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POTENTIAL RUNOFF ACCUMULATION IN WHEATBELT TOWNS OF WESTERN AUSTRALIA

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by

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Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

Contents

POTENTIAL RUNOFF ACCUMULATION IN WHEATBELT TOWNS OF WESTERN AUSTRALIA

1 Introduction

The objective of this study, as part of the Rural Towns Program-Community Bores Project was to develop a methodology to determine the flood risk (high, moderate or low) that could be applied to selected rural towns in south-western Australia. The towns involved in the Rural Towns Program are displayed in Figure 1. This report covers the development and application of that methodology to two rural towns.

The method employed assessed flood risk by calculating the peak flood flow and volume of runoff generated by the catchment in which the townsite was located at a point just downstream of the town. The volume of runoff that could be generated within the townsite is also calculated. The combined volumes and peak flow characteristics are then assessed against the flow continuity and accumulation characteristics of the catchment.

The XP-Urban Drainage Design (UDD) model is applied to two townsites, Bakers Hill and Beacon and is used to calculate peak flows for their respective catchments. The model accounts for the spatial variation in flow rates across catchments, whereas other methods (e.g. Rational and Time-Area approaches) assume flow is uniform across catchments. The model allows precipitation rate, catchment slope, surface roughness, interception, depression storage, infiltration and evaporation to be considered.

The catchment peak flow and the townsite run-off volume are calculated for 1-, 6- and 24-hour rainfall events, for 2-, 5-, 10-, 20-, 50- and 100-year Average Recurrence Intervals (ARI's).

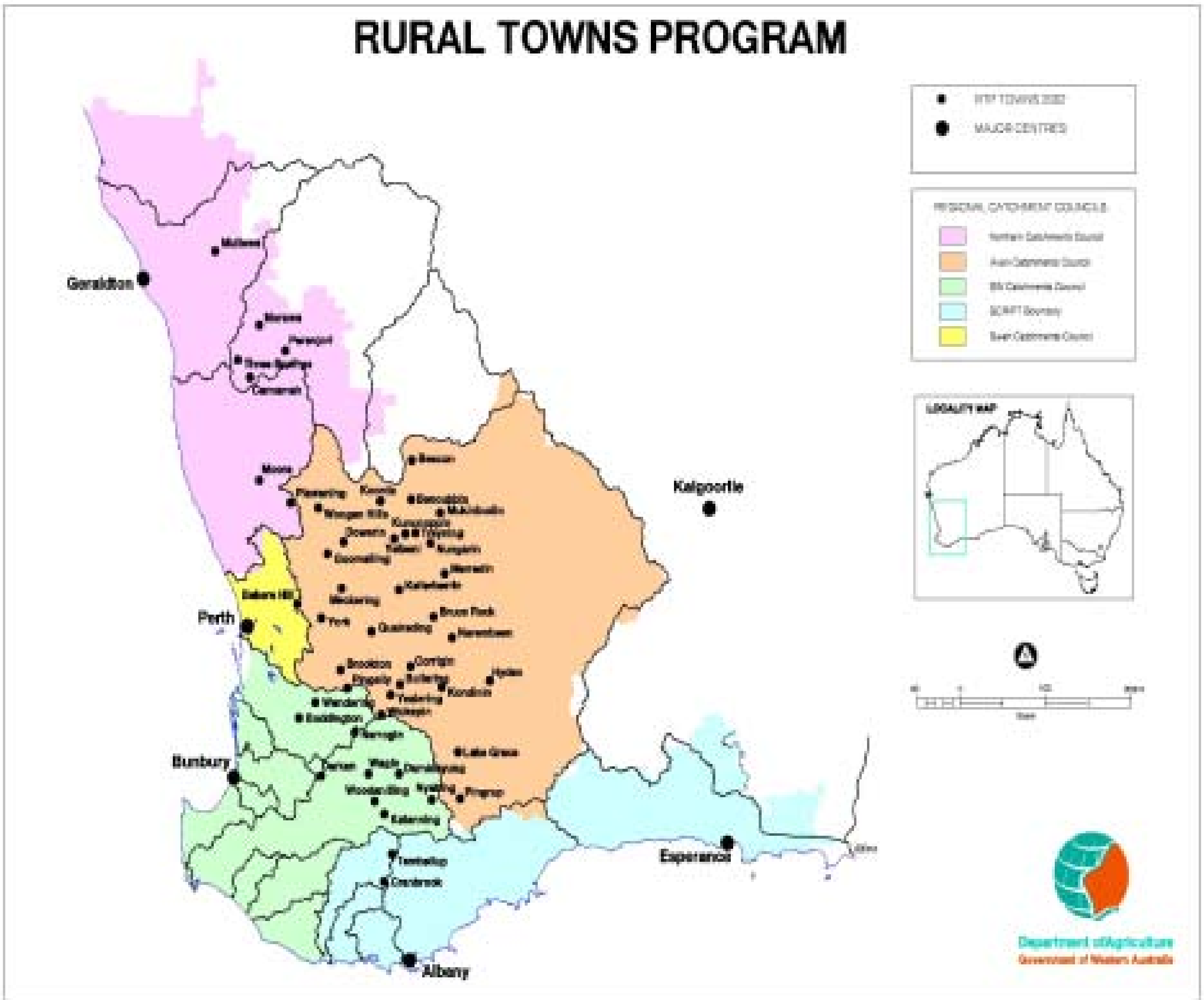

Figure 1 Locality map for towns included in the Rural Towns Program.

1.1 Data requirements

The information required to run the model and calculate run-off volumes was derived from available data sets and from site visits. The XP-UDD computer model was used for the flood risk study, due to the complexity of the problem.

The model applies the kinematic wave theory to the problem of flood estimation to overcome some of the perceived shortcomings in the Rational and Time-Area methods. Rational and Time-Area methods are based on the assumption of uniform flow throughout the catchment. In reality this is not the case, as the depth of flow would increase along the catchment.

Kinematic wave models have the potential to consider this spatial variation in flow rate throughout the catchment.

In addition to the spatial variation of flow rate, the model includes a number of other parameters to estimate surface runoff. These include precipitation rate, catchment slope and surface roughness, interception, depression storage, infiltration and evaporation. The model is also designed to:

- minimise the calibration effort;
- guide the modeller through the intricacies of numeric modelling;
- improve the speed of model simulation by using efficient data entry, and;
- check data consistency and remove data entry errors.

1.2 Available information

The following information was collated for each town catchment:

- rainfall intensities (estimated from ARR 1987)
- 2-metre elevation contours derived from a digital elevation model (DEM).
- area of catchment (pervious and impervious);
- area generating high run-off;
- area generating high recharge;
- infiltration (maximum and minimum likely rates);
- roughness coefficient (Manning's ‘n’).

2 Data Analysis

The data was used as a basis for spatial analysis of the DEM and to provide input into the XP-UDD model to estimate:

- Flow Accumulation;
- Roughness Coefficient, and;
- Peak Flood Flow and Runoff Volume.

2.1 *Flow Accumulation Modelling*

The physical characteristics of a surface determine the characteristics and behaviour of flow across it, and the flow across that surface changes its physical characteristics. The aspect at each location determines the direction of flow across a surface and the slope determines the energy of flow.

The evaluation of two townsites (i.e. Bakers Hill and Beacon) have demonstrated the importance of small scale catchment areas which have low slope angles, low flow lengths and concavities. Curvature of a surface will delineate where the surface is concave or convex, which results in acceleration or deceleration and convergence or divergence of flow. Convergent flow indicates a concentration of runoff in a valley or depression storage. Alternatively, divergent flow would indicate a ridge or rise within the landscape.

Schmidt *et al.* (1998) also concluded that models describing soil distribution in relation to geomorphology could assist in rationalisation of spatial heterogeneity of catchment geometry and soil parameters relevant to hydrologic modelling. Moreover, they suggest that quantification of the geo-morphometric catchment structure, e.g. in terms of contributing areas, is needed to describe the significant parameters important in estimating catchment runoff response to rainfall events. A general quantification of these techniques is still required, however recent advances in the analysis of landforms through the availability of high resolution DEMs has provided a useful dataset and with the relevant GIS techniques and tools, runoff response for upslope catchments for rural towns can be estimated.

The method employed in this analysis includes using a flow analysis that is generated using a spatial representation of the geomorphic landform for the catchment. The methodology uses a DEM, generated from ortho-photos and stored as ASCII file in Easting, Northing, and elevation (x, y, z) format.

The DEMs are interpolated and analysed by Arcinfo (ESRI, 2000) to create an ASCII raster format file and then imported into Arcview (ESRI, 2000). Arcview software with Spatial Analyst Extension is used to generate a grid of the study area, and a prediction of flow direction, flow accumulation, streamlines, watershed boundaries, slope and length of the streams. The process is illustrated in Figure 2.

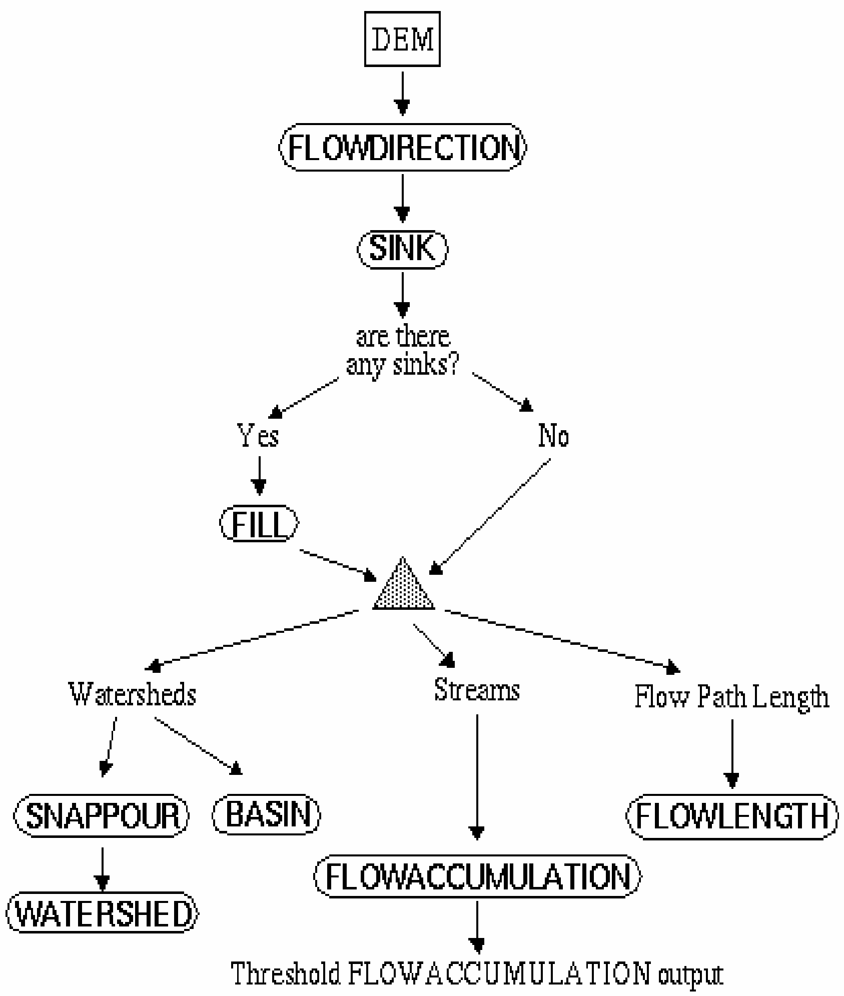

Figure 2. The process of extracting hydrologic information from a DEM

2.2 Estimation of Roughness Coefficient Values.

Values of Manning's roughness coefficient (n) are not as well known for overland flow as for channel flow because of the considerable variability in ground cover, transitions between laminar and turbulent flow, very small depths, and other factors. Some values of Manning's roughness coefficient are given in Tables 1 a & b, were used to estimate the value of the Manning roughness coefficient for each town and upslope catchment areas.

Table 1(a): Values of Manning's 'n' for different surfaces

Ground Cover	**"n" values**
Smooth Asphalt	0.012
Asphalt or concrete paving	0.014
Packed clay	0.03
Light turf	0.025
Dense turf	0.06
Dense shrubbery and forest litter	0.1

Table 2(b). Ground cover and ranges of Manning's n (adopted from Engman 1986).

Ground Cover	**"n" values**	**Range**
Concrete or asphalt	0.011	0.01 - 0.013
Bare sand	0.01	0.01 - 0.016
Gravelled surface	0.02	0.012 - 0.033
Bare clay-loam (eroded)	0.02	0.012 - 0.033
Range (natural)	0.13	0.01 - 0.32
Bluegrass sod	0.45	0.39 - 0.63
Short grass prairie	0.15	0.10 - 0.20
Bermuda grass	0.41	0.30 - 0.48

2.3 Estimating Peak Flow

Rainfall is the major source of water within agricultural catchments. Every rainfall event has different characteristics of temporal and spatial distribution and rainfall intensity and duration. Soil moisture deficit, topography and vegetation cover are critical factors in assessing the catchment (runoff) response to a proscribed rainfall event (Coles 1993). For instance a 1 in 10 year rainfall event may generate a 1 in 10, 20 or 50 year average recurrence interval (ARI) runoff event on the same catchment depending on the "wetness" or saturation of the catchment and the vegetation cover (Bligh, 1989).

The XP-UDD model was used to estimate the peak flood flow for the trial townsites. The model was selected because it can simulate the antecedent condition of the catchment, which is used to estimate peak flood flow in conjunction with infiltration and evaporation rates, topography, ARI Rainfall data, catchment area, Manning's coefficient, and detention storage. The model simulates real storm events based on the average rainfall (hyetograph) and other meteorological inputs and the catchment's or townsites physical characteristics (slope, area, surface type, conveyance, and storage) to predict the response to each rainfall event.

In simplest terms the program is constructed in the form of "blocks". Each runoff Block generates surface and subsurface runoff based on estimated rainfall hyetographs, antecedent conditions, land use, and topography. Manning's 'n' values represent the cumulative resistance (roughness) to the natural flow of water from a sub-catchment depending on the soil cover. This is most sensitive parameter in estimating the peak flood flow using the model. The input values of these parameters used in the simulations varied from 0.3-0.4.

2.4 Model Calibration

To ensure that the best representative estimates are obtained using this approach, the model should be calibrated using actual flow data. However, as there is no gauging station in any of the town catchments in the rural towns program except Moora, values used in the model simulations were substituted based on a calibrated model derived for the Moora town site.

3 Model Application

Achieving the best estimates of runoff and peak flows from any catchment is dependent on having a good understanding of the catchment characteristics, geomorphology, rainfall characteristics and flow hydraulics. These parameters vary between catchments and townsites, so it requires a degree of expert knowledge and understanding of modelling techniques to estimate and apply the critical parameters, particularly in regions where gauging data or flood frequency information is limited.

3.1 Peak Flow

The model simulations were run for 1, 6, and 24 hours rainfall storms for 2, 5, 20, 50 and 100 year ARI's based on historical events. The rainfall intensities for these events were estimated from ARR (Australian Rainfall and Runoff, 1987). Appropriate values of other input parameters were obtained from catchment visits and literature reviews. In some cases weighted averages have been used to simulate the site conditions within the catchment.

Simulations were run for estimating the peak flood flow for each town for 20, 50 and 100 years ARI rainfall storms using the rainfall intensities of 24 hour duration rainfall and other input data with the results of the model applied to two towns given in Table 2 as an example.

Table 2. Estimated peak flood flow for various ARI rainfall events the towns of Bakers Hill and Beacon.

	Est. Peak flood (m^3/s)	
ARI (years)	**Beacon**	**Bakers Hill**
2	0.7	2.8
5	1.2	4.5
10	2.3	9.3
20	3.1	16.3
50	4.3	26.2
100	8.7	43.9

Any change in the critical input parameters will produce significantly different results, therefore the peak flood flow and runoff values estimated in this report should not be used as an input for the design of any engineering structure like drains, culvert and diversion banks. ***Note that it is recommended that for any specific use the peak flood flow should be estimated again for the revised catchment conditions.***

3.2 Runoff Volume

The runoff volume generated by the town catchment was estimated for pervious and impervious sectors in the catchment separately. Runoff coefficients of 0.1 and 0.9 were used for pervious and impervious areas respectively. The following formula was used to estimate runoff:

V = ARCK

Where:

V = Runoff volume in cubic metres

A = Area of catchment (Pervious or impervious) in hectares

R = Rainfall amount in mm for different ARI (Rainfall intensity x Duration)

K = Conversion factor, (equal to 10)

Runoff volumes generated for the town catchments of Beacon and Bakers Hill are given in Tables 3a & b as an example.

Table 3(a) Run-off volumes for the pervious and impervious areas of the Baker Hill townsite generated by rainfalls of various ARI duration and intensities

Average recurrence interval (years)	Rainfall duration (h)	Rainfall intensity (mm/h)	Rainfall (mm)	Townsite (pervious) run-off volume (m^3)	Townsite (impervious) run-off volume (m^3)
20	**1**	29.5	29.5	1770	10620
	6	9.0	54.0	3240	19440
	24	3.5	84.0	5040	30240
50	**1**	35.8	35.8	2148	12888
	6	11.0	66.0	3960	23760
	24	4.4	105.6	6336	38016
100	**1**	39.1	39.1	2346	14076
	6	12.6	75.6	4536	27216
	24	5.1	122.4	7344	44064

Table 3(b). Run-off volumes for the pervious and impervious areas of the Beacon townsite generated by rainfalls of various ARI durations and intensities

Average recurrence interval (years)	Rainfall duration (h)	Rainfall intensity (mm/h)	Rainfall (mm)	Townsite (pervious) run-off volume (m^3)	Townsite (impervious) run-off volume (m^3)
20	1	29.5	29.5	575	1725
	6	8.5	51.0	1000	2975
	24	4.25	78.0	1525	4575
50	1	38.0	38.0	750	2225
	6	11.5	69.0	1350	4025
	24	4.0	96.0	1875	5625
100	1	45.0	45.0	875	2625
	6	14.0	84.0	1650	4925
	24	5.0	120.0	2350	7025

4 Flood Risk Assessment

The criteria to classify a town's relative flood risk level were based on the calculated rates of flow, the *accumulation potential* of the townsite and the catchment above the town. The accumulation potential depends on the relative magnitudes of the potential inflows and outflows. This potential depends on the upstream and downstream slopes of the natural drainage line passing within or nearby the town.

If the upstream and downstream slope is same then the runoff generated from the catchment above the town is not expected to accumulate in the town if free flow conditions prevail downstream. If downstream slope of drainage line is less than upstream slope or free flow conditions do not persist then the runoff is expected to accumulate within the townsite.

The peak flows for the catchment for 20-, 50- and 100-year ARIs generated for events of 24 hours duration were used to assess the flood risk within the townsites of Bakers Hill and Beacon with the risk summarised in Tables 4 a & b.

Table 4(a). Flood risk to the Bakers Hill townsite for various ARI events of 24 hours duration

ARI (years)	Peak flow for catchment (m^3/s)	Volume generated by townsite (m^3)	Accumulation risk	Flood risk	Overall flood risk
20	16.3	35280	Low	Low	Low
50	26.2	44352	Low	Low	
100	43.9	51408	medium	Medium	

Table 4(b). Flood risk to the town of Beacon for various ARI events of 24 hours duration

ARI (years)	Peak flow for catchment (m^3/s)	Volume generated by townsite (m^3)	Accumulation risk	Flood risk	Overall flood risk
20	3.1	6100	Low	Low	Low
50	4.3	7500	Low	Low	Low
100	8.7	9375	Low	Low	Low

Based on the modelled outputs Bakers Hill is at low risk from flooding from storm events with up to 50-year ARIs and at medium risk from storms with 100-year ARIs. Localised flooding may be associated with rainfall events with ARIs greater than 20 years, with low-lying areas mainly affected. For storm events with ARI's greater than 50 years, a considerable area of the town may have localised flooding.

Similarly, using the same approach Beacon is considered to be at low risk from flooding; however localised flooding may be associated with rainfall events with ARIs greater than 50 years. Town infrastructure may be at risk if located in low elevation areas on designated flow paths.

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