THE DEVELOPMENT OF A RAINFALL-RUNOFF-ROUTING (RRR) MODEL

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Abstract

Most mathematical models used in Australia to simulate runoff events from catchments were developed in the 1960s and 1970s. Models in use include the ILSAX model for urban catchments, and runoff routing models such as RORB, RAFTS and WBNM for both urban and rural catchments.

Research in the past decades has been generally directed towards the calibration and determination of regional parameters without review of the basic structure of the models. There has been limited success in the development of generalised parameters, with no consistent factors being found which govern catchment response apart from the length of the main stream within the catchment, and average annual rainfall.

This study commences with an investigation into intrinsic links between the runoff routing models. A relationship between RORB and RAFTS is determined but the relationship does not apply to RAFTS models having more than one node or sub-area. It is shown that the cause is the non-linearity of the model storages affecting the total storage and thus storage lag in the model as the number of nodes or sub-areas changes. Examination of other runoff routing models reveals that all the runoff routing models have similar problems. RORB, RAFTS and WBNM are not internally consistent and regional relationships will give appropriate results only if applied to a model having the same number of sub-areas as the model used to determine the relationship.

It is suggested that the limited success in deriving generalised relationships for storage parameters arises because they are capable of modelling only one runoff process. Hydrologists are aware that a continuum of processes occurs, for which different responses are likely. The continuum of processes is however generally dominated by one process for an individual catchment. Present model usage has favoured this type of catchment.

A new model (named the Rainfall Runoff Routing or RRR model) is developed to overcome the limitations of internal consistency and the single runoff process. The application of the new model is verified on a range of catchments in South Australia, New South Wales and the Northern Territory, and the model is applied successfully to two catchments having mixed urban and rural land use. The model is also applied to a group of catchments in the Mount Lofty Ranges, and generalised parameter values found. The storage lag due to hillside processes appears to be related to the water holding capacity and the depth of the soil within the catchment.

Three identified processes were found to occur during runoff events, namely baseflow, slow and fast runoff. The climatic zone in which the catchment is situated, the initial state of the catchment and the magnitude of the rainfall event can all influence the processes that occur in a catchment.

It is concluded that the RRR model with these three processes being modelled will provide more consistent regional storage parameters than other runoff routing models.

STATEMENT

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

DAVID KEMP
29/07/02

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SYMBOLS AND ABBREVIATIONS

α	In WBNM the ratio of interbasin lag to ordered basin lag
A	catchment area (km^2)
A	channel cross section area (m^2)
Ad	area of downstream sub-catchment of a catchment having two sub-catchments (km^2)
A_i	area of sub-catchment i (km^2)
A_r	channel area (m^2)
AMC	Antecedent Moisture Condition
ARBM	Australian Representative Basins Model
Au	area of upstream sub-catchment of a catchment having two sub-catchments (km^2)
b	exponent in the relationship $K=aA^b$
B	storage delay time coefficient
B	width of the catchment element (m)
BFI	baseflow index
Bi	impervious area B value
Bp	pervious area B value
BS	moisture in the baseflow store (mm)
BX	a calibration factor in the RAFTS model
c	a catchment lag parameter, equal to RORB k_c/d_{av}
cd2	number of type 2 conceptual storages in the RORB model
Cg	the sub-surface supply parameter in the KINDOG model
circ	catchment area / perimeter^2
CL	Continuing Loss (mm/hr)
c_p	catchment characteristic lag parameter in the RRR model
Cr	channel conveyence coefficient in the KINDOG model
Cs	the surface supply parameter in the KINDOG model
d	the longest flow path length in a catchment (km)
d_{av}	average flow distance of the channel network (km)
d_g	depth of flow at the gutter face (mm)
d_p	depth of flow at the edge of pavement (mm)
f	soil infiltration capacity (mm/hr)

F	flow correction factor
f_c	final soil infiltration rate (mm/hr)
F_i	A factor depending on the type of reach in the RORB model
f_0	initial soil infiltration rate (mm/hr)
for	fraction of forest
GIS	Geographical Information System
GUT	gutter flow factor used in ILSAX
Hg	depth in the sub-surface store (mm)
HYDSYS	a HYDrological data storage SYStem
I	rainfall intensity (mm/hr)
I	channel inflow (m^3/s)
IBFL	a modifier of the B parameter to account for older sub-catchments
IL	initial loss (mm)
ILSAX	ILLUDAS-SA, with something extra
k	a shape factor
k	a dimensional empirical coefficient
k	sub-catchment storage delay time (hrs)
k	channel storage lag in the RRR model (hrs)
K	catchment lag (hrs)
K	channel conveyence (m^3/s)
K_B	ordered basis lag in the WBNM model
k_c	RORB storage parameter
Kd	storage lag of the downstream sub-area of a catchment having two sub-areas
K_D	dimensionless storage delay time
K_I	interbasin lag in the WBNM model
Ki	impervious area storage lag (hours)
K_i	lag of an individual sub-catchment I
KINDOG	A catchment model incorporating KINematic wave
K_M	average storage delay time
Kp	pervious area storage lag (hours)
k_p	process lag in the RRR model
k_{pi}	urban unconnected area process lag parameter
k_r	relative delay time

k_{ri}	relative delay time of storage i
KS	surface store recession constant
K_{split}	the true lag of a split catchment RAFTS model
Ku	storage lag of the upstream sub-area of a catchment having two sub-areas
k^*	k_c/dav
L	flow path length (m)
L	channel reach length (m)
Lg	gutter flow length (m)
L_i	length of channel reach represented storage i (km)
lmns	lnn / the mainstream length
lnn	length of streams having an order of one less than the outlet
Lo	overland flow length (km)
Lp	pipe flow length (m)
lrat	ratio of the largest RORB sub-catchment to the total area
LRRM	Laurenson Runoff Routing Method
m	a dimensionless exponent
medrn	median annual rainfall
minel	elevation of the catchment outlet
n	Manning's n, a measure of channel or pipe roughness
n	storage non-linearity exponent (used in RAFTS)
n	number of hydrograph ordinates
N	number of reservoirs
n_g	Manning's n of the gutter
ni	Manning's roughness for the impervious area
nn	number of streams of order one less than the outlet
NN	the number of nodes in a RAFTS model
n_p	Manning's n of the pavement
np	Manning's roughness for the pervious area
ns	number of sub-catchments upstream of the point of interest
O	channel outflow (m^3/s)
OF	an objective function used to measure the goodness of fit
P	wetted perimeter (m)
pe	ratio of mean annual rainfall to evaporation

pem	the ratio of median annual rainfall to evaporation
PERN	a modifier of the B parameter to account for catchment roughness
PEST	Parameter ESTimation program
PHI	the objective function used by PEST
PL	Proportional Loss
q	instantaneous runoff rate (m^3/sec)
Q	discharge (m^3/sec)
$Q_c(t)$	calculated hydrograph at time t (m^3/s)
q_m	total mean flow ((m^3/s)
$Q_o(t)$	observed hydrograph at time t (m^3/s)
Q_{op}	peak flow of the observed hydrograph (m^3/s)
Qp	peak flow (m^3/s)
q_{split}	the flow from one part of a split-sub-catchment RAFTS model
RAFTS	Runoff Analysis and Flow Training Simulator
RF	annual rainfall (mm)
r_i	the hydraulic radius of the ith pipe (m)
rla	RORB length over area
rlen	length of the reaches in the RORB model
rlm	RORB length over the mainstream length
rlt	RORB stream length / total stream length
r_m	the mean hydraulic radius (m)
RORB	RunOff Routing developed on a Burroughs computer
rr	relief ratio (maximum elevation - minimum elevation over main stream length)
rrd	number of raindays per year
RSWM	Regional Stormwater Drainage Model
s	storage volume (hrs x m^3/sec), used in RAFTS
s	slope (m/m)
S	slope (m/m)
S	storage (m^3)
sa	the number of sub-catchments in the RORB model
S_c	slope of catchment (%)
S_g	gutter slope (m/m)
Sg	rate of sub-surface supply (mm/hr)

S_i	the slope of the ith pipe (m/m)
So	overland flow slope (m/m)
S_o	Soil sorptivity
S_p	pipe slope (m/m)
ss	surface supply rate in the KINDOG model
SS	moinsture in the surface store (mm)
strm	stream order at the outlet
SWMM	StormWater Management Model
t	time from the start of rainfall (minutes)
t_1	lag of sub-catchment 1 (hrs)
t_2	lag of sub-catchment 2 (hrs)
t_{end}	the end time of calculations (minutes)
$t_{overland}$	overland flow time (minutes)
t_{r2}	translation time between sub-catchments (hrs)
t_{rm}	mean translation time for all sub-catchments
TRRL	Transportation and Road Research Laboratory (UK)
U	fraction of catchment urbanised
v_c	channel characteristic velocity in the RRR model (m/s)
Vd	runoff volume of the downstream sub-area of a catchment having two sub-areas (m^3)
Vu	runoff volume of the upstream sub-area of a catchment having two sub-areas (m^3)
WBNM	Watershed Bounded Network Model
y	channel flow depth (m)
y_o	original channel flow depth (m)
z	reciprocal of channel side slope (m/m)
Z_G	reciprocal of gutter cross-slope (m/m)
Z_p	reciprocal of pavement cross-slope (m/m)
γ	hillslope flow exponenent in KINDOG
ϕ	final infiltration rate (mm/hr)