REVIEW OF URBAN HYDROLOGIC MODELLING SOFTWARE

SKRIPSI

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PROGRAM STUDI TEKNIK SIPIL KELAS INTERNASIONAL
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ABSTRACT

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Hydrology plays important role in urban development thus hydrologic event that occurs has to be accurately estimated in order to satisfy the needs of the area in infrastructure. The advance technology has helped the engineers to model the event which should lead into better decision-making and visualisation in undertaking most hydrological cases. This thesis reviews four urban hydrological modelling softwares and discusses the essential components of the modelling that includes catchment model, loss model, storage discharge relations, and its input parameters. The aim of the review is to provide basic understanding of the hydrology processes by using modelling software in accordance to the basic theory and standard design. The review does not seek to be a comprehensive technical of urban hydrology management and modelling.

Keywords: hydrological modelling software; urban hydrology; WBNM; DRAINS; RORB; RAFTS

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Sanggam Hendrick Lumbangaol

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1.0 Introduction

1.1 Background

Hydrology involves the study of the movement and distribution of water throughout a catchment addressing both the hydrologic cycle and water resources within a catchment. Hydrology plays important role in urban development thus hydrologic event that occurs has to be accurately estimated in order to satisfy the needs of the area in infrastructure. The advance technology has helped the engineers to model the event which should lead into better decision-making and visualisation in undertaking most hydrological cases. This thesis reviews four urban hydrological modelling softwares and discusses the essential components of the modelling that includes catchment model, loss model, storage discharge relations, and its input parameters. The aim of the review is to provide basic understanding of the hydrology processes by using modelling software in accordance to the basic theory and standard design. The review does not seek to be a comprehensive technical of urban hydrology management and modelling.

1.2 Objectives

The objective of the thesis is literature view on current hydrologic modelling software and its approach analysis and input parameters.

The modelling software has different type of analysis based on the current hydrologic modelling theory, as described in more details in chapter 3. To satisfy the needs of analysing storage discharge, the parameters need to be input into the modelling software according to information available over the catchment. The software has different type of analysis for representing the catchment characteristics which will be discussed further in chapter 4.

1.3 Scope of Thesis

The thesis focused on four hydrologic modelling softwares that mainly have been used in Australia, such as WBNM, DRAINS, RORB, and RAFTS.

1.4 Form of Presentation

<u>Section 2:</u> overview of hydrology in general and brief understanding on urban hydrology with effect of urbanisation to hydrology processes.

<u>Section 3:</u> briefly provide list of hydrologic modelling and the relevance formula that is currently used as in the software.

<u>Section 4:</u> an overview of each hydrologic model from its origins and development to current usage, as well as the governing equations and parameters, is provided including catchment models, loss models and storage/discharge relationship, and input parameters to the modelling software.

Section 5: conclusion of the software usage according to their different input parameters.

2.0 Hydrology

Hydrology involves the study of the movement and distribution of water throughout a catchment addressing both the hydrologic cycle (Figure 2.1) and water resources within a catchment.

The water falls to the earth through precipitation phenomena needs to be managed its movement and distribution in order to avoid flood and to keep the water balance in ecosystem. It was started by Sumarians, Egyptians and Chinese where early civilization developed that people has to maintain water quantity to sustain life and grow food crops. However, it was not until the 17th century that the work of the Frenchman, Perrault, provided convincing evidence of the form of the hydrological cycle which is currently accepted; measurements of rainfall and stream flow in the catchment of the upper Seine proved that quantities of rainfall were sufficient to sustain river flow (Shaw, 1983).

2.1 Hydrologic Cycle

The hydrologic cycle is the central focus of hydrology. The cycle has no beginning or end, and its many processes occur continuously (Chow, 1988).

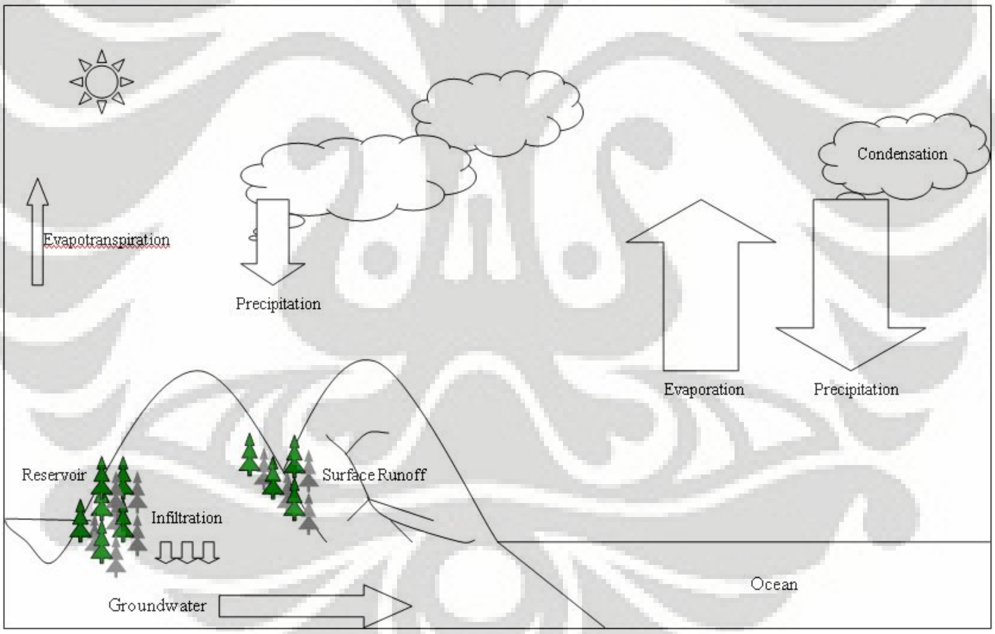


Figure 2.1 Water Cycle

The circulation of water is shown in figure 2.1. Heating the sea surface and water reservoir causes evaporation, the transform of water to gaseous state, to form part of the atmosphere. Water vapour is transported and lifted in the atmosphere until it condenses and precipitates on the land or the ocean. Precipitate water may be intercept by vegetation, discharge into streams as surface runoff, become overland flow over the ground surface, infiltrate into the ground, and flow through soil as subsurface flow.

The portion of rain water that infiltrate into the ground either percolate deep into the ground water table or remain within top soil layers as soil moisture. Percolated water that reached the ground water table flows towards the channels or the receiving bodies. This flow is generally referred as base flow or ground water flow. The portion of water remains within top soil eventually evaporates or evapotranspirate during dry weather. The surface runoff and groundwater flow join together flowing out to the sea or evaporating into the atmosphere as the hydrologic cycle continues.

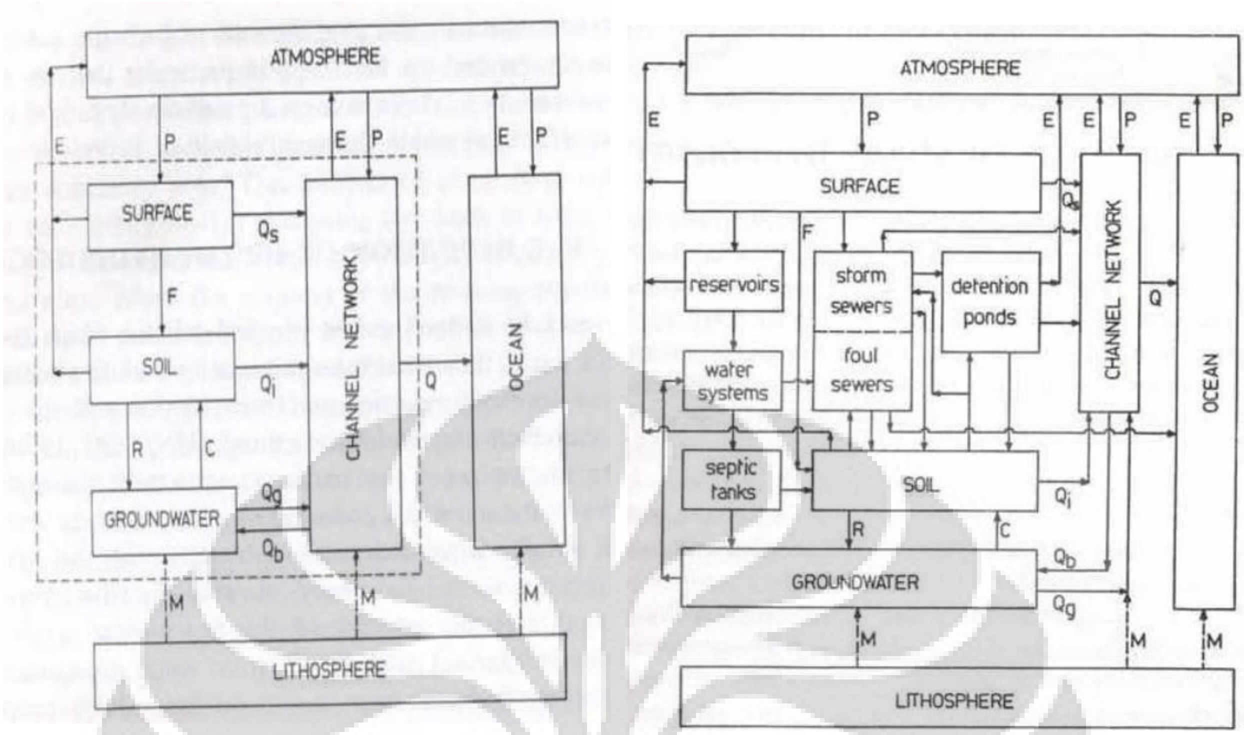
2.2 Urban Hydrology

Urbanisation is the process of removal the rural characteristic in a town or area associated with technology and population growth. In urban area, the surface is mainly impervious such as asphalt and concrete path which makes the precipitated water harder to infiltrate the soil but flowing on top of the surface. Some studies have been developed and show there are several considerations that makes the hydrology of urban area is actually far from simple: the urban environment is highly heterogeneous in terms of land use, sub-soil characteristics and other factors, which influence all the processes comprising the water cycle: rainfall, surface runoff, infiltration and movement of water in urban subsoils, interactions between surface water and groundwater, interactions between the drainage network and groundwater and evapotranspiration in urban areas (Andrieu et al., 2004).

However, the further study on urban hydrology shows the hydrological behaviour of urban areas can no longer be restricted to the runoff of rainwater on impervious surfaces, which constitutes the dominant flow component for design purposes (Rodriguez et al., 2007). This will make hydrologic design in urban area more thorough and detail in consideration.

2.2.1 Urban Hydrological Cycle

The urban hydrological cycle is basically the same with the general hydrologic cycle. However, there is a change in natural drainage systems which supplemented by sewerage. As shown in figure 2.2, the main hydrologic cycle is still remain and some processes happen before the water infiltrates to the soil in urban hydrologic cycle.



(a) (b)

Figure 2.2 (a) The hydrological cycle in systems notation; (b) The urban Hydrological cycle

(Source: Urban Hydrology, M.J.Hall, 1984)

2.2.2 Scope of Urban Hydrology

The particular aspects of urbanisation which exert the most obvious influence on hydrological processes are the increase in population density and the increase in building density within the urban area. As the population increases, water demand begins to rise. The consequences of the urbanisation in one area are shown in figure 2.3.

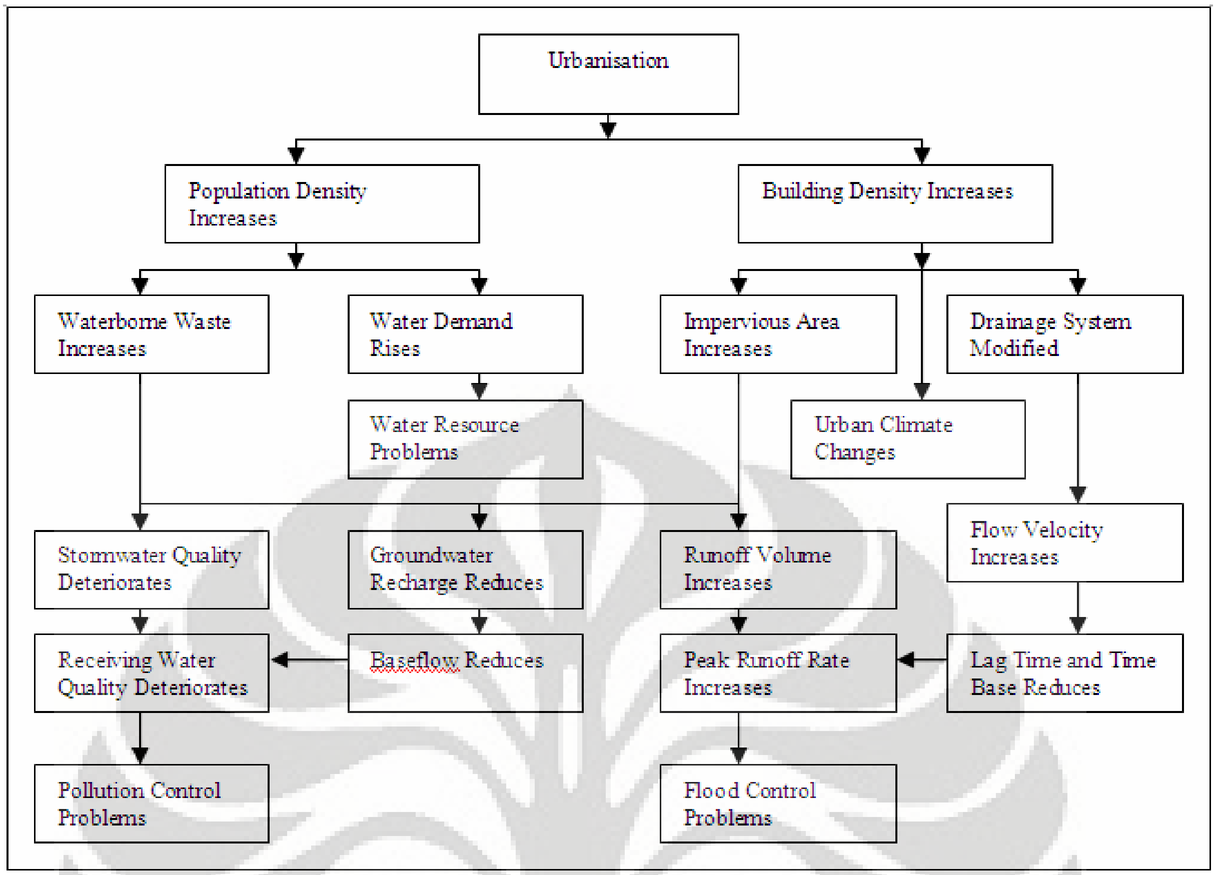


Figure 2.3 The effects of Urbanisation on Hydrological Processes

(Source: M.J Hall Urban Hydrology 1984)

The extent of impervious area increases as the latter rises, the natural drainage system is modified and the local microclimate changes. Owing to the larger impervious area, a greater proportion of the incident rainfall appears as runoff than was experienced when the catchment was in its rural state.

The increase in flow velocities directly affects the timing of the runoff hydrograph. Since a larger volume of runoff is discharged within a shorter time interval, peak rates of flow inevitably increases, giving rise to the hydrological problem which is flood control.

3.0 Hydrologic Modelling

Hydrologic design used in two different types of design such as water control and water use. Hydrologic design for water control is concerned with high flows or flood effects. The parameters of flood will be used in hydrologic design of different types of flow control structures (detention basins, reservoirs, drainage channel, etc). Hydrologic design for water use is concerned with the developments of water resources to meet human needs and with the conservation of the natural life in water environments. As the population and economic growing from time to time, so do the water demands. However the balanced of the supply provided by the nature and the use for human needs and ecosystem has to be satisfied. Hydrologic information plays a vital role in managing the balance between supply and demand for water resources and in planning water resource development projects.

Designing a system of stormwater drainage in an area will require rainfall data and runoff or discharge. In Australia, rainfall data can be retrieved from Australian Rainfall and Runoff (ARR 1998) or using software AusIFD (Australia Intensity Frequency Duration). Estimating runoff or discharge from rainfall measurements is very much dependent on the timescale being considered. The time interval used in the measurement of the two variables affects the derivation of the discharge of any relationship, although with continuously recorded rainfall and stream discharge this constraint is removed and only the purpose of the study influences choice of time interval. Size and type of natural surface of the area being considered also effects the relationship between rainfall and runoff. In the intermediate scale of both area and time, other physical and hydrological factors, such as evaporation, infiltration and groundwater flow are very significant as well.

3.1 Rational Method

3.1.1 General

The Rational Method is presented herein as a probabilistic or statistical method for use in estimating design floods. It is used to estimate a peak flow of selected ARI from an average rainfall intensity of the same. The runoff coefficient represents the ratio of a peak flow and a rainfall rate of selected duration determined for the same ARI from frequency analyses of flood peaks and rainfalls.

The idea behind the rational method is that if a rainfall of intensity I begins instantaneously and continues indefinitely, the rate of runoff will increase until the time of concentration t_c, when all of the watershed is contributing to flow at the outlet. The product of rainfall intensity *i* and watershed area *A* is the inflow rate for the system, *iA*, and the ratio of this rate to the rate of peak discharge (which occurs at time tc) is termed the runoff coefficient *C* ($0 < C < 1$). (Ven Te Chow et al., 1988)

3.1.2 Rational Method Formula

The formula of rational method is

$$Q_y = 0.278 C_y I_{tc,y} A$$

Where Q_y = peak flow rate (m^3/s) of average recurrence interval (ARI) of Y years

C_y = runoff coefficient (dimensionless) for ARI of Y years. As shown in table 3.1

$I_{tc,y}$ = average rainfall intensity (mm/h) for design duration of tc hours and ARI of y years

A = area of catchment (km^2)

3.1.3 Time of Concentration

The critical rainfall duration is t_c, which is considered to be the travel time from the most remote point on the catchment to the outlet, or the time taken from the start of rainfall until all of the catchment is simultaneously contributing flow to the outlet. Formulae are specified for estimating t_c. The specified formula must be used with the particular procedure. In other cases where a complete procedure based on observed data is not available, the Bransby Williams formula has been adopted as an arbitrary but reasonable approach. The formula is:

$$t_c = \frac{58L}{A^{0.1} S_e^{0.2}}$$

Where tc =time of concentration (mins)

L = length of the mainstream from the highest to the outlet of catchment (m)

A = area of catchment (km^2)

S_e = equal area slope of the main stream projected to the catchment divide (m/km). This is the slope of a line drawn on a profile of a stream such that the line passes through the outlet and has the same area under it as the stream profile.

Other time of concentration formula is shown in Appendix A.

3.1.4 Runoff Coefficient

The runoff coefficient, C, is the least precise variable of the rational method. The value in table below is as percentage of total rainfall that becomes runoff while the rest will infiltrate to the soil.

Categorized by use		Categorized by Surface	
farmland	0.05-0.3	forested	0.059-0.2
pasture	0.05-0.3	asphalt	0.7-0.95
unimproved	0.1-0.3	brick	0.7-0.85
parks	0.1-0.25	concrete	0.8-0.95
cemeteries	0.1-0.25	shingle roof	0.75-0.95
railroad yard	0.2-0.4	lawns, well drained (sandy soil)	
playgrounds (except asphalt or concrete)	0.2-0.35	□ up to 2 % slope	0.05-0.1
business districts		□ 2 % to 7 % slope	0.10-0.15
□ neighborhood	0.5-0.7	□ over 7 % slope	0.15-0.20
□ city (downtown)	0.7-0.95	lawns, poor drainage (clay soil)	
residential		□ up to 2 % slope	0.13-0.17
□ single family	0.3-0.5	□ 2 % to 7 % slope	0.18-0.20
□ multi-plexes, detached	0.4-0.6	□ over 7 % slope	0.25-0.35
□ multi-plexes, attached	0.6-0.75	driveways, walkways	0.75-0.85
□ suburban	0.25-0.4		
□ apartments, condominiums	0.5-0.7		
industrial			
□ light	0.5-0.8		
□ heavy	0.6-0.9		

Table 3.1 Runoff Coefficient C

(source: www.geocities.com/Eureka/Concourse/3075/coef.html)

3.2 Time-Area Method

The basic principle of time-area method is that a catchment can be divided into zones of equal travel time, i.e. the time taken by a water particle to travel from its point of impact to a specified outfall.

The average flow recorded at the outfall during the first time increment of a storm will be:

$$Q_1 = a_1 \times I_1$$

Where a_1 is the area of the first time zone and I_1 is the rainfall intensity over the first time increment. Over the next interval the average flow will be:

$$Q_2 = a_1 \times R_2 + a_2 \times R_1$$

Where a_2 is the area of the second time zone and I_2 is the rainfall during the second period.

In general terms, the flow at a time t for time area method can be expressed as:

$$Q_{(t)} = \sum_{n=0}^{n_{\max}-1} (A_{n+1} - A_n) \times I_{(t-n)}$$

Where A is the cumulative time area up to a time t.

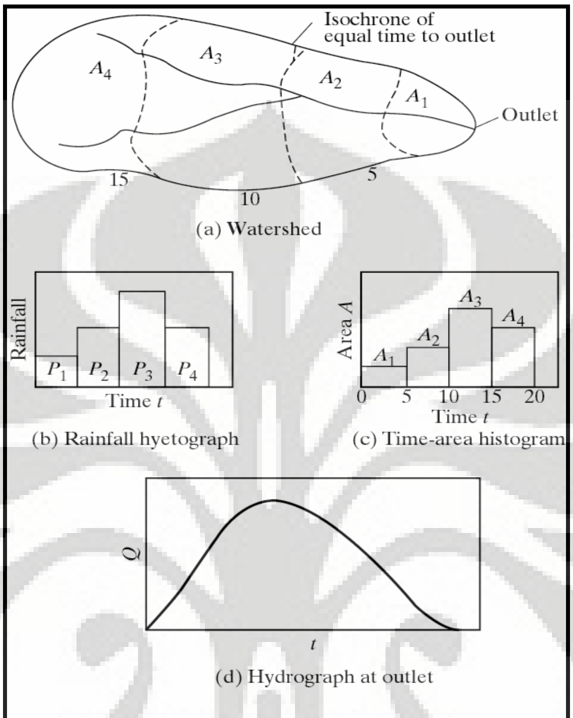


Figure 2.6
Time-area method.

Figure 3.1 Time-area method
(source: doctorflood.rice.edu/ceve101/Handouts/ch02.ppt)

Meanwhile, the time-area method in software DRAINS is considering the runoff coefficient C and time of concentration in overland flow for determining the rainfall intensity. The time-area method for drains is shown in section 4.2.4.

3.3 Reservoir Routing Model

The rainfall that remains at the surface, called the ‘rainfall excess’ (i.e. the total rainfall less the losses), is converted to runoff and must move through the catchment. The transport of the runoff is affected firstly by its distance from the outlet, and secondly by storage effects which may arise from factors such as different types of land usage i.e. urban or rural, depressions etc. If the surface the rain falls on is impervious (e.g. urban) the rain will be converted to runoff much quicker and will travel over the impervious surface much faster. If the surface the rain falls on is pervious (i.e. rural) the rain will take longer to be converted to runoff due to the large amounts of losses and will travel slower over the pervious surface due to higher friction and volume losses.

In models involving storage routing the distributed nature of these processes is simplified by using a series of concentrated storages with a storage-discharge relationship of the form:

$$S=f(Q,k,m)$$

where '*S*' is storage and '*Q*' is flow. '*k*' and '*m*' are catchment constants.

The catchment constants *k* and *m* are important calibration values in model development. The parameter *m* refers to the degree of non-linearity of a catchment's response to rainfall excess. It is usually expressed as an exponent and thus a value of unity implies a linear catchment response. The parameter *k* describes the speed of the catchment response to rainfall excess. It is often referred to as a lag parameter as it accounts for the delay between rainfall falling on the catchment and the generation of a flood in a channel or floodplain, thus, a decrease in *k* will result in an increase in flow rates.

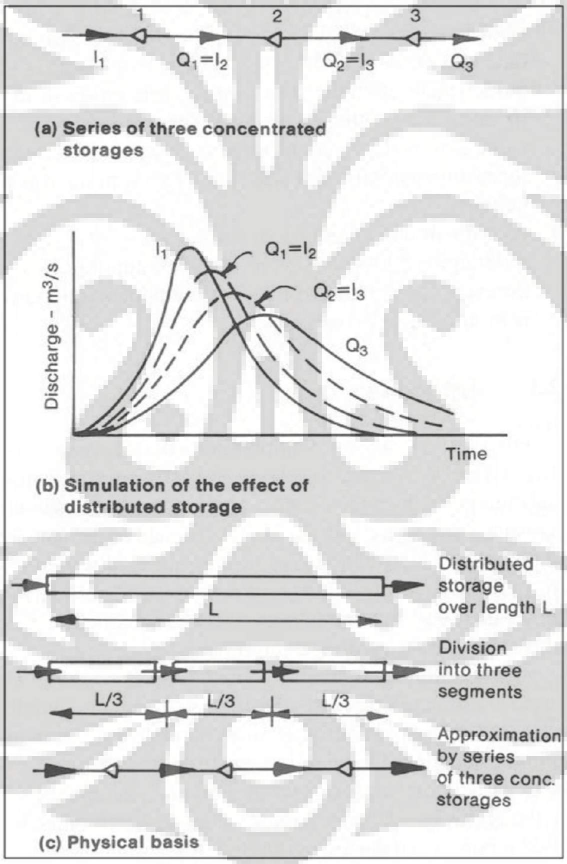


Figure 3.2 Series of Concentrated Storage

(Source : Figure 3.2 Book5-Estimation of design flood hydrographs, ARR 1998)

Figure 3.2 shows how a series of concentrated storages is utilised to represent the more complex distributed nature of catchment storage. Part (a) is a schematic of three distributed storages, part (b) shows how these concentrated storages simulate the distributed nature of storage and part (c) illustrates the physical basis for the approach.

3.4 Loss Model

When rainfall occurs on the catchment it will not all be converted to surface runoff. Various hydrological processes may include:

- transpiration
- evaporation
- interception
- infiltration.

These will divert rainfall to paths other than direct overland flow. These processes constitute what are considered 'losses' and there are various types of loss models (see Figure 3.3) which seek to quantify these processes in a simplified manner, including:

- initial loss–continuing loss model
- initial loss–proportional loss model
- infiltration models using procedures such as Horton's equation.

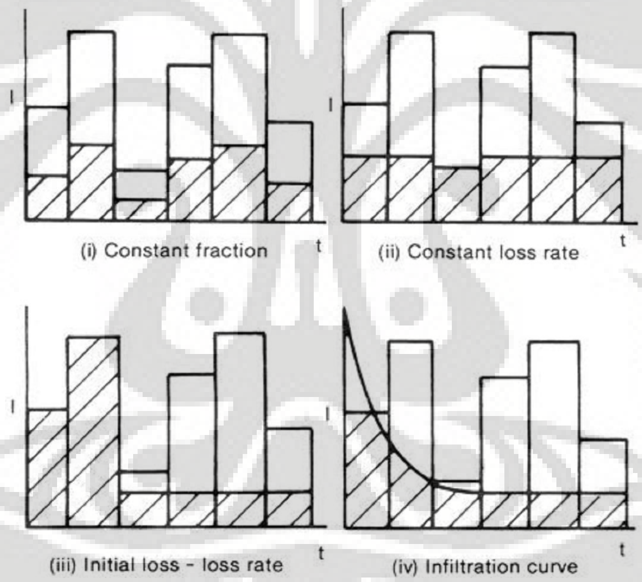


Figure 3.3 Loss Models to estimate rainfall excess

(Source: Adapted from Figure 3.1 Book 2-Design Rainfall Conditions, ARR 1998)

The initial loss represents the threshold value of rainfall that must occur before any rainfall excess is produced. The initial loss for a particular storm directly affects the temporal distribution of rainfall excess and hence the hydrograph peak.

After this initial loss, it will continue to be losses throughout the duration of a storm. One way of modelling these losses is as a *'continuing loss'*. This method simply assigns a continuing loss rate (i.e. mm/hr) throughout the rest of the storm. The continuing loss rate may be constant with time or decreasing with time. This assumption does have some physical meaning in that as the rainfall proceeds the ground typically becomes wetter, the infiltration capacity decreases and so the continuing loss decreases.

Another way of modelling the losses after the initial loss is the *'proportional loss'*. This method specifies that the ongoing losses vary in proportion to the intensity of rainfall. There are also more complex methods such as Horton's *Infiltration Model*. The Horton method is described in section 4.2.3.

The catchment storage model is based on the availability of water in catchment storages and will continue to operate as long as there is water in catchment storages. The rainfall excess model is based on the excess volumes of water from rainfall, thus this model will only operate whilst there is rainfall and will stop at the end of a storm. The significant distinction between these loss models is that the parameters required as inputs to these models will be fundamentally different due to the different time periods over which they operate.

4.0 Hydrologic Modelling Software

4.1 WBNM

4.1.1 Overview

WBNM is a shorter name of **W**atershed **B**ounded **N**etwork **M**odel. It was originally developed by Boyd, Pilgrim and Cordery in 1979 and has undergone several times of revision since then.

WBNM was originated to be a physically realistic representation of the catchments as it transforms storm rainfall into a flood hydrograph and originally developed for natural catchments. The stormwater catchment is divided into subareas by first identifying the main stream, the the major tributaries. The boundaries of the subarea draining to each tributary are then drawn, following the surface contours in where the area being identified (as shown in figure below).

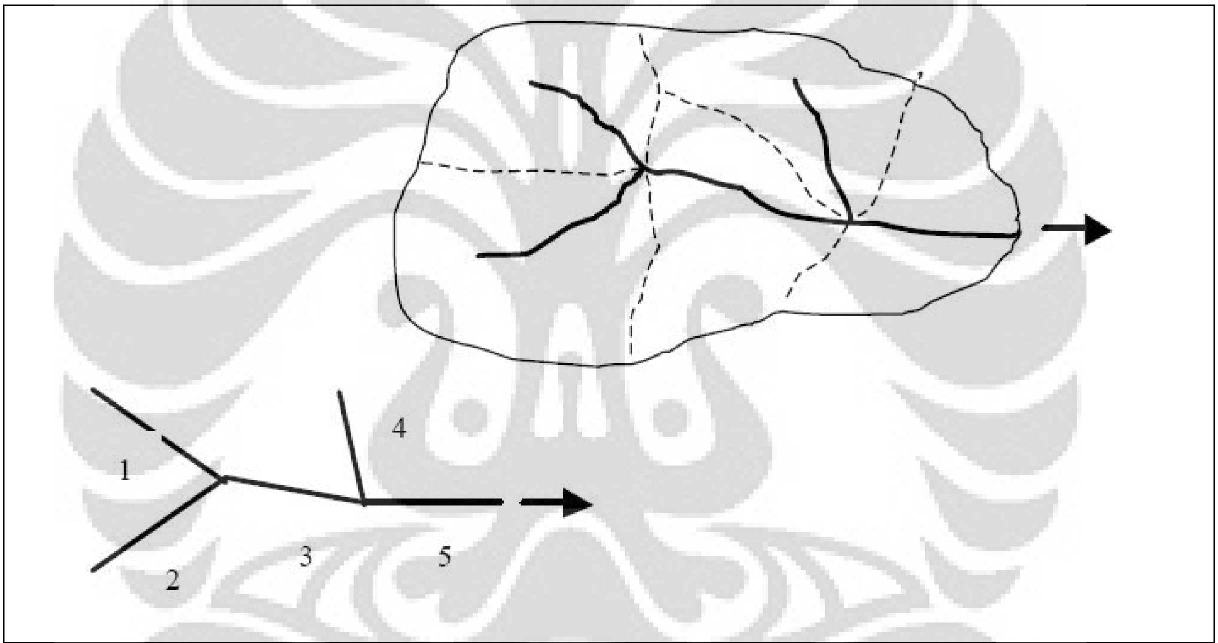


Figure 4.1 Typical Catchment in WBNM
(source : Figure 1. Dividing Cathcment into Subareas. WBNM Theory.2007)

Each subarea can contain the following components:

- A stream channel from top to bottom
- Pervious and impervious surfaces
- Onsite detention storage for local runoff from the subarea (Local Structures)
- Storage reservoir/flood detention basin on the main stream channel (Outlet Structure)
- Subarea outflows directed to top of nominated downstream subareas (as nominated in the topology block)

Outlet structure outflows directed to top or bottom of nominated downstream subareas (as nominated in the Outlet Structures block)

4.1.2 Catchment Model

A catchment is divided into smaller subareas which based on stream network. Each subarea is bounded by its ridge line (or watershed) and forms a catchment within the larger catchment. It is represented by a unit in the model which has the lag properties of the corresponding subarea, and which takes as input the rain falling on the subarea. WBNM calculates hydrographs at the outlets of all subareas, thus producing hydrographs at many points within the catchment. This allows detailed and complex flood studies to be carried out.

4.1.3 Loss Model

Pervious surface runoff losses are first substracted from the subarea's rainfall hyetograph. WBNM allows four types of Loss Models, as summarised below:

- Initial Loss – Continuing Loss Rate
- Initial Loss – Runoff Proportion
- Horton Infiltation
- Time varying rainfall losses

4.1.4 Storage Discharge Relation

The distributed nature of catchment storage in WBNM is related to the areas of the subcatchments. For each subarea, Conservation of Mass is used

$$I - Q = dS/dt$$

WBNM routes rainfall per modular subcatchment thus the following relationship for routing excesses on each subcatchment area:

$$S = K_B Q$$

Where: Q = discharge, m^3/s

$K_B = cA^{0.57}Q^{-0.23}$ = Overland Flow Lag Time, hours

A = subcatchment area, km^2

c = lag parameter

For routing through the stream network, the transmission storage parameter K_I is:

$$K_I = 0.6cA^{0.57}Q^{-0.23} = 0.6K_B$$

Where: K_I = Stream Channel Lag Time

4.1.5 Input Parameters

The input parameters that include in WBNM are subarea topology, subarea parameters (area, percent impervious), lag parameter, rainfall intensity data and loss parameters.

The lag parameter is specified for the natural surface and then adjusted for each different type of surface and is also different with lag parameters in stream. Thus the lag parameter is used in the conversion of the rainfall into runoff in the pervious surfaces.

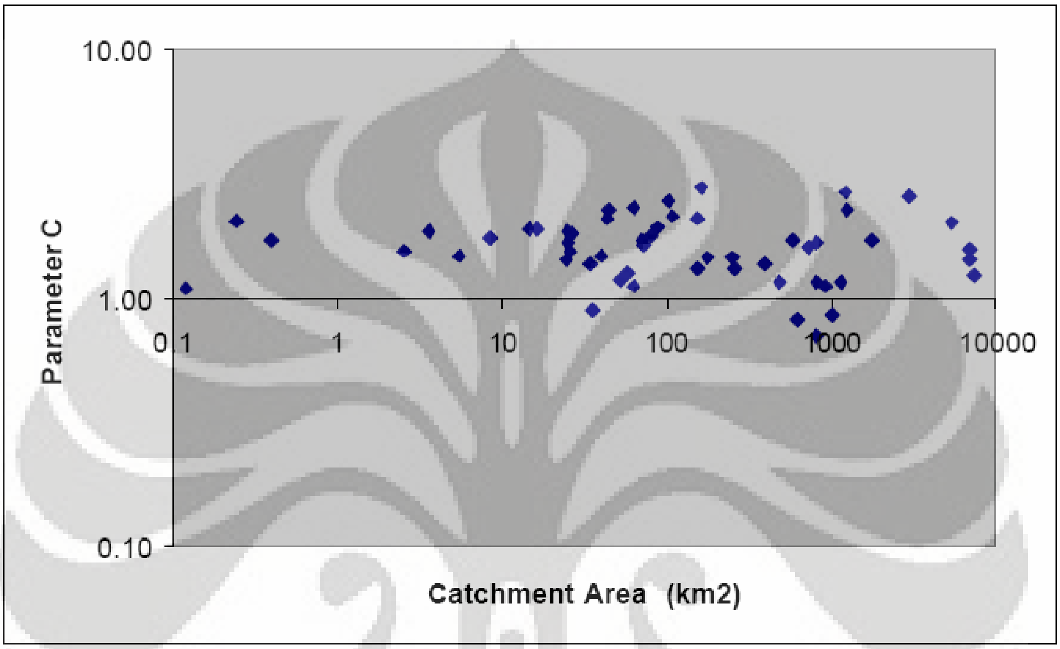


Figure 4.2 WBNM Lag Parameter C versus Catchment area

(Source : Figure 5. WBNM Lag Parameters versus Catchment Size – 584 storms on 54 catchments in QLD, NSW, Victoria and South Australia. WBNM Theory.2007)

There are other results to determine the value of lag parameter c. The figure above shows the minimum of lag parameter value compare to others. It can be concluded that a value of lag parameter near to 1.6 is recommended. The same value of the Lag Parameter should be used for all subareas (global value), unless there is good evidence for varying it (Boyd and Cordery, 1989)

4.2 DRAINS

4.2.1 Overview

DRAINS is a multi-featured modelling application which can be hydrologically classed as a rainfall-runoff model producing . The hydrologic modelling performed by DRAINS is based in the ILSAX model, however additional models are incorporated in the package, including the rational method, extended rational method, as well as the storage or runoff routing methods. This evaluation of the model will concentrate on the ILSAX hydrological model.

4.2.2 Catchment Model

The catchment model for ILSAX is primarily associated with an urban or semi-urban catchment. The catchment is divided into subcatchments based on the structure of the urban drainage system, pipes and channel sections. The subcatchments are then classified internally by their percentage area of each type of surface as defined below:

Paved Areas	Impervious areas directly connected to the pipe system including road surfaces, driveways, roofs connected to street gutters, etc.
Supplementary Areas	Impervious areas not directly connected to the pipe system, but draining onto pervious surfaces which connect to this system (these may include tennis courts surrounded by lawns, house roofs draining onto pervious ground etc.)
Grassed Areas	Pervious areas directly connected to the pipe system, including bare ground and porous pavements as well as lawns.

4.2.3 Loss Model

The loss calculations used by the ILSAX hydrologic model are different for each catchment surface type. Paved and supplementary areas are considered very simply by specifying the only loss to be an initial loss which will be equal to the volume of the depression storages in that area. The loss model for the grass area uses the Horton equations for infiltration capacity:

$$f = f_c + (f_0 - f_c)e^{-kt}$$

Where: f = infiltration capacity (mm/h)

fo = initial infiltration rate

fc = final infiltration rate

k = shape factor, here taken as $2h^{-1}$

t = time from the start of rainfall (mins)

The Horton infiltration curves are used to determine *f0* and *fc* which based on the soil type and antecedent moisture conditions. It is shown in figure 4.3.

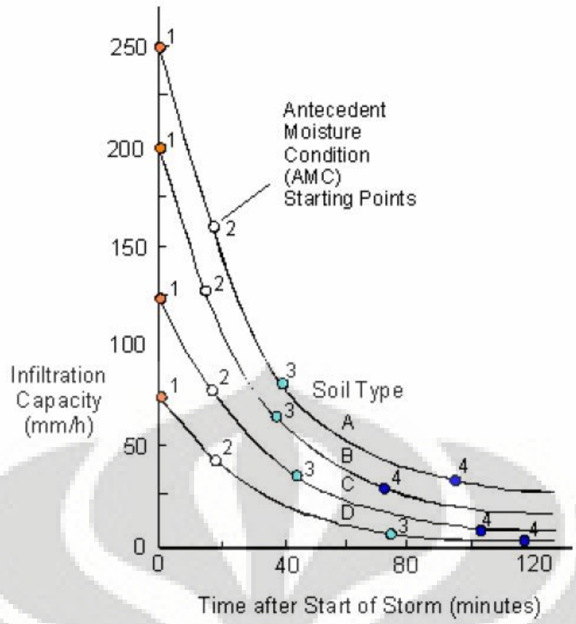


Figure 4.3 Horton Infiltration Curves

(Source: DRAINS Manual)

4.2.4 Storage Discharge Relation

The ILSAX model undertakes a time-area routing method that converts a rainfall hyetograph into flow across the catchment. The rainfall hyetograph is divided into time steps as is the time area diagram, and the catchment area is then divided up by the area contributing after a given number of time steps. This concept is understood as isochrones representing lines of equal time of travel to the catchment outlet. The process is outlined in the diagram below and is fundamentally based on the following equation:

$$Q_y = C_y I_{tc,y} A$$

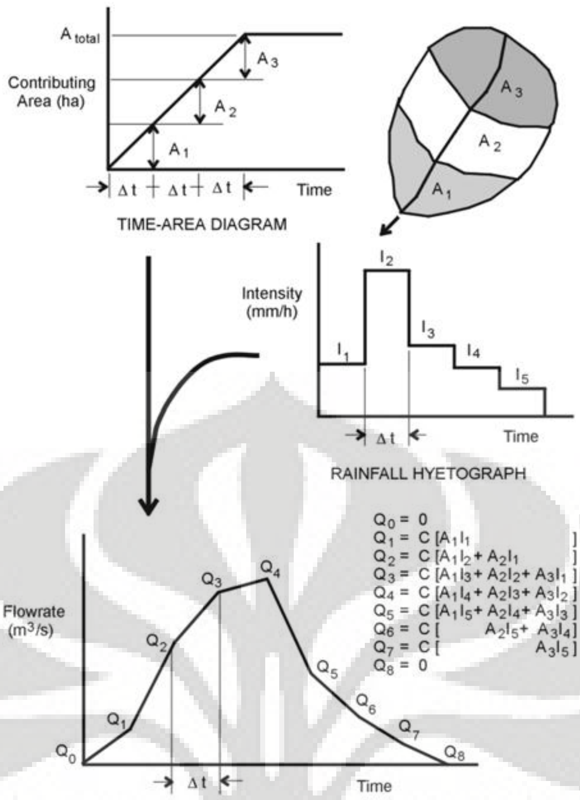


Figure 4.4 Time-Area Calculations
(DRAINS Manual)

In DRAINS the time of concentration is determined in a similar manner to the rational method. These concentration times set the base lengths of the time-area diagrams used to create hydrographs. For an urban catchment there are three stages in these concentration times, termed Constant time, Overland flow time, Gutter flow time. The constant time represents the path from the roof of the furthest buildings to its property boundary, the time taken is estimated by the user.

The time of concentration for overland flow can be determined by the steady state 'kinematic wave' equation of overland flows (Ragan and Duru 1972):

$$t_{overland} = 6.94\frac{(Ln)^{0.6}}{I^{0.4}S^{0.3}}$$

Where $t_{overland}$ = time of concentration (mins)

S = Slope (m/m)

L = Flow Path Length (m)

I = rainfall intensity (mm/h)

n = manning surface roughness. Shown in table 3.2

Surface Type	Roughness Coefficient n
Concrete or Asphalt	0.01 – 0.013
Bare Sand	0.01 – 0.016
Gravelled Surface	0.012 – 0.03
Bare Clay-Loam Soil (eroded)	0.012 – 0.033
Short Grass Prairie (Veldt or Scrub)	0.10 – 0.20
Lawns	0.17 – 0.48

Table 4.2 Manning Surface Roughness
(Source : DRAINS Manual)

The time of concentration therefore represents the time for rain falling on an urban property to flow to storage such as a drainage pit, and this time is made up of the three components (paved areas, supplementary areas, grassed areas). By separating the calculation of each time component the model is able to use only one component if that is all that is necessary depending on catchment type.

4.2.5 Input Parameters

The primary inputs to run the hydrological model include:

- Catchment topography and areas
- Subcatchment surface types
- Rainfall hyetograph, and
- Loss model parameters including soil types and antecedent moisture conditions (for pervious areas of catchment)

4.3 RORB

4.3.1 Overview

Runoff Routing Burroughs (RORB) was developed by Eric Laurenson and Russell Mein at the Monash University Department of Civil Engineering. RORB was first released in 1975, and since then it has undergone six major revisions.

RORB is a spatially distributed catchment model which uses the Muskingum method of routing rainfall excess through stream systems and is able to simulate both linear and non- linear catchment behaviour. It is event-based and able to be used on both rural and urban catchments. An overall flowchart of how the RORB model deals with the catchment conceptually is presented in Figure 4.3 below.

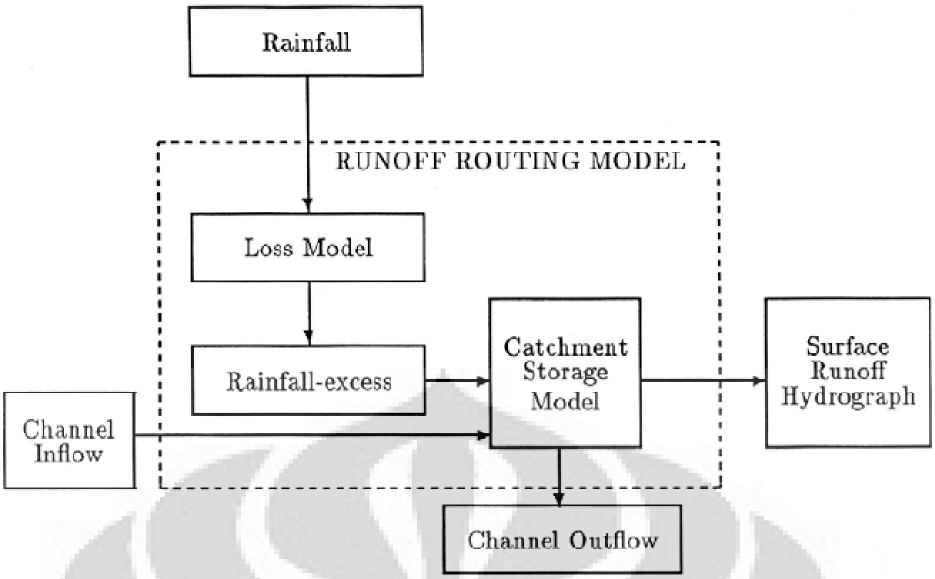


Figure 4.5 Overall Runoff Routing Model

(Source: RORB Manual)

4.3.2 Catchment Model

The idea behind the catchment model used by RORB is that the catchment area is divided into sub-areas on the basis of their homogeneity and that sub-areas meet at stream confluences. The rainfall excess from each sub-area is assumed to be concentrated at a node on the main stream adjacent to the sub-area centroid. Model nodes are placed at key points such as stream confluences; flow gauging stations, storage reservoirs and the catchment outlet. An example is presented in Figure 4.6 below.

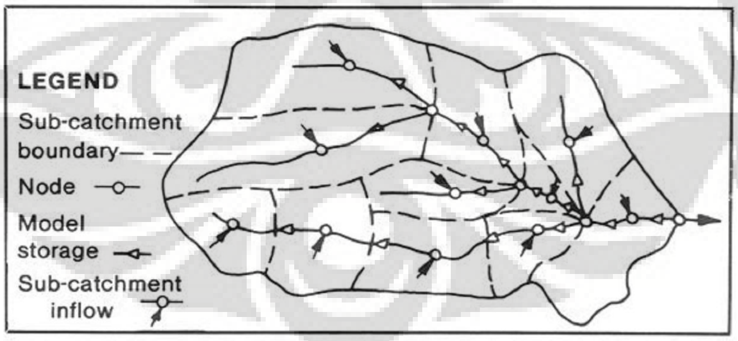


Figure 4.6 Typical Catchment in RORB

(Source: Figure 3-5 Book 5-Estimation of Design Flood Hydrographs, ARR 1998)

Additional features include level-pool routing for the modelling of reservoirs and the ability to model lateral outflows from the systems. These can be specified as a function of upstream discharge, or as a user input hydrograph.

4.3.3 Loss Model

RORB incorporates a traditional loss model where the excess is determined from the rainfall less infiltration and evaporation. Losses may be accounted for in two different ways:

- Initial loss with continuing loss rate (IL/CL)
- Initial loss with proportional loss option (IL/PL)

4.3.4 Storage Discharge Relation

The distributed nature of catchment storage in RORB is represented by a series of conceptual storages with a storage-discharge relationship. The rainfall excess for each subcatchment is converted to a surface runoff hydrograph which is routed using the following relationship:

$$S = 3600kQ^m$$

Where S = storage (m^3)

k = $k_c k_r$ = dimensionless coefficient which is the product of two coefficients

k_c = empirical coefficient which require calibration

k_r = dimensionless ratio called the relative delay time which is determined from stream characteristics including length, average flow distance and bed type.

Q = Outflow discharge (m^3/s)

m = dimensionless exponent

4.3.5 Input Parameters

The primary input for RORB include:

- Topography
- Spatial and temporal distributions of rainfall
- Catchment area
- Stream length
- Loss parameters, and
- Catchment routing parameters (k_c and m)

4.4 RAFTS

4.3.1 Overview

The Runoff Analysis and Flow Training System Model (RAFTS) was first developed in 1974 by Goyen and Aitken as RSWM and has since undergone constant development. From this beginning the model was developed and became known separately as RAFTS in 1981. Snowy Mountains

Engineering Corporation (SMEC) (Goyen and Aitken 1976, Black and Codner 1979) was the original developer of the model.

RAFTS is a rainfall-runoff-routing package that includes several loss options, baseflow computation, separate routing of impervious and pervious areas, Muskingum-Cunge channel routing and the tools to simulate weirs, dams and retarding basins.

The latest version of RAFTS is now a fully Windows-compatible program and also includes many features and benefits not available with the DOS-based software. These include:

- advanced result engine
- greatly reduced solve times
- import and export of global data
- greatly simplified river reach routing
- unlimited node sizing
- more accurate representation of spatial rainfall distribution
- extended retardation basin provisions to allow more complex outlet conditions
- long-term continuous simulation facilities including flood frequency results
- results have been greatly enhanced to provide truly professional presentation graphics.

4.3.2 Catchment Model

The catchment for the RAFTS model is divided into subcatchments in a similar manner to RORB. Each subcatchment is represented by the non-linear model developed by Laurenson (1964) consisting of a separate series of nine equal non-linear concentrated storages followed by a tenth storage with half the delay time of the other storages. The sub-areas providing input to each of these storages are defined by ten isochrones at equal increments of travel time.

The number of subcatchments used is not as important as for RORB and WBNM, as each individual subcatchment is represented by a complete model which should provide a reasonable estimate of the subcatchment outflow. The division of the catchment is aimed at giving fairly homogenous subcatchments.

Spacing of the isochrones in each subcatchment model is based on Laurenson's (1964) original assumption that travel time is proportional to travel distance and inversely proportional to the average slope of the reach. Runoff from a subcatchment flows into the top of a link and is routed down the channel system; subcatchment hydrographs are added in the sequence corresponding to catchment model arrangement.

An example of a RAFTS catchment model is illustrated in Figure 5.4.

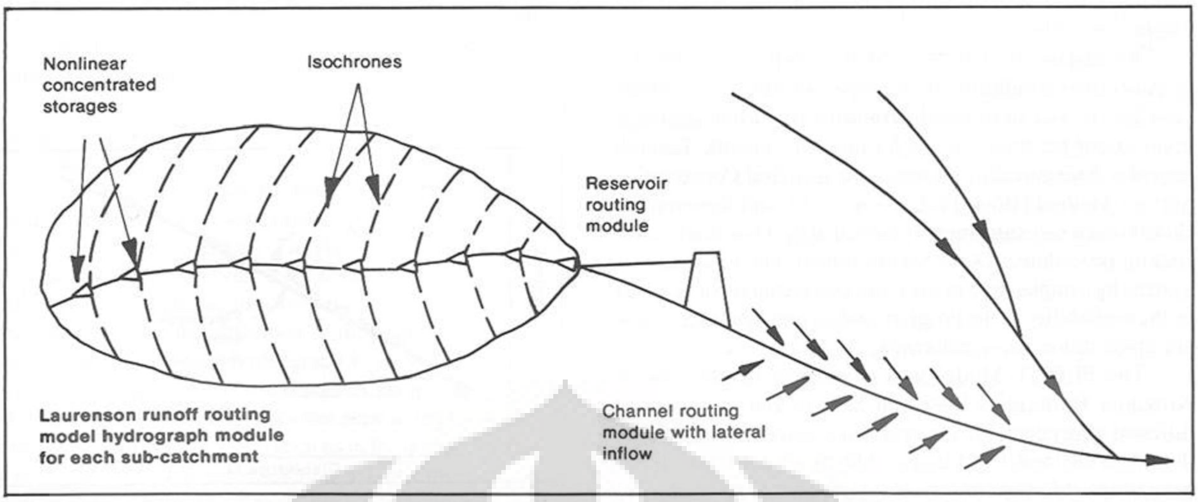


Figure 4.7 Typical Catchment in RAFTS

(Source: Figure 3-7 Book 5-Estimation of Design Flood Hydrographs, ARR 1998)

4.3.3 Loss Model

The RAFTS model incorporates more sophisticated loss routines than other models. It uses the Australian Representative Basins Model (ARBM) (Black and Aitken 1977). In this model the soil storage is divided into upper and lower soil stores and a groundwater store. The Phillips infiltration equation (Phillips 1969) and algorithms for wetting and drying the soil profile are used to model the redistribution of water within the profile.

Further to ARBM, other loss models that can be employed include:

- IL/CL model
- IL/PL model
- stochastic-deterministic loss model (Goyen 1983), which uses the joint probability of rainfall and soil moisture to determine the frequency curves of rainfall excess and flood runoff.

4.3.4 Storage Discharge Relation

The distributed nature of catchment storage is accounted for by each of the sub-areas in each subcatchment being treated as a concentrated non-linear storage with the storage-discharge relation equation:

$$S = KQ$$

Where S = Storage volume (m^3)

Q = Rate of runoff (m^3/s)

K = BQ^n = storage delay time

B = Storage delay time coefficient

n = storage non-linearity exponent

The storage delay time coefficient B may be estimated using the formula:

$$B = 0.285A^{0.52}(1+U)^{-1.97}Sc^{-0.5}$$

Where A = area of subcatchment (km^2)

Sc = main drainage slope of the subcathcment (%)

U = Fraction of Catchment that is urbanised

4.3.5 Input Parameters

The input for the model include:

- Catchment area
- Main drainage slope
- Channel slope and cross section dimension
- Loss rates
- Observed/design rainfall information

Rainfall data may be in the form of gauged daily rainfall.

5.0 Conclusion

The selection of a hydrologic model for a catchment should be based on the understanding of catchment characteristics and the overall aims, objectives and final outcome required from the modelling. Each catchment will have unique hydrologic characteristics which must be taken into consideration when selecting a model. The type hydrologic model selected will also be influenced by the required outcome of the modelling and thus the model selected must be compatible with the requirements of the entire project.

It should also be noted that all flood models are a conceptualisation of the real world, and thus, have inherent inaccuracies, and all results will require interpretation. For this reason hydrologic modelling should always be undertaken by an experienced hydrologic modeller. Sensitivity analyses of major assumptions and parameters are essential to ensure the model is robust, representative and suitable to overall objectives. It is only through extensive experience in hydrologic modelling that a reliable hydrologic model may be produced and interpreted.

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Appendix A

Summary of Time of Concentration Formula

TABLE 15.1.2
Summary of time of concentration formulas

Method and Date	Formula for t_c (min)	Remarks
Kirpich (1940)	$t_c = 0.0078L^{0.77}S^{-0.385}$ L = length of channel/ditch from headwater to outlet, ft S = average watershed slope, ft/ft	Developed from SCS data for seven rural basins in Tennessee with well-defined channel and steep slopes (3% to 10%); for overland flow on concrete or asphalt surfaces multiply t_c by 0.4; for concrete channels multiply by 0.2; no adjustments for overland flow on bare soil or flow in roadside ditches.
California Culverts Practice (1942)	$t_c = 60(11.9L^3/H)^{0.385}$ L = length of longest watercourse, mi H = elevation difference between divide and outlet, ft	Essentially the Kirpich formula; developed from small mountainous basins in California (U. S. Bureau of Reclamation, 1973, pp. 67–71).
Izzard (1946)	$t_c = \frac{41.025(0.0007i + c)L^{0.33}}{S^{0.333}i^{0.667}}$ i = rainfall intensity, in/h c = retardance coefficient L = length of flow path, ft S = slope of flow path, ft/ft	Developed in laboratory experiments by Bureau of Public Roads for overland flow on roadway and turf surfaces; values of the retardance coefficient range from 0.0070 for very smooth pavement to 0.012 for concrete pavement to 0.06 for dense turf; solution requires iteration; product i times L should be $\leq$ 500.
Federal Aviation Administration (1970)	$t_c = 1.8(1.1 - C)L^{0.50}/S^{0.333}$ C = rational method runoff coefficient L = length of overland flow, ft S = surface slope, %	Developed from air field drainage data assembled by the Corps of Engineers; method is intended for use on airfield drainage problems, but has been used frequently for overland flow in urban basins.

TABLE 15.1.2 *(cont.)*
Summary of time of concentration formulas

Method and Date	Formula for t_c (min)	Remarks
Kinematic wave formulas Morgali and Linsley (1965) Aron and Erborge (1973)	$t_c = \frac{0.94L^{0.6}n^{0.6}}{(i^{0.4}S^{0.3})}$ L = length of overland flow, ft n = Manning roughness coefficient i = rainfall intensity in/h S = average overland slope ft/ft	Overland flow equation developed from kinematic wave analysis of surface runoff from developed surfaces; method requires iteration since both i (rainfall intensity) and t_c are unknown; superposition of intensity–duration–frequency curve gives direct graphical solution for t_c
SCS lag equation (1973)	$t_c = \frac{100\ L^{0.8}[(1000/CN) - 9]^{0.7}}{1900\ S^{0.5}}$ L = hydraulic length of watershed (longest flow path), ft CN = SCS runoff curve number S = average watershed slope, %	Equation developed by SCS from agricultural watershed data; it has been adapted to small urban basins under 2000 acres; found generally good where area is completely paved; for mixed areas it tends to overestimate; adjustment factors are applied to correct for channel improvement and impervious area; the equation assumes that $t_c = 1.67 \times$ basin lag.
SCS average velocity charts (1975, 1986)	$t_c = \frac{1}{60}\Sigma\frac{L}{V}$ L = length of flow path, ft V = average velocity in feet per second from Fig. 3-1 of TR 55 for various surfaces	Overland flow charts in Fig. 3-1 of TR 55 show average velocity as function of watercourse slope and surface cover. (See also Table 5.7.1)

Source: Kibler, 1982, Copyright by the American Geophysical Union.