Hydro 2000, 3rd International Hydrology and Water Resources Symposium, Institution of Engineers Australia, Interactive Hydrology, pp. 674-679. Perth, Nov 2000.

Multi Stage Outlet Compensating Basins for Multi ARI Design

S. Sivanathan (1), S. Martens (2), M. Sivapalan (3) and J. Davies (2)

(1) The Geo-Eng Group, Leederville, WA, Australia
(2) JDA Consultant Hydrologists, Subiaco, WA, Australia
(3) Centre for Water Research, University of Western Australia, Australia

SUMMARY

Compensating basins reduce the peak runoff discharging from an urbanised catchment by the temporary storage of runoff in excess of the discharge capacity of the basin outlet pipe. Basins are generally designed to attenuate post-development peak runoff rates to pre-development levels for a specific design Average Recurrence Interval (ARI) storm event, typically 5 to 10 years, via an outlet pipe. Contrary to common belief this design technique however does not provide attenuation of post-development peak runoff to predevelopment levels over the full range of ARI's. Indeed for more frequently occurring storm events (eg. 1 to 2 year ARI), post-development can exceed pre-development runoff rates.

Hence there is a risk that compensating basins, unless properly designed, will not perform the function of reducing the frequent, low ARI flow rates to those which occurred pre-development.

This is a critical consideration for stormwater management in areas where receiving environments are susceptible to erosion. This paper details the development of a model (CBASIN) to assist in the design of multiple outlet configurations to enable attenuation of post-development peak runoff to pre-development levels over a wide range of ARI's. A design procedure for using the model in conjunction with the RAFTS-XP runoff routing model is presented together with case examples of the models application in design.

1. INTRODUCTION

Urbanisation of land increases both the volume and rate of runoff from pre-development conditions, and peak flow attenuation is an important objective of urban stormwater management to control the impacts of urbanisation on receiving environments. Compensating basins are widely used to achieve this objective. A basin schematic and hydrographs are illustrated in Figure 1.

Compensating basins temporarily store that portion of runoff which is in excess of outlet pipe capacity to reduce peak flow downstream of the basin. Traditional basin design practice in Western Australia and elsewhere involves a single or multiple pipe outlet (with common invert and diameters) typically sized for flow attenuation for a specific ARI (5 or 10 years), and a spillway to pass major (100 yr ARI) storm events.

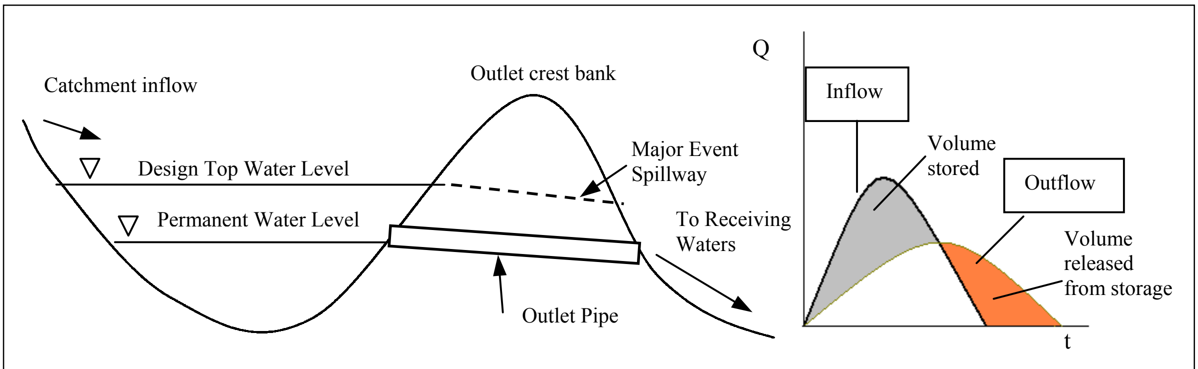

Figure 1 Compensating Basin Schematic and Hydrograph

This design approach cannot provide attenuation of post-development peak runoff rates to pre-development rates over the full range of ARI's. In particular, for more frequently occurring storm events (1 to 2 year ARI) than the design storm event, post-development peak runoff may still significantly exceed pre-development levels. This is because the designed outlet pipe diameter is too large to provide the required attenuation for more frequent events.

Figure 2 shows that for a pre-development runoff event of Y_D year ARI, the design event with peak flow Q_D, a post-development peak in excess of Q_D and a compensated basin outflow of Q_D. Figure 2 also shows that for

Hydro 2000, 3rd International Hydrology and Water Resources Symposium, Institution of Engineers Australia, Interactive Hydrology, pp. 674-679. Perth, Nov 2000.

more frequent events $Y_1 < Y_D$ year ARI, a lower pre-development peak Q_1 however both post-development basin inflow and outflow exceed Q_1, indicating that the basin is not attenuating small ARI flows $Y_1<Y_D$ to predevelopment levels.

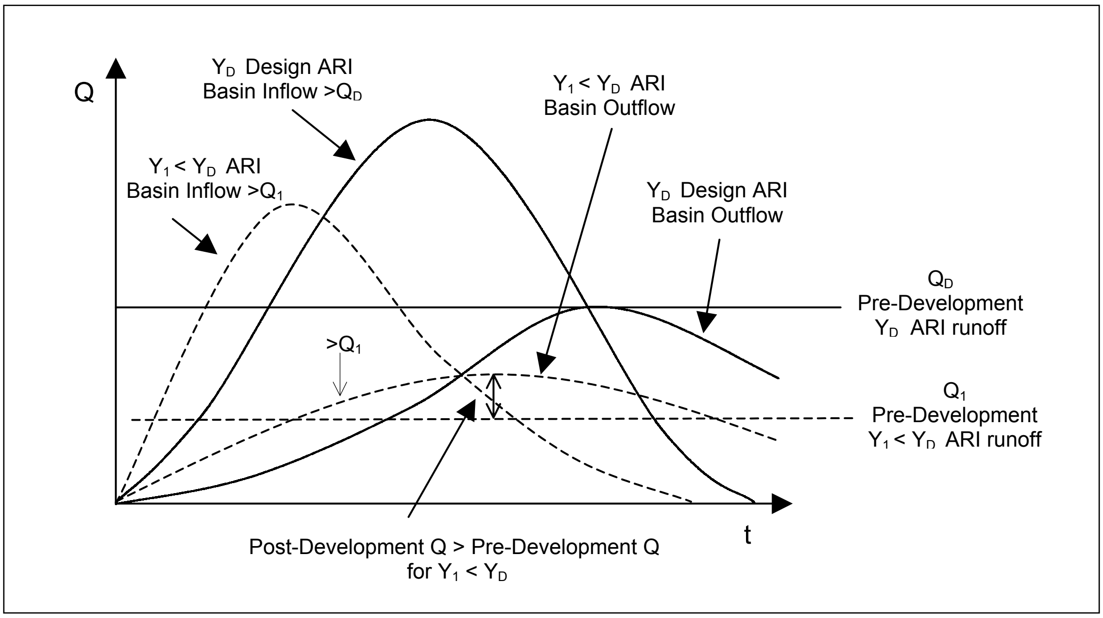

Figure 2 Traditional (Single Invert Outlet) Basin Hydrographs Compared with Pre-Development

This is a critical consideration for stormwater management, particularly in areas where receiving environments are susceptible to erosion. This is the case in urbanised catchments worldwide, especially where there is significant topography and erodible soils. In Western Australia this is particularly important in the context of urban development in steeper catchment with comparatively higher erosion risk located on the Darling Scarp, but less of a consideration on the coastal plain including the city of Perth (Figure 3).

Whereas attenuation of major flow events is a consideration for flood protection of downstream communities, the insidious process of erosion of drains and creeks downstream of urban areas is more evident on a routine basis. This is particularly an issue for local government engineering departments whose responsibilities typically include maintenance of a myriad of minor flow channels, where ongoing erosion in minor storm events is very evident.

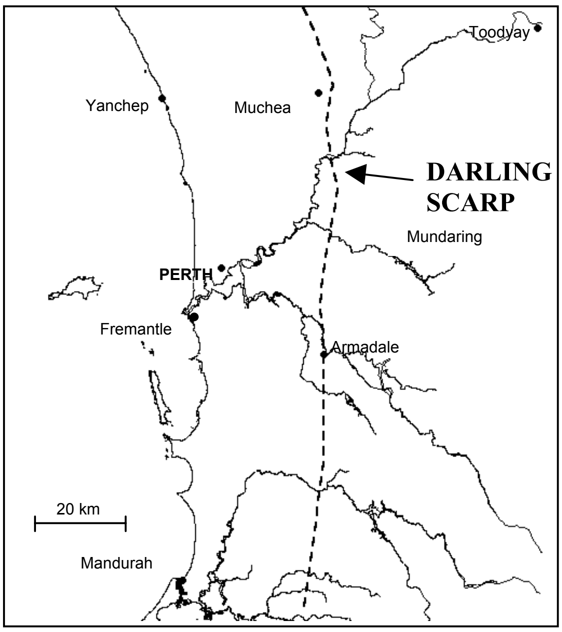

Figure 3: Location of Perth and the Darling Scarp

The approach recommended in this paper is a refinement of a procedure described in a WA manual for managing urban stormwater quality (WRC, 1997). The manual incorporates water sensitive design principles and provides guidelines for best planning and management practices.

The manual recommends the use of multiple stage outlets in constructed wetland and basin design, however design techniques are primarily presented in terms of increasing retention time to manage discharge water quality rather than design techniques for managing peak discharge.

This paper provides a specific methodology and guidelines to assist practitioners in design of these outlets for peak flow attenuation over a wide range of ARI's. The paper supports the approach of WRC (1997), and facilitates its interpretation.

Hydro 2000, 3rd International Hydrology and Water Resources Symposium, Institution of Engineers Australia, Interactive Hydrology, pp. 674-679. Perth, Nov 2000.

2. MULTIPLE STAGE & RISER OUTLETS

A riser outlet comprises of a series of orifices along a vertical pipe, with a spillway at the top of the riser to take flows when the capacity of the riser is exceeded. The riser outlet is designed by determining the diameter, spacing, and number of orifices required, and a spillway level and capacity if required.

Assuming inlet control, the stage/discharge relationship can be derived as follows. When an orifice is not fully immersed, outflow can be determined by the circular-crested weir equation (Ramamurthy & Vo, 1993) :

$$Q = \frac{2}{3} C_D \sqrt{(2gH)^3} \qquad \text{---- (Eqn 1)}$$

Where Q is the discharge passing over a unit length of the weir (m^3/s), C_D is the coefficient of discharge, g is acceleration due to gravity (m/s^2), and H is the total head of the approaching flow above the weir (m).

When fully immersed, outflow is determined using the orifice equation (Ramamurthy & Vo, 1993) :

$$Q = C_d A_o \sqrt{(2gH)} \qquad \text{---- (Eqn 2)}$$

Where Q is the discharge (m^3/s), A_o is the orifice diameter (m^2), C_d is the orifice drag coefficient and H is the height of water level above the centre of the orifice (m).

3. CBASIN SPREADSHEET MODEL

CBASIN (Sivanathan, 1999) is a spreadsheet based model developed to assist in the design of riser outlets and enable the testing of various riser and spillway configurations, including variable orifice numbers, diameters, and levels to attenuate flows over a wide range of ARI's. CBASIN calculates a stage discharge relationship for flow through each orifice, which are accumulated to determine a total stage discharge relationship for a given outlet configuration.

Application of riser outlet theory in CBASIN is illustrated (Figure 4) considering a riser with three orifices. Assuming the changing water level is denoted by h_w, the orifices are of equal diameter D, and Q is the outflow:

(1) if $h_w < h_1$, then Q = 0

(2) if $h_1 < h_w < (h_1 + D)$, then Q = weir formula for first outlet

$$\Rightarrow Q = \frac{2}{3} C_D \sqrt{2g}(h_w - h_1)^{3/2}$$

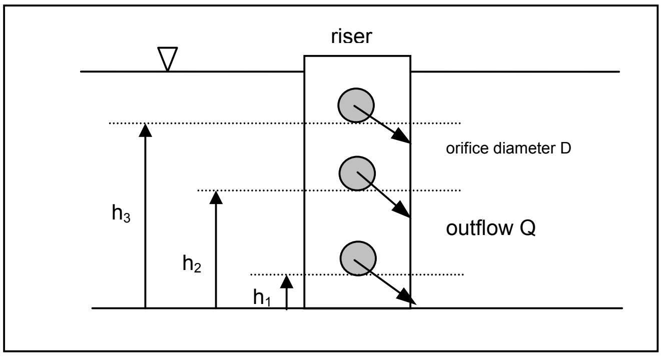

Figure 4: Schematic of Riser with 3 Orifice Outlet

(3) if $(h_1 + D) < h_w < h_2$, then Q = orifice formula for first outlet $\Rightarrow Q = C_D \frac{\pi D^2}{4} \sqrt{2g\left\{h_w - (h_1 + \frac{D}{2})\right\}}$

(4) if $h_2 < h_w < (h_2 + D)$, then Q = weir formula for second outlet add $Q_{ORIFICE\_1}$; the discharge from the first outlet $\Rightarrow Q = \frac{2}{3} C_D \sqrt{2g}(h_w - h_2)^{3/2} + Q_{ORIFICE\_1}$

(5) if $(h_2 + D) < hw < h_3$, then Q = orifice formula for second outlet add $Q_{ORIFICE\_1}$ $\Rightarrow Q = C_D \frac{\pi D^2}{4} \sqrt{2g\left\{h_w - (h_2 + \frac{D}{2})\right\}} + Q_{ORIFICE\_1}$

(6) if $h_3 < h_w < (h_3 + D)$, then Q = weir formula for third outlet, add $Q_{ORIFICE\_1}$ and $Q_{ORIFICE\_2}$, the discharge from the second outlet. $\Rightarrow Q = \frac{2}{3} C_D \sqrt{2g}(h_w - h_3)^{3/2} + Q_{ORIFICE\_1} + Q_{ORIFICE\_2}$

(7) if $(h_3 + D) < h_w$, then Q = orifice formula for third outlet add $Q_{ORIFICE\_1}$ and $Q_{ORIFICE\_2}$ $\Rightarrow Q = C_D \frac{\pi D^2}{4} \sqrt{2g\left\{h_w - (h_3 + \frac{D}{2})\right\}} + Q_{ORIFICE\_1} + Q_{ORIFICE\_2}$

4. DESIGN TECHNIQUE USING RAFTS-XP & CBASIN

The RAFTS-XP runoff routing model (WP Software, 1994) is widely used in the design of compensating basins. The model has limited capacity to model multiple outlet configurations. Use of CBASIN in conjunction with RAFTS-XP involves a technique of iterative RAFTS-XP modelling to determine the stage discharge curve to attenuate post-development flows to pre-development levels for the required range of ARIs. The resulting stage discharge curve is then input to CBASIN and riser outlet parameters iterated to match the required discharge characteristics (Figure 5).

Application of CBASIN is valid assuming free discharge from the basin with no backwater effects.

5. CASE EXAMPLE

This case example is based on a 50 ha residential development located approximately 30 km east of Perth in the Darling Scarp, where a compensating basin with single outlet pipe and spillway was constructed for 10 year ARI attenuation of post-development flows to pre-development levels. Downstream of the development and its compensating basin, the receiving environment is largely agricultural land on moderate slopes and susceptible to erosion. Downstream farm dams are periodically filled by sediment deposition and perceived increases in the quantity of sediment since residential development has resulted in community concern.

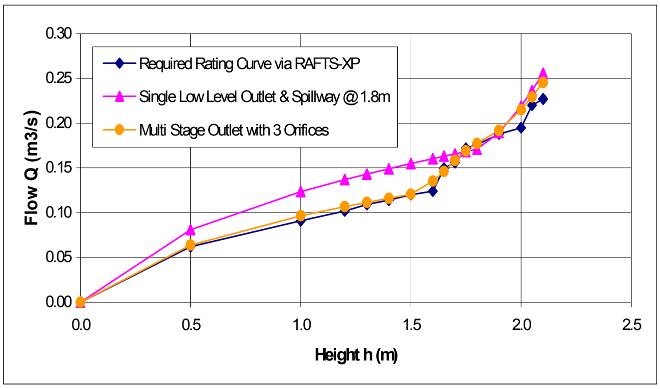

Figure 5 Comparison of rating curves using CBASIN

Site constraints limited the basin size to a maximum storage capacity of approximately 3800 m^3. The outlet pipe diameter of the basin was 300 mm, the minimum acceptable outlet diameter of the governing local authority. This resulted in the post-development flow at the 10 year design ARI being virtually equal to pre-development. The spillway level was set at the 10 year ARI basin water level.

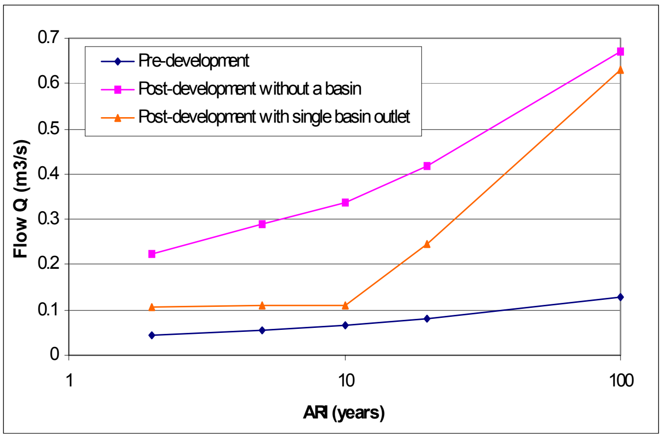

Figure 6 : Flood Frequency Curve for Case Example

Modelling of pre-development and post-development conditions using RAFTS-XP for the compensating basin for 2 to 100 year ARI events showed that while the basin provided the required attenuation to predevelopment levels at the 10 year ARI event, for all other storm events post-development basin outflows exceeded pre-development levels.

For frequently occurring events, flows were still typically in the order of two times greater (Figure 6) than pre-development levels.

It is these flows which occur year after year and rapidly cause erosion problems, soon after basin construction, rather than the rarer flood events

Iterative modelling using RAFTS-XP was completed to derive the required storage discharge relationship for attenuation of the full range of ARI's. CBASIN was then used to analyse various multiple stage outlet configurations. Examples of multi stage orifice arrangements providing attenuation over a range of ARI's are shown in Figures 7a and 7b. The orifice arrangement shown in Figure 7b consisting of five vertical orifices with multiple horizontal orifices at the higher stage levels was found to provide the best attenuation.

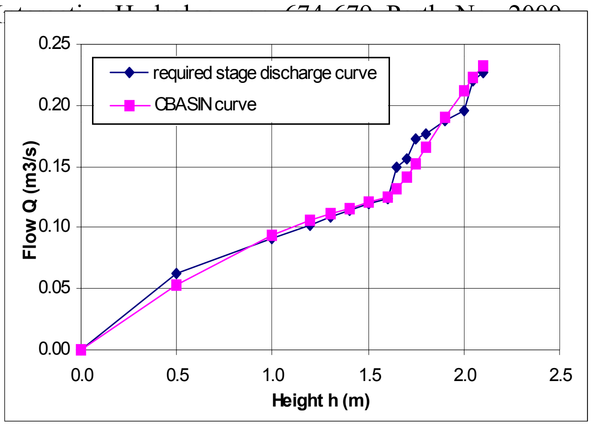

Figure 7a : Four Vertical Orifices Configuration

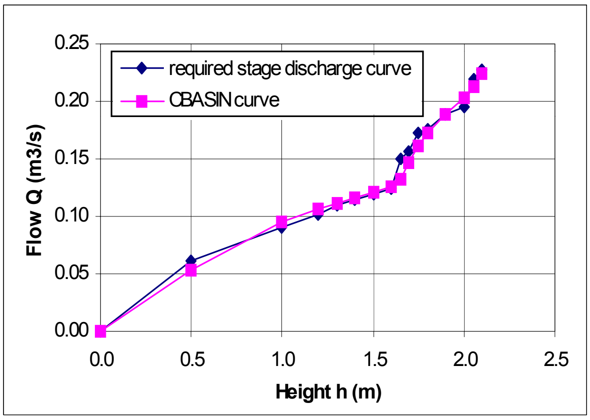

Figure 7b : Five Vertical Orifice Levels with Multiple Horizontal Orifices at Higher Levels

6. CONCLUSION

Traditional compensating basin design which adopts a single outlet configuration does not ensure that post-development basin outlet is reduced to pre-development rates over a broad range of ARI's. In fact in most cases post-development basin outflow will exceed pre-development for all but the specific ARI design event.

Multiple stage outlet however can satisfy this condition by allowing for an increase in attenuation storage with stage, commensurate with the increasing ARI.

The program CBASIN was developed to assist in the analysis of multiple stage outlets to provide attenuation over the full range of ARI's. It has been used in this paper to demonstrate a simple alternative basin design methodology for considering peak flow attenuation which can be adopted through conjunctive use of a spreadsheet based model together with existing basin design software (RAFTS-XP).

7. RECOMMENDATION

Design of compensating basins should ensure that flow events both less than and greater than the design event are adequately reduced to protect downstream receiving environments. Where problems are considered likely, appropriate software should be developed and expert advice obtained.

8. ACKNOWLEDGEMENTS

Research for this paper was undertaken as a final year honours project by S Sivanathan at the University of Western Australia (UWA) under the supervision of M. Sivapalan and assisted by S Martens and J Davies. The authors acknowledge the assistance of XP-Software in providing the model RAFTS-XP to UWA at a discount rate.

9. REFERENCES

1. Nix, S (1994), Urban Stormwater Modelling and Simulation, CRC Press, Inc, USA.
2. Stormwater Management – Volume One: Stormwater Policy Handbook (1997), MA Dept of Environmental Protection & MA Office of Coastal Zone Management.
3. Guo, Y. & Adams, B.J. (1999), "An analytical probabilistic approach to sizing flood control detention facilities", Water Resources Research, Vol 35 (8), p 2457-2468.
4. Boenisch, M.E. & Ogle, A.P. (1989), "Detention Storage for Controlling Discharges from Development Sites", Fifth National Local Government Engineering Conference, Sydney.
5. Rosener, L.A (1989), "Current Water Quality Issues in Stormwater Management in the United States" Hydrology and Water Resources Symposium, University of Cantebury Christchurch, New Zealand.
6. Waters & Rivers Commission (1998), A Manual for Managing Urban Stormwater Quality in Western Australia, The Institution of Engineers.
7. Ramamurthy, A.S. & Vo, N.D. (1993), "Characteristics of Circular-Crested Weir", Journal of Hydraulic Engineering Vol 119.
8. Curtis, D.C & McCuen, R.H (1997), "Design Efficiency of Stormwater Detention Basins", Journal of the Water Resources Planning and Management Division, Vol 103, p125-140.

Hydro 2000, 3rd International Hydrology and Water Resources Symposium, Institution of Engineers Australia, Interactive Hydrology, pp. 674-679. Perth, Nov 2000.

9. Sivanathan, S. (1999) The Role of Compensating Basin in Reducing Peak Flow, Velocity and Erosion University of Western Australia.
10. WP Software (1994) RAFTS-XP : Users Manual Version 4.0, January 1994.
11. Wong, T.H.F., Breen P.F., Somes N.L.G., and Lloyd, S.D., (1999) "Managing Urban Stormwater Using Constructed Wetlands", Cooperative Research Centre for Catchment Hydrology, and Cooperative Centre for Freshwater Ecology, Industry Report 98/7 Second Edition.