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Preliminary Estimation Methods for Sizing Detention Basins in Queensland

C. J. Scraggs and C. J. Lemckert

School of Engineering,
Griffith University, QLD, 4215 AUSTRALIA

Abstract
The Queensland Urban Drainage Manual gives four methods for the preliminary sizing of detention basins, but it does not give any guidelines as to when to use each method. This paper develops some guidelines based upon the modelling of numerous detention basins and comparing the modelled detention volumes to the estimates given by each of the four methods.

Introduction
Urban stormwater management systems typically include detention and retention facilities (basins) to mitigate the negative impacts of urbanisation on stormwater drainage. These basins act as a filter mechanism and are primarily designed to hold water and slowly release it at a rate similar or less than that of encountered before urbanisation. That is, the intent is to allow water out of the urbanised region at an artificial, but pseudo natural, rate.

To size a basin for the quantity control of stormwater runoff an initial estimate is obtained from one of the numerous preliminary sizing methods described in literature, (eg. [1, 2, 3, 4, 5, 6, 7, 8, 9]). From this preliminary estimate and the site topography, the basin, including the outlet structure can then be designed. To determine the efficiency of the basin, various runoff hydrographs are then routed through the basin using stormwater management software. The basin and the outlet structure are then reconfigured until the outflow hydrograph satisfies the criteria set by the designers.

The Queensland Urban Drainage Manual (QUDM) [10] gives four methods for the preliminary sizing of a detention basin. However, QUDM does not give any guidelines as to when to use each method, but it does state 'these procedures may give widely different answers and should be used with care'. This paper develops some guidelines as to which method to use for any given situation.

Queensland Urban Drainage Manual
The four methods for the preliminary sizing of detention volumes given in QUDM [4] yield the following four equations:

$$\frac{V_s}{V_i} = \frac{r(1+2r)}{3} \tag{1}$$

$$\frac{V_s}{V_i} = r \tag{2}$$

$$\frac{V_s}{V_i} = \frac{r(3+5r)}{8} \tag{3}$$

$$\frac{V_s}{V_i} = \frac{r(2+r)}{3} \tag{4}$$

where V_s is the storage volume, V_i is the inflow volume, and r is a reduction ratio calculated by:

$$r = \frac{(Q_i - Q_o)}{Q_i} \tag{5}$$

Q_i and Q_o are the peak inflow and outflow rates of the detention basin.

Equations 1-4 are referred to, after the authors of which each method is based, as the Culp, Boyd, Carroll and Basha methods respectively.

Method Comparisons
The pre- and post-development catchment hydrology details were obtained for several urban developments using the rational method as described in QUDM [10]. A detention basin for each catchment was then designed to reduce the post development flow rates to below the pre-development flow rates.

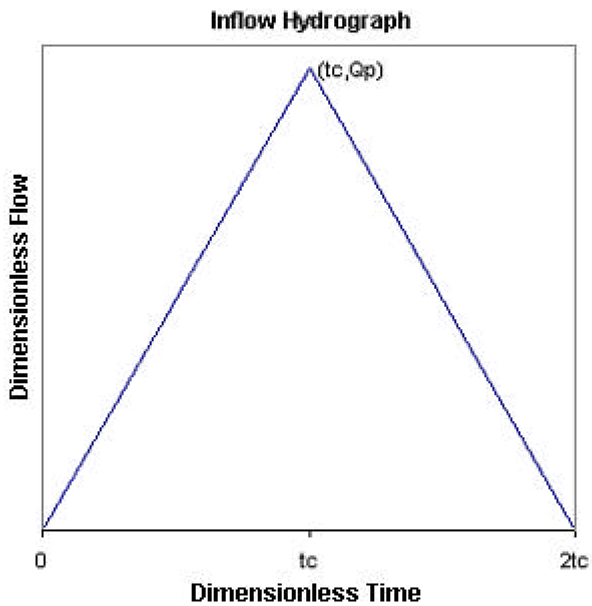

Figure 1. The general shape of the inflow hydrographs that were routed through the detention basins.

To model the detention basins, a commercial software package entitled XP-SWMM was used. XP-SWMM is a link-node model that performs hydrology, hydraulics and quality analysis of stormwater and wastewater drainage systems including sewage treatment plants, water quality control devices and Best Management Practices (BMP's). For the modelling of detention basins, the stage versus area relationship and the outlet structure were defined set. The software uses the St. Venant dynamic flow equations to route flows through the basin.

The flows that were routed through the basins were hydrographs from storm events up to a 1 in 100 year storm. These hydrographs were derived from the rational method. A triangular hydrograph as shown in Figure 1 was used, with a peak flow rate of *Qp* (from the rational method), and the time to peak flow being equal to the time of concentration of the catchment. Typical peak flow rates through the basin ranged between 0.3 and 8.0 m^3s^{-1}, however some basins had flow rates up to $15m^3s^{-1}$ routed through them.

The typical basin shape consisted of a square base, and side slopes equal to 1 vertical to 6 horizontal. The length of the basin base was determined so that the storage from a 1 in 20 year storm was chosen to be no deeper than 1.2 m. The lengths ranged between 8 and 55 m, but the majority were between 10 and 20 m.

A typical outlet structure of the detention basins consisted of two pipes and a weir. For smaller reductions in the flow, a greater number of pipes were used, the greatest consisting of six pipes and a weir.

The preliminary estimates from Equations 1-4, an average of these estimates, and the detention volume given by the stormwater management software for each storm event were then compared. For each of the basins the typical results are shown in Figure 2. These results show that the modelled detention volumes lie between the estimates obtained by using the Basha and Boyd methods. However, there was one catchment where the modelled volume was better represented by the Carroll method. Figure 3 shows these results.

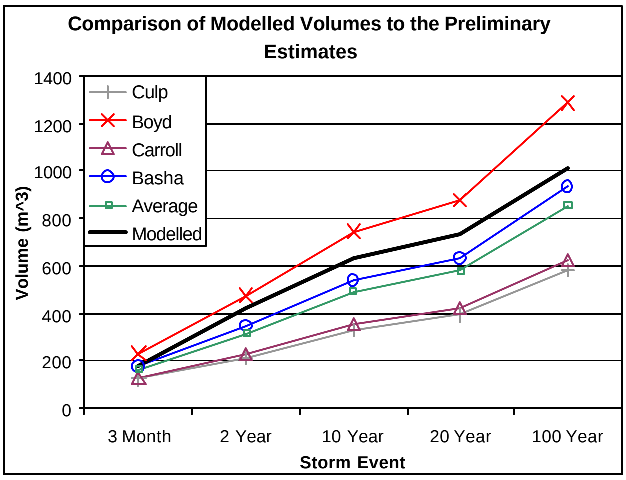

Figure 2. Typical results obtained from the comparison of the preliminary and modelled detention volumes.

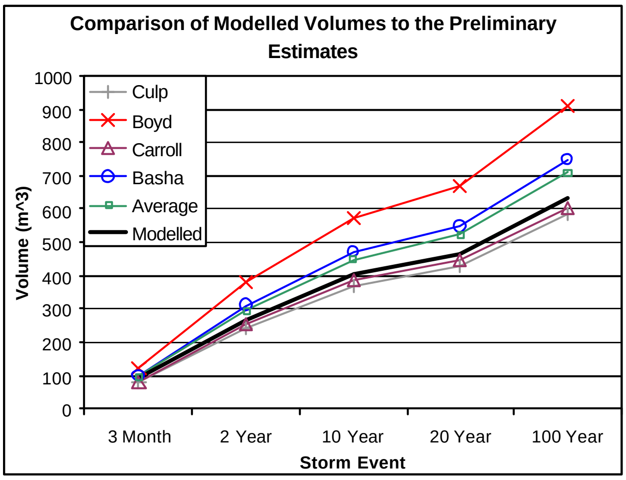

Figure 3. Results showing the modelled detention volumes are more accurately estimated by the Carroll method.

A comparison of the catchment data, including size, slopes and shape showed that this catchment did not differ greatly from the majority of the others. However, the extent of the development of this catchment did differ greatly being that it was the sole catchment that is completely contained within the development. Due to this a greater reduction in the post-development flow rate was needed. Figures 4 and 5 show the pre and post development hydrographs calculated by using the rational method, along with the outflow hydrographs given by the flood routing software. What should be noted is that the reduction in the post-development peak flow rates in Figure 5 is much greater than that of Figure 4.

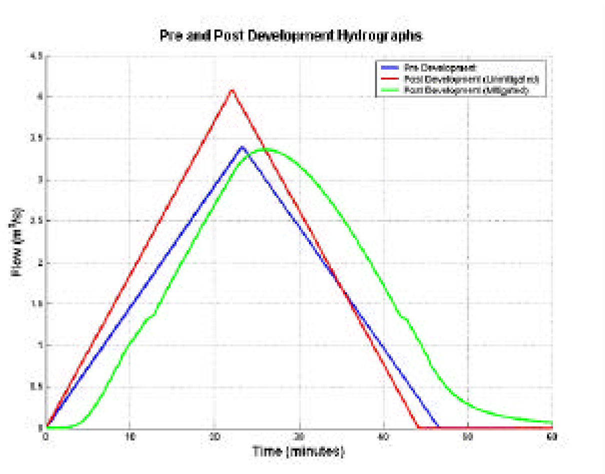

Figure 4. Typical hydrographs where the modelled detention volume is best estimated by the Basha or Boyd methods.

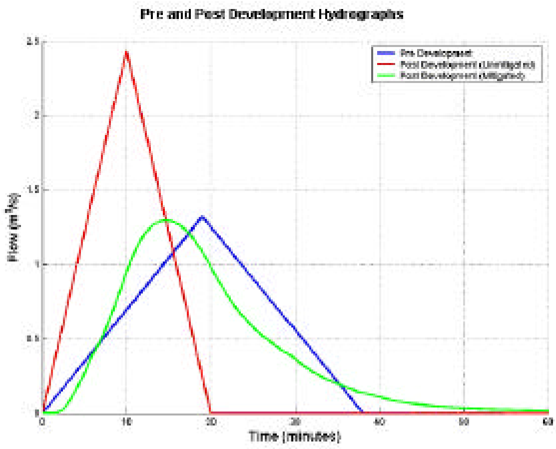

Figure 5. Hydrographs from the same catchment as that for figure 3.

The results suggest that there may be a relationship between the accuracy of each preliminary method and the reduction in the flow that is to be achieved. However, the majority of the catchments that were modelled had reduction ratios between 0.2 and 0.3. To determine the relationship between the preliminary methods and the reduction ratio, *r*, numerous detention basins were designed and modelled for a number of catchments with reduction ratios between 0.05 and 0.95. Figures 6 through 8 show the modelled and preliminary estimates of the detention volume for a single catchment with detention basins designed for varying reductions in the peak flow rate. Figure 6 shows the results after a reduction of 15%, and as can be seen the modelled volume is best represented by the Basha estimates. As the reduction in the flow increases the modelled volumes decrease with respect to the preliminary estimates.

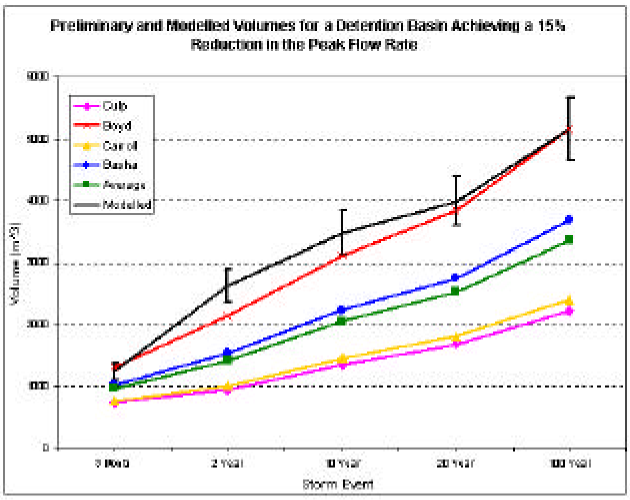

Figure 6. A comparison of the preliminary and modelled detention volumes showing the Boyd method produces the best approximation for a reduction ratio of 0.15 for this catchment.

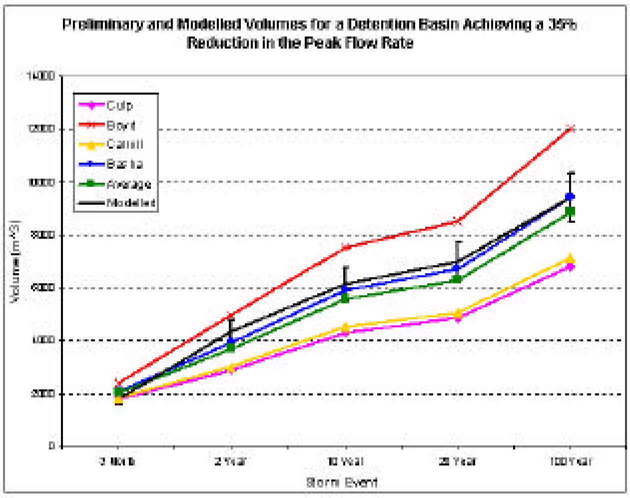

Figure 7. A comparison of the preliminary and modelled detention volumes showing the Basha method produces the best approximation for a reduction ratio of 0.35 for this catchment.

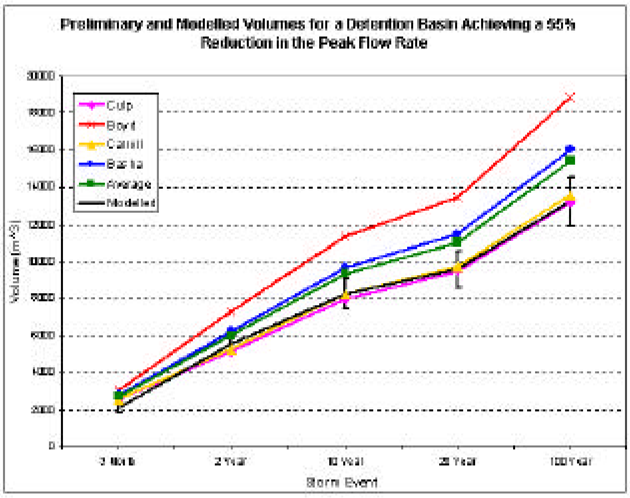

Figure 8. A comparison of the preliminary and modelled detention volumes showing the Carroll and the Culp methods produce the best approximation for a reduction ratio of 0.55 for this catchment.

This trend was typical of each of the catchments that were modelled. As the reduction ratio increased the modelled volume tended towards the smaller estimates obtained from the Carroll and the Culp methods.

Using the results from the catchments obtained from the urban developments, and the results from the additional catchments with varying degrees of reduction, guidelines for the use of each preliminary estimation method were produced and are given in Table 1.

Table 1. Recomendations for the use of the preliminary detention storage methods given in QUDM [1].

Condition	Method
0.00 = *r* = 0.25	Boyd Method
0.25 = *r* = 0.45	Basha Method
0.45 = *r* = 0.60	Carroll Method
0.60 = *r* = 1.00	Culp Method

Conclusion

By modelling numerous detention basins, and comparing the modelled detention storage volumes to the preliminary estimates obtained by four methods outlined in the Queensland Urban Drainage Manual, it was found that the use of each preliminary method was dependent on the required mitigation of the flow. Recommendations for the use of each equation, based on the reduction ratio, have been presented in table 1. The results show that no one method was suitable for all cases.

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