Towards sustainability of waterways in urbanising catchments

Deux stratégies pour améliorer la durabilité des systèmes urbains d'assainissement pluvial

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RESUME

La **rétention** est le processus dominant qui caractérise le comportement des précipitations/ruissellements d'un bassin versant forestier. Toute tentative de création de paysages urbains durables doit inclure des pratiques de rétention aussi larges que possible au moyen de jardins sur toiture, de réservoirs d'eau de pluie, de dispositifs de goutte à goutte dans le sol, d'accès aux aquifères, etc. Ceci induit un transfert de l'égalité de avant-et-après $\mathbf{Q_{peak}}$ (pratique de rétention de développement de sous-zone) à l'égalité de **Runoff Volume** à partir de l'élément de sous-zone comme critère pour le développement/redéveloppement urbain *durable*. Cette approche est illustrée pour le cas d'une sous-division résidentielle de 60 unités. Ce résultat peut être généralisée aux cas de développement de bassins versants forestiers. L'article conclut par une revue et un rejet des objections avancées contre l'utilisation des pratiques de rétention pour la collecte des eaux pluviales au prétexte de l'impact des flux environnementaux et des conséquences des successions d'orages.

ABSTRACT

The dominant process that characterises the rainfall/runoff behaviour of a forest catchment is **retention**. Any attempt to create *sustainable* urban landscapes must incorporate retention practices as widely as possible including roof gardens, rainwater tanks, in-ground 'leaky' devices, access to aquifers, etc. A consequence of this is the shift from equality of before-and-after $\mathbf{Q_{peak}}$ (sub-area development detention practice) to equality of **Runoff Volume** from the sub-area element as the criterion for *sustainable* urban development/re-development. This approach is illustrated for the case of a 60-unit residential sub-division. The result can be generalised to forest catchment development cases. The paper concludes with a review and rebuttal of objections raised against retention practice use in storm drainage on the grounds of impact on environmental flows and the consequences of storm successions.

KEYWORDS

Forest catchment, retention, sustainability, urbanising, waterways

INTRODUCTION

When storm rainfall of sufficient magnitude to produce runoff is generated in a forest catchment, it passes into creeks and waterways within time period measured, typically, in hours: the *annual* total of such runoff – in temperate zone catchments – is likely to be less than 20% of rainfall input. There is a second stream of flow which is discharged from the natural catchment, that delivered to waterways as 'base flow' from aquifers: considered on an annual basis, this stream is comparable in magnitude to the surface runoff flow but its delivery period is measured in weeks, months or years. These elements of the hydrological performance of a (temperate zone) forest catchment are illustrated in Figure 1.

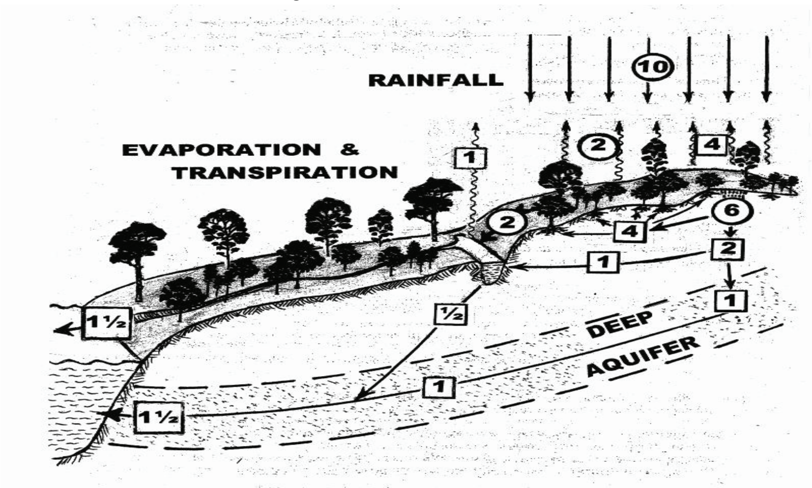

Figure 1: Destiny of 10 units of annual rainfall input in a temperate zone forest catchment (notional values)

Primary elements (circled) : 10 units of (annual) rainfall - 2 units are intercepted and evaporate; 2 units become surface runoff; 6 units infiltrate.

Secondary elements (boxed) : 1 unit of s*urface runoff* evaporates. 4 units of *infiltrated water* are taken up by tree roots leading to transpiration while the other 2 units are divided between seepage to streams, lakes and deep aquifers. ½ unit of stream/lake water percolates to the deep aquifer.

Outflows to the ocean : surface runoff - 1½ units; aquifer discharge - 1½ units.

The goal of **sustainability** in the waterways of urban catchments needs to be informed by these assessments, in particular, that the dominant hydrological process operating in a natural catchment is **retention** (see Chandler, 2001). Traditional stormwater drainage practice has followed an opposite path by seeking to collect and dispose of storm runoff "…as completely and as quickly as possible".

1 DETENTION OR RETENTION ?

The first, significant move away from the 'rapid removal' approach to urban storm drainage design was the introduction of detention technology (Wright-McLaughlin Engineers, 1969). **Detention** refers to the holding of surface runoff for relatively short periods to reduce peak flow rates before releasing it into, typically, constructed watercourses which convey the flow downstream to the ocean. *The volume of surface runoff involved in the temporary (detention) ponding process is relatively unchanged by it.* The conventional way in which detention technology has been applied in an urban catchment is to ensure that -

> ***Q_{peak} flows*** *from a site before and after development (or re-development) are equal, in the design storm of critical duration.*

Retention of storm runoff in the context of urban drainage includes procedures and schemes whereby stormwater is held for relatively long periods causing it to continue in the urban water cycle via domestic use (in-house and outdoors), industrial uses and the natural processes of infiltration, percolation, evaporation, transpiration and aquifer recharge. It is embodied in the **regime-in-balance** strategy which requires that (Argue, 2004) -

> ***Runoff volumes*** *from a site before and after development (or re-development) are equal, in the design storm of critical duration.*

2 ILLUSTRATION

Consider a hypothetical, 60 lot sub-division in Parramatta, NSW, where each developed allotment (1,000 m^2), illustrated in Figure 2, is re-developed for dual-occupancy. Modelling using the catchment-wide critical design storm (1-hour, ARI, Y = 100-years) for which intensity, i = 68.8 mm/h, is carried out on the sub-division. Equivalent impervious areas (EIAs) for the two cases are listed in Table 1.

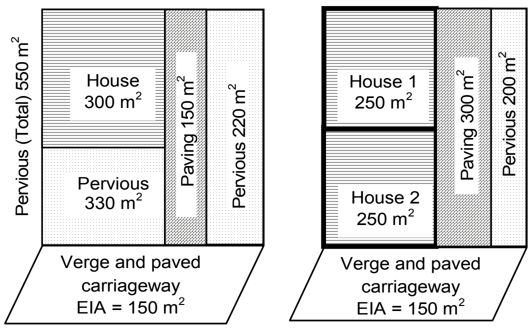

Figure 2 : Layouts of residential original and re-developed allotments

Component	ORIGINAL SITE	RE-DEVELOPED SITE
Roof area	300 m^2	500 m^2
Paved area	150 m^2	300 m^2
Pervious area	132 m^2	48 m^2
Share of road reserve	150 m^2	150 m^2
TOTAL EIA	**732 m^2**	**998 m^2**

Table 1 : Components of original and re-developed sites (EIAs)

Runoff volumes - Original allotment: **732 m^2 × 0.069 = 50.5 m^3**

Re-developed allotment: **998 m^2 × 0.069 = 68.9 m^3**

Hence, on-site *retention* storage volume required per allotment for **regime-in-balance** strategy equals (68.9 – 50.5) m^3 = **18.4 m^3**. Figure 3 shows design storm hydrographs for the original and re-developed cases –

- *Single allotments* with runoff uncontrolled: Figure 3a ;
- *60 allotments* each 'lagged' by one minute: Figure 3b ;
- *Re-developed allotment* with **18.4 m^3** retention storage: Figure 3c ;
- *60 re-developed allotments* - **18.4 m^3** retention storage each: Figure 3d.

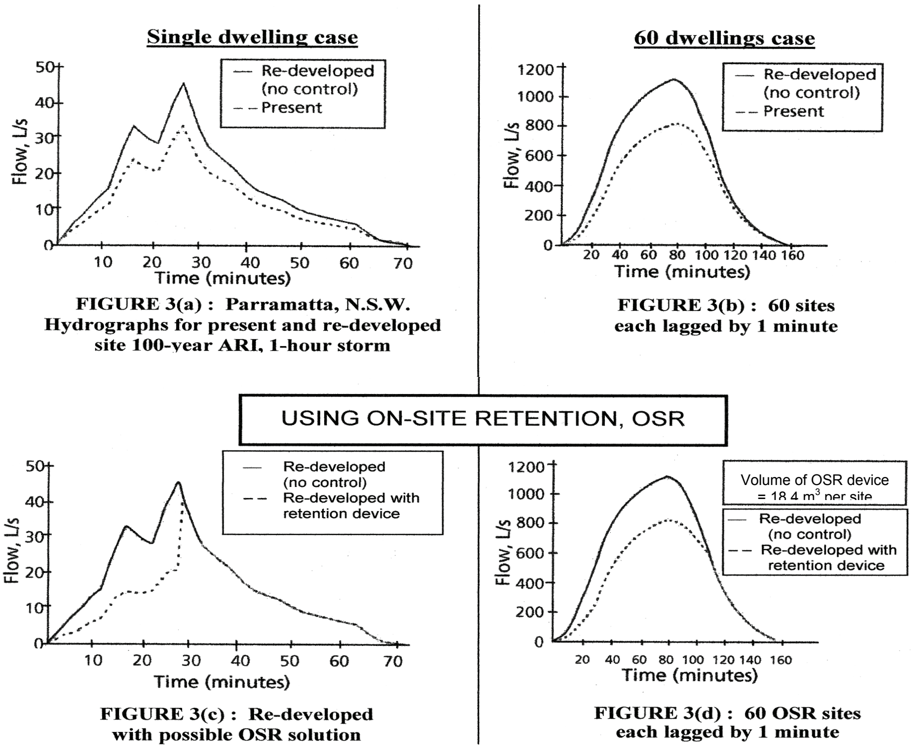

Figure 2 : Regime-in-balance strategy applied to 60 residential allotments

3 DISCUSSION

The prospect of using retention technology as a major element of stormwater management planning raises a number of issues. First among these is the **regime-in-balance** strategy itself: does it lead to true sustainability ? Then there is the need to know what retention 'tools' are available to implement the technology. This leads to the question: what are the consequences for environmental flows of using retention systems widely in an urban catchment. Finally, there is the issue of storm successions: if retention storages are employed in an urbanising catchment, how confident can the designer be that they will empty between successions of significant storms ? These matters are addressed in the following sub-sections.

3.1 The *regime-in-balance* strategy

Comparison of Figures 3b and 3d reveals great similarity in the two surface runoff hydrographs for –

- 60 *original* allotments with flow uncontrolled (present system); and,
- 60 *re-developed* allotments with **18.4 m^3** on-site retention storage.

This shows that application of the **regime-in-balance** strategy leads to almost identical surface runoff hydrographs – for the *original* (developed) and *re-developed* catchment states - under conditions of the design storm of critical duration. Corresponding modelling of the transformation from forest or 'greenfields' to urban development under the same design storm condition produces the same outcome. The implications of this are –

1. The main waterways and associated aquatic and terrestrial ecosystems of a forest or rural catchment can be *substantially sustained* in their natural states provided all development (outside the defined floodplain) is ordered in that catchment under the **regime-in-balance** strategy; and,

2. The stormwater infrastructure (formal waterways) of a developed catchment can continue to function without the need for augmentation provided all development (outside the defined floodplain) is ordered in that catchment under the **regime-in-balance** strategy.

Of course, these claims must be qualified: the strategy reviewed above employs *one*, only, design storm condition in its implementation, whereas *true* sustainability demands correspondence being observed over the **full range of storm inputs.** This ideal is sought in some contemporary practices, in particular UK (CIRIA, 2001) and the Pacific north-west of North America (Stephens et al, 2002).

"Substantial sustainability" in (1), above, sees the 'before and after' correspondence delivered by the **regime-in-balance** strategy as applied to a mid-range design storm condition arrived at by consensus among stakeholders in the urbanising catchment. This may be the 5-year, 10-year or 20-year event. In relation to the developed catchment (formal) stormwater infrastructure – case (2) above – the 'consensus' frequency is likely to be in the range 20-years to 100-years.

3.2 Retention practices

There is an extensive range of devices and systems available to the practitioner for designing and reaping the benefits of stormwater retention. These include roof gardens, green roofs, rainwater tanks; porous and permeable paving; in-ground 'leaky' devices; above-ground and underground devices with aquifer access; and above-ground or underground storages with slow-drainage provision, termed 'extended detention'.

Numerous papers presented at the ICUD series of conferences (Eriksson et al, 2005) and previous Novatech conferences (Chocat et al, 2005)) should be consulted to access the literature of the subject as well as national practice/guideline manuals such as ATV (1990) – Germany; CIRIA (2001) – UK; Ontario Ministry of the Environment (2003) – Canada; and Argue (2004) – Australia.

3.3 Environmental flows

It is sometimes claimed that widespread inclusion of retention practices in a 'mixed' catchment with significant urban and remnant (forest) components, will adversely affect environmental flows in the natural waterways. In a typical application of the **regime-in-balance** strategy, some stormwater is retained – typically, part of roof-originating runoff – and the remainder (ground-level runoff) passes downstream. Figure 3c, above, illustrates this clearly. While the destiny of the surface runoff component is well understood, that of its subterranean counterpart held, temporarily, in, say, a 'leaky' device, is less certain. What is known is that this component along with other products of surface infiltration enters the soil moisture store, is taken up by tree roots (leading to transpiration) and provides 'base flow' to local streams via shallow aquifer routes, as illustrated in Figure 1.

Certainly, the paths taken by the two streams – surface runoff and 'base flow' reaching local waterways - are very different, as are their journey time scales, but this should not disguise the fact that their *quantities,* considered on a catchment-wide basis over the course of an average year, are similar. Retention techniques and processes can therefore be employed to 'mimic' natural catchment hydrological behaviours and, therefore, provide a basis for claiming waterway sustainability.

Environmental flow considerations also affect the *scale* at which the **regime-in-balance** strategy should be applied in an urbanising catchment. Simple application might see 'before and after' (surface runoff) volume equality approved on a site-by-site basis by a regulatory agency. But this ignores the consequences of 'over-supply' of surface runoff delivered from catchment components such as paved carriageways and multi-storey carparks which present little or no opportunity for 'site' application of the strategy.

It would seem prudent to embrace this aspect of catchment performance at a *neighbourhood* or *district* rather than *site* scale in such circumstances. Neighbourhood-scale (or district-scale) planning to compensate for 'over-supply' would see on-site storages on residential allotments or other land use elements therefore set at *greater* magnitudes than required, individually, by the strategy.

3.4 Storm successions

Another objection often brought against on-site retention of stormwater relates to the situation which may occur when a storage, partly drained after a significant storm event, is subject to additional input from a new storm following the first in close succession. This issue raises two questions of prime importance –

- How long will a typical, in-ground, 'leaky' retention device take to empty from full under 'natural' (percolation) drainage conditions ? and,
- What time delay can be expected between successive storms of significant magnitude ?

The **first** of these questions has been answered for the most commonly used devices – 'leaky' wells, gravel-filled (and similar) trenches and "soakaway" (mattress-shaped) installations - in the following formulae (Argue, 2004) -

'leaky' wells:

$$T = -\frac{4.6D}{4k_h}\log_{10}\left[\frac{\frac{D}{4}}{H+\frac{D}{4}}\right], \text{s} \quad \textbf{(1)}$$

gravel-filled (or similar) trench :

$$T = -\frac{4.6Lbe_s}{2k_h(L+b)}\log_{10}\left[\frac{Lb}{Lb+2H(L+b)}\right], \text{s} \quad \textbf{(2)}$$

"soakaways" and 'dry' ponds:

$$T \approx \frac{2H.e_s}{k_h}, \text{s} \quad \textbf{(3)}$$

Where T = emptying time in seconds; D = 'leaky' well diameter (m); k_h = soil hydraulic conductivity (m/s); L = length of trench (m); b = width of trench (m); $e_s = \frac{\text{void space available}}{L\,b\,H}$;

H = depth of 'leaky' well, trench, "soakaway" or 'dry' pond.

The **second** question requires a set of criteria against which to compare the emptying times determined for devices. These are also offered as 'interim' values (Table 2) which display a semi-log relationship between frequency (ARI) and emptying time (Argue, 2004). The values are considered generally conservative by practitioners using them in Australia. However, they enable the well-known design storm method to be used with confidence to dimension stormwater retention (storage) installations required under the **regime-in-balance** strategy.

Ave Recurr Interval (ARI), years	1-year or less	2-years	5-years	10-years	20-years	50-years	100-yrs
Emptying time, **T** in days	0.5	1.0	1.5	2.0	2.5	3.0	3.5

TABLE 2 : INTERIM RELATIONSHIP BETWEEN ARI AND 'EMPTYING TIME'

4 CONCLUSION

The dominant hydrological process which affects the movement of water within a forest or natural catchment – from the first point of rainfall contact with its canopy to the discharge of 'base flow' into streams and the ocean - is **retention.** Traditional urban storm drainage, on the other hand, has sought to collect and dispose of stormwater "…as completely and as quickly as possible".

Any attempt to create sustainable stormwater systems in urbanising landscapes should therefore be directed towards mimicking the processes of nature and – in the case of urban waterways – to adopt **retention** as the practice of first priority. The **regime-in-balance** strategy reviewed in the paper provides a systematic and practical way to implement this approach.

However, its use must be accompanied by an understanding on the part of practitioners that it does **not** reproduce complete natural catchment waterway matching across the *full range* of flood circumstances as urbanisation takes its course. It is therefore recommended that the strategy be applied to a 'median' level of flooding appropriate to the catchment and its place in the life of the basin community. The adopted level of (flood) risk should result from consensus reached among catchment stakeholders.

The paper concludes with discussion and resolution of some common 'misgivings' about retention technology applied in urbanising catchments, in particular, the issues of environmental flows and storm successions.

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