ICSM: a strategy to manage flooding in urban catchments experiencing regrowth

ICSM : une stratégie pour la gestion des inondations dans des bassins versants en redéveloppement

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RÉSUMÉ

Face à un redéveloppement urbain important, la pratique conventionnelle pour les organismes municipaux et gouvernementaux en Australie consiste à moderniser leurs infrastructures (séparées) d'évacuation des eaux pluviales tous les 20 à 50 ans. L’investissement occasionné par ces travaux se révèle problématique pour des raisons à la fois de coût direct et de coût indirect causé par les perturbations commerciales et industrielles dans la communauté locale. Une stratégie différente, à la fois rentable et bénéfique pour l’environnement, est proposée – la gestion des eaux pluviales conforme aux infrastructures (ICSM) – une approche de « contrôle des sources » orientée sur la poursuite de l’utilisation – sans modernisation ou agrandissement – des infrastructures existantes et efficaces de drainage des eaux pluviales. Cet objectif peut être atteint dans la plupart des milieux urbains, grâce à l’application de la stratégie du régime d’équilibre (Argue, 2004/2013) pour chaque cas de redéveloppement. L’essence de cette stratégie est la mise en quarantaine de l’écoulement supplémentaire par rapport à celui généré sur le site (existent) développé, et l’élimination de cet écoulement temporairement stocké grâce à un ou plusieurs moyens disponibles – approvisionnement en eau pluviale pour un usage domestique ou industriel, infiltration, amélioration de l’humidité du sol, recharge des aquifères, etc. Lorsque la réglementation locale, l’état du sol ou les conditions géologiques rendent impossible l’application de ces solutions, des critères de « temps de vidage » sont invokés pour veiller à ce que les stockages soient vides avant une succession d’orages. Une seconde stratégie – rendement minimum – est nécessaire pour tenir compte du redéveloppement dans le cas des infrastructures déjà surchargées de drainage des eaux pluviales.

ABSTRACT

Conventional practice among Australian municipal/government agencies faced with extensive urban regrowth is to upgrade their (separated) storm drainage infrastructures every 20 – 50 years. Investment in these works is proving problematic for reasons of both direct cost and the indirect cost of community and local commercial/industrial disruption. An alternative cost-effective and environmentally beneficial strategy is proposed - Infrastructure Compliant Stormwater Management (ICSM) - a ‘source control’ approach focussed on the continuing operation – without upgrade or enlargement - of existing, competently-performing stormwater infrastructures. This objective can be achieved in most urban settings through application of the regime-in-balance strategy (Argue, 2004/2013) to every case of re-development. The essence of this strategy is the quarantining of additional runoff above that generated on the (existing) developed site, and disposing of this temporarily-stored runoff by one or more of the available options – rainwater supply for domestic or industrial uses, infiltration, soil moisture enhancement, aquifer recharge, etc. Where local regulations or soil/geological conditions preclude these options, ‘emptying time’ criteria are invoked to ensure storages are empty ahead of storm successions. A second strategy – yield-minimum – is needed to account for regrowth/re-development in already overloaded stormwater infrastructure cases.

KEYWORDS

Infrastructure, regrowth, ‘source control’, stormwater, urban
1 INTRODUCTION

1.1 Some background on detention practice

It can be reasonably claimed that the most important single advance made in urban storm drainage design practice up to the latter years of the 20th Century was the development we know as detention technology. This advance has found wide application internationally – in urban concentration situations ranging from the regional scale installation, through residential and industrial sub-division detention basins down to the allotment scale on-site (OSD) facility. Researchers and practitioners have developed the intellectual property element of this technology, replacing the original trial-and-error routing solutions (Bennet and Mays, 1985) with progressively more sophisticated design and optimisation (including cost) approaches that continue to this day (Guo, 2004; Lee et al, 2005; Park et al, 2012; Tao et al, 2014; Shamsudina et al, 2014; Oxley and Mays, 2014).

But this story of progressive thinking about detention technology has been impacted by the rise of a new awareness in recent time - environmental as well as hydraulic - which has led to the topic being broadened into a parallel stream of research and practice focussed on pollution control/treatment capabilities of constructed wetlands employing detention practice in the process (Zhen et al, 2004) and, more recently, the use of retention in place of detention (Travis and Mays, 2008).

1.2 Drainage and regrowth in an urban catchment: the conventional approach

Figure 1 presents, first, the layout of a typical developed catchment served by a formal stormwater drainage network comprising underground pipes and hard-lined channels. The accompanying graph represents the hydrograph of runoff that can be determined by appropriate hydrologic modelling (O’Loughlin & Stack, 2001) at the catchment discharge point, O, in the average recurrence interval, ARI, Y-years storm upon which the design of the network is based. It is assumed that the drainage network is competently designed and well-matched to the catchment and that it satisfactorily conveys all storms up to and including the “Y-years” event having critical (storm) duration determined for the defined catchment.

![Figure 1: Developed catchment element and ARI, Y-years runoff hydrograph](image)

The single, shaded element shown in Figure 1 is proposed for re-development: this may mean change from a ‘low’ development use, such as a large residential allotment, to a ‘high’ use, for example, a factory building. Its former (‘low’) contribution to the total runoff hydrograph is also shown in the right-hand graph as a mini-hydrograph labelled “flow from developed element”: this flow is ‘matched’ to the (formal) stormwater infrastructure An enlarged version of this hydrograph is presented in Figure 2a, labelled “developed element”. Also shown in Figure 2a is the (modelled) hydrograph of runoff from the same element in its re-developed state, labelled “re-developed element”.

[Figure 2b illustrates the ‘detention solution’ to stormwater management and associated flooding issues. An on-site detention facility temporarily stores runoff which it delivers progressively into the (formal) drainage path with peak flow reduced (dashed hydrograph) to be equal to that calculated for the original development. Downstream successions of such hydrographs – the consequence of regrowth – are cumulative, leading to channel overload.]
Figure 2: (a) Runoff hydrographs for selected element - developed and re-developed; and (b) Conventional on-site detention facility outflow hydrograph.

Clearly, such re-development, particularly where it is carried out extensively in a catchment, places great (capacity) strain on the existing stormwater infrastructure. This problem is then solved by upgrading the infrastructure through augmentation, usually by channel enlargement.

There are two high-cost elements involved in this process. First: the, typically, massive cost of the work that is involved running into tens if not hundreds of millions of dollars for each upgrade; second: the cost of disruption in the region local to the upgrade – impact on community activities, business, traffic diversions, etc. These surges of stormwater infrastructure construction activity occur at time intervals that may be 20-years, 30-years or 50-years apart. Their cost to a developed nation like Australia - with over 150 metropolitan councils involved - may be conservatively estimated at tens of billions of dollars (present value) over the long-term future. Can this cost be avoided by municipal agencies and governments? Is there a better way?

2 A BETTER WAY: INTRODUCING ICSM

2.1 Infrastructure Compliant Stormwater Management (Ahammed et al, 2014)

Let us return to the analysis presented in Figures 1 and 2. The existing ‘developed catchment’ scenario illustrated in Figure 1 remains unaltered for our new considerations. It is important to the argument which follows to recognise that the formal (original) drainage paths illustrated in Figure 1 are well-matched to runoff generated in the contributing catchment in the design ARI, Y-years (critical) storm and manage this event in a competent manner. All regrowth in the contributing catchment is subsequently managed according to the following simple ‘source control’ principle -

Figure 3: (a) Runoff hydrographs for selected element - developed and re-developed; and (b) ‘Volume-retained’ approach under the regime-in-balance strategy

“Volume of stormwater passing from each catchment element following re-development (ARI, Y-years) must be equal to the volume discharged from that same (catchment) element before re-development, during passage of the floodwave in the design storm of critical duration”.
This principle, called the *regime-in-balance* strategy (Argue, 2004/2013), requires retention – at each re-developed site – of the volume difference between the runoff hydrographs generated by the (proposed) re-development and of its predecessor. This is labelled in Figure 3b as volume retained (shaded).

[Also shown on Figure 3b is the basin outflow curve (broken) for the conventional on-site detention solution to the same re-development scenario. Those familiar with this design approach will recognise the detained volume required for the basin as the difference between the runoff hydrographs of the re-developed element and of the detention basin outflow hydrograph (for the same element). It is clear that the storage volumes required for both solutions - retention and detention - are remarkably similar in magnitude. The hydrological consequences of their roles in temporary storage of surface runoff are, however, profoundly different.]

The ‘volume retained’ in an application of the *regime-in-balance* strategy is, effectively, quarantined from the floodwave for (at least) its duration and disposed of through use (variously interpreted) if at all possible: the environmental opportunities that arise from this disposal requirement give the *regime-in-balance* strategy a further advantage over conventional detention practice. For it is water, made available in the urban landscape other than from potable supply sources that is required to support a range of ‘green’ practices when we observe good environmental behaviour (see Section 3.1, below).

These diversions receive the ‘first call’ of the retained resource. It is often the case that they (the diversions) account for the entire volume retained in a substantial flood event: this is ideal but not always possible. Frequently, “unused” stored water must be directed into the (formal) drainage path as extended detention (US Dept of Transportation, 1996), appearing long after the main flood wave has passed (see Figure 3b). Special consideration must be given to this aspect of the technology as all temporarily stored water must be released in a time-frame that guarantees storage availability in the face of storm surges. This important aspect of the strategy is re-visited in Section 3.2.

It follows that, with these provisions in place, the volume of runoff discharged from the (proposed) re-developed element will be substantially the same as passed from it in its earlier developed state during flooding (see Figure 1b) and, further, that the time when that contribution reaches the ultimate discharge point, O (see Figure 1a), will also be the same. An over-riding condition which governs these phenomena is their direct association with the (unique) design storm of critical duration in the catchment.

It is not claimed that the two outflow hydrographs generated in the catchment element – its (earlier) developed and its re-developed versions - are, necessarily, identical. But that they have the same basic properties – same volume and same time-position within the total (catchment) runoff hydrograph. [The argument here is the same as that which gives us the area-moment formulation in calculus: the shape of the element is not important, only its area and position.]

Having established the (almost) unchanged nature of the basic properties of the elemental flow contribution to the (total) runoff hydrograph following re-development, it is but a small step to integrate this across all re-development elements of the entire catchment, leading to the proposition that –

“Equal ‘before’ and ‘after’ (re-development) surface runoff volumes delivered to the drainage path at each catchment element during the passage of a floodwave will result in ‘before’ and ‘after’ (total) runoff hydrographs at outflow point, O, having similar characteristics of peak flow and shape.”

[To achieve this equality, any water remaining in site storages – after use and other disposal options have been exhausted – should, strictly, not be released until the main floodwave has passed. Early release of extended detention water violates this and should, therefore, be kept to a minimum.]

This is a remarkable claim because it implies that any level of re-development can occur in an already developed catchment – from ‘low’ to quite ‘high’ density land uses – without significantly changing the main characteristics of the (design) flood runoff hydrograph (ARI, Y-years) that was well-matched to the capacity of the storm drainage infrastructure designed for the original developed landscape. The *regime-in-balance* strategy incorporating the principle of ‘source control’ can therefore avoid the costly periodic upgrades referred to earlier. Furthermore, its benefits are linked – seamlessly – to regrowth taking place in the catchment and are therefore ongoing for all time (see Argue, 2014). The conventional approach, by comparison, expresses itself in surges of upgrade activity which only terminate when re-development reaches the 100% impervious limit characteristic of the typical CBD.

### 2.2 Historical re-development

Practitioners engaged in applying the *regime-in-balance* strategy to progressive stages of re-development need to be mindful of its fundamental relationship to the original developed catchment and the (formal)
stormwater infrastructure to which it was matched (Figure 1). In particular, retention of, only, the volume difference between two successive re-developments invalidates the competence of the original infrastructure as a satisfactory system.

Figure 4: ‘Volume retained’ in two stages of (historical) re-development

Figure 4 illustrates (by appropriate shading) the correct interpretation of “volume retained” in two (historical) stages of re-development in an urban catchment where it is intended to use the original (formal) stormwater infrastructure in perpetuity. The “volume retained” after Re-development 2 must be the (full) volume difference between the Re-development 2 and original (development) hydrographs, not (just) the difference between the Re-development 2 and Re-development 1 hydrographs.

This review of the regime-in-balance strategy together with its supporting illustrations of application to various development/regrowth urban catchment scenarios presumes that the action takes place in municipal situations where the management of storm drainage has high priority. In such circumstances, the regime-in-balance strategy provides a sound and cost-effective base upon which to plan all future re-development in the sure knowledge that the communities served by the resulting networks will remain flood-secure.

However, not all municipal situations can be described in this way and there are many examples of ‘overloaded’ drainage networks in our major cities and urban concentrations. What can ‘source control’ technology offer in these circumstances? The answer to this question lies in the yield-minimum strategy.

2.3 The yield-minimum strategy (Argue 2004/2013)

The theoretical base for this ‘source control’ strategy is almost identical to that of the regime-in-balance strategy, reviewed above. The two components of Figure 1 apply equally except that in this case the peak flow of the surface runoff hydrograph (right-hand illustration) significantly exceeds the defined capacity of the formal drainage network illustrated on the left. As previously, the mini-hydrograph included in the right-hand graphic is that of the site selected for re-development.

Figure 3a is equally applicable to the yield-minimum case: this shows an enlarged version of the runoff hydrograph from the site selected for re-development together with its ‘new’, re-developed runoff hydrograph.

This brings us to Figure 3b and a significant departure from the earlier interpretation. The mismanagement of past practice cannot be corrected by retaining on site (only) the difference between the ‘new’ runoff hydrograph and the ‘old’, as in the regime-in-balance strategy. The yield minimum approach demands that the entire volume of runoff generated on the re-developed site in the design storm event (ARI, Y-years) be retained during passage of the floodwave. The conditions which apply to this retained volume are identical to those of the regime-in-balance case. It must be quarantined from the floodwave and disposed of through uses identical to those referred to in the regime-in-balance approach; likewise – as previously - any left-over stored water must be released downstream in the manner of ‘extended detention’.
The ultimate goal of applying the *yield-minimum* strategy is to convert catchments and storm drainage networks serving them from being "overloaded" cases into balanced relationships, characteristic of *regime-in-balance* waterways. In 'normal' catchment circumstances, this process may take some years to achieve, depending on the severity of the overloading condition, the size of catchment and the rate of re-development that is taking place. Councils facing this scenario should be pro-active in attracting new re-development – constrained by the *yield-minimum* strategy - into their areas: this will speed up the remediation process.

It is quite possible for the required transformation to take place in one, massive re-development initiative occupying the entire catchment: this could involve, for example, the construction of a shopping centre taking over the complete area of a formerly overloaded network. A more common scenario would be application of the *yield-minimum* strategy opportunistically to site-by-site re-development within the catchment of an already overloaded network. Unlike the single "...massive operation..." considered above, this approach would not deliver an immediate overall solution but, rather, a satisfactory outcome in the fullness of time. The 'satisfactory outcome' is, of course, a good match between runoff generated in the catchment in the ARI, Y-years event and the capacity of the storm drainage network *as originally designed*. With this stage reached, the *yield-minimum* strategy can be abandoned and the subsequent history of the catchment and drainage network can be the same as for any *regime-in-balance* application.

The ICSM approach applying the *yield-minimum* strategy has been adopted by one council to date – City of Gosnells in Western Australia – which was beset with 'overload' in many of its street drainage networks. The City has avoided a conventional infrastructure upgrade costed at $ 120 million and, since 2010, has carried out nearly 900 infill re-developments. It has no plans or intentions to upgrade the existing stormwater infrastructure; anecdotal evidence suggests that previously overloaded street drainage networks are now moving towards a "within capacity" regime. The ICSM design approach has been included among practices recommended by Engineers Australia for application in urban re-development scenarios across the nation (Engineers Australia, 2015).

### 3 TWO IMPORTANT CONSEQUENCES

#### 3.1 ‘Volume retained’: options/opportunities within re-development scenarios

The essence of the *regime-in-balance* and *yield-minimum* strategies described above is their reliance on a set quantity of floodwater being temporarily quarantined (off-line) from the waterway while the main floodwave passes. The destiny of this stored volume can vary greatly. Consider the simplest of the 'green' practice destinies: the retained volume (roof runoff) can be held in rainwater tanks – above- or in-ground - and used to replace mains water in a variety of domestic, open space and/or industrial uses. In situations where discharge to sensitive receiving environments is of particular concern, then part of the retained water (surface runoff) can be diverted to off-line stormwater quality improvement facilities such as bio-retention installations, raingardens, constructed wetlands, etc.

Recognition of the *regime-in-balance* and *yield-minimum* strategies as addressing, primarily, flood management concerns provides no conflict whatever between the roles of volume retention to achieve *quantity* objectives on the one hand and meeting 'green' *practice* goals on the other. A project calling for satisfaction of both sets of objectives – the common experience - can be readily accommodated within a single, dual-purpose installation incorporated into a re-development case.

A comprehensive list of the destinies and options that designers/planners should consider for the ‘volume retained’ includes –

Allocation of part of the volume to green roofs and/or roof gardens; Diversion of portion of the water to in-ground “soakaway” devices to enhance soil moisture in the catchment and hence support vegetation; recharge of deep aquifers; baseflow supply to local waterways.

#### 3.2 Storm successions and 'emptying time':

It was noted in the explanation offered in Section 2.1 that emptying of assigned storages between successive storms was a vital element of successful stormwater ‘source control’ practice. But it was also noted that such emptying should not create flood-wave conditions in the receiving waterway. These two requirements present the designer with an apparent conflict which can only be resolved by recourse to a criterion which provides answers to the question: "What time is available to empty the storage before arrival of the next design storm?" The preferred method for finding a scientific answer to this question is to use continuous simulation modelling – measured or derived - including periods of particularly severe storm activity. This approach should be followed in all large-scale re-development schemes.
An alternative approach is available for use with relatively small or minor re-growth operations: this employs a table of (target) emptying times which vary (directly) with storm magnitude, represented by ARI – Table 1. The table is based on anecdotal rather than scientific evidence and is an interim measure pending more rigorous research/investigation. However, it has been well-received over the past 10 years by practitioners in the cyclone-prone regions of tropical Australia and provides, at least, a good first approximation method for setting (target) outflow rates for minor flood control.

### TABLE 1 (Argue 2004/2013)

<table>
<thead>
<tr>
<th>Ave Recurr. Interval (ARI), Y-years</th>
<th>1-year or less</th>
<th>2-years</th>
<th>5-years</th>
<th>10-years</th>
<th>20-years</th>
<th>50-years</th>
<th>100-years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emptying time, $T$ in days</td>
<td>0.5</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
<td>3.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Application of the Table 1 criteria in any practical case leads to storage outflow rates which are, typically, quite small. Practitioners encountering this for the first time must resist the temptation to treat such flow rates as minimum (required) values which can be exceeded thoughtlessly, to achieve an engineering outcome. This action is counter to the basic intention of a valid ‘source control’ practice and runs the risk of outlet works being dimensioned to create the “… flood-wave conditions in the receiving waterway” which must be avoided. The calculated outflow rates should be seen as ‘target’ values which should neither exceed nor fall short of the ‘target’ by a significant margin.

4 CONCLUSION

Conventional practice among Australian municipal/government agencies faced with extensive urban regrowth generating significant additional surface runoff is to carry out major upgrade works every 20 to 50 years on their (separated) storm drainage infrastructures. Direct as well as indirect costs of these works have become prohibitive. ICSM is explained as a ‘source control’ approach which accepts as “given” (or “fixed”) the presence of an existing, competently-performing stormwater infrastructure and seeks to focus all modification required in the catchment resulting from regrowth, within the urban landscape itself and **not** on infrastructure upgrades.

Two strategies are described which enable this objective to be realised – **regime-in-balance** and **yield-minimum**. The essence of each of these strategies is the **quarantining** of a set portion of the runoff generated on each re-developed site and the diversion of this flow quantity into a variety of **green infrastructure** avenues such as roof gardens, rainwater tanks, “raingardens”, etc. Practical difficulties encountered in diverting all of the quarantined water into these avenues are recognised and provision made for disposal of “left over” water into the central drainage waterway: emptying time criteria provide for the orderly management of this process.

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