWMM ID	Screen No.
1	EXTRAN Simulation Control	Title		A1	1
		Inlet Hydrographs		B3,K1,K2,K3 (if USEHP is selected)	
		Computational Control and Unit		B1,B3,B2	
		Simulation and print control	Solution technique, flow condition, and conduit elevation	B0,BB	2
			Print cycle	B1	
2	Sewer System Description	Channels/Conduits	Channels/Conduits Table	C1	3
			Natural Channel (HEC-2 format)	C2-C4	4-5
		Junctions	Regular Junction	D1,I1,I2,J1	6
			Storage Junction	E1,E2	7-8
			Orifice	F1,F2	9-12
			Weir	G1	13-14
			Pump	H1	15-16
			Outfall	J2-J4	17-18
3	Output print and plot	Printed and plotted Junctions for elevations		B4,B6	19,21
		Printed and plotted channels for flows and velocities		B5,B7	20,22
		Plotted channels for US/DS elevations		B8	23

The naming convention of files in SWMM is as follows: the first four characters are the interface block name, the next three digits are sequentially assigned numbers that indicate the number of the input file that are currently created, and the file extension indicates the file type. Table 5.6 summarizes naming conventions of the SWMM interface for each function. There are three file extensions in the MET input files. The first extension is (.MET) which indicates user defined meteorological data, the second one is (.DAT) that contains hourly precipitation data, and the last one is (.ATH) that indicates long term meteorological data. The file extensions in the RUNOFF and TRANSPORT interfaces are also standardized. For instance, (*.INP) is the input file and (*.OUT) is the output file. Also, The RUNOFF Interface has:

SWRPP*.INP	Tables file based on RNOFF*.INT
SWRGR*.INP	Graphics file based on RNOFF*.INT
SWRCA*.INP	Calibration file based on RNOFF*.INT

Table 5.6 Naming Conventions of SWMM Interface (Lahlou et al., 1995)

INTERFACE BLOCKS	FILE NAME	FILE TYPE (Fmt)[1]	CONTENT
METeorological data editor (MET)	SMET###.MET	Input (A)	MET Windows interface input.
	*.DAT	Input (A)	Hourly precipitation data.
	*.ATH	Input (A)	Daily meteorological data for NOAA first order stations in the U.S. Provided by the EPA in Athens, GA.
	SMET###.MT1	Output/Input (B)	A Rain interface file that contains precipitation data. An input file to the Runoff Block.
	SMET###.MT2		A Temp interface file that contains maximum and minimum temperatures. This is an input file to the Runoff Block.
	SMET###.MT3		An monthly evaporation and wind speed file. To be placed in F1 and C2 lines in a Runoff input file.
	SMET###.MT4		A air temp data file for single snow melt simulation. To be placed in C5 line in a Runoff input file.
RUNOFF	RNOFF###.INP	Input (A)	RUNOFF Windows interface input.
	RNOFF###.RUN	Input (A)	RUNOFF run file which can be executed under DOS.
	RNOFF###.OUT	Output (A)	Runoff output generated by SWMM.
	RNOFF###.INT	Output (B)	Runoff interface file generated by SWMM.
USEr defined Hydrographs and Pollutographs (USEHP)	USEHP###.HP	Input (A)	USEHP Windows interface input.
	USEHP###.HP1	Output/Input (A)	An inlet hydrograph and/or pollutograph file. To be placed in the NINPUT, NPOLL, F1, I1, and R1 lines in a Transport input file.
	USEHP###.HP2		
	USEHP###.HP3		
	USEHP###.HP4		An inlet hydrograph file to be placed in K1-K3 lines and NJSW in EXTRAN input file.
TRANSPORT	TRANS###.INP	Input (A)	TRANSPORT Windows interface input.
	XTANK###.PIP		Storage tank data file defined by the user.
	XSHAP###.PIP		New shapes data file defined by the user.
	XHEC2###.PIP		Natural channel (HEC-2 format) file defined by the user.
	TRANS###.RUN		TRANSPORT run file which can be executed under DOS.
	TRANS###.OUT	Output (A)	Transport output generated by SWMM
	TRANS###.INT	Output (B)	Transport interface file generated by SWMM.
EXTRAN	EXTRN###.INP	Input (A)	EXTRAN Windows Interface input
	EXTRN###.RUN		EXTRAN run file which can be executed under DOS.
	EXTRN###.OUT	Output (A)	Extran output generated by SWMM
	EXTRN###.INT	Output (B)	Extran interface file. can be used for subsequent blocks.

[1]File format can be either ASCII (A) or Binary (B).

When the user completes the input file for the interface he is in, he selects the RUN button to run the model with the input file created. When the RUN option is selected, all the entries in the file will be validated. If any errors are detected during the validation, SWMM will put up a message informing the user of the type of error detected and will then take the user to the prompt that is incorrect. Once all the values are valid, the file is submitted to the appropriate block for execution. An icon will appear at the bottom of the screen for those blocks for which the SWMM model is called. When the processing of the input file is complete and the output results, SWMM will ask whether the user wishes to view them. If he indicates that he did wish to view the output file, SWMM will show them using a data editor allowing the user to annotate the results if he so chooses.

The Windows Interface options all have a series of "buttons" designed to make using the system as easy as possible. These are NEXT, BACK, INDEX, HELP, CALC, TOP, RUN, TABLES, GRAPHICS, CALIBRATION buttons.

5.2 EXAMPLE RUN

This section contains an example run to illustrate how to best use the SWMM Windows interface. The example run is selected in an attempt to exercise the major portions of the SWMM interface. The SWMM interface contains five blocks: MET, RUNOFF, USEHP, TRANSPORT, and EXTRAN. Each block has its own components, and each component may be divided into sections if applicable. This example illustrates the combination of two blocks: MET and RUNOFF; it includes the applications on:

1) how to generate precipitation data for a single event simulation using MET; and
2) how to describe a drainage system with channels and subwatersheds and simulate runoff and water quality (Only total suspendid solid in mg/L, or in Kg/day) using RUNOFF.

5.2.1 A User-Defined Hyetograph-MET and RUNOFF Block

This is an example of a user-defined time series of rainfall with a total precipitation of 28.0 mm. A user defined hyetograph is shown in Table 5.7 and is shown in Figure 5.2. The format required by MET is the same one used in Rain Block interface file. A single catchment with a total drainage area of 300 hectares receives rainfall through an inlet. The catchment characteristics are 20% impervious area, a length of 100 meters for catchment width, and 0.001 ground slope (Figure 5.3). The total simulation lasts 3 days. This example is there to show how to use MET and RUNOFF and to perform a Runoff Block Run. Only hydrologic simulation is involved. The steps that must be followed for this screening-level example are explained in detail below:

Table 5.7 A user defined hyetograph in MET

Julian Date	Hour (Sec)	Time Interval THISTO (sec)	Rainfall Intensity (mm/hr)	ΔP (mm)
88001	3600	300	12	1
88001	7200	300	24	2
88001	10800	300	0	0
88001	25200	300	12	1
88001	26100	300	12	1
88001	27900	300	12	1
88001	30600	300	24	2
88001	34000	300	42	3.5
88002	37800	300	54	4.5
88002	41400	300	66	5.5
88002	45000	300	78	6.5
				Σ 28 mm

STEP 1: We select the SWMM Windows Interface option from the main SWMM menu. Next, we select the MET Block, which is the first option in the flow chart, by clicking on the option.

STEP 2: In the MET Block, we could enter our data that is the user-defined hyetograph, on the screen or select the MET data file from the FILE option, followed by the OPEN option by clicking. In this example SMET001.MET file was used for MET data file.

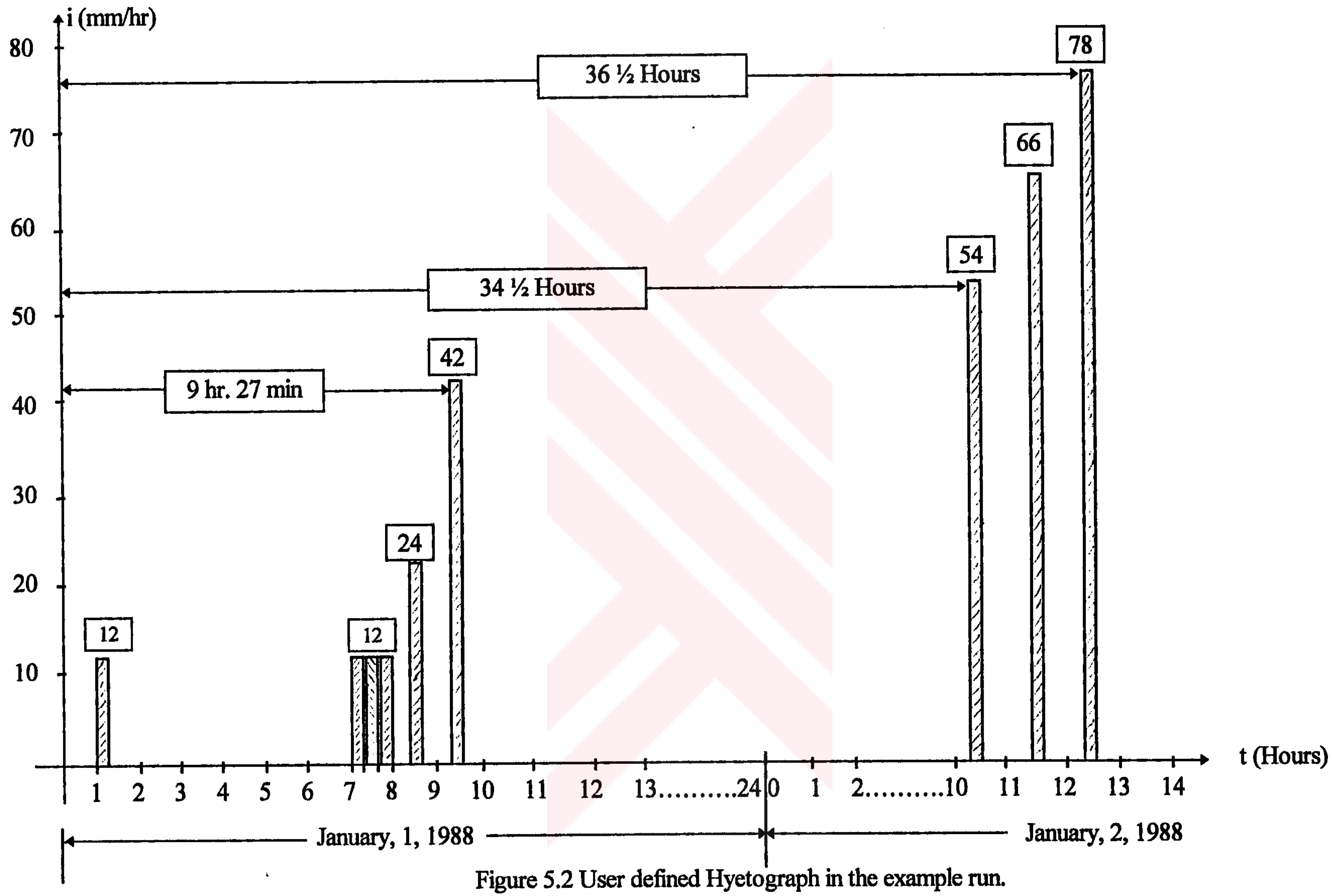


Figure 5.2 User defined Hyetograph in the example run.

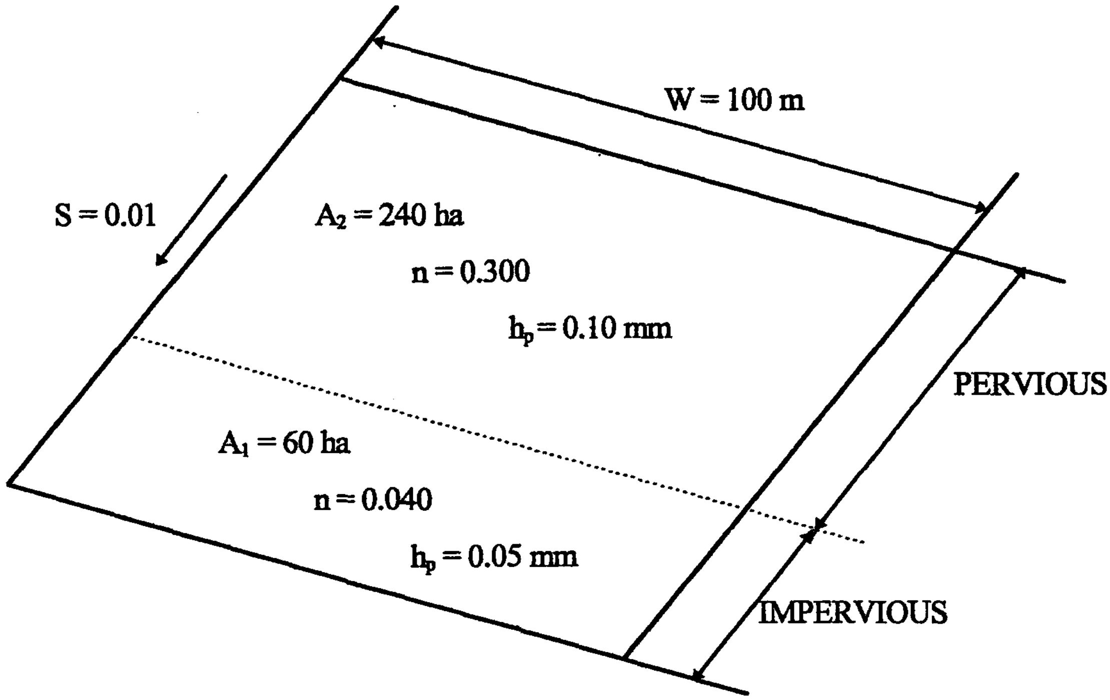


Figure 5.3 Simulated catchment in the Example run.

STEP 3: After restoring all the data on screens, we could click the RUN button to generate the MET data file before we proceed to the next block in SWMM. Thus, if we did not use the RUN button from the MET interface, we will not be able to use the MET data since the interface file will not exist.

STEP 4: Next, we could exit the MET block to select the RUNOFF Block.

STEP 5: We could enter our data the same way as we did in the MET Block. In this example RNOFF001.INP file was used for RUNOFF data file. After selecting this file from the FILE option, we follow the OPEN option by clicking them all parameters will be entered on screens by this file. The first screen for the RUNOFF block also allows the user to enter the Meteorological Input file. If the file that is created for the MET option does not show in the input option for the file name, the user has to click on the arrow key to the right of the option. A list of existing meteorological file names will appear select SMET001.MET.

In summary, the hydrologic simulation was started at January 1, 1988 and the simulation length was three days. Three time steps should be entered. Screen 2 in RUNOFF determines the complexity of the simulation. In this example, snowmelt was not included, default evaporation rates were used, and metric units were selected. Screens 3 through 8 were empty because no snowmelt was simulated.

Screen 10 gives the physical representation of the watershed. For this example, there is a single watershed without a connecting channel. One inlet is defined as a raingage station in MET for this watershed.

In Screen 12 we notice that two infiltration equations are available : (1) the Horton and (2) the modified Green-Ampt equation. The Horton model is empirical and is perhaps the best known of the infiltration equations. Many hydrologists have a "feel" for the best values for its three parameters despite the fact that little published information is available. The Green-Ampt equation is a physically-based model that can give a good description of the infiltration process. The Mein-Larson (1973) formulation of the Green-Ampt equation is a two-stage model. The first step predicts the volume of water, which will infiltrate before the surface becomes saturated. From this point onwards, infiltration capacity is predicted directly by the Green-Ampt equation. This equation is applicable also if the rainfall intensity is less than the infiltration capacity at the beginning of the storm. Both equations require three different coefficients. The user will be required to enter these coefficients in Screen 13. The Windows interface has an additional function to help users with these coefficients. Depending on the equation selected by the user, definitions of each of these coefficients will appear when the user clicks on the appropriate variable. For this example, the Green-Ampt equation has been selected. The three coefficients are 4.0 cm for the average capillary suction of water, 1.0 cm/h for the saturated hydraulic conductivity of soil, and 0.34 for the initial moisture deficit for soil.

At the end of the screen, we could submit the RUNOFF input file to the SWMM model for execution by clicking on the RUN button. An icon will appear on the bottom of the screen with the words SWMM MODEL EXECUTION on the icon. It shows the steps of the computation. After processing is complete, the output will be shown in RNOFF001.OUT output file. This file describes the summary of the input and output parameter values as shown in **Appendix B.**

The graphics option in SWMM provides access to six different type of graphs: hydrograph, pollutograph, loadograph, flow volume, mass, and land use. In this example, only RUNOFF Block was executed, and four graphs plotted. These are : hydrograph, pollutograph, loadograph, and flow volume (Figure 5.4).

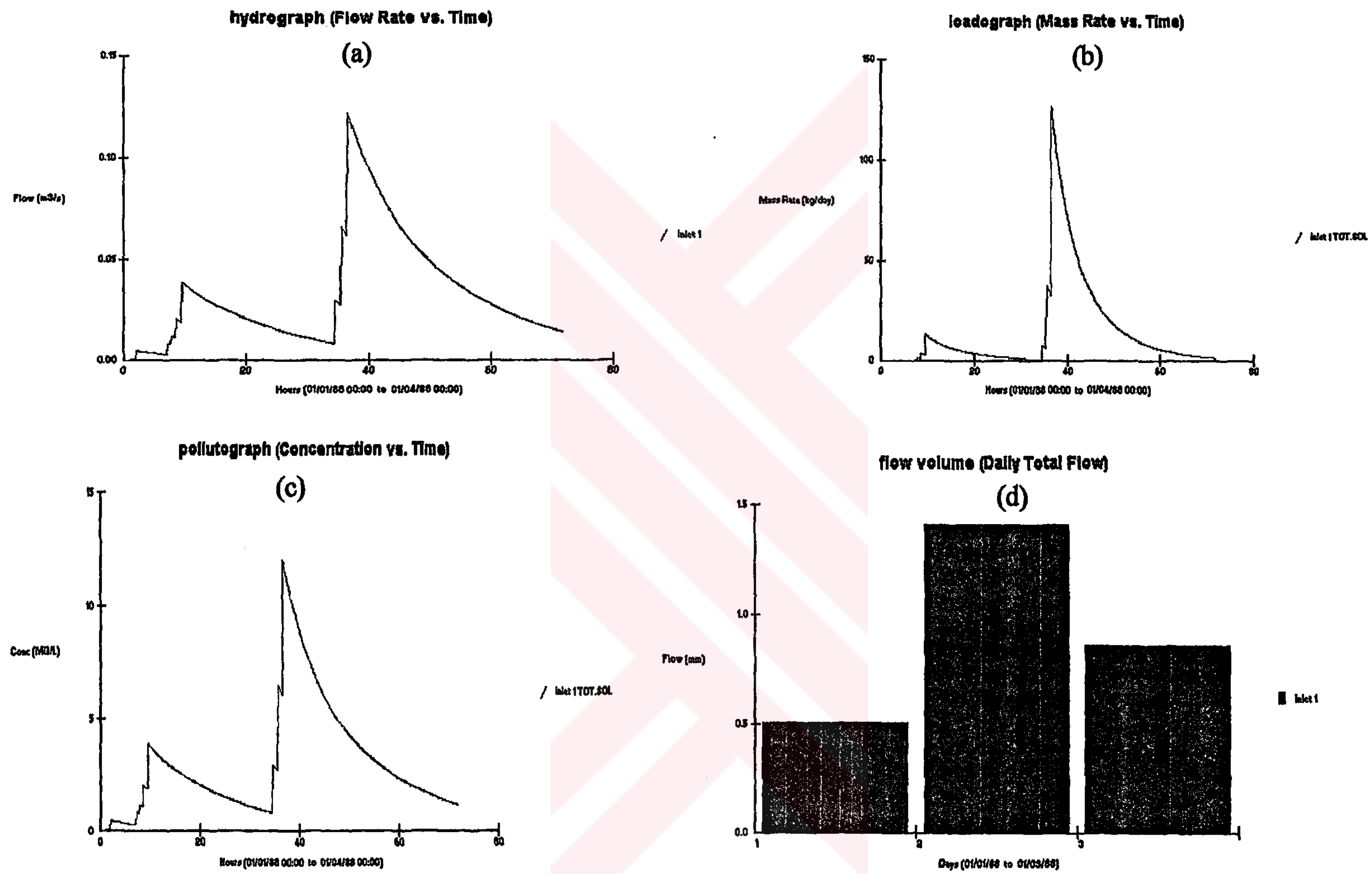


Figure 5.4 RUNOFF Block Graphics

The data used in the example run are totally assumed inputs; thus they do not represent a real case. The rainfall hyetograph of the hypothetical basin is shown in Figure5.2. The expected runoff hydrograph resulting from this hyetograph is computed by SWMM with respect to the specified simulation period. Figure 5.4(a) shows this hydrograph; Figure5.4(d) present the total flow volumes entering the basin for each simulation period.

The pollution loads in the basin have been initially specified for the program. SWMM produces the pollutograph in Figure 5.4(c) which describes the transport of such pollutants via runoff computed again by the model. The loadgraph of Figure 5.4(b) presents the pollutant loads in (kg) for each simulation period.

The example presented shows in detail the transformation of a rainfall hyetograph into runoff and the resulting transport of pollutants within the basin for each specified simulation period. The detailed results of the example run are presented in Figure 5.4 and in the output files of **Appendix B.**

CHAPTER SIX
CONCLUSION

The objective of the presented study has been to investigate capabilities and properties of SWMM in simulating urban drainage and to apply it in a simple hypothetical basin so that basic requirements for a real case study can be identified.

The analysis of model characteristics has shown that SWMM is a powerful tool to predict the peak carrying capacity of the sewer system, to rank the relative frequency and quantity of combined sewer overflows, to define locations of potential street flooding, and pollutant loadings based on flow projections and water quality data. Thus, it can be effectively used to solve management problems associated with urban drainage problems.

The first version of SWMM which was provided in 1971 was written in FORTRAN and involved complicated data entry procedures. The version used in presented study is the Windows version of the model. The Windows processing system provides the user with various alternative means of the entering the data. Thus, input preparation for the Windows version of SWMM is quite easy for the modeler. In addition, the model does not have extensive hardware requirements; it only needs a Windows operations system.

As described in the previous sections, SWMM analyzes urban watersheds with respect to both water quantity and quality. In the presented study, the MET-RUNOFF blocks of the model have been used to simulate runoff resulting form a given rainfall hyetograph. Next, the transport the pollutant loads and erosion which occur via the simulated runoff have been investigated in the form of pollutographs and loadgraphs. Since the objective of the study has been to investigate model features, the above procedures were applied to a hypothetical basin.

The results of the application has shown that to effectively simulate urban runoff, simultaneous measurements of rainfall and runoff are required. These measurements are essentially needed to calibrate and verify the model. In addition, information on basic properties of the urban watershed, e.g. perviousness, soil types, vegetation, etc., is needed to calibrate model parameters. Data are also needed on water quality and other processes like build-up and wash-off and street sweeping. All these data most likely are not readily available in our urban watersheds. Thus, to produce realistic model output, appropriate and adequate data must be collected in the first place.

Provided that data required by the model are obtained, the SWMM model can be effectively used in the planning and design of urban drainage systems of major cities in Turkey. The presented study points out to capabilities of the model in this respect. It is expected that SWMM will be employed by urban planners and managers in our country. On this respect, the presented study serves the delineate model requirements and data needs for effective applications of SWMM. Having noted the characteristics and data requirements of the model at this stage, it is intended to run the model on the case of a real urban watershed as part of future studies.

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APPENDIX-A

INPUT VARIABLES

AND

SCREEN SEQUENCE

IN

RUNOFF

Variable	Description	SID	SCR	CS	CT	Item	Type	Range	Default	Units
	RUNOFF Simulation Time Control									
TITLE	Description of this run	A1	1	1	1		C160			
	Meteorologic Data		1	2	1		C40			
	Simulation Time Period		1		5					
NHR	Starting time of the storm hr	B1	1	3	1		I	0-24	0	
NMN	min	B1	1	4	1		I	0-60	0	
NDAY	Day storm starts [mm/dd/yy]	B1	1	5	1		I	0-31		
MONTH		B1	1	5	1		I	0-12		
IYRSTR		B1	1	5	1		I	00-99	42	
LONG	Simulation Length	B3	1	6	1		F			
LUNIT	Units of simulation length	B3	1	7	3		C11			
	Seconds		1		9	1			0	
	Minutes		1		9	2			1	
	Hours		1		9	3			2	
	Days		1		9	4			3	
	Ending Date		1		9	5			4	
WET	Wet time step (sec)	B3	1	8	1		F	>=1	3600,0	second
WETDRY	Transition time step (sec)	B3	1	9	1		F		7200,0	second
DRY	Dry time step (sec)	B3	1	10	1		F		86400,0	second
	Simulation Control Parameters		2							
	Simulation Type		2		5					
	Groundwater Flow		2	1	4		I	0,1		
KWALTY	Quality Simlation	B1	2	2	4		I	0,1	1	
ISNOW	Snowmelt Simulation	B1	2	3	5		I	0-2	0	
ISNOW	Not simulated	B1	2	4	6		I	0		
ISNOW	Single event	B1	2	5	6		I	1		
ISNOW	Continuous	B1	2	6	6		I	2		
IVAP	Evaporation	B1	2	7	5			0,>0	>0	
	Evaporation data from met. data file		2	8	6					
	Default evaporation rate		2	9	6				0	
METRIC	UNIT	B1	2	10	5		C15	0,1	0	
	U. S. units		2	11	6			0		
	Metric units		2	12	6			1		
	Snow Melt		3							

Variable	Description	SID	SCR	CS	CT	Item	Type	Range	Default	Units
ELEV	Average watershed elevation	C1	3	1	1		F		0,0	ft [m]
FWFRAC(1)	Ratio of free water holding capacity to snow	C1	3	2	1		F		0,0	w.e. in [mm]
	depth on snow covered impervious area									
FWFRAC(2)	Ratio of free water holding capacity to snow	C1	3	3	1		F		0,0	w.e. in [mm]
	depth on snow covered pervious area									
FWFRAC(3)	Ratio of free water holding capacity to snow	C1	3	4	1		F		0,0	w.e. in [mm]
	depth for snow on normally bare impervious area									
SNOTMP	Dividing temp. between snow and rain	C1	3	5	1		F		0,0	F [C]
SCF	Snow gage correction factor	C1	3	6	1		F		1,0	
TIPM	Weight used to compute antecedent temp. in	C1	3	7	1		F	0.0-1.0	0,0	
RNM	Ratio of negative melt coeff. to melt coeff.	C1	3	8	1		F		0,6	
ANGLAT	Average latitude of watershed (degree north)	C1	3	9	1		F		0,0	
DTLONG	Longitude correction	C1	3	10	1		F		0,0	min
	Areal Depletion Curve for Impervious Area (%)		4					0.0-1.0		
ADCI(1)	ADCI (1-10)	C3	4	1	1		F		0,0	
	Aeral Depletion Curve for Pervious Area (%)		5					0.0-1.0		
ADCP(1)	ADCP (1-10)	C4	5	1	1		F		0,0	
	Water Quality		6							
NQS	Number of constituents (1-9)	J1	6	1	1		I	1-9		
JLAND	Number of land uses (1-5)	J1	6	2	1		I	1-5	0	
DRYDAY	Number of dry days prior to storm	J1	6	3	1		F	>0.0	0,0	days
CBVOL	Average catchbasin storage volume	J1	6	4	1		F		0,0	ft3 [m3]
DRYBSN	Dry days required to recharge to catchbasin	J1	6	5	1		F	>0.0	1,0	days
IROS	Erosion Simulation	J1	6	6	4		I		0	
IROSAD	Erosion added to constituent number	J1	6	7	1		I		0	
RAINIT	Higest average 30-minute rainfall intensity	J1	6	8	1		F		0,0	in/hr
										[mm/hr]
	Groundwater Quality		6	9	4					
	Street Sweeping Parameters				5					
REFFDD	Street sweeping efficiency for "dust and dirt"	J1	6	10	1		F		0,0	
KLNBGN	Day of year on which street sweeping begins	J1	6	11	1		I		0	
KLNEND	Day of year on which street sweeping ends	J1	6	12	1		I		367	

Variable	Description	SID	SCR	CS	CT	Item	Type	Range	Default	Units
	Constituent Table	J3	7							
PNAME(K)	CNAME	J3	7	1	1		C			
PUNIT(K)	CUNIT	J3	7	2	1		C			
NDIM(K)	TYPE UNIT	J3	7	3	2		C	0-2	0	
	mg/l		7			1		0		
	MPN/l		7			2		1		
	OTHER		7			3		2		
KALC(K)	BUILDUP	J3	7	4	2		C	0-4	0	
	Fraction		7			1		0		
	Power-linear		7			2		1		
	Exponential		7			3		2		
	Mich-Men		7			4		3		
	No buildup		7			5		4		
KWASH(K)	WHSHOFF	J3	7	5	2		C	0-2	0	
	Power-Exp		7			1		0		
	R. Curve/N		7			2		1		
	R. Curve/B		7			3		2		
KACGUT(K)	FUNCTION	J3	7	6	2		C	0-2	0	
	F(gutter len)		7			1		0		
	F(area)		7			2		1		
	Constant		7			3		2		
LINKUP(K)	LINK-SNOW	J3	7	7	2		C	0,1	0	
	No		7			1		0		
	Yes		7			2		1		
QFACT(1,K)*	LIMIT	J3	7	8	1		F		0,0	
QFACT(2,K)*	POWER	J3	7	9	1		F		0,0	
QFACT(3,K)*	COEFF	J3	7	10	1		F		0,0	
QFACT(4,K)*	FOURTH	J3	7	11	1		F		0,0	
QFACT(5,K)*	FIFTH	J3	7	12	1		F		0,0	
WASHPO(K)*	POWERW	J3	7	13	1		F		0,0	
RCOEF(K)*	COEFFW	J3	7	14	1		F		0,0	
CBFACT(K)*	INICON	J3	7	15	1		F		0,0	8(3)
CONCRN(K)*	CONPRE	J3	7	16	1		F		0,0	8(3)
REFF(K)*	EFFI	J3	7	17	1		F		0,0	

Variable	Description	SID	SCR	CS	CT	Item	Type	Range	Default	Units
	Land Use Table		8							
LNAME(J)	LNAME	J2	8	1	1		C			
METHOD(J)	METHOD	J2	8	2	3		C	-2,-1,0-2	0	
	New values		8			1		-2		
	New Ratio		8			2		-1		
	Power-linear		8			3		0		
	Exponential		8			4		1		
	Michaelis-Menton		8			5		2		
JACGUT(J)	FUNCTION	J2	8	3	3		C	0-2	0	
	F(gutter len)		8			1		0		
	F(area)		8			2		1		
	Constant		8			3		2		
DDLIM(J)*	LIMIT	J2	8	4	1		I		10	
DDPOW(J)*	POWER	J2	8	5	1		F		0,0	
DDFACT(J)*	COEFF	J2	8	6	1		F		0,0	
CLFREQ(J)*	DAYS1	J2	8	7	1		F		0,0	days
AVSWP(J)*	FRACTION	J2	8	8	1		F		0,0	
DSLCL(J)*	DAYS2	J2	8	9	1		F		0,0	days
	Fractional Constituent Table	J4	9							
KTO	CNAME1	J4	9	1	1		I		0	
KFROM	CNAME2	J4	9	2	1		I		0	
F1(KTO,KFROM)	FRACTION	J4	9	3	1		F		0,0	
	Groundwater Concentration	J5	10							
	GCONC(1-10)				1		F		0,0	8(3)
	*** Array									
	Channel /Pipe Table	G1	11							
NAMEG	NAME	G1	11	1	1		C			
NGTO	CHA/INLET #	G1	11	2	1		C			
NPG=NP	TYPE	G1	11	3	3		C	1-7		
	Trapezoidal		11			1		1		
	Circular		11			2		2		
	Dummy		11			3		3		
	Parabolic		11			4		4		

Variable	Description	SID	SCR	CS	CT	Item	Type	Range	Default	Units
	Trap w/ weir		11			5		5		
	Cir w/weir		11			6		6		
	Par w/weir		11			7		7		
GWIDTH*	WIDTH	G1	11	4	1		F		0,0	ft [m]
GLEN*	LENGTH	G1	11	5	1		F		0,0	ft [m]
G3*	INV SLOPE	G1	11	6	1		F			ft/ft
GS1	L SLOPE	G1	11	7	1		F			ft/ft
GS2	R SLOPE	G1	11	8	1		F			ft/ft
G6*	Manning's n	G1	11	9	1		F		0,014	
DFULL*	DEPTH	G1	11	10	1		F			ft [m]
GDEPT*	INI DEPTH	G1	11	11	1		F			ft [m]
WTYPE	WTYPE	G2	11	12	3			0,1,2	0	
	B N weir		11			1	C	0		
	V N weir		11			2	C	1		
	Orifice		11			3	C	2		
WELEV	WELEV	G2	11	13	1		F		0,0	ft [m]
WDIS	COEEF	G2	11	14	1		F		3,3	ft1/2/s
										[m1/2/s]
SPILL	SPILL	G2	11	15	1		F		1,0	
	Watershed Parameters (subcatchments)		12							
	Number of subcatchments (1-100)		12	1	1		I			
INFILM	Infiltration Equation	B1	12	2	3		C	0	0	
	Horton		12			1		0		
	Green-Ampt		12			2		1		
REGEN	Regeneration coeff. using Horton Eq.	B4	12	3	1		F		0,01	
PCTZER	Percent of impervious area with zero detentio	B4	12	4	1		F		25	%
	Subcatchment Surface Water Table		13							
JK	HYETO #	H1	13	1	1		I		1	
NAMEW	NAMEW	H1	13	2	1		C			
NGTO	CHA/INLET #	H1	13	3	1		C			
WW(1)*	WIDTH	H1	13	4	1		F		0,0	ft [m]
WAREA*	AREA	H1	13	5	1		F		0,0	area [ha]
WW(3)*	% IAREA	H1	13	6	1		F		0,0	%
WSLOPE*	SLOPE	H1	13	7	1		F		0,0	ft/ft

Variable	Description	SID	SCR	CS	CT	Item	Type	Range	Default	Units
WW(5)*	IMP 'n'	H1	13	8	1		F		0,0	
WW(6)*	PER 'n'	H1	13	9	1		F		0,0	
WSTORE1*	ISTORE	H1	13	10	1		F		0,0	in [mm]
WSTORE2*	PSTORE	H1	13	11	1		F		0,0	in [mm]
WLMAX*	COEFF1	H1	13	12	1		F		0,0	
WLMIN*	COEFF2	H1	13	13	1		F		0,0	
DECAY*	COEFF3	H1	13	14	1		F		0,0	
	Subcatchment Groundwtaer Table	H2	14							
NMSUB	NAMEW	H2	14	1	1		C		0,0	
NGWGW	CHA/INLET #	H2	14	2	1		C		0,0	
ISFPF	GPRINT	H2	14	3	3		I	0,1	0	
	Yes					1	I	0		
	No					2	I	1		
ISFGF	GGRAPH	H2	14	4	3		I	0,1	0	
	Yes					1	I	0		
	No					2	I	1		
BELEV	BELEV	H2	14	5	1		F		0,0	ft [m]
GRELEV	GELEV	H2	14	6	1		F		0,0	ft [m]
STG	IELEV	H2	14	7	1		F		0,0	ft [m]
BC	CB/TS ELV	H2	14	8	1		F		0,0	ft [m]
TW	TW	H2	14	9	1		F		0,0	
A1*	GCOEFF	H3	14	10	1		F		0,0	in/hr-ft
			14							[mm/hr-m]
B1*	GEXPON	H3	14	11	1		F		0,0	
A2*	CHCOEFF	H3	14	12	1		F		0,0	in/hr-ft
			14							[mm/hr-m]
B2*	CEXPON	H3	14	13	1		F		0,0	
A3*	GCCOEFF	H3	14	14	1		F		0,0	in/hr-ft
			14							[mm/hr-m]
PRO*	PROSITY	H3	14	15	1		F		0,0	
WP*	WP	H3	14	16	1		F		0,0	
FC*	FC	H3	14	17	1		F		0,0	
HKSAT*	HKSAT	H3	14	18	1		F		0,0	in/hr [cm/hr]
TH1*	TH1	H3	14	19	1		F		0,0	
HCO*	HCO	H3	14	20	1		F		0,0	

Variable	Description	SID	SCR	CS	CT	Item	Type	Range	Default	Units
PCO*	PCO	H4	14	21	1		F		0,0	frac [m/frac]
CET*	CET	H4	14	22	1		F		0,0	
DP*	DP	H4	14	23	1		F		0,0	in/hr [cm/hr]
DET*	DET	H4	14	24	1		F		0,0	ft [m]
	Subcatchment Snow Melt Data		15							
JK1	NAMEW	I1	15	1	1		C			
SNN1	FRACIMP	I1	15	2	1		F		0,0	
SNCP(N)	FRACPER	I1	15	3	1		F		0,0	
WSNOW(N,1)	DEPIIMP	I1	15	4	1		F		0,0	v.e. in [mm]
WSNOW(N,2)	DEPIPER	I1	15	5	1		F		0,0	v.e. in [mm]
FW(N,1)	FWIMP	I1	15	6	1		F		0,0	in [mm]
FW(N,2)	FWPER	I1	15	7	1		F		0,0	in [mm]
DHMAX(N,1)*	MELTIMP	I1	15	8	1		F		0,0	in w.e./hr -F
									0,0	m w.e./hr -C
DHMAX(N,2)*	MELTPER	I1	15	9	1		F		0,0	in w.e./hr -F
									0,0	m w.e./hr -C
TBASE(N,1)*	TBASEIMP	I1	15	10	1		F		32,0	F [C]
TBASE(N,2)*	TBASEPER	I1	15	11	1		F		32,0	F [C]
	Subcatchment Snow Input for Continuous Simulati		16							
JK2	NAMEW	I2	16	1	1		C			
WSNOW(N,3)	DEPIMP	I2	16	2	1		F		0,0	in [mm]
FW(N,3)	WATIMP	I2	16	3	1		F		0,0	in [mm]
DHMAX(N,3)*	MAXCOE	I2	16	4	1		F		0,0	in w.e/hr-F
										[mm w.e./hr-C]
TBASE(N,3)*	TEMIMP	I2	16	5	1		F		32,0	F [C]
DHMIN(N,1)*	MINSIMP	I2	16	6	1		F		0,0	in w.e/hr-F
										[mm w.e./hr-C]
DHMIN(N,2)*	MINSPER	I2	16	7	1		F		0,0	in w.e/hr-F
										[mm w.e./hr-C]
DHMIN(N,3)*	MINBEAR	I2	16	8	1		F		0,0	in w.e/hr-F
										[mm w.e./hr-C]
SI(N,1)*	DEPSIMP	I2	16	9	1		F		0,0	w.e. in [mm]
SI(N,2)*	DEPSPER	I2	16	10	1		F		0,0	w.e. in [mm]
WEPLOW(N)	REDISTR	I2	16	11	1		F		0,0	w.e. in [mm]

Variable	Description	SID	SCR	CS	CT	Item	Type	Range	Default	Units
SFRAC(N,1)	FRATIMP	I2	16	12	1		F	0.0-1.0	0,0	
SFRAC(N,2)	FRATPER	I2	16	13	1		F	0.0-1.0	0,0	
SFRAC(N,3)	FRATLAS	I2	16	14	1		F	0.0-1.0	0,0	
SFRAC(N,4)	FRATOUT	I2	16	15	1		F	0.0-1.0	0,0	
SFRAC(N,5)	FRACIMP	I2	16	16	1		F	0.0-1.0	0,0	
	Subcatchment Erosion Table		17							
NAMEW	NAMEW	K1	17	1	1		C			
ERODAR*	EAREA	K1	17	2	1		F		0,0	acres [ha]
ERLEN*	ELENG	K1	17	3	1		F		0,0	ft [m]
SOILF*	SOIL K	K1	17	4	1		F		0,0	
CROPMF*	CROP C	K1	17	5	1		F		0,0	
CONTPF*	CONT P	K1	17	6	1		F		0,0	
	Subcatchment Quality Table									
N=NAMEW	NAMEW	L1	18	1	1		C			
KL	LAND USE	L1	18	2	1		C			
BASIN(N)*	# CHACHBA	L1	18	3	1		F		0,0	
GQLEN(N) *	CURBL	L1	18	4	1		F		0,0	100 ft [km]
	*** number of constituents up to 10									
PSHED(1,N)	INI LOAD (1)	L1	18	5	1		F		0,0	
.	.	L1	18		1		F		0,0	
PSHED(10,N)	INI LOAD (10)	L1	18	14	1		F		0,0	
	Print Control									
IPRN(1)	RUNOFF Input	B2	19	1	5		C21	0-7	0	
	Print all input data	B2	19	2	6	1		0		
	Control information	B2	19	3	6	2		1		
	Possible combinations	B2	19	4	6	3				
	Channel/Pipe	B2	19	5	4	4		2		
	Snowmelt	B2	19	6	4	5		3		
	Subchachment	B2	19	7	4	6		4		
	Water Quality	B2	19	8	4	7		5		
	RUNOFF Output									
IPRN(3)	SWMM output control	B2	19	9	5		C	0-2	0	

Variable	Description	SID	SCR	CS	CT	Item	Type	Range	Default	Units
	Do not print totals		19	10	6	1		0		
	Monthly and annual totals only		19	11	6	2		1		
	Daily, monthly and annual totals		19	12	6	3		2		
IPRN(2)	Plot graphs	B2	19	13	4		I	0,1	0	
INTERV	Detailed print option	M1	19	14	5			0	0	
	statistical summary only		19	15	6	1	C	0		
	every time step		19	16	6	2		1		
	every K time steps		19	17	6	3		K		
	K=		19	18	1		I			
	*** provide starting and ending date Max=10									
	Detailed Printout Periods (mm/dd/yy)									
STAPTP(1-NDET)	STARTING DATE (mm/dd/yy)	M2	20	1	1		I		0	
STOPPR(1-NDET)	ENDING DATE (mm/dd/yy)	M2	20	2	1		I		0	
NDET	Number of detailed printout periods	M2					I			
	Channel/Inlet Number for Printing Inflows and Concentrations									
IPRNT(1-NPRNT)	Channel/Inlet number	M3	21	1	7		I		0	
	Channel/Inlet Number for Printing Outflows and Concentrations									
IPRNT(1-NPRNT)	Channel/Inlet number	M3	22	1	7		I		0	
	Channel for Printing Depths		23							
KDEEP(1-MDEEP)	Channel number	M4	23	2	7		I		0	
NPRNT	Number of channels/inlets ffor which non-zer	M1					I			
	to be printed									
MDEEP	Number of depth locations for printout	M4					I			

APPENDIX-B

RUNOFF BLOCK OUTPUT FILE

Environmental Protection Agency
Storm Water Management Model
Windows Version

Developed by

Metcalf & Eddy, Inc.

University of Florida

Water Resources Engineers, Inc.

(Now Camp, Dresser and McKee, Inc.)

September 1970

Entry made to the Runoff Block, last updated

by

Oregon State University, CDM, and XP Software,

April 1994.

File names by SWMM Block

JIN -> Input to a Block JOUT -> Output from a Block

NSCRAT #	1	File #	20	SMET001.MT1
NSCRAT #	2	File #	21	SCRT2.UF
NSCRAT #	3	File #	30	SMET001.MT2
NSCRAT #	4	File #	40	SCRT4.UF
NSCRAT #	5	File #	50	SCRT5.UF
NSCRAT #	6	File #	60	SCRT6.UF
NSCRAT #	7	File #	70	SCRT7.UF

Parameter Values on the Tapes Common Block

Number of Subcatchments in the Runoff Block (NW)	100
Number of Channel/Pipes in the Runoff Block (NG)	150
Number of Runoff Water Quality Constituents (NRQ)	10
Number of Runoff Land Uses per Subcatchment (NLU)	5
Number of Elements in the Transport Block (NET)	200
Number of Storage Junctions in Transport (NTSE)	100
Number of Input Hydrographs in Transport (NTH)	80
Number of Elements in the Extran Block (NEE)	200
Number of Groundwater Subcatchments in Runoff (NGW)	100
Number of Interface locations for all Blocks (NIE)	200
Number of Pumps in Extran (NEP)	20
Number of Orifices in Extran (NEO)	60
Number of Tide Gates/Free Outfalls in Extran (NTG)	25
Number of Extran Weirs (NEW)	60
Number of Extran Printout Locations (NPO)	30
Number of Tide Elements in Extran (NTE)	20
Number of Natural Channels (NNC)	50

Number of Storage Junctions in Extran (NVSE)	20
Number of Time History Data Points in Extran(NTVAL).	50
Number of Data Points for Variable Storage Elements in the Extran Block (NVST)	25
Number of Input Hydrographs in Extran (NEH)	100

Example 1 - User Defined Precipitation to RUNOFF

Snowmelt parameter - ISNOW	0
Number of rain gages - NRGAG	1
Green-Ampt infiltration equation used - INFILM	1
Quality is simulated - KWALTY	1
Default evaporation rate used - IVAP	0
Hour of day at start of storm - NHR	0
Minute of hour at start of storm - NMN	0
Time TZERO at start of storm (hours)	0.000
Use Metric units for I/O - METRIC	1

Note: Ft-sec units used in all internal computations

Runoff input print control	0
Runoff graph plot control	1
Runoff output print control	0
Limit number of groundwater convergence messages to	10000 (if simulated)
Month, day, year of start of storm is	1/ 1/88
Wet time step length (seconds)	300.
Dry time step length (seconds)	86400.
Wet/Dry time step length (seconds)	300.
Simulation length is	3.0 Days
Percent of impervious area with zero detention depth	25.0

Data Group F1 - Evaporation Rate (mm/day)

JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00

****No Channel or Pipe Network**

SUBCATCHMENT DATA*

SUB CATh	GUTR OR INLET	NO	WIDTH (m)	AREA (ha)	IMP (%)	SLOPE	RES. IMPR n_1	FAC PER n_2	DEPR IMPR (mm) $hp_{,1}$	STOR PER (mm) $hp_{,2}$	GREEN INFIL SUCTN φ	AMPT PARM HYD CON K_2	fMD
1	1	1	100	300	20	0.001	0.040	0.300	0..050	0.100	4.0	1.0	.34

TOTAL NUMBER OF SUBCATCHMENTS	1
TOTAL TRIBUTARY AREA (HECTARES)	300.00
IMPERVIOUS AREA (HECTARES)	60.00
PERVIOUS AREA (HECTARES)	240.00
TOTAL WIDTH (METERS)	100.00
PERCENT IMPERVIOUSNESS	20.00

Arrangement of Subcatchments and Channel/Pipes

INLET

1 No Tributary Channel/Pipes

Tributary Subareas........ 1

Quality Simulation

General Quality Control Data Groups

Description	**Variable**	**Value**
Number of quality constituents	NQS	1
Number of land uses	JLAND	2
Standard catchbasin volume	CBVOL	20.00 cubic meters
Erosion is not simulated	IROS	0
DRY DAYS PRIOR TO START OF STORM	DRYDAY	5.00 DAYS
DRY DAYS REQUIRED TO RECHARGE CATCHBASIN CONCENTRATION TO INITIAL VALUES	DRYBSN	1.00 DAYS
DUST AND DIRT STREET		

SWEEPING EFFICIENCY	REFFDD	0.500
DAY OF YEAR ON WHICH STREET SWEEPING BEGINS	KLNBGN	0
DAY OF YEAR ON WHICH STREET SWEEPING ENDS	KLNEND	367

Land Use Data on Data Group J2

LAND USE (LNAME)	BUILDUP EQ. TYPE (METHOD)	BUILDUP PARAMETER (JACGUT)	BUILDUP QUANTITY (DDLIM)	BUILDUP POWER (DDPOW)	BUILDUP COEFF. (DDFACT)	INTERVAL IN DAYS (CLFREG)	FACTOR FRACTION (AVSWP)	LAST SWEEPI (DSLCL)
SINGLE	POWER LINEAR	CHAN. LENGTH	1.00E+04	1.00	1.00	30.00	.800	15.00
MULTI	POWER LINEAR	CHAN. LENGTH	1.00E+04	1.00	1.00	30.00	.800	15.00

Constituent data on data group J3

	TOT.SOL
Constituent units	MG/L
Type of units	0
KALC	O
Type of buildup calcul	FRACT. BLDUP(0)
KWASH	0
Type of washoff calcul	POWER EXPONEN.(0)
KACGUT	0
Dependence of buildup	CHAN. LENGTH(0)
LINKUP	0
Linkage to snowmelt	NO SNOW LINKAGE
Buildup param 1 (QFACT1)	100.000
Buildup param 2 (QFACT2)	100.000
Buildup param 3 (QFACT3)	0.000
Buildup param 4 (QFACT4)	0.000
Buildup param 5 (QFACT5)	0.000
Washoff power (WASHPO)	2.000

DATA GROUP M3

CHANNEL/INLET PRINT DATA GROUPS 1

End of time step DO-loop in Runoff

Final Date (Mo/Day/Year)	1/ 4/88
Total number of time steps	853
Final Julian Date	88004
Final time of day	0 seconds
Final time of day	0.00 hours.
Final running time	72.0000 hours.
Final running time	3.0000 days.

Continuity Check for Surface Water

	cubic meters	Millimeters over Total Basin
Total Precipitation (Rain plus Snow)	8.399817E+04	28.000
Total Infiltration	6.064549E+04	20.216
Total Evaporation	1.172494E+04	3.908
Surface Runoff from Watersheds	8.310305E+03	2.770
Total Water remaining in Surface Storage	3.320889E+03	1.107
Infiltration over the Pervious Area	064549E+04	25.270
Water remaining in Snow Cover	8.400162E+04	00.000
Total Precipitation + Initial Storage	8.399816E+04	28.000

Continuity Check for Channel/Pipes

	cubic meters	Millimeters over Total Basin
Initial Channel/Pipe Storage	0.000000E-01	0.000
Final Channel/Pipe Storage	0.000000E-01	0.000
Surface Runoff from Watersheds	8.310305E+03	2.770
Groundwater Subsurface Inflow	0.000000E-01	0.000
Evaporation Loss from Channels	0.000000E-01	0.000
Channel/Pipe/Inlet Outflow	8.310305E+03	2.770
Initial Storage + Inflow	8.310306E+03	2.770
Final Storage + Outflow	8.310306E+03	2.770

SUMMARY STATISTICS FOR SUBCATCHMENTS

SUB CAT NO	GUT. OR INLET NO	AREA (ha)	PER. IMPER	TOTAL SIMUL RAIN FALL (mm)	PERVIOUS AREA TOTAL RUNOFF DEPTH (mm)	TOTAL LOSS	PEAK RUN DEPT (mm)	IMPR AREA RUN. DEPT (mm)	PEAK RUN RATE (CMS)	TOTAL RUN DEPT (mm)	SUBC. PEAK RUN RATE (CMS)	AREA PEAK UNIT RUN mm/hr
1	1	300.0	20.0	28.0	0.064	27.93	0.01	13.59	0.11	2.77	0.12	0.148

RUNOFF QUALITY SUMMARY

	TOT.SOL
Inputs	**(mg/l)**
1. INITIAL SURFACE LOAD	2.50E+02
2. TOTAL SURFACE BUILDUP	2.52E+02
3. INITIAL CATCHBASIN LOAD	4.00E+01
4. TOTAL CATCHBASIN LOAD	0.00E-01
5. TOTAL CATCHBASIN AND SURFACE BUILDUP (2+4)	2.52E+02
Remaining Loads	
6. LOAD REMAINING ON SURFACE	2.10E+02
7. REMAINING IN CATCHBASINS	0.00E-01
8. REMAINING IN CHANNEL/PIPES	0.00E-01
Removals	
9. STREET SWEEPING REMOVAL	0.00E-01
10. NET SURFACE BUILDUP (2-9)	2.52E+02
11. SURFACE WASHOFF	4.18E+01
12. CATCHBASIN WASHOFF	0.00E-01
13. TOTAL WASHOFF (11+12)	4.18E+01
14. INSOLUBLE WASHOFF	0.00E-01
15. PRECIPITATION	0.00E-01
16. TOTAL GROUNDWATER LOAD	0.00E-01
16a. TOTAL I/I LOAD	0.00E-01
17. TTL SUBC LD(13+14+15+16+16a)	4.18E+01
18. TOTAL LOAD TO INLETS	4.18E+01
19. FLOW WTD AVE.CONCENTRATION (INLET LOAD/TOTAL FLOW)	5.03E+00

Percentages

20. STREET SWEEPING (9/2)	0.000
21. SURFACE WASHOFF (11/2)	16.580
22. NET SURFACE WASHOFF(11/10)	16.580
23. WASHOFF/SUBCAT LOAD(11/17)	100.000
24. SURFACE WASHOFF/INLET LOAD(11/18)	100.000
25. CATCHBASIN WASHOFF/ SUBCATCHMENT LOAD (12/17)	0.000
26. CATCHBASIN WASHOFF/ INLET LOAD (12/18)	0.000
27. INSOLUBLE FRACTION/ SUBCATCHMENT LOAD (14/17)	0.000
28. INSOLUBLE FRACTION/ INLET LOAD (14/18)	0.000
29. PRECIPITATION/ SUBCATCHMENT LOAD (15/17)	0.000
30. PRECIPITATION/INLET LOAD (15/18)	0.000
31. GROUNDWATER LOAD/ SUBCATCHMENT LOAD (16/17)	0.000
32. GROUNDWATER LOAD/ INLET LOAD (16/18)	0.000
32a.INFILTRATION/INFLOW LOAD/ SUBCATCHMENT LOAD (16a/17)	0.000
32b.INFILTRATION/INFLOW LOAD/ INLET LOAD (16a/18)	0.000
33. INLET LOAD SUMMATION ERROR (18+8-17)/17	0.000

User Defined Precipitation to RUNOFF

Date Mo/Da/Yr	Time Hr:Min		Flow cum/s	TOT.SOL (mg/l)
1/ 1/88	9	15	0.019	1.902E+00
1/ 1/88	17	35	0.023	2.339E+00
1/ 2/88	1	55	0.014	1.418E+00
1/ 2/88	10	15	0.008	8.173E-01
1/ 2/88	18	35	0.079	7.155E+00
1/ 3/88	2	55	0.047	4.015E+00
1/ 3/88	11	15	0.029	2.442E+00
1/ 3/88	19	35	0.018	1.494E+00

Flow wt'd means	0.0321	5.031E+00
Flow wt'd std devs	0.0269	3.123E+00
Maximum value	0.122	1.202E+01
Minimum value	0.000	0.000E-01
Total loads	8.31	0E+03 4.181E+01
	Cub-Met	KILOGRAM

Runoff simulation ended normally.

Your input file was named : RNOFF001.run

Your output file was named: RNOFF001.out