A COMPUTER SOFTWARE PACKAGE FOR FLOOD STUDIES

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Abstract

The flood hydrograph model WBNM calculates flood runoff from rainfall hyetographs. It divides the catchment into subcatchments, thus allowing spatial variability of rainfall and rainfall losses to be modelled. It separates overland flow routing from channel routing, thus allowing changes to either or both of these processes, for example in urbanising catchments. The computer program for WBNM contains many useful features for flood studies, including built in design storms, runoff from impervious and pervious catchment surfaces, flood routing through storage reservoirs, built in culvert and weir hydraulics, and diversion of surcharging flows. The program is menu driven and designed to satisfy quality assurance requirements. Full graphics displays are included.

Key Words
Flood hydrograph; Flood detention basin; Computer graphics.

1. Introduction

The Watershed Bounded Network Model WBNM was developed by Boyd, Pilgrim and Cordery [1] and is included in Australian Rainfall and Runoff [2], the Institution of Engineers guide to flood estimation in Australia. The model calculates the flood hydrograph resulting from storm rainfall using a runoff routing approach, whereby the catchment is divided into subcatchments using the stream network, and each subcatchment is allocated a lag time depending on its size. The model has recently been built into a comprehensive computer program which includes the following features :

Spatial variation of rainfall and rainfall losses
Range of rainfall loss models
Multiple rain gauges
Design storms, including Probable Maximum Precipitation
Natural and urban catchments
Modifications to stream channels
Separate runoff from impervious and pervious surfaces
Diversion of flows exceeding the channel capacity
Rating tables to give maximum water levels
Flood routing through reservoirs and detention basins
Culvert and weir hydraulics
Recorded hydrographs

A full menu system allows easy organisation, copying and editing of input data files. All results are written to a metafile as a permanent record for quality assurance purposes. Additionally, built in graphics allow viewing of the schematic catchment layout, hydrographs from all subcatchments, rainfall hyetographs, rating curves, and storage reservoir elevation-discharge-storage curves. FORTRAN is used for computations and PASCAL for graphics. The program runs under DOS on IBM compatibles.

This paper describes the background to the model, and the structure of the computer program WBNM.

2. Modelling Catchments with WBNM

The catchment to be modelled is divided into subcatchments based on the stream network. Each subcatchment or watershed drainage area is bounded by its ridge line, hence the name Watershed Bounded Network Model. Guidelines on the division into subcatchments are given in Boyd et al [3]. Generally, small catchments are divided into only a few subcatchments while large catchments may be divided into 100 or more subcatchments.

Equations for overland flow on each subcatchment are:

Continuity $I(t) - Q(t) = dS(t)/dt$ (1)

where

I(t)	=	AREA*R(t)/3.6 = inflow from excess rainfall on the subcatchment (m^3/s)
R(t)	=	excess rainfall (mm/hour)
AREA	=	subcatchment area (km^2)
Q(t)	=	outflow from subcatchment (m^3/s)
S(t)	=	volume of water stored on subcatchment surface (m^3)
t	=	time (seconds)

Storage-Discharge $S = kQ^m$ (2)

which relates the volume of water on the subcatchment surface at any time t to the corresponding discharge from the subcatchment, k is a scaling parameter and m indicates the nonlinearity of the relation.

Solving (1) and (2) gives the routing equation for the subcatchment

$$I(t) - Q(t) = dS/dQ.dQ/dt \qquad (3)$$

The term dS/dQ represents the lag time of the subcatchment. If $m \neq 1$ the catchment response is nonlinear and the lag time varies with the discharge from the subcatchment. Detailed studies of lag times in natural catchments [4] show that the lag time depends on the size of the subcatchment as well as on the discharge Q. The relation is :

$$LAG = C\ AREA^{\,0.57} Q^{-0.23} \qquad (4)$$

so that LAG (hours) is larger for large subcatchments and decreases as the flood discharge Q increases ($m = 0.77$). Equation (4) is built into the model WBNM so that only the subcatchment sizes are needed to calculate flood hydrographs. The model has one parameter, C, which controls the magnitude of the catchment lag time, and can be adjusted for calibration on recorded events.

3. Rainfall Hyetographs and Rainfall Losses

Up to 10 rain gauges can be used. The rainfall hyetograph for each subcatchment is calculated using Thiessen weights applied to the each rain gauge. Alternatively, by specifying grid coordinates for subcatchments and rain gauges, WBNM automatically calculates weighting factors depending on the inverse square of the distance of each gauge from the subcatchment.

Four rainfall loss models can be used: Initial loss-continuing loss rate; Initial loss-runoff proportion; Horton exponential; and Initial loss-stepped loss rate. Spatially varying losses can be modelled by specifying different values for each subcatchment.

4. Design Storms

A principal use of flood hydrograph models is to calculate design floods resulting from design storms. WBNM does this according to procedures set out in Australian Rainfall and Runoff [2], the guide for design flood estimation in Australia. The procedure is to select a design storm frequency and duration. WBNM automatically calculates the design rainfall intensity (mm/hour) for this storm, using built in relations for all regions of Australia. The procedure uses log Pearson type III frequency distributions for recurrence intervals of 1, 2, 5, 10, 20, 50, 100, 200 and 500 years, with interpolation for storm durations between 5 minutes and 72 hours. Next, WBNM distributes this rainfall into a temporal pattern, using built in data for all regions of Australia. Naturally, these design storms apply only to Australian conditions, however users in other countries can build in their own design storm procedures by modifying the DESRAIN.INC file.

Probable Maximum Precipitation estimates use the generalised short duration methods of the Australian Bureau of Meteorology [5], which in turn are based on US Weather Bureau procedures [6]. These apply to storm durations up to 6 hours and catchment sizes up to 1000 km^2.

5. Modelling Urban Catchments

It is well known that urbanisation of a catchment increases both flood volumes and flood peaks. The increased volumes result from replacement of naturally vegetated surfaces by impervious surfaces such as roofs, roads and pavements. The increased flood peaks result from faster flow velocities and consequently shorter lag times, both for overland flow on impervious surfaces, and for flow in more hydraulically efficient pipes and channels.

WBNM models urbanisation in two ways. For overland flow, each subcatchment is split into a directly connected impervious part and the remaining pervious and semi pervious part. Runoff from the impervious surfaces has a user specified initial loss and zero continuing loss, and a significantly reduced lag time. Values of impervious surface rainfall losses were selected from the survey by Boyd, Bufill and Knee [7]. The impervious surface lag parameter is based on studies of Rao et al [8], Aitken [9] and NERC [10], plus testing on 9 urban catchments in Australia.

The second urbanisation effect which WBNM models is the decreased lag time in watercourse channels due to the increased flow velocities in the hydraulically more efficient channels of the urban catchment. Two options are available for flood routing in these channels, either Muskingum routing with lag parameter K and distributed routing parameter x, or a simple delay of the hydrograph as it passes through the reach.

6. Storage Reservoirs and Flood Detention Basins

Storage reservoirs consisting of dams with spillways or detention basins with culvert and weir outlets can be placed at any point in the catchment, and WBNM performs reservoir flood routing. This requires a table of elevation H- discharge Q- storage volume S values for the storage, from the hydraulics of the outlet and the contours of the storage site. WBNM has built-in culvert and weir hydraulic relations [11] and calculates the H-Q relation given the number, type, size and invert elevations of the culvert and weir.

The invert level of the outlet can be above the floor of the storage, in which case the "dead" volume between the floor and outlet must be filled by the inflowing flood before outflow commences. The initial water level at the start of the flood can be at any elevation and WBNM commences flood routing from this point.

7. Flow Diversions

In large floods on real catchments, the capacity of the channel may be exceeded, and in this case the excess flow leaves the channel and travels down a floodway to rejoin the channel at some downstream point. In some cases the diverted flow leaves the catchment altogether, and overflows into the adjacent subcatchment. WBNM models this by diverting a specified percentage of the excess flows to a nominated downstream point.

8. Computer Program

The computer program WBNM is structured around three blocks, a MENU block, a COMPUTATION block, and a GRAPHICS block.

The MENU block organises files under a Catchment directory and various Project sub directories, for different projects on the same catchment. Within each of these, pull down menus allow the user to:

Change the catchment (or project)
Add a new catchment (or project)
Delete a catchment (or project)
List all catchments (or projects)

This allows efficient organisation of data files in a directory tree which corresponds to the organisation of jobs in the design office.

For each project there will be several Datafiles, for example some will contain recorded rainfall and flood data for use in calibration runs, while others will contain details of design storms. The Datafile pull down menu allows the user to :

Build a new datafile
Check an existing datafile for errors
Run the WBNM model
Prepare a Summary report
Show the GraphicDisplay
Set the Echo flag
Set the Debug flag
Nominate the plotter Port
Nominate the plotter Type

The summary report summarises important results of the run, including :

total rain depth; excess rain depth; peak discharges and time of peak discharge for all subcatchments; volumes flowing into and out of all subcatchments plus a volume balance check; and runoff volumes and peak discharges from the impervious and pervious surfaces of all subcatchments.

The COMPUTATION block performs all numerical calculations. These include design storm rainfall intensities, using log Pearson type III distribution and a library of standard temporal patterns; subtraction of rainfall losses; routing excess rainfall on subcatchments using (3) and (4); channel routing, either nonlinear, Muskingum, or time delay; flood routing through storage reservoirs; and flow diversions. The computation block also calculates the summary statistics.

All calculated values are written to a metafile which is automatically overwritten on each run. Copying the metafile allows a permanent record of all settings and results for the run to be kept for quality assurance purposes. The metafile is also accessed by the graphics routines.

The GRAPHICS block first displays a master screen containing all graphics displays (Fig. 1). Graphics can be maximised or minimised by mouse clicks. The graphics displays available are :

Catchment showing location of rain gauges
Rainfall hyetographs at all rain gauges
Rating curves
Storage reservoir elevation-discharge-storage curves
Summary table
Rainfall hyetograph and flood hydrographs

For each subcatchment, hydrographs can be viewed for runoff from impervious surfaces, from pervious surfaces, at the top end of the watercourse, at the bottom end of the watercourse after channel routing, diverted flows, and finally, the outflow hydrograph from the subcatchment. If recorded hydrographs are available, these can also be viewed (Fig. 1).

9. Conclusions

The Watershed Bounded Network Model for flood hydrograph estimation has been built into a comprehensive computer software package which is menu driven, allows efficient data file handling, satisfies quality assurance requirements, and has built in graphics. The computational part of the model allows for spatially varying rainfall and catchment conditions, urban and natural catchments, modifications to watercourses, flow diversions, storage reservoir routing, and detention basins. The computer program has built in culvert and weir hydraulic relations, and built in design storm rainfall. The program contains a README file which gives detailed information on the background and application of the model, including examples.

WBNM is a general flood hydrograph model which can be applied in all countries. In the current version, design storm rainfall is calculated using Australian data and procedures. However this can be modified for other countries.

Copies of the computer program are available, without charge, from Associate Professor Michael Boyd, Dept. of Civil and Mining Engineering, University of Wollongong, Australia 2522, fax +61 42 213238, email m.boyd@uow.edu.au

References

1. M.J. Boyd, D.H. Pilgrim, and I. Cordery. "A storage routing model based on catchment geomorphology". J. Hydrology. 42, 1979, 209-230.

2. Institution of Engineers Australia. "Australian Rainfall and Runoff- A Guide to Flood estimation". 2 volumes. 1987. ISBN 085825 434 4.

3. M.J. Boyd, B.C. Bates, D.H. Pilgrim, I. Cordery. "WBNM-a general runoff routing model". University New South Wales Water Research Laboratory Report 170. 1987. ISBN 0 85824 379 2.

4. A.J. Askew. "Derivation of formulae for variable lag time". J. Hydrology. 10, 1970, 225-242.

5. Bureau of Meteorology. "The estimation of probable maximum precipitation in Australia: Generalised short duration method". Australian Govt. Publishing Service, 1994. ISBN 0 644334193.

6. US National Weather Service. "Probable maximum precipitation estimates". 1988. Report No. 55A.

7. M.J. Boyd, M.C. Bufill, and R.M. Knee. "Pervious and impervious runoff in urban catchments". Hydrological Sciences Journal. 38(6), 1993, 463-478.

8. A.R. Rao, J.W. Delleur, and P.B.S. Sarma. "Conceptual hydrologic models for urbanising basins". Proc. ASCE. 98(HY7), 1974, 1215-1220.

9. A.P. Aitken. "Hydrologic investigation and design in urban stormwater drainage systems". Australian Water Resources Council Technical Paper 10. Australian Govt. Publishing Service. ISBN 0 642 501 343.

10. Natural Environment Research Council. "Flood Studies Report". Vol. 1 Hydrological Studies. 1974. ISBN

11. M.J. Boyd. "Head-discharge relations for culverts". Proc. 21st Congress International Association for Hydraulic Research. Vol. 6 Keynote Addresses. 1987. 118-122. ISBN 0858252805.

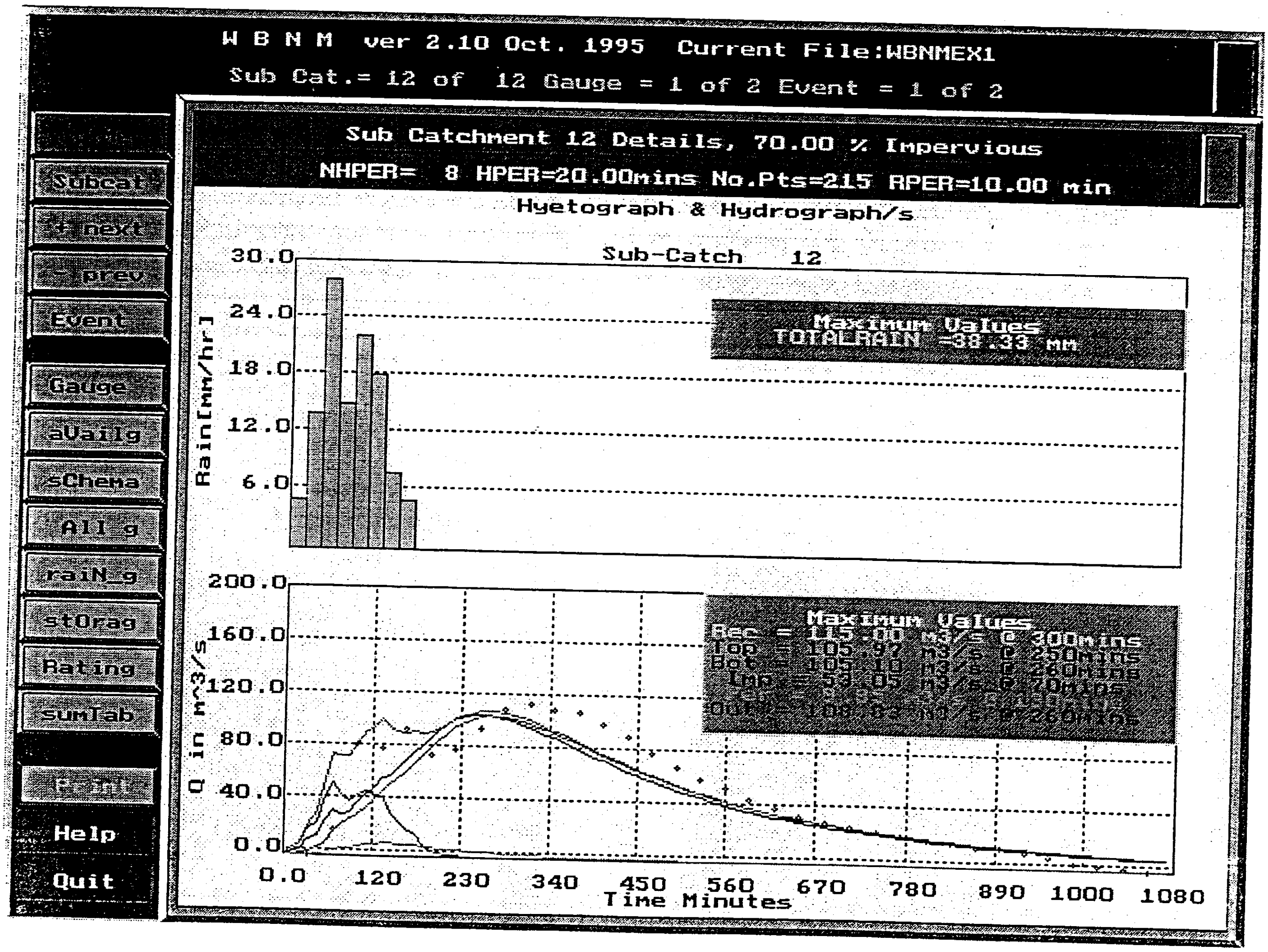

Fig 1 Graphic Display of Storm Rainfall and Hydrograph