The unaccounted costs of conventional urban development: protecting stream systems in an age of urban sprawl

Geoff J. Vietz[1], Ian D. Rutherfurd[2], Christopher J. Walsh[1] , Yung En Chee[3] , and Belinda E. Hatt[4]

1 Waterway Ecosystem Research Group, Department of Resource Management and Geography, The University of Melbourne 500 Yarra Boulevard, Richmond, 3121. Email: g.vietz@unimelb.edu.au

2. Department of Resource Management and Geography, The University of Melbourne, Parkville 3010

3. School of Botany, The University of Melbourne, Parkville 3010

4. Monash Water for Liveability, Department of Civil Engineering, Monash University, Clayton, 3800

Key Points

- Rapid urban sprawl in major cities and centres throughout Australia with conventional stormwater drainage may have unaccounted impacts and costs for downstream waterways.
- Alternative stormwater management in greenfield developments, such as stormwater harvesting and biofiltration, can generate local benefits, cost savings and avoided costs to downstream waterways
- Downstream waterway benefits include reduced fluvial flooding, increased amenity opportunities along waterways, protection of biodiversity, and healthier receiving estuaries and bays.
- The business case for greenfield urban developments should consider the benefits of alternatives at both the local scale and for downstream waterways

Abstract

The development of new suburbs dramatically increases stormwater volumes into streams, much of which is of poor quality. In recent years, stormwater harvesting has increasingly been considered a significant source for water supply augmentation, but also as a means to improve human comfort and general amenity through cooling provided by irrigated urban vegetation at the development and surrounding landscape. To these recognised 'local' benefits of stormwater management, we add the avoided costs to downstream waterways. It is well known that conventional urban stormwater systems in headwaters degrade the biodiversity of streams and rivers, exacerbate downstream flooding, damage infrastructure through erosion, and impact on the condition of estuaries and bays. This damage can be so extensive as to be effectively irreversible. At present, the cost of repairing this damage is borne by the broader community rather than developers . We argue that there is a compelling business case for alternative stormwater management in new suburbs, if the avoided costs downstream of the development are coupled with the multiple local scale benefits (within the development).

Keywords

Urban stream, river rehabilitation, waterway management, urbanisation, stormwater harvesting, water sensitive urban design, business case

Introduction

The population of urban areas in Australia is growing by 1.6% per year (Australian Bureau of Statistics, 2008). This increase is accommodated by increasing the density of existing areas, combined with expansion of cities into new areas. In Melbourne, 40,000 new dwellings are being constructed each year, and half of these are built in greenfield sites. New suburbs on the urban fringes are commonly constructed using conventional drainage approaches, such as kerb and gutters, stormwater pits and drainage pipes connected to constructed stream channels. These approaches, designed to efficiently remove excess stormwater runoff from impervious surfaces, give little regard to downstream impacts of that stormwater.

Until recently, stormwater management for environmental protection has focused on reduction of pollutant loads primarily for the protection of downstream coastal waters (Fletcher et al., 2007; Burns et al., 2012; Wong et al., 2013). However, better understanding of the detrimental impacts of altered flow regimes means new objectives go beyond pollutant reduction, to reducing disturbances to flow regimes (Fletcher et al., 2014). This "flow regime management" (Burns et al 2012) or "ecohydrologic approach" (Fletcher et al., 2014) to urban stormwater management is enabled by technologies such as dispersed stormwater harvesting and infiltration systems.

Vietz, G. J., Rutherfurd, I. D., Walsh, C. J., Chee, Y. U. & Hatt, B. E. The unaccounted coasts of conventional urban development: protecting stream systems in an age of urban sprawl, in Vietz, G; Rutherfurd, I.D, and Hughes, R. (editors), Proceedings of the 7th Australian Stream Management Conference. Townsville, Queensland, Pages 418-424.

Increasing populations increase water demand and urban catchments generate excess stormwater flows - up to 10 times the volume of undisturbed catchments. Therefore mimicking the pre-urban flow regime requires purposefully diverting large volumes of water either via uses that result in the water ultimately flowing to the wastewater system, or via irrigation so that the water is ultimately lost to the air through vegetation (Walsh et al., 2012a). The rationale for this "alternative stormwater management" is compelling, but the practice is uncommon in greenfield developments. We suggest the main reason for the poor uptake of alternative stormwater management is that the business cases often do not account for the full gamut of benefits, so that the value of the alternative is seen as marginal. At the development there is often a single focus on stormwater harvesting as a source of alternative water supplies (Coombes et al., 2002; Tam et al., 2010), even though outside the business cases some of the downstream waterway benefits are recognised (Wong, 2007; Water by Design, 2010).

Downstream waterway costs of conventional suburban stormwater are almost never included in cost-benefit assessments. We are not talking here just about general environmental degradation of aquatic systems, which is very real, but about the additional damage that requires expenditure by communities downstream throughout the system (sometimes tens of kilometres). In terms of arguments for alternative stormwater management, these can be expressed as costs avoided by the developer, the waterway authority or by the community. Better understanding and accounting for these avoided costs in a business case may sway the economic argument away from conventional stormwater management approaches.

In this discussion paper we attempt to identify the full range of benefits (such as additional water) and avoided costs (such as protected infrastructure) that come from alternative stormwater management. With a focus on greenfield developments, and their connected waterways, we conceptualise benefits (or avoided costs) so that they may be better quantified and incorporated into the business case for alternatives to conventional stormwater drainage.

Benefits at two scales

The benefits of an alternative to conventional stormwater drainage for greenfield sites can be divided into two main parts: local benefits at the development and surrounds, and downstream waterway benefits (Figure 1).

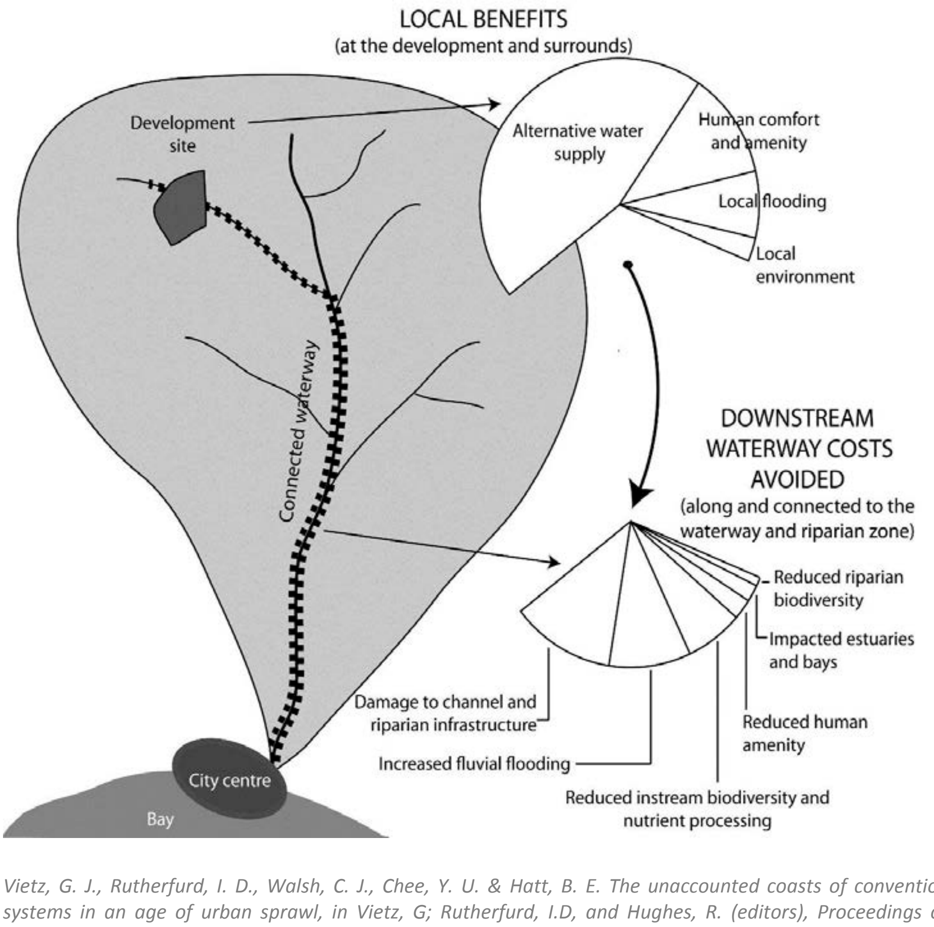

Figure 1. Benefits (or avoided costs) of alternatives to conventional urban drainage design at two scales: locally at the development and to the downstream waterway. The relative size of each segment is a conceptual estimate of their relative magnitude.

Local benefits at the development

Alternative water supplies

As urban populations grow the demand for water increases. Opportunities for a distributed, household tank based water supply system, capturing stormwater from roofs, are often central to the business case for alternative stormwater management: and the case can be compelling. For example, Coombes et al. (2002) found that rainwater tanks could delay the construction of new water supply headworks by up to 34 years, for case studies in the Lower Hunter and Central Coast of NSW. Tam et al. (2010) found that rainwater tanks could save households up to $240 per year compared with options such as dams and desalinisation, for case studies in Brisbane, Gold Coast and Sydney. Across a range of climatic conditions, dispersed stormwater retention, including harvesting at the property scale (designed for stream protection) can provide equivalent water yield to third-pipe recycled wastewater at substantially lower cost (Walsh et al., 2014).

Human comfort, health and amenity

At the development there are a range of tangible and monetary benefits of alternative stormwater approaches. Retaining water in the urban environment (such as through harvesting and infiltration) can improve human thermal comfort and health. For example, Coutts et al. (2013) highlighted that retention of stormwater at a site reduces excessive heating and drying from urban development, increases soil moisture and can provide energy savings. In extreme heat periods even small reductions in temperature of 1-2°C could decrease heat stress and mortality (Coutts et al., 2013). Greener spaces have been linked to reductions in disorders such as asthma, anxiety, depression, and cardiac disease (Maas et al., 2009), and open water bodies are desirable for amenity in the urban environment. Reductions in excessive stormwater flows also opens up possibilities by enabling waterway designers to focus less on utilitarian objectives of channel stability and flood capacity and more on waterway access, social values, interactions and uses. These alternative stormwater approaches can translate into real economic benefits for a developer. For instance, Water by Design (2010) found that alternative stormwater approaches made houses more desirable, resulting in increased house prices of $11,000-$44,000/ha.

Local flooding

Localised flooding at the street and precinct scale, particularly flooding caused by insufficient pipe-capacity, can be reduced through the use of water tanks capturing roof runoff. Burns et al. (2014) found that these treatments can reduce flooding from rainfall up to a magnitude of 25 mm of rainfall (a significant rainfall event in Australian cities).

Local environment

Through increased cooling, retaining moisture within soils, and providing open water bodies, biodiversity can be improved within the urban environment. For example, Kazemi et al. (2009) found that street scale bioretention systems increased biodiversity relative to grass or garden beds. For the waterway through the development, reduced disturbance flows from excessive stormwater runoff are likely to increase the potential for protection or restoration of frog, platypus, fish and macroinvertebrate populations (Walsh et al., 2013).

Avoided costs to the downstream waterway

Stormwater from new developments can cause considerable damage to downstream waterways. At present, these impacts are externalised, but the damage may ultimately require reparation. We identify different types of downstream impacts and how alternative stormwater management can help prevent future costs.

Damage to channel and riparian infrastructure

Urbanisation is arguably the land-use change that leads to the most change in the geomorphology of stream channels. Excessive erosion of the channel is caused by increased flow, and decreased sediment supply, (Vietz, 2013). While downstream impacts are most common, some channel changes may also lead to upstream head cuts. The extent of channel incision (preferential deepening of channels) is more than twice as severe for streams draining urban catchments with more than 5% effective imperviousness (Vietz et al., 2014). This commonly leads to enlarged channels that threaten infrastructure (e.g. bridges, paths and buildings) and require ongoing capital works and maintenance.

To protect infrastructure along streams, channels are often rock-lined. The cost of such channel construction approaches can range from \$2,500-\$3,000/m (Brisbane City Council (Water by Design, 2010) to >\$6000/m (outskirts of Melbourne, (Sammonds et al., In-review). Alternative stormwater management that effectively reduces stormwater flows can avoid the need for such expenditure. For example, for a low-density residential development in Queensland, Water by Design (2010) estimated that development with alternative stormwater management avoided stream rehabilitation and maintenance costs of \$8,000-\$60,000/ha of development. This figure varied with climate and stream geomorphology. Hawley et al. (2013) compared the costs of stormwater runoff storage (11,000 m^3/km^2) against stream restoration works to combat increased stream powers for a 0.8 km^2 catchment with 26% imperviousness. They found that stormwater would cost approximately \$2.9 million/km^2 and stream restoration works approximately \$12 million/km^2.

Increased fluvial flooding

The influence of stormwater harvesting on flooding downstream of developments is poorly understood. The effect of one greenfield development on stormwater flows downstream may be small but since most Australian cities are located at the end of major waterways the cumulative effects of developments may influence a large proportion of the stream network including the city centre. Developments may also transfer flooding downstream through the construction of large channels to convey design events, reducing the ability of the local floodplain to 'park' floodwaters (Vietz et al., 2012).

Burns et al. (2012) suggested that reasonably sized rainwater tanks (2.5 KL/100 m^2 of roof area) can reduce the frequency of stormwater events to near natural conditions, and reduce runoff volumes, noting that the influence is highly dependent on site characteristics. These benefits will be most effective for small- to medium-sized events and are dependent on antecedent conditions. While the influence may be small, theoretically even a 5% reduction from each development, ultimately covering 40% of a catchment, could reduce these events downstream by 2%. A 2% reduction on a 1-in-5-year Average Recurrence Interval (ARI) event could mean the difference between complete inundation of a road (and possible road damage) or an event that just laps the verge. Also, while the reduction in runoff might be small, the influence may extend over tens of kilometres and prevent localised flood damage to assets along the length of the stream.

Reduced human amenity

Excess stormwater runoff from conventional stormwater drainage systems can reduce human engagement with streams and riparian zones since channel morphology is commonly altered (by flow or in response to it), stream velocities are often increased, and flooding infrastructure reduce amenable recreation space. Recreation and amenity of streams is the second most common motivation for stream rehabilitation (following stabilisation and asset protection), according to a study of industry professionals (Zavadil, 2009). There are avoided costs in reducing the need to rehabilitate streams for recreational and amenity following urbanisation. Quantification of these values, however, is a vexing problem.

Reduced instream biodiversity and nutrient processing

Excess stormwater draining urban catchments is a well known agent of degradation for the ecology of streams, with changes at very low levels of urbanization with as little as 2-5% of impervious surfaces connected to the stream via pipes (Walsh et al., 2005a; Walsh et al., 2005c). The effects from increased disturbance events, and poor water quality, lead to changes in the physical habitat, reduced diversity in substrates and loss of species richness and diversity. Walsh et al. (2013) demonstrated that development in the headwaters of Merri Creek with conventional stormwater drainage would result in the loss of tens of species from each reach of the creek.

In 2006, 2,002 of the Melbourne regions 9,763 km of streams had been degraded by urban stormwater runoff. Following development of Melbourne to its urban growth boundary, >900 km of additional stream length will be degraded if it is developed using conventional drainage practices. The cost of reversing such impacts and reinstating in-stream biodiversity and ecological function is poorly understood but can be expected to be extremely high, since restoration will require coordinated catchment-scale actions to effectively address excessive stormwater runoff (Bernhardt et al., 2007; Walsh et al., 2012b).

Reduced riparian biodiversity

Riparian biodiversity and ecological function is degraded by urban stormwater runoff in several ways. These include reduced interactions between channel flows and the soils of the floodplain, hydrologic isolation from the water table leading to drier riparian soils that can switch from sinks of nitrogen to sources of nitrogen (Groffman et al., 2003), and increased weediness resulting from increased pollutants in riparian soils (Riley et al., 1996). Loss of riparian vegetation may further lead to bank instability, loss of habitat for water dependent flora and fauna and loss of amenity.

Impacted estuaries and bays

Streams and riparian zones degraded by urban stormwater runoff are likely to have reduced capacity to retain and transform important contaminants such as nitrogen, which pose significant threats to regionally important coastal waterways such as Port Phillip Bay (Harris et al., 1996). Such effects are particularly pronounced when small upland drainage lines, widely recognised as hotspots for retention of contaminants such as nitrogen (McClain et al., 2003), are transformed into hydraulically efficient stormwater drainage pipes, as is common practice under conventional stormwater management (Elmore et al., 2008).

Excessive delivery of sediments during the construction phase of developments and subsequent erosion of stream channels are also likely to have deleterious impacts on the functioning of downstream estuaries and bays.

Who pays?

Who pays for the costs of conventional stormwater management in greenfield developments? The costs of remedial mitigation works, such as channel armoring, riparian revegetation and gross pollutant trapping are currently borne by the broader community through authorities responsible for waterway management. The costs of damage that remains unmitigated, such as living with polluted waterways, is borne by downstream communities.

There is also a legacy cost. Streams are extremely sensitive to even small areas of directly connected impervious surface (Walsh et al., 2005b; Vietz et al., 2014) and restoring such degraded streams is extremely expensive. Degrading these systems now condemns future generations to huge costs if they want to return the lost values to the streams. These legacy costs may be particularly high if consideration is given to the increasing value of ecological systems over the last two decades, and how we might value our urban environment several decades from now. Hence, shifting valuation may need to be factored into the life-cycle cost of development, This may require consideration of the generational increases in valuing aquatic and riparian ecosystems and opportunity costs (or “regrets”) of not acting when it was easiest.

The unaccounted costs of a development also depend on the condition of the downstream waterway: the avoided costs of a development upstream of an intact channel will be far greater than if the channel is already degraded. Conversely, a conventionally drained development may be another nail in the coffin making future opportunities and recovery of the downstream channel less likely.

Given the observations above, the best outcome would be if the impacts of urban stormwater runoff were to be avoided by regulators ensuring that urban developers manage the stormwater at source. We suggest the substantial downstream costs of conventional stormwater drainage in the development are going to be greater than the costs of preventing the damage through alternative stormwater management, if the co-benefits of alternative approaches are accounted for.

Conclusions

The business case for alternative stormwater management approaches to greenfield development may be more compelling if the downstream waterway benefits are combined with the benefits at the development and surrounds. The ability to monetise some of the unaccounted costs of conventional stormwater approaches will assist the process. Nevertheless, the inability to put a dollar value on benefits, such as improved amenity and ecosystem protection, should not preclude them from holistic economic consideration.

Acknowledgments

We would like to thank Dan Borg for reviewing this paper, and Tim Fletcher and Matt Burns for valuable discussions. Vietz and Walsh would like to acknowledge funding for this research from the Cooperative Research Centre for Water Sensitive Cities and Melbourne Water through the Melbourne Waterway Research-Practice partnership.

References

Australian Bureau of Statistics, 2008. Australian Social Trends pp.

Bernhardt, E.S., Palmer, M.A., 2007. Restoring streams in an urbanizing world. Freshw. Biol. 52, 738-751.

Burns, M.J., Fletcher, T.D., Walsh, C.J., Ladson, A.R., Hatt, B.E., 2012. Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. Landscape and Urban Planning 105(3), 230-240.

Burns, M.J., Fletcher, T.D., Ladson, A.R., Walsh, C.J., 2014. Flow-regime management at the urban-parcel scale: a test of feasibility. Journal of Hydrological Engineering.

Coombes, P.J., Kuczera, G., Kalma, J.D., Argue, J.R., 2002. An evaluation of the benefits of source control measures at the regional scale. Urban Water 4, 307-320.

Coutts, A.M., Tapper, N.J., Beringer, J., Loughan, M., Demuzere, M., 2013. Watering our cities: The capacity for water sensitive urban design to support urban cooling and improve human thermal comfort in the Australian context. Progress in Physical Geography 37(1), 2.

Elmore, A.J., Kaushal, S.S., 2008. Disappearing streams: patterns of stream burial due to urbanization. Frontiers in Ecology and the Environment 6, 308-312.

Fletcher, T.D., Mitchell, V.G., Deletic, A., Ladson, T.R., Seven, A., 2007. Is stormwater harvesting beneficial to urban waterway environmental flows? Water Sci. Technol 55(4), 265-272.

Fletcher, T.D., Vietz, G.J., Walsh, C.J., 2014. Protection of stream ecosystems from urban stormwater runoff; the multiple benefits of an ecohydrological approach. Progress in Physical Geography Published online May 27, doi: 10.1177/0309133314537671

Groffman, P.M., Bain, D.J., Band, L.E., 2003. Down by the riverside: urban riparian ecology. Frontiers in Ecology and the Environment 1(6), 315-321.

Harris, G., Batley, G., Fox, D., 1996. Port Phillip Bay Environmental Study Final Report, CSIRO, Canberra.

Hawley, R.J., MacMannis, K.R., Wooten, M.S., 2013. How poor stormwater practices are shortening the life of our nation's infrastructure - Recalibrating stormwater management for stream channel stability and infrastructure sustainability, World environmental and water resources congress. ASCE, Cincinnati, Ohio, May 19-23, 193-207 pp.

Kazemi, F., Beecham, S., Gibbs, J., 2009. Streetscale bioretention basins in Melbourne and their effect on local biodiversity. Ecol. Eng. 35(10), 1454-1465.

Maas, J., Verheij, R.A., de Vries, S., Spreeuwenberg, P., Schellevis, F.G., Groenewegen, P.P., 2009. Morbidity is related to a green living environment. Journal of Epidemiology and Community Health (1979-)(12), 967.

McClain, M.E., Boyer, E.W., Dent, C.L., 2003. Biogeochemical hot spots and hot moments at the interface of terrestrial and aquatic ecosystems. Ecosystems 6, 301-312.

Riley, S.J., Banks, R.G., 1996. The role of phosphorous and heavy metals in the spread of weeds in urban bushlands - an example from the Lane Cove valley, NSW, Australia. Science of The Total Environment 182(1), 39-52.

Sammonds, M., Vietz, G., In-review. Using catchment history to define a naturalized urban stream when restoration is impossible. Area - Special Issue Urban Geomorphology.

Tam, V.W.Y., Tam, L., Zeng, S.X., 2010. Cost effectiveness and tradeoff on the use of rainwater tank: An empirical study in Australian residential decision-making. Resources, conservation and recycling 54, 178-186.

Vietz, G.J., Stewardson, M.J., Walsh, C.J., Fletcher, T.D., 2012. Another reason urban streams are stuffed: geomorphic history, challenges and opportunities. In: Grove, J.R., Rutherfurd, I.D. (Eds.), Proceedings of the 6th Australian Stream Management Conference Canberra, Australia, 1-7 pp.

Vietz, G.J., 2013. Water(way) sensitive urban design: Addressing the causes of channel degradation through catchment-scale management of water and sediment. In: Institution of Engineers Australia (Ed.), Proceedings of the 8th International Water Sensitive Urban Design Conference, Gold Coast, Australia, 25-29 November 2013, 219-225 pp.

Vietz, G.J., Sammonds, M.J., Walsh, C.J., Fletcher, T.D., Rutherfurd, I.D., Stewardson, M.J., 2014. Ecologically relevant geomorphic attributes of streams are impaired by even low levels of watershed effective imperviousness. Geomorphology 206, 67-78.

Walsh, C.J., Fletcher, T.D., Ladson, A.R., 2005a. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. J. Am. Water Resour. Assoc. 24(3), 690-705.

Walsh, C.J., Fletcher, T.D., Ladson, A.R., 2005b. Stream restoration in urban catchments through redesigning stormwater systems: looking to the catchment to save the stream. J. N. Am. Benthol. Soc. 24(3), 690-705.

Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., Morgan, R.P., 2005c. The urban stream syndrome: current knowledge and the search for a cure. J. N. Am. Benthol. Soc. 24(3), 706-723.

Walsh, C.J., Fletcher, T.D., Burns, M.J., 2012a. Urban stormwater runoff: a new class of environmental flow problem. PLoS ONE 7(9), e45814.

Walsh, C.J., Fletcher, T.D., Vietz, G., Thompson, R., Tapper, N., Beringer, J., Coutts, A., Allen, R., 2012b. New urban stormwater management: Using the water generated by cities for ecosystem services. City Green pp.

Walsh, C.J., Bond, N., Fletcher, T.D., 2013. Possible ecological futures for Merri and Darebin creeks, Melbourne Waterway Science-Practice Partnership, the University of Melbourne, September 2013.

Walsh, C.J., Eddy, R.L., Fletcher, T.D., Potter, M., 2014. Feasibility and cost of stormwater management for stream protection at property, street and precinct scales. Melbourne Waterway Research Practice Partnership Technical Report 14-1 pp.

Water by Design, 2010. A business case for best practice urban stormwater management (Version 1.1). South East Queensland Healthy Waterways Partnership, Brisbane, Queensland.

Wong, T.H.F., 2007. Water sensitive urban design; the journey thus far. Australian Journal of Water Resources 110(3), 213-222.

Wong, T.H.F., Allen, R., Brown, R.R., Deletić, A., Gangadharan, L., Gernjak, W., Jakob, C., Johnstone, P., Reeder, M., Tapper, N., Vietz, G., Walsh, C., 2013. Blueprint 2013 - Stormwater management in a water senstive city. 978-1-921912-02-3, Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia.

Zavadil, E., 2009. Understanding how we manage urban streams, Report P109064_R01 by Alluvium for Melbourne Water, Melbourne, Australia.