12d Model

Civil and Surveying Software

Drainage Analysis Module

Detention/Retention Basins

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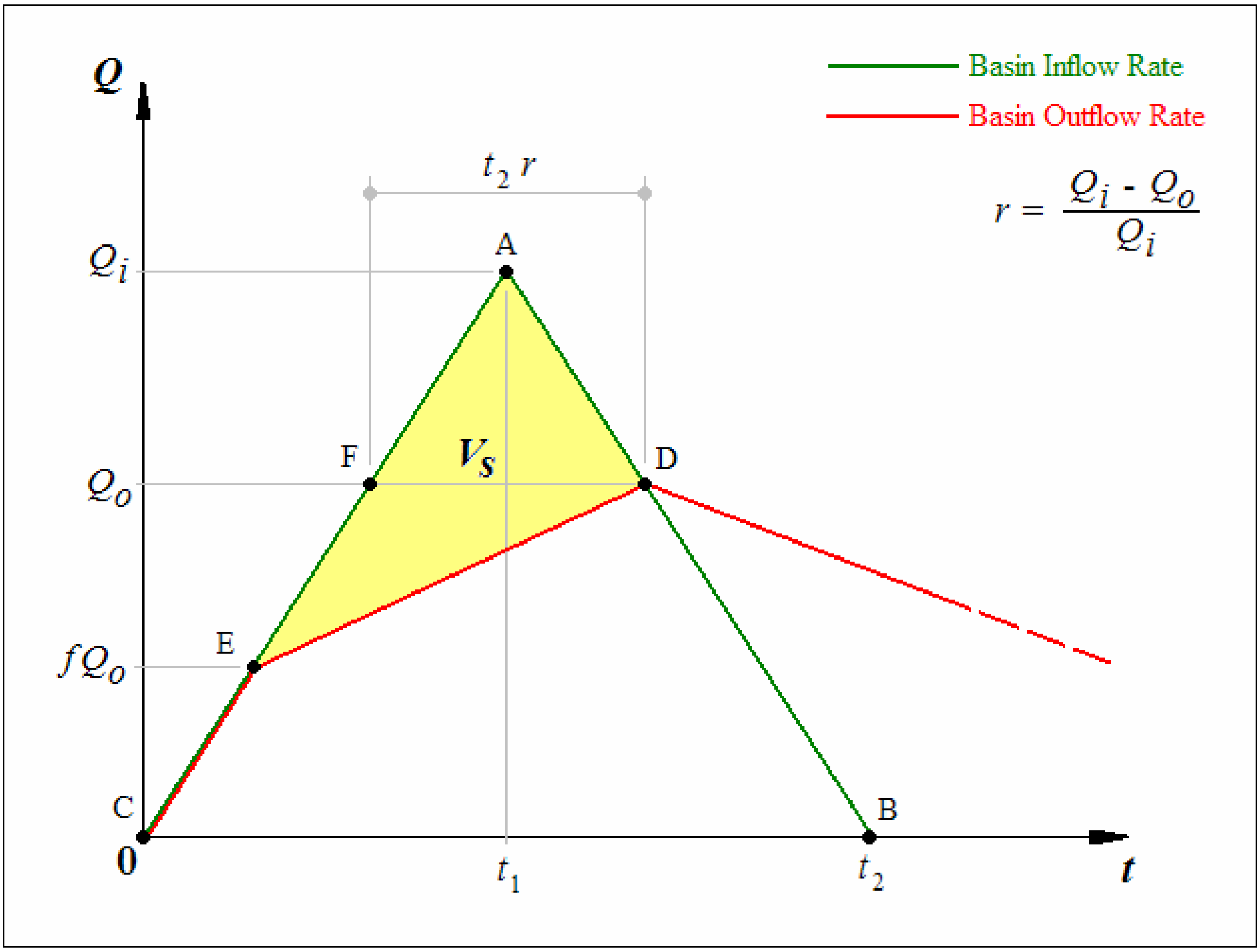
This document describes the approximate method
for sizing detention basins via the *Rational Method*,
as implemented in the
Drainage Analysis module of *12d Model*.

An Approximate Method for Sizing Basins when using the Rational Method

For the design of stormwater detention and retention basins, a variety of simple and approximate methods may be adopted when using the *Rational Method*. These methods *do not* require detailed inflow hydrographs (derived from unsteady flow simulations), nor an accurate storage-discharge relationship, as would otherwise be required for the more complex and sophisticated method of solving the *Storage Equation*. For feasibility studies and preliminary design, these approximate methods should generally prove adequate. And for relatively small basins, or larger basins with *flow reduction ratios* (r) large enough to lessen the effect of storm temporal patterns, some approximate methods may even prove adequate for final design – though the *Storage Equation* may still need to be solved for verification of this.

An approximate method, attributed to Boyd, has been presented in both the ARR (1987) and the QUDM (2007), and three more, attributed to Basha, Carroll and Culp, in the QUDM (2007) only. All four methods are based on an assumed triangular inflow hydrograph with peak Q_i , and an assumed outflow hydrograph with a lesser peak Q_o , lying somewhere on the falling limb of the inflow hydrograph.



With reference to the inflow and outflow hydrographs shown in the figure above, the total basin inflow volume is given by the area below the inflow hydrograph:

$$V_i \quad = \quad \text{area ABCA} \quad = \quad \tfrac{1}{2}\, t_2\, Q_i \tag{1}$$

And the required basin storage volume is given by the area contained between the inflow and outflow hydrographs:

$$\begin{aligned} V_s &= \text{area ADEA} = \text{area ADFA} + \text{area FDEF} \\ &= \tfrac{1}{2} t_2\, r\left(Q_i - Q_o\right) + \tfrac{1}{2} t_2\, r\left(Q_o - f\,Q_o\right) \qquad (2) \\ &= \tfrac{1}{2} t_2\, r\left(Q_i - f\,Q_o\right) \end{aligned}$$

where the factor *f*, between zero and one, defines the ratio of the initial outflow rate (with an empty basin), to the peak outflow rate, Q_o (with a basin full to capacity). For dry basins with a low-level outlet invert *below* the minimum basin water level, the outlet may begin discharging at some considerable rate, almost immediately as the basin begins to fill – thereby reducing the required size of the basin. It is for this type of outlet design where *f* should be set to an appropriate value greater than zero, and as such, f has been termed the *drop pit factor*.

The ratio of equations (1) and (2) may be expressed in terms of *r* and *f*, as:

$$\frac{V_s}{V_i} = r\left(\left[1-f\right] + f\,r\right) \tag{3}$$

Substitution of different values for f into equation (3), yields the four methods referred to above:

$$f = 0 \rightarrow \frac{V_s}{V_i} = r \quad \text{… attributed to Boyd} \tag{4}$$

$$f = 1/3 \rightarrow \frac{V_s}{V_i} = r\left(2+r\right)/3 \quad \text{… attributed to Basha} \tag{5}$$

$$f = 5/8 \rightarrow \frac{V_s}{V_i} = r\left(3+5r\right)/8 \quad \text{… attributed to Carroll} \tag{6}$$

$$f = 2/3 \rightarrow \frac{V_s}{V_i} = r\left(1+2r\right)/3 \quad \text{… attributed to Culp} \tag{7}$$

It should be noted that results obtained from equation (3) are independent of the time at which the inflow peaks (t_1). So, while the *Storage Equation* can account for the differences caused by an early inflow peak, or a late inflow peak, for instance, equation (3) cannot. In most cases, however, such concerns are secondary. It is more important to estimate adequately, the design values for Q_i and V_i.

The *Rational Method* is normally only considered adequate for determining the *maximum peak inflow rate* ($Q_{i\,\max}$) when the *storm duration* (t_d) is equal to the *time of concentration* (t_c) of the catchment feeding the basin. It is far more common, however, for the critical t_d – the storm duration requiring the greatest basin storage volume – to be *considerably* longer than the t_c of the catchment. To correct for this, some have suggested that $Q_{i\,\max}$ be used for Q_i and that ($4\, t_c\, Q_{i\,\max} / 3$) be used for V_i, but this often under-predicts the basin size significantly, and there is little theoretical basis to support it. Instead, to follow the (ARR preferred) statistical interpretation of the *Rational Method* – which for the same average recurrence interval, applies the same runoff coefficients to storms of different durations – the design values for Q_i and V_i should be determined for longer storms as follows:

$$t_2 = t_d + t_c \quad \cdots \quad V_i = t_d\, Q_{i\,\max} \frac{I_d}{I_c} \quad \cdots \quad Q_i = \frac{2V_i}{t_2} \tag{8}$$

where I_c and I_d are the average rainfall intensities for storms of duration t_c and t_d, respectively (as determined from IFD data) and $t_d \geq t_c$. The important thing to note about this formulation is that, for the same average recurrence interval, storm duration and runoff/infiltration model, V_i will *always* be the same as that of a hydrograph derived from a variable-intensity storm with *any* form of temporal pattern. Also note that Q_i is derived from a triangular hydrograph of volume V_i and base time t_2, to better represent the peak flow rate of a storm with an average temporal pattern.

Implementation in 12d Model

In *12d Model*, input values for f and either Q_o or V_s may be specified at the outlets of the drainage network – via the *Pit => Main* tab of the *Drainage Network Editor*.

The *Storm Analysis* process then uses equations (8) and (3) to solve for either V_s or Q_o, for a range of up to 52 different t_d values between 5 and 4320 minutes, including but not less than the full-area t_c of the catchment feeding the basin, and only those which yield an r between zero and one.

For each basin, a range of results is thus obtained, where the storm duration yielding either the greatest V_s or Q_o is selected as the critical t_d.

The following pit attributes are set on the drainage string outlets, upstream of each basin:

Inputs:

`"basin drop pit factor"` = f

`"basin discharge"` *or* `"basin volume"` = Q_o *or* V_s

Outputs:

`"calculated basin inflow"` = critical Q_i

`"calculated basin inflow volume"` = critical V_i

`"calculated basin tc"` = full-area t_c of catchment

`"calculated basin storm duration"` = critical t_d

`"calculated basin storm intensity"` = critical I_d

`"calculated basin volume"` *or* `"calculated basin discharge"` = V_s *or* Q_o

In addition, a detailed design report for each basin is reported in CSV format to the *Output Window*, which may be pasted into a spreadsheet for auditing and to produce design graphs. An example report with corresponding graphs is shown on the last page.

References

ARR (1987) "Australian Rainfall and Runoff : A Guide to Flood Estimation", Vol. 1, Section 7.5.6, *Instn. Engrs. Aust.*

QUDM (2007) "Queensland Urban Drainage Manual", Vol. 1, Section 5.05.1, *Queensland Govt. Dept. of NR&W, Brisbane.*

12D MODEL - BASIN DESIGN REPORT
Basin downstream of Outlet "1.1X"

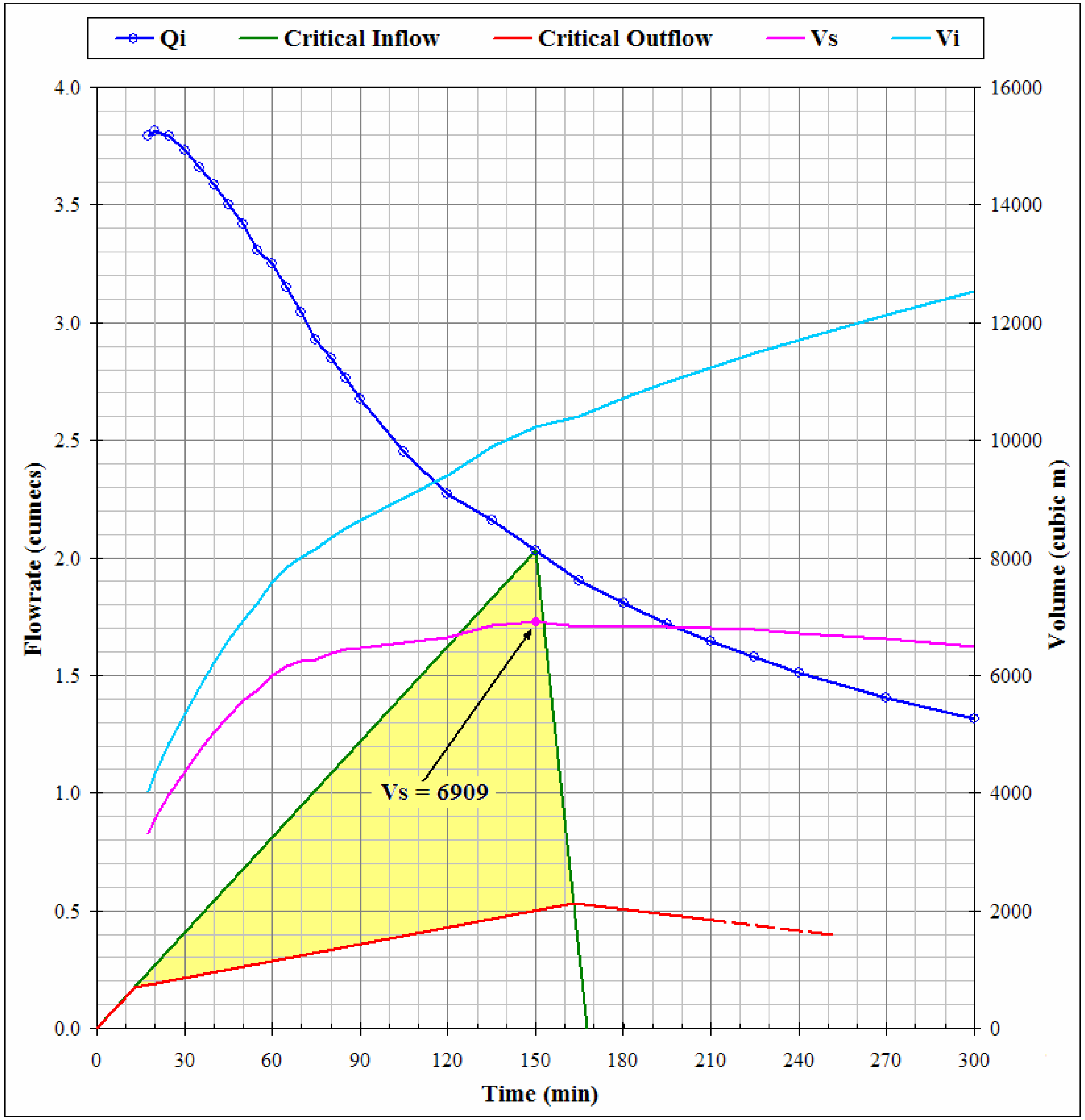
ARI	*Qo*	*tc*	*f*
(yr)	(cumecs)	(min)	(-)
50	0.530	17.7	0.33

td	*Vs*	*Vi*	*Qi*	*r*	*I*
(min)	(cubic m)	(cubic m)	(cumecs)	(-)	(mm/hr)
17.7	3314	4038	3.794	0.860	180.3
20	3547	4318	3.814	0.861	171.0
25	3988	4861	3.791	0.860	154.0
30	4367	5341	3.729	0.858	141.0
35	4714	5789	3.659	0.855	131.0
40	5035	6212	3.586	0.852	123.0
45	5314	6591	3.501	0.849	116.0
50	5567	6944	3.417	0.845	110.0
55	5745	7222	3.309	0.840	104.0
60	5998	7575	3.248	0.837	100.0
65	6147	7824	3.152	0.832	95.3
70	6238	8013	3.044	0.826	90.7
75	6270	8143	2.927	0.819	86.0
80	6378	8350	2.848	0.814	82.7
85	6445	8514	2.762	0.808	79.3
90	6470	8636	2.672	0.802	76.0
105	6558	9015	2.448	0.784	68.0
120	6649	9393	2.273	0.767	62.0
135	6853	9886	2.157	0.754	58.0
150	**6909**	**10227**	**2.032**	**0.739**	**54.0**
165	6819	10416	1.900	0.721	50.0
180	6849	10727	1.808	0.707	47.2
195	6825	10980	1.720	0.692	44.6
210	6811	11242	1.645	0.678	42.4
225	6772	11477	1.576	0.664	40.4
240	6720	11696	1.513	0.650	38.6
270	6620	12136	1.406	0.623	35.6
300	6490	12537	1.315	0.597	33.1
360	6138	13227	1.167	0.546	29.1
420	5787	13893	1.058	0.499	26.2
480	5385	14484	0.970	0.454	23.9
540	4935	14999	0.896	0.409	22.0
600	4516	15529	0.838	0.368	20.5
660	4062	15999	0.787	0.326	19.2
720	3537	16363	0.739	0.283	18.0

Critical Storm Duration = 150 min

Critical Hydrographs:

	t	*Q*
	(min)	(cumecs)
Inflow	0.0	0.000
	150.0	2.032
	167.7	0.000
Outflow	0.0	0.000
	12.9	0.175
	163.1	0.530
	251.6	0.398



Example of a Basin Design Report created by *12d Model*, showing the results for each storm duration tested, along with the inflow and outflow hydrographs of the *critical* storm duration. The corresponding graph on the right hand side shows each duration as a dot on the Q_i curve, and confirms that for the required 50Yr peak Q_o of 530 L/s, the storage volume required reaches a maximum of 6909 cubic metres, during the storm of 150 minutes duration.