MISMANAGEMENT OF STORMWATER MANAGEMENT
A CASE STUDY

P Allen Pr Eng BSc (Civil Engineering), IMESA Retired Fellow

ABSTRACT

Stormwater management is an essential municipal function, not given enough attention in many municipalities. It becomes particularly important when people desperate for housing invade apparently-available land. The paper traces the constitutional and legislative stormwater mandate, gives a brief overview of the hydrological factors involved (without being a lecture on stormwater hydrology) and highlights some misunderstanding of those factors. A simple detention-storage equation is presented, with discussion on misapplication of this equation. The focus of the paper is that stormwater management must be implemented, but implementation must be rational, and stormwater management must be integrated into wider developmental policies of the municipality.

INTRODUCTION

Section 156 of the Constitution of the Republic of South Africa allocates responsibility for stormwater management systems in built up areas to local government. Section 84 of the Municipal Structures Act reserves some of those responsibilities to District Municipalities, but not stormwater management. Section 85 of the Structures Act allows the MEC for Local Government to reallocate responsibilities between district and local municipalities, but such reallocation, when it has been invoked, has generally involved water and sanitation. Stormwater management remains the responsibility of local municipalities.

Following a severe storm in East London in August 2002, Buffalo City Municipality ("BCM" - East London and King William's Town, now a Metro in the Eastern Cape Province) formalised their stormwater management responsibility by gazetting a by-law which requires individual property owners to apply stormwater runoff attenuation measures. This is detailed in the following extracts from Provincial Gazette 1530 dated 15 May 2006:

> ***"All developments or re-development proposals, building alterations, extensions or paving to existing structures exceeding 100m² submitted to the Council shall be accompanied by a Stormwater Management Plan designed by a registered Professional Engineer. .... The Stormwater Management Plan must be based on the following principles:***
>
> - ***That all stormwater flows, over and above a 1:5 year flood event is*** *[sic]* ***contained on site (in a designated detention facility) and released to a suitable watercourse or stormwater system at a rate equal to or less than a 1:5 year pre-development peak;***
>
> - ***That the detention facility be designed and constructed to accommodate a flood peak of at least equal to a 1:50 year post-development flood event."***

BCM will not approve building plans unless the plans are accompanied by the required stormwater management plan.

As an aside, one of the unintended consequences of the wording of the by-law is that many plans are submitted showing proposals marginally below the 100m² limit, with a later submission showing the remainder of the intended full development.

Stormwater management in urban areas has long been given too low a priority, and BCM must be commended for their formalisation of attention to storm runoff.

APPLICATION OF THE BCM REQUIREMENTS

Further requirements set by BCM, issued in a pamphlet and in official correspondence, are as follows:

1 Runoff rates must be calculated from the Rational Equation

$q = \frac{1}{6}\, x\, C\, x\, I\, x\, A$ (Eqn 1)

where q is the rate of runoff from the area under consideration, (m^3/minute)
C is the runoff coefficient, or proportion of rain not soaking directly into the ground,
C = 0.4 for pre-development conditions;
C = 1.0 for post-development conditions
(BCM will accept only minor deviations from these values.)
I is the intensity of the rainfall, (mm/hour)
I_5 = 145mm/h for the 5-year rainfall event
I_{50} = 225mm/h for the 50-year rainfall event
(These intensities were later found to be a mis-reading of published figures, and were replaced by corrected intensities)
A is the area of the catchment (ie erf) under consideration (hectares).

2 Storm duration of 15 minutes must be used in the calculation of runoff.

3 The ***Abt & Grigg*** equation must be used for detention facility size determination.

Abt & Grigg equation

$$V_{st} = 60 \text{ x } ½(1 + m) \text{ x } t_{ca} \text{ x } q_{pa} \text{ x } (1 - q_{pb}/q_{pa})^2 \qquad \text{(Eqn 2)}$$

where V_{st} is the detention storage volume required (m^3)
m is the ratio of hydrograph recession to time of peak
t_{ca} is the post-development time of concentration (minutes)
q_{pa} is the post-development peak runoff (m^3/sec)
q_{pb} is the pre-development peak runoff (m^3/sec).

In checking submissions, BCM uses a nominal time of concentration t_{ca} of 15 minutes.

PRACTICAL CONSIDERATION OF THE BCM SPECIFICATIONS

Calculations of this nature are simplifications, and, at best, educated guesses. Numerous statistically-determined parameters, usually derived from historical records, each with its own margin of error, are combined to arrive at a single number (in this case a detention facility volume) which in itself has a statistical chance of being wrong. (There is a 64% chance that the 50-year return period rainfall will be exceeded at least once in 50 years.)

The point to be made here is that, provided there is a real need for the calculation, and provided the (chosen or specified) calculation is correctly carried out using best-available parameters, the result should be accepted without being adjusted by further arbitrary factors which add to the uncertainty.

The use of the Rational Formula (Eqn 1) for the calculation of runoff from catchments of up to about 3000ha is not unreasonable. The formula is simple and intuitively understood.

Some care is needed in the selection of the runoff coefficient, which is generally presented as a constant, but in reality depends on ground characteristics as well as rainfall history, and is seldom constant with time or across any area under consideration. The values specified by BCM (0.40 for pre-development conditions and 1.00 post-development) are probably high for residential erven.

There is even greater uncertainty in the selection of rainfall intensity to use in the Rational Formula. For practical purposes, the variables in the rainfall for a given site may be reduced to the severity of the event (rated as the return period of the storm) and the depth of precipitation over the given time period. For a given depth of precipitation, shorter storm duration will result in more severe runoff effects. Stated in another way, if the return period is specified, then the duration must be known in order to predict the depth of precipitation.

Once the return period and duration have been assumed or specified for design purposes, the design rainfall intensity is usually determined from Hydrological Research Unit or Water Research Commission publications for the region under consideration.

Selection of storm duration in relation to catchment characteristics is discussed below. The BCM-specified duration of 15 minutes does not feel intuitively wrong, but further discussion on the appropriateness of this duration would be beneficial.

When dealing with urban stormwater at residential erf level, it is the rate of runoff that is important, not the total quantity of runoff over a period of time. The requirement is to deal with the magnitude of flow, not the overall volume. Flow will build up from the start of the rainfall, to a peak, before declining again at the end of the rainfall. It is assumed that the rain falls evenly over the whole area under consideration (the catchment), and the peak flow from the catchment will be reached when runoff from the highest point of the catchment reaches the lowest point. Thereafter, assuming the rainfall remains constant, runoff will be constant at this peak flow.

The time taken for runoff from the highest point to reach the point under consideration is the "Time of Concentration", Tc. Traditionally, storm duration is taken as being equal to Tc, as there is no further increase in flow rate after this time. (Note that this must not be taken to imply that Tc for any area is equal to the storm duration.) Graphically the runoff may be represented by a triangular hydrograph, with peak flow q_p occurring at time Tc, returning to zero flow after recession time (m x Tc).

Assessment of Tc is itself subject to interpretation and subjective judgement. The time taken for stormwater to reach one side of a catchment from the other depends on numerous factors such as the length and gradient of the flow path, the characteristics of the material over which it flows, flow depth, and even the duration and intensity of the rainfall. Manning's equation, or variations thereof, may be used to estimate Tc, and various nomograms have been developed to make the estimation easier.

Adoption of storm duration equal to Time of Concentration is acceptable for "small catchments" in general, but it is questionable whether this philosophy is applicable to catchments as small as residential erven (400 to 1000 square metres), where Tc is of the order of 2 to 3 minutes.

BCM specifies that the storm duration should be taken as 15 minutes, and in the absence of any specific knowledge of storm behaviour in the BCM area, such storm duration might be reasonable.

Using the above factors in the Rational Equation allows the runoff rates for the 5- and 50-year return period storms to be calculated. These flow rates are then used to determine the size of the detention facility, which must store the flow generated by the rainfall event, and discharge runoff at a rate not greater than the 5-year storm flow.

Mis-use of the Abt & Grigg detention volume formula

The operating principle of a detention facility is that stormwater flows into the facility faster than it flows out; the size of the facility, or detention volume, is the difference between the inflow and the outflow over the duration of the storm.

A simple spreadsheet may be constructed to perform the necessary calculation. Manual calculation is long-winded, and the Abt & Grigg formula (Eqn 2) performs the same function more quickly and easily, **provided the variables of the equation are correctly used**.

Examination of Eqn 2 shows the familiar “half base times perpendicular height” formula for the area of a triangle (here calculating the volume of the 1:50 year rainfall hydrograph), with an adjustment for the 1:5 year outflow. This is illustrated in Fig 1 below.

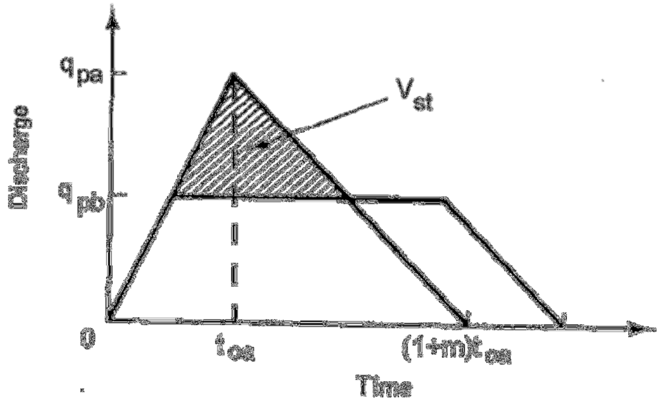

Fig 1: Hydrographs illustrating the Abt & Grigg calculation

It is important to understand that Eqn 2 is based on a triangular hydrograph. Discharge rate rises linearly to a maximum value at the Time of Concentration Tc, and then falls off linearly to zero after the recession period (m x Tc), because the storm is assumed to have stopped at time Tc.

Tc is a physical characteristic of a given catchment, and if storm duration **not equal** to Tc is selected, Eqn 2 will not yield the correct answer. In particular, for urban properties, if storm duration is much greater than the calculated Tc, then the discharge will reach a maximum value at time t before time t_{ca} of Fig 1 (specified by BCM to be 15 minutes), and this maximum value will endure until a time after t_{ca}, producing a quadrilateral hydrograph, rather than triangular.

This is illustrated in the following diagram, superimposed on Fig 1:

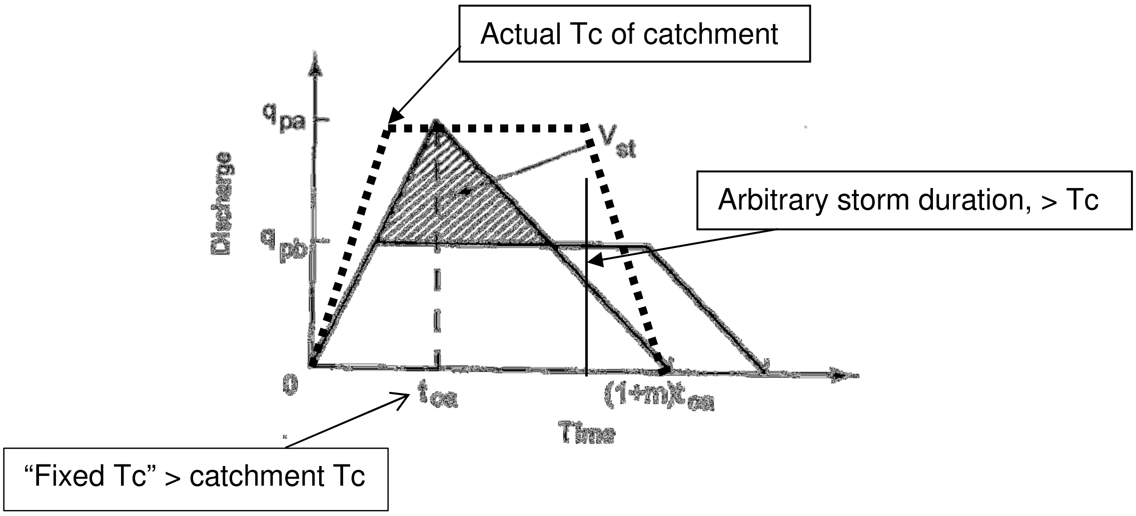

Fig 2: Hydrograph for storm duration exceeding catchment Tc

Example:

Assume for a given (very small, or erf-sized) catchment that

1:5 year runoff	q_{pb} =	0.010 m^3/s
1:50 year runoff	q_{pa} =	0.042 m^3/s
Catchment Tc	t_{ca} =	1 minute
Recession time ratio	m =	1

Direct application of Eqn 2 yields a detention storage volume v_{st} = 1.5 m^3

If an arbitrary t_{ca} = 15 minutes is utilised, then Eqn 2 yields a detention storage volume of 21.9 m^3
This is the value that BCM will calculate when checking a design submitted with these parameters.

As discussed above, this is a misapplication of Eqn 2. The correct detention volume where the storm duration is 15 minutes and the calculated Tc is 1 minute, is 28.4 m^3.

1.46 to 28.4 m^3 is a significant range of detention volumes from which to choose.

The blanket requirement of individual runoff calculation for each building plan submission might be considered illogical. The blanket requirement of an on-site detention facility on each erf is arguably excessive. BCM has not carried out any sensitivity analyses to determine areas of greater or lesser potential for flood-damage, and there are numerous examples of developments where unattenuated runoff would have no effect, or would cause only minor inconvenience.

Of further concern is that the by-law does not compel, or even address the need for, assessment of stormwater effects outside of individual erven. There is no requirement that the municipality itself should consider runoff attenuation from public open spaces, or in urban stream valleys.

CONCLUSIONS

It is not clear that the Rational Equation and the convention of assuming a storm duration equal to the time of concentration is appropriate for very small catchments (area 500 to 1000 m^2, time of concentration between 1 and 5 minutes). It is wrong to assume that the time of concentration is equal to the storm duration.

Further clarity is needed on the appropriate storm duration for very small catchments, in an urban environment.

The Abt and Grigg formula for detention storage volume is a simple and easily-applied method of calculating detention requirements, but it is not applicable when the storm duration is significantly greater than the calculated time of concentration for the catchment.

The direct result of rigorous application of the BCM by-law is extra cost to property-owners of BCM in the appointment of a professional engineer to carry out the calculations, and the extra cost involved in construction of the detention facility. If most of the variables involved in the detention calculation are specified by the municipality, as with BCM, there is little or no scope for professional opinion, and the necessary calculations could be carried out by the developers or property-owners themselves on a deemed-to-satisfy basis. (It should also be accepted that the resultant detention volume will be arbitrary).

The BCM by-law implies that their constitutional stormwater management responsibilities will be met by the construction of erf-level detention facilities. However, the focus of the by-law is too narrow. New developments would be more economically and efficiently served by area-wide stormwater management, and a significant omission is any consideration of open spaces within the municipality.

Open spaces have rainfall-runoff characteristics that change with time. Not only does the vegetation cover change, but formal and informal development takes place in the open spaces. A by-law may well require any development to accommodate on-site runoff, but unless the municipality is continuously monitoring runoff from open spaces, the cumulative effects of vegetation, and formal as well as informal development may be unexpected.

Informal development brings its own significant stormwater effects, in that a high-density informal settlement may well have 100% runoff in any rainfall event, without any of the attenuation required by the gazetted by-law. Uncontrolled development of informal settlements often leads to well-documented flooding and human suffering of the residents during any heavy rainfall (even if the rainfall is not a statistically-significant event as defined in any by-law), and increased runoff may have unanticipated effects on downstream developments.

RECOMMENDATIONS

Stormwater management must be applied.

The principles of stormwater management must be applied across the whole municipality, and not merely within formal erven. Requirements should be applied at individual erf level only where an area-wide analysis has determined that this is warranted.

The importance of stormwater management must also be understood outside of the technical directorate of any municipality, and stormwater management must be integrated into wider municipal policy. The Human Settlements directorate must control informal settlements – this is not impossible, but it does require considerable political will.

It must be accepted that hydrology has a statistical basis, and while hydrology does make use of empirical factors, the principles must be rationally applied without the imposition of arbitrary subjective adjustments.

If design by a registered professional engineer is required in terms of any by-law, that engineer must be allowed to exercise professional judgement and take professional responsibility for the design, or else the by-law and the result become meaningless.

REFERENCES

Abt S & Grigg N 1978: An approximate method for sizing detention reservoirs. American Water Resources Association – Water Resources Bulletin Vol 14 No 4.
Berrington I c 2006: Stormwater Management Plan. Buffalo City Municipality information brochure.
Republic of South Africa 1996: Constitution.
Republic of South Africa 2000: Municipal Structures Act 117 of 1998, amended 2000.
Technical Note 2.120 2003: Storm Water Detention/Retention System Design. Advanced Drainage Systems.