Enhanced Runoff Routing Model WBNM94

M.J. Boyd, Dept of Civil and Mining Engineering, University of Wollongong
E.H. Rigby, Forbes Rigby Consulting Engineers
M.G. Sharpin, GHD Consulting Engineers
R. VanDrie, Drainage Section, Wollongong City Council

Summary This paper outlines enhancements which have been made to the 1994 version of the watershed bounded network model for calculating flood hydrographs from rainfall. Emphasis is placed on modelling urban catchments by treating runoff from pervious and impervious surfaces separately, and by separate routing of overland flow from excess rainfall and flows in watercourses. The computer program automatically generates design rainfall intensity and temporal patterns, and culvert and weir height-discharge tables. Quality assurance requirements are considered in the structure of the input and output data files.

1 INTRODUCTION

The watershed bounded network model WBNM for calculating flood hydrographs from rainfall was first developed by Boyd, Pilgrim and Cordery(1) and subsequently revised by Boyd et al(2). Over the last several years considerable developments in knowledge of hydrologic processes and urban stormwater management practices, developments in computer technology, and quality assurance requirements have made a major revision of the model desirable. This paper outlines many of the new features incorporated in the 1994 version of the model.

2 WBNM94 RUNOFF ROUTING MODEL

2.1 General

WBNM94 is an event based nonlinear runoff routing model for calculating flood hydrographs from rainfall hyetographs. The model structure is based on the geomorphology of the catchment and its stream network, and model nonlinearity and lag parameter values are based on measured catchment lag times(Askew, 3).

In addition to this basic structure, various modelling options are available to suit a wide range of applications. Five rainfall loss models are provided. Three watercourse routing options can be used, allowing both natural streams and constructed channels to be modelled. Effects of catchment urbanisation, as well as flood detention basins can be modelled. Flood routing through major dams with spillways is also possible.

2.2 Division of Catchment into Subcatchments

The catchment is divided into subcatchments depending on the catchment topography and stream network. The number of subcatchments generally ranges from 1 for small urban catchments to 50 or more for large natural catchments. Guidelines are given in Boyd(4) and Boyd et al(2).

Headwater subcatchments (1,3,6 and 8 in Figure 1a) transform excess rainfall into overland flow at the subcatchment outlet. Other subcatchments (2,4,7,10 and 11 in Figure 1a) transform excess rainfall into runoff, and also route runoff from upstream subcatchments through the watercourse.

Storage reservoirs(5,9 in Figure 1a), consisting of dams with spillways or detention basins with culvert and weir outlets, can be placed at any point.

Virtual subcatchments with zero area can, if needed, be used to print a hydrograph or to divert flow to or from a point on the stream network.

2.3 Modelling Rainfall

WBNM94 allows the user to specify three types of rainfall:

(i) REC-a recorded event at one or more gauges
(ii) DES-a design event of given ARI and duration at each gauge
(iii) OLD-an old WBNM datafile converted to run on the new model

Recorded event hyetographs for each gauge are read in intensity format (mm/hour) with the rainfall time step set by the user to suit the event. This time step is independent of the routing and printing time steps chosen.

In design mode, the model extracts coordinates, zone and IFD data for each gauge named in the input file from a user prepared (ascii) IFD datafile. This data is then used to calculate the burst intensity associated with the specified ARI and duration and to construct the design storm hyetograph. Design gauges may be added/removed/updated easily, and utilities are provided to generate IFD tables and graphs from the IFD datafile for reporting purposes.

WBNM94 permits the user to specify a design rainfall spectrum by accepting a range of standard ARIs and durations for analysis in a particular run. Output options permit selective review of the results of such a run.

WBNM94 includes the storm temporal patterns for all Australian rainfall zones, for ARIs from 1 to 100 years and burst durations from 10 minutes to 72 hours (I.E.Aust.,5).

Once the rainfall hyetograph at each gauge has been read in or constructed, WBNM94 calculates the hyetograph for each subcatchment using the temporal pattern of the nearest gauge, and an average intensity at the gauge calculated from surrounding gauges weighted according to the inverse of the squared distance from the subcatchment.

2.4 Modelling Rainfall Losses

Five alternative loss models are available:

(i) Initial loss-constant loss rate
(ii) Initial loss-loss rate varying in steps
(iii) Initial loss-runoff proportion
(iv) Horton continually time varying loss rate
(v) Green-Ampt time varying loss, with recovery after period of low rainfall

Once a rainfall loss model is selected, WBNM94 calculates the excess rainfall hyetograph for each subcatchment.

2.5 Modelling Overland Flow

Overland flow on each subcatchment is modelled by a nonlinear reservoir with lag equation based on the studies of Askew(3):

$$K = c*A^{0.57}*Q^{-0.23} \quad (1)$$

where K = subcatchment lag (hours)
A = subcatchment size (km^2)
Q = stream discharge at time t (m^3/s)
c = model parameter

For subcatchments in natural condition, parameter c is typically 1.3, but will vary above and below this (Webb et al,6; Sobinoff et al, 7). Because (1) includes the size of the subcatchment, similar values of parameter c should apply to both large and small catchments. The applicability of (1) to runoff routing models has been verified by applying it to a range of catchment sizes and flood events (Figure 2).

2.6 Modelling Watercourses

Watercourse segments, either the natural stream network or constructed channels, can be modelled in three ways :

(i) Nonlinear routing, using (1) with a factor to allow for the reduced lag time in the channel segment compared to overland flow. The default factor is 0.6 as in earlier versions of WBNM, but it can be varied to model channels in various conditions.
(ii) For short watercourse segments, in which the hydrograph is translated without attenuation, hydrographs can be delayed by a specified time.
(iii) Muskingum Cunge routing in which both attenuation and translation are modelled.

2.7 Modelling Storage Reservoirs

Puls' level pool routing is used for storage reservoirs, dams with spillways, and detention basins with pipe, culvert and weir outlets. The reservoir height-discharge-storage relation is required. If the number, size, type and invert elevation of combined culverts and weirs is given, WBNM94 calculates the height-discharge relation. Hydrographs for flow into and out of the basin can be obtained, together with a summary of peak discharges and volumes. Dead storage which must be filled before outflow commences from the basin is also modelled.

2.8 Modelling Flow Diversions

WBNM94 recognises the concept of major/minor drainage systems and provides the ability to model flow diversions from points of surcharge to a downstream point. If the runoff from a subcatchment surcharges the minor drainage system, the excess flow can be diverted to any nominated node in the catchment, or can be diverted completely out of the drainage system. Diverted flows can be delayed by a specified time, or they can be routed through drainage structures, such as channels or detention basins.

2.9 Modelling Urban Catchments

Detailed modelling of urban catchments requires that runoff from pervious and impervious surfaces be treated separately, and that overland flow from catchment surfaces and flow in watercourses be modelled separately, rather than lumped together as in some models (Sharpin, 8).

Urbanisation affects catchment flood hydrology in three ways:

(i) Increased excess rainfall and runoff from the impervious surfaces.
(ii) Increased flow velocities and shorter travel times for overland flow on the impervious surfaces and overland flow drainage paths.
(iii) Increased flow velocities and shorter travel times in constructed watercourse stream segments and channels.

WBNM94 can be used to model each of these three processes:

(i) An initial loss of 1 mm with zero continuing losses is adopted for impervious surfaces.
(ii) The lag parameter for overland flow on impervious surfaces is automatically reduced, based on the studies of Rao et al(9), Aitken(10) and NERC(11).
(iii) Modification of the watercourse from a natural to a constructed condition can be modelled in three ways (section 2.6). Given the watercourse cross section details, length, slope and roughness (both main channel and flood plain) WBNM94 calculates the depth-discharge-velocity-travel time relations to be used in each of these methods.

WBNM94 calculates overland flow and watercourse flow separately. If a subcatchment overland flow surface is modified, for example by urbanisation, but the watercourse remains in natural condition, this can be modelled directly. Conversely, if the watercourse is reconstructed but the overland flow surface is unchanged, this can also be modelled.

3 WBNM COMPUTER PROGRAM

3.1 Input Data File

For quality assurance purposes, WBNM94 uses a single input data file, which contains all information on the catchment, storm rainfall, rainfall losses, parameter values and detention basin culvert, weir and storage details. A standard template is used for the data file, which is edited for each job. A facility is available to convert old WBNM files to the new input and rainfall file format.

3.2 Output Data File

The output file structure has been developed to satisfy a number of requirements, namely quality assurance, model behaviour assessment, flexibility and rapid identification of key results. The output file prints:

* input and rainfall file names and creation dates for quality assurance purposes
* key input data parameters for data checking
* rainfall and runoff depths and volumes, and a runoff volume balance for each subcatchment as well as at the catchment outlet
* peak flows and times to peak for subcatchment overland flow, and for watercourse and storage reservoir inflows and outflows, as well as for diversions and total flows from the subcatchment
* maximum flows for all ARIs modelled and flags the corresponding critical storm duration

Output can be selected for all or for nominated subcatchments. Overland flow and total subcatchment hydrographs can be sent to separate files for use by other programs such as unsteady flow hydraulic modelling.

3.3 Graphic Displays

WBNM94 now has the ability to graphically display a number of useful plots. These include a Schematic plot of the catchment layout scaled proportionally to fit the screen, the Rainfall Hyetographs at each of the rain gauges as well as the weighted hyetographs at each sub-area. Output plots include Hydrographs at each subarea including inflow/outflow plots at basins. Finally, for each basin, height-discharge-storage plots are available. Future enhancements are planned to produce output in DXF format.

4 AN EXAMPLE OF WBNM94 APPLICATION

This application is to two adjacent catchments in Canberra. Gungahlin is 112 ha in size and in natural condition. Giralang is 94 ha and is 85% urbanised with residential housing.

Plots of rainfall and streamflow depths show that the directly connected impervious fraction is 35% (Boyd et al.,12). Because of the different land use, the hydrology of the two catchments is very different (Figure 3). The natural Gungahlin catchment was modelled first, with parameter c=0.9. Giralang was modelled next, with only one change, the directly connected impervious percentage was set at 35%. This automatically adjusts the rainfall losses and lag parameter of the impervious surfaces. WBNM94 was able to model the significantly different flood response of these two catchments (Figure 3).

5 CONCLUSIONS

The revised version of WBNM94 greatly expands its range of application, particularly to urban catchments. Flood routing through storage reservoirs, and watercourse routing can be modelled. Built in functions allow easy calculation of design storm intensities and temporal patterns as well as storage reservoir height-discharge relations. The program has been developed to satisfy quality assurance requirements.

Copies of the program can be obtained for a nominal charge from the first author, Dept. of Civil and Mining Engineering, University of Wollongong, WOLLONGONG 2522 (Tel.042 213054 Fax.042 213238 E-mail m.boyd@uow.edu.au).

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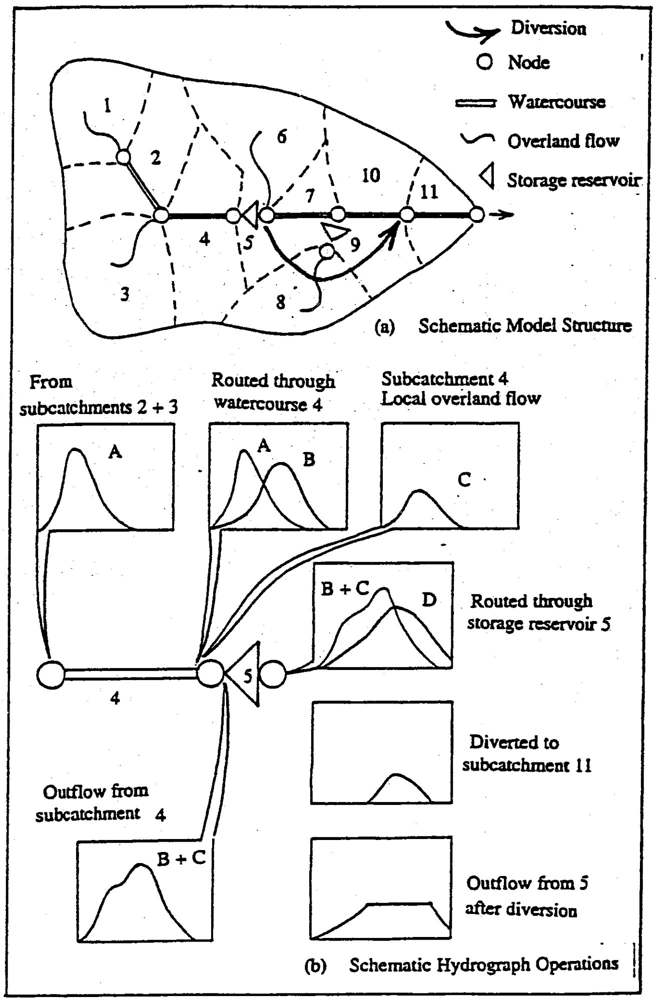

Figure 1 WBNM94 Schematic Model

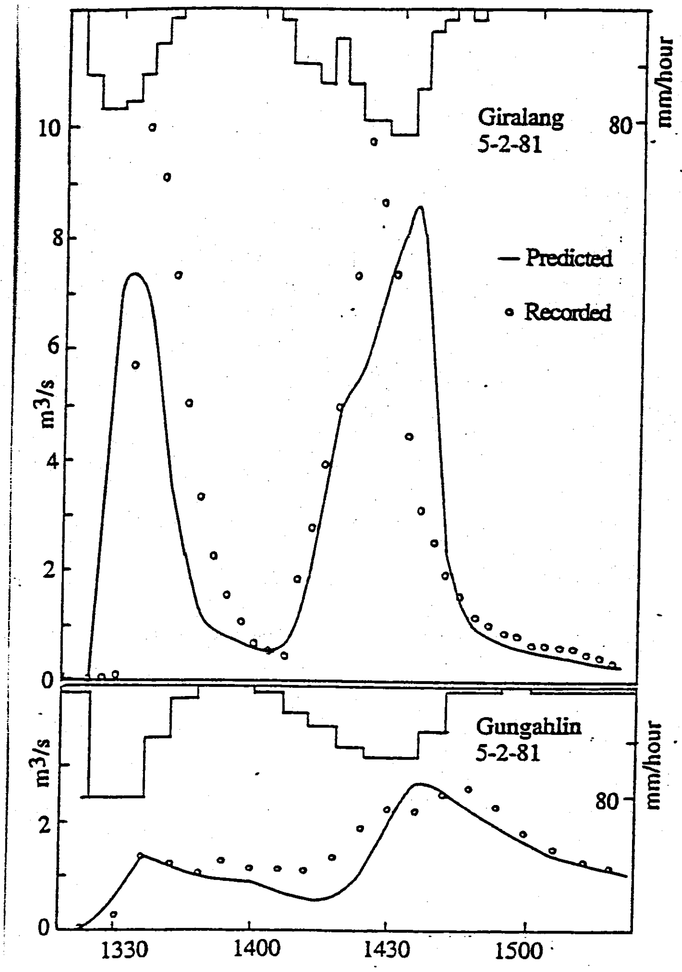

Figure 3 Hydrographs on Natural and Urban Catchments

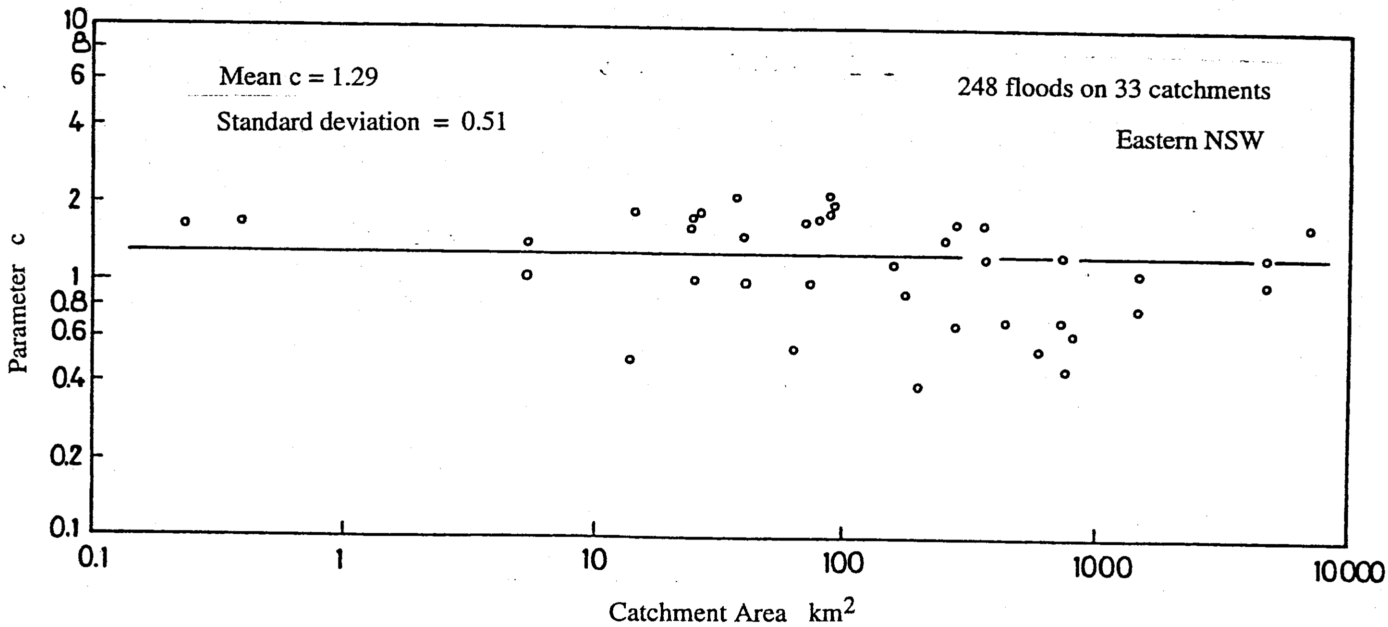

Figure 2 Model Parameter for a Range of Catchments