Impediments and constraints in the uptake of water sensitive urban design measures in greenfield and infill developments

Ashok K. Sharma, Stephen Cook, Grace Tjandraatmadja and Alan Gregory

ABSTRACT

Water sensitive urban developments are designed with integrated urban water management concepts and water sensitive urban design measures. The initiatives that may be included are the substitution of imported drinking water with alternative sources using a fit-for-purpose approach and structural and non-structural measures for the source control of stormwater. A water sensitive approach to urban development can help in achieving sustainability objectives by minimising disturbance to ecological and hydrological processes, and also relieve stress on conventional water systems. Water sensitive urban developments remain novel in comparison with conventional approaches, so the understanding and knowledge of the systems in regards to their planning; design; implementation; operation and maintenance; health impacts and environmental impacts is still developing and thus the mainstream uptake of these approaches faces many challenges. A study has been conducted to understand these challenges through a detailed literature review, investigating a large number of local greenfield and infill developments, and conducting extensive consultation with water professionals. This research has identified the social, economic, political, institutional and technological challenges faced in implementing water sensitive urban design in greenfield and infill developments. The research found in particular that there is the need for long-term monitoring studies of water sensitive urban developments. This monitoring is important to validate the performance of novel approaches implemented and improve associated guidelines, standards, and regulatory and governance frameworks, which can lead to mainstream acceptance of water sensitive urban development approaches. The dissemination of this research will help generate awareness among water professionals, water utilities, developers, planners and regulators of the research challenges to be addressed in order to achieve more mainstream acceptance of water sensitive approaches to urban development. This study is based on existing water sensitive urban developments in Australia, however, the methodology adopted in investigating impediments to the uptake of these developments can be applied globally. It is hoped that insights from this study will benefit water professionals in other countries where there is also a move towards water sensitive urban development.

Key words | alternative water sources, integrated urban water management, sustainability, urbanisation, water recycling, water sensitive urban design

INTRODUCTION

The rapid urbanisation of Australia over the last 100 years has placed pressures on the natural environment through the extraction of freshwater resources, pollution of waterways from urban runoff, the discharge of treated wastewater to receiving waters, and disturbance of natural hydrological regimes. These pressures are driving the need for a paradigm shift in the way in which urban water services are provided in order to move towards ecologically sustainable development and the long-term reliability of urban water services.
Urban developments planned with Integrated Urban Water Management (IUWM) and Water Sensitive Urban Design (WSUD) approaches are becoming increasingly common across Australia. These developments, which we refer to as Water Sensitive Urban (WSU) developments, aim to incorporate sustainability principles in the planning of urban water services, and have been designed at a range of development scales for greenfield, infill and retrofit developments. The planning of WSU developments differs from conventional systems by taking a total urban water cycle perspective in planning services, and matching different water sources to end uses based on a fit for purpose approach, which may include the adoption of decentralised technologies. WSU developments also consider the environmental impacts of urban water services on the larger ecosystem and catchment.

As WSU developments are comparatively novel compared with conventional approaches, the understanding and knowledge of these systems in regards to planning; design; implementation; operation and maintenance; health impacts and environmental impacts is still developing. In addition, the current institutional, political and legislative frameworks support the conventional model of water service provision and are not necessarily able to capture the full benefits from WSU developments. Research is required to understand WSUD systems and the framework required to ensure adequate governance, and to develop management models for increased uptake, operation and integration into the urban landscape.

Building upon existing research, including an increasing number of guidelines developed by state and federal agencies, the existing water sensitive urban developments planned and implemented in Australia were investigated to identify gaps in knowledge and lessons for implementing and promoting future WSU developments.

This paper describes the impediments and constraints in the uptake of WSU developments based on the assessment methodology described in a following section. Although the study was conducted in Australian context, the outcome of the investigation will benefit water professionals across the globe in implementing sustainable WSU developments.

**WATER SENSITIVE URBAN DEVELOPMENTS**

WSU developments incorporate both IUWM and WSUD approaches at different development scales. Specific initiatives may include substitution of imported drinking water with alternative sources for non-consumptive uses, including: recycled water (reclaimed wastewater), stormwater harvesting (urban run-off harvested from drains or streams) and rainwater harvesting (roof run-off). Also, WSU developments can include structural and non-structural measures for source control of stormwater and other measures to minimise the impact of urban development on ecological and hydrological processes.

Several structural and non-structural tools can be applied to achieve IUWM and WSUD objectives, the selection of which is guided by site-specific suitability factors including: the type of development, catchment conditions, climate, customer acceptance and allocation of financial resources (Sharma et al. 2008).

A list of structural tools for water supply, wastewater and stormwater systems is shown in Table 1. Examples of non-structural tools are demand management approaches, water restrictions and financial incentives. The list provides an insight into the diversity of approaches that can be applied in matching WSUD objectives with a development setting, which differs from the relatively uniform approach taken for conventional systems.

**ASSESSMENT METHODOLOGY**

The methodology (Figure 1) was developed with the aim of identifying the impediments and constraints faced in the various stages of planning, design, development, implementation, maintenance and operation of WSU developments. The methodology was also designed to elicit water industry lessons learnt from existing WSU developments. The methodology is based on the following tasks:

<table>
<thead>
<tr>
<th>Water supply options</th>
<th>Wastewater options</th>
<th>Stormwater options</th>
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<tr>
<td>Rainwater harvesting systems</td>
<td>On-site wastewater treatment</td>
<td>On-site detention tanks</td>
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<td>Greywater reuse systems</td>
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<td>Dual pipe system</td>
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- Review of national and international literature
- Analysis of existing greenfield/infill developments in Australia
- Detailed investigation of nine existing greenfield and infill developments
- Consultation with water professionals, utilities and other stakeholders

**Literature review**

The literature was reviewed to identify and summarise significant barriers that have been found to WSU development becoming a mainstream practice. A summary of the literature review is provided in this section.

The majority of barriers inhibiting the adoption of WSU development are social and institutional rather than technical; in addition, water industry professionals perceive barriers and drivers depending on the technologies that are to be implemented (Brown *et al.*, 2011). Dolnicar & Hurlimann (2009) highlighted that alternative water sources are technically feasible but their implementation is dependent upon acceptance by politicians and the community. Mitchell (2004) suggested the existing institutional structures of water authorities, local government, government departments and private industries have evolved to deliver conventional water services. Mitchell highlighted the need to re-evaluate roles and responsibilities within these organisations in order to deliver urban water services with integrated urban water management concepts.
also the need for aquatic environmental protection and waterway amenity to be included in the current governance structures together with established values of flood protection, public health and economic efficiency (Brown & Clarke 2007).

Newman & Mouritz (1996) made the point that transitioning from a traditional approach to a system incorporating WSUD principles will not be easy for those who have been part of an institutional system in which all expertise and power for the urban water system are controlled in a top-down management system. The professional memes of the urban water industry are based on engineering methods and rationales that are often poorly suited to community consultation and engagement activities (Pearson et al. 2010). Organisations are faced with the challenge of adapting their regulatory frameworks and community engagement approaches to manage water resources in a way consistent with the principles of WSUD and IUWM.

The fragmented nature of organisations and policies relevant to the management of water resources can constrain the uptake of WSU developments. MacDonald & Dyack (2004) found that the overarching institutional impediment to water conservation and reuse is the poor coordination of policies and regulations governing water conservation and reuse. Brown (2005) also draws attention to jurisdictional and institutional fragmentation in the management of urban stormwater, possibly leading to overlap and undefined responsibilities between organisations. Nancarrow et al. (2010) highlighted that uptake of alternative water sources is heavily influenced by Government pricing regulators that make decisions based on a least-cost basis that does not necessarily incorporate community preferences and values.

A key attribute preventing mainstream adoption of sustainability technologies is the lack of acceptance across all stakeholders and institutions. Shipton & Mitchell (2002) highlight the inefficiency of current organisational structures for urban water management in which water supply, stormwater management and wastewater services are managed as separate entities. Pahl-Wostl et al. (2011) argued that the level of organisational and institutional integration for IUWM approaches is one of the impediments in transitioning IUWM to a mainstream practice.

Community perceptions and lack of support have been significant barriers to the implementation of recycled water schemes in Australia (Dimitriadis 2005). Foley et al. (2007) also identified community support and acceptance for water recycling schemes as the biggest challenges for widespread implementation. Communities in general accept the need to conserve natural resources through initiatives such as recycled water schemes; however, there is reluctance to use the water (Radcliffe 2004). Nancarrow et al. (2009) identified that building trust with the community is essential for acceptance of alternative water sources. This trust can be built with ongoing and meaningful communication among developers, planners, and the local community.

A move to alternative water sources, such as recycled water for non-consumptive use, requires community support as it requires a change in practice as well as technology (Marks 2006). The Gold Coast City Council implemented an extensive stakeholder engagement and community consultation process to ensure local ownership and commitment to proposed water recycling schemes. Mankad & Tapsuwan (2011) identified there has been significant research into community acceptance of centralised alternative water sources, such as recycled wastewater, but there is the need for more research into household scale water sources, such as rainwater harvesting and greywater recycling.

Po et al. (2003) highlighted that the importance of community support for success of a water recycling scheme is commonly acknowledged, but there is paucity of research that seeks to understand the drivers of public perception of water recycling and the emotional factors that influence the decision-making processes. Lloyd (2004) discussed market research, undertaken in Melbourne, to determine community acceptance of a range of WSUD strategies. Positive aspects that people associated with these features included improved aesthetics, greener surroundings and improved local habitat. McManus & Morison (2007) identified community ignorance as a threat to the widespread adoption of WSUD in the Botany Bay Catchment. The Healthy Waterways Partnership (2005) report shows that community demand for WSUD is not likely to be widespread, with WSUD elements and their associated costs more likely to appeal to higher socio-economic groups.

The institutional inertia in transitioning to approaches consistent with WSU development in some cases may be attributed to insufficient skills and capacity within the relevant organisations, such as local government, state government agencies and water authorities. Burkhard et al. (2000) asserted that, despite the wide diversity of techniques available for the planning of water and wastewater management services, many are not well known to mainstream engineers. Mitchell (2004) found that many parties involved in leading edge WSU development case studies often experienced delays due to the time required in
‘breaking new ground’. The difficulty in accessing the skills and experience required for WSU development is attributed to the novel nature of many techniques to the water industry. The technical knowledge required to implement initiatives associated with WSU development is often well-developed, but in many cases there is a lack of practical experience within institutions that can retard their uptake (Livingston et al. 2006). Shipton & Mitchell (2002) point out that while many water professionals have embraced the concepts of WSU development there are still a number of challenges to overcome to fully realise it. A current knowledge gap identified is the lack of research on the relationship between urban water and land use planning.

The perceived health risks associated with alternative water sources, such as recycled water, has been an impediment to uptake of WSU development. The potential risks include a cross-connection at any point in a plumbing system in which it is possible for non-drinking water sources to contaminate drinking water supplies. At the Rouse Hill recycling scheme, the main issue faced in the commissioning and ongoing operation of the scheme has been the reliability of plumbing work undertaken by private contractors between the Sydney Water mains and house fittings (Radcliffe 2004).

WSUD features, such as decentralised water and wastewater systems, are relatively untried and unproven, when compared with centralised conventional urban water systems (Makropoulos & Butler 2010). There is a general lack of information on the performance of WSUD projects over their life cycle. To improve our knowledge, more water quality monitoring needs to be undertaken, more operation and maintenance requirements (including costs) needs to be collected and the results published in the public domain. Lack of data on maintenance costs has been identified by professionals involved in the sector as a barrier to uptake of sustainable urban water management technologies (Brown et al. 2007). There is the need for a re-evaluation of the roles and responsibilities in urban water management to ensure that the performance of WSUD features aligns with design specifications, and perform reliably over the life cycle of the asset (Moglia et al. 2010).

The Victorian EPA (2008) released a document to provide information to local councils and developers regarding expected tasks and costs for managing WSUD elements. It is hoped that this document will address the uncertainty around the maintenance of WSUD features that is a significant barrier to local governments.

To address the lack of information on WSUD features, Lloyd (2004) undertook a monitoring program of a biofiltration system (Lynbrook Estate, Victoria). Technical, economic and social performance was quantitatively assessed. Whilst there are many publicly published examples related to performance of WSUD measures (e.g. RossRakesh et al. 1999; Somes et al. 2000; Greenway et al. 2002; Marsalek et al. 2002; Deletic & Fletcher 2006; Siriwardene et al. 2007; Bratieres et al. 2008; Singh & Kandasamy 2009), they relate to performance over months and years rather than decades or the life of the asset. Kadurupokune & Jayasuriya (2009) simulated the performance of a pervious pavement over seventeen years and found that the approach is effective in reducing the volume of runoff and peak flows; however, the authors recognised the need to extend laboratory base simulations to field sites.

Burns & Mitchell (2008) recognised that uncertainties on the operational performance of existing stormwater harvesting system are an impediment to their wider uptake. There are examples in the literature which relate to operation and maintenance requirements together with performance. Some of these examples address operation and maintenance qualitatively (e.g. Dechesne et al. 2002; Oldenburg et al. 2002; Brattebo & Booth 2003; Grant et al. 2005), and others quantitatively, by expressing the requirements in dollar terms (e.g. Coombes et al. 1999; Lloyd 2004; Grant et al. 2006). There are some examples reporting cost data (e.g. Coombes et al. 2000; Grant & Hallmann 2003; Taylor & Fletcher 2004; Taylor 2005; Water by Design 2010), but many more are needed. Urrutiaguer et al. (2010) noted that data on capital and operating costs for WSUD approaches is limited. Taylor & Fletcher (2007) made the point that stormwater managers faced with the selection of appropriate structural and non-structural stormwater management approaches need reliable information on their design specifications, performance and cost. This information can only be collected through rigorous monitoring and evaluation programs.

The relatively low value of drinking water remains a barrier for uptake of alternative water sources (Dimitriadis 2005). As drinking water prices do not incorporate externalities, some water recycling schemes fail because in comparison they do not seem economically viable (Dimitriadis 2005). The cost of producing recycled water is highly variable, depending on site-specific factors. In general, recycled water is artificially priced lower than drinking water in order to provide an incentive for substituting recycled water in place of drinking water for non-consumptives uses (Foley et al. 2007). The capital costs for technologies associated with WSU developments are seen
as a barrier by water industry professionals (Brown et al. 2007). Holt (2006) argues that in order for a equitable evaluation of decentralised options there is the need for consideration of the true cost of water to the community that takes into consideration externalities such as ecosystem impact.

WSUD aligns with the principles of sustainability as the concept incorporates social, economic and environmental considerations (Sharma et al. 2009, 2010). WSU developments, in general, will incorporate objectives related to maintaining, or when possible, improving water quality and water related environmental values of an area.

The provision of urban water infrastructure in a WSU development needs to consider environmental constraints, such as limiting greenhouse gas emissions and discharge of nutrients. Sharma et al. (2009) presented an environmental and economic framework for the evaluation of alternative water servicing options that combines analysis tools such as water balance analysis, life cycle costing and life cycle assessment.

A shift to alternative water sources can sometimes require more energy than a conventional system. Conventional water supplies were designed to minimise energy consumption through use of gravity, while decentralised technologies, such as wastewater treatment and reuse, can require more energy (Medeazza & Moreau 2007). Even rainwater tanks can use a relatively large amount of energy due to inefficient pumping (Gardner et al. 2006). Hoban et al. (2006) explored interactions between climate change adaptation and WSUD. Hoban argues that urban environments that have self-sufficient water supplies are more likely to be resilient to impacts of climate change.

Based on the literature review the barriers identified were organised into the following eight themes: (1) governance, regulations and guidelines; (2) community acceptance and social impacts; (3) skills and knowledge; (4) public health; (5) system evaluation, performance and monitoring; (6) financial incentives for WSUD; (7) system operation and maintenance and (8) sustainability and broader system impacts. These themes have also been used to classify information garnered from the review of WSU developments and stakeholder survey, which are described in detail in subsequent sections.

**Desktop analysis of existing greenfield/infill developments in Australia**

An inventory of nearly 30 WSU developments in Australia was developed recording: the location; state; year of development; size of development – number of lots or area of development; type of development - residential, commercial or industrial; technologies and water sensitive measures implemented and the drivers for WSUD/ IUWM (Tjandraatmadja et al. 2008). In many cases, the developments selected for investigation were, at the time of their construction, leading edge examples of WSUD approaches. The investigation assessed the performance of WSUD features in reducing overall water consumption, substituting municipal water supply with alternative sources, source control of stormwater quantity and quality, and the energy footprint of on-site treatment systems.

Stakeholders involved in initiating the WSU developments were consulted to understand the key drivers for incorporating WSUD elements, and factors that enabled WSUD features, such as the awarding of grants. The particular WSUD features implemented were considered in terms of the level of innovation, and how WSUD was integrated in the overall planning process. The developments were also assessed for how they engaged stakeholders and planned for the ongoing operation and maintenance of WSUD features.

The desktop analysis of existing WSU developments was used to inform the selection of nine developments for more detailed investigation through site interviews and stakeholder interviews, as detailed in the following section. The desktop analysis of WSU developments was also used in framing the issues to be explored through the survey.

**Detailed investigation of main existing greenfield and infill developments**

Nine WSU developments were investigated in detail for their planning, design, approval processes, implementation, operations and maintenance to investigate associated impediments and constraints. These developments were selected through a process based on locations, to understand State and Territory policies and programs; development types classified as greenfield and infill; development scale defined as allotment, cluster and large scale; physical infrastructure for alternative water resources supply/reuse/treatment/distribution/collection, monitoring status and implementation process. Table 2 summarises the nine sites selected for detailed analysis. The information presented in this section is a brief summary of the overall information collected from all the nine developments.

The purpose of this section is to highlight issues in implementation of WSUD as revealed through review of the case study sites, discussions with local residents,
developers, consultants and operators. Each of the nine sites is unique and the barriers faced are in many cases specific to the particular context, however, a broad overview revealed many common issues and lessons for future developments.

The following section distils lessons learnt and how this knowledge could be applied in improving outcomes in future WSU developments. The following are the key learnings for improving outcomes of future WSU developments:

- The regulatory authority must oversee implementation, ongoing maintenance and operation of decentralised water and wastewater systems – particularly for small-scale operations that do not have access to skills and resources necessary to adequately operate and maintain decentralised systems.
- Extensive community engagement and consultation is important to ensure local ownership and commitment to the approaches proposed as part of a WSU development. In the case of greenfield development, when there is no existing community, prospective residents may be represented by community groups from surrounding areas.
- Communication between all parties involved is important to ensure key planning and design objectives are realised during construction. Several examples were identified through the case study review in which WSUD elements were not performing to design objectives due to poor installation or construction.
- Sharing of risks (mainly costs) can expedite uptake of water sensitive features by developers. In some cases a government agency or water utility may need to underwrite a new technology or approaches, so the risk burden is not carried entirely by the developer.
- Maintenance plans need to be clearly defined from the initial planning and design phase. The maintenance plan should be developed for the expected service life of the assets and specify clearly tasks required, responsible authority, and expertise and resources required. Parties that may be gifted infrastructure should be involved throughout the process to ensure they understand and are comfortable with WSUD elements that they will assume responsibility for.
- Ongoing monitoring and evaluation of WSUD elements is essential for addressing research gaps, such as the life cycle cost and performance of different WSUD elements. This role is best taken by academic and government research units, as it is unlikely that developers will have the inclination, necessary resources and expertise.

Table 2  |  WSU Developments selected for detailed analysis

<table>
<thead>
<tr>
<th>Development name</th>
<th>Type</th>
<th>Distinguishing features</th>
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<tr>
<td>Aurora (Victoria)</td>
<td>Large scale</td>
<td>Greenfield residential development with IUWM features including reclaimed water supply</td>
</tr>
<tr>
<td>Payne Rd (Queensland)</td>
<td>Cluster</td>
<td>A cluster (22 lots) residential development integrating IUWM technologies with traditional services</td>
</tr>
<tr>
<td>St. Elizabeth Church Carpark (South Australia)</td>
<td>Infill</td>
<td>Small-scale retrofit of existing car park and public open space demonstrating best practice WSUD to capture stormwater for irrigation of public open space</td>
</tr>
<tr>
<td>Pimpama-Coomera (Queensland)</td>
<td>Large scale</td>
<td>Framework approach guiding water sensitive design of a residential growth corridor that minimises environmental impact on receiving water and reduces potable water demand</td>
</tr>
<tr>
<td>Rouse Hill (New South Wales)</td>
<td>Large scale</td>
<td>Large scale implementation of dual reticulation to supply recycled water for non-potable purposes to reduce environmental impact and substitute demand for drinking water</td>
</tr>
<tr>
<td>Mawson Lakes (South Australia)</td>
<td>Large scale</td>
<td>Aquifer Storage and Recovery (ASR) and recycled water for non-potable applications, WSUD features and innovative approaches for community engagement</td>
</tr>
<tr>
<td>Lakelands Private (Western Australia)</td>
<td>Large scale</td>
<td>WSUD features designed to separate residential runoff from environmentally sensitive lakes</td>
</tr>
<tr>
<td>New Haven (South Australia)</td>
<td>Cluster</td>
<td>A cluster (65 dwellings) of medium density residential development. Commissioned an onsite wastewater treatment plant, with effluent recycled for non-potable applications</td>
</tr>
<tr>
<td>Docklands (Victoria)</td>
<td>Infill</td>
<td>A large-scale urban renewal project with high density commercial and residential development. Implemented WSUD approaches to provide an exemplar project that demonstrate approaches could be commercially viable in other developments</td>
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</table>
Consultation with water practitioners, utilities and other stakeholders

Semi-structured interviews and an online survey of practitioners, water utility managers and other stakeholders involved in WSU developments were undertaken. The purpose of this consultation was to understand the industry experts’ perceptions of constraints and knowledge gaps that are impeding WSU development. Individuals were targeted based on their involvement with WSU developments or their experience with WSUD/IUWM, and survey participants included the following groups: (1) developers of WSU developments, (2) residents of WSU developments, (3) agencies and water utilities involved in providing services to WSU developments, (4) engineering consultants involved in design and implementation of WSUD elements, (5) Australian WSU development experts, including academics, (6) peak organisations, including the Urban Development Institute of Australia (UDIA) and the Municipal Association of Victoria, and (7) State agencies with regulatory/administrative roles in WSU developments.

The survey was sent to 95 individuals with 54 participating in the survey (a response rate of 56%). The expertise of survey respondents was mostly associated with the initial phase of WSU development: planning, design and feasibility assessment (45%). 14.3% of survey participants’ involvement in WSU development was associated with approvals and compliance with regulations. Other areas such as capacity building and construction were by comparison less well represented in survey respondents (<7%). The day to day running and particularly validation were the least represented among respondent’s specialties: only 2% were involved in evaluation and monitoring and only 7% had expertise in management and ownership.

The survey comprised two sections:

(a) Part 1 asked respondents about the following: their main field of expertise, for both the individual survey participant and the organisation they worked for; the number of developments they have been involved in; and their experiences related to a specific WSU development in regards to design, post-development evaluation, approval processes, and arrangements for ongoing operation and maintenance.

(b) Part 2 encouraged respondents to share their broader opinions on water sensitive urban design, gaps in legislative and guideline frameworks, and the fundamental research that is need to inform improved legislation and more complete guidelines for WSUD options. Participants were also asked about the main constraints and barriers to WSUD uptake in Australia. Participants contributed suggestions on how to encourage greater uptake of WSUD.

The survey was distributed using Survey-Monkey, an online survey software tool. Their responses classified and analysed according to the eight themes that emerged from the literature review.

The survey results demonstrated that the main drivers for adopting WSUD features in new developments had been the demonstration of best practice (33%), followed by policy compliance (20%), environmental protection (20%), while service constraints of existing centralised infrastructure was only the primary driver in 8% of developments. Other drivers for the adoption of WSUD, mentioned by respondents, included economic benefits, a local champion and a combination of drivers.

The majority of respondents (57%) considered that the availability of cost data on WSUD elements was either poor or very poor. Also, many survey respondents (56%) saw the availability of skilled workers for implementing WSUD elements as either poor or very poor. Other survey results are included in the synthesis in the subsequent section, including responses to open-ended questions.

SYNTHESIS OF IMPEDIMENTS AND CONSTRAINTS IN THE UPTAKE OF WSU DEVELOPMENTS

Based on the literature review, desktop study, detailed investigations of WSU developments and consultation with water industry professionals, a set of themes were defined to classify the knowledge gaps and barriers identified as impeding the broader uptake of WSU development in Australia. This section summarises these eight themes and lists the authors’ recommendations to expedite the mainstream uptake of WSU development. In some cases the recommendations were formed on the basis of suggestions provided by the survey participants and water professionals consulted. The themes are:

**Governance, regulations and guidelines**

The integrated approach necessary for WSU development is in many cases at odds with the current governance structures, which do not necessarily consider the impact of
urban water services on other sectors, such as the natural environment. There is a need for changes to the current regulatory and legislative frameworks to enable a holistic approach to providing urban residential water services that considers key service requirements, such as flood protection, the reliability and quality of water supply, and also externalities, such as the impact on local hydrology and receiving waters.

Survey participants considered policies and guidelines for WSUD elements to be inconsistent between different jurisdictions and levels of government. A lack of clarity on policies and guidelines for WSU development was seen to result in a climate of perceived risk aversion, resulting in extended delays in approval processes and discouraging WSU development proponents.

WSUD approaches have developed rapidly over the previous two decades and in many cases WSUD practice is seen to be ahead of the guidelines and regulations. It is recognised that many of the gaps in regulations have been addressed or are in the process of being addressed. However, the project has identified that many stakeholders view current guidelines as inadequate. A common issue raised was the need for uniformity and consolidation of guidelines that would provide consistency for the approval of WSUD features and post-development performance evaluation. Survey participants considered the current WSUD guidelines to be deficient in the areas of sewer mining, WSUD for medium and high-density buildings and retrofit developments, and integration of multiple supply sources.

Survey participants’ suggestions to address governance issues included: increased coordination within and between the three tiers of government and the industry involved in the management of urban water resources, establishment of consistent policies with regard to WSU developments, alignment of WSUD/IUWM regulations and development of guidelines, consistent accreditation practices and approval processes for WSU developments. However, consistent regulations and guidelines still need to allow for flexibility so that WSUD elements are planned in consideration of local aspects.

Community acceptance and social impacts

A shift from conventional water and wastewater systems to systems designed according to the principles of WSUD will often require increased involvement and understanding from the community due to the decentralised nature of these systems. In this research we found a key factor for the success of WSU developments was an effective strategy to engage the community in developing acceptable models for the management and ownership of decentralised water systems. Issues faced in WSU developments studied included communities having a poor understanding of WSUD features and householders inappropriately using non-potable water sources, which increased the public health risks.

Water industry professionals provided the following suggestions to overcome community acceptance issues: ongoing engagement with residents during the lifetime of the project to ensure that WSUD features suit their needs, practicality and operation and maintenance (O&M) requirements; involving stakeholders (councils, water service providers and regulators) during the planning and design processes. Ongoing education of residents on WSUD features and functions increased understanding and acceptance of WSUD features and encouraged their appropriate use. Another suggestion was the dissemination of information to developers on best practices for public engagement and community interaction.

Skills and knowledge

WSU development presents a challenge to many professionals and organisations, as it requires a departure from the more familiar conventional approach to the provision of urban water services that is based on more than a century of practice. Capacity development is required at all levels of government and in all industry sectors (e.g. public service, builders, and contractors) to facilitate the shift to WSU development. For example, one case study development had problems with the performance of WSUD features that was related to the poor implementation of design during the construction phase of the development. Also, in the case study development with a large-scale recycled water scheme there were early problems with cross-connections due to plumbers being unfamiliar with dual reticulation systems.

It was highlighted that technical institutes, universities and professional bodies can play a greater role in capacity building in the design and construction sectors through introducing WSUD approaches into their curricula. The awareness and expertise at local government level of WSU development can be increased through programs targeting local governments. Survey and interview participants also indicated the following would be beneficial in improving skills for WSUD: the establishment of a national institute or centre to coordinate research and educational needs; the development of a national information database; and
the creation of a website with links to latest guidelines, regulation updates, information on emerging technologies, updated information and case studies.

Public health

The application of alternative water sources like greywater, treated wastewater, stormwater and rainwater requires consideration of health and safety risks to the public. Community concerns regarding perceived health and safety risks of recycled water schemes has been a barrier for a number of Australian developments. Recycled water schemes in Australia have faced issues with cross connections between recycled water and drinking water supplies, posing a health risk to the public.

Survey and interview participants suggested that research is needed to determine the standard of water treatment achieved by WSUD features, including the reduction of environmental contaminants and microorganisms. Participants proposed the development of national standards and methodologies for the validation of WSUD technologies including through the long-term performance monitoring of WSUD systems. The education of industry professionals and public on risks and appropriate use of WSUD technologies was also suggested for improving the understanding and management of inherent health risks.

System evaluation, performance and monitoring

Limited information is available on the performance of WSUD systems, particularly for new technologies. Most available data are associated with short term monitoring and there is the need to determine the ongoing impact of WSU development on conventional systems. Guidance is especially needed for small scale operators (commercial buildings, strata title) on best practices for system selection, evaluation and monitoring. The lack of detailed on-going operation data to ascertain if WSUD systems are performing to design specifications is one of the major barriers to mainstream uptake.

Some survey and interview participants advocated that WSU developments should be evaluated for their long-term performance, and to achieve this uniform post-development evaluation methodologies need to be developed. It was highlighted by participants that the broader dissemination of scientific, technological and performance data to stakeholders could help inform the revision and expansion of WSUD guidelines. The ongoing monitoring of water quality, flow and energy needs of WSUD elements is important in validating system performance, which may encourage mainstream uptake of these WSUD elements.

Financial incentives for WSUD

A number of research participants saw the lack of financial incentives that recognise the externality benefits of WSU developments as a significant impediment to mainstream uptake of WSU development. For example, in some WSU case study developments it was highlighted that WSUD elements reduced demand for centralised services, but there was no discount given for development headworks charges. Similar concerns were expressed for on-going water and/or sewerage charges for developments not connected to centralised systems or those that have reduced reliance on centralised services.

Data are lacking on long-term performance of systems and technologies, integration between conventional and WSUD infrastructure, capital cost, and operation and maintenance cost. Life cycle cost data are required for the application of models that are used for assessing and planning integrated water systems for urban developments.

The study highlighted that headworks charges and rates for water and wastewater services should reflect any reduced load from developments applying WSUD/IUWM approaches and that there is a need to establish economic models for the assessment of such infrastructure projects. Appropriate policy and regulation to account for externalities and long-term payback of investment in the assessment of developments is equally required. For example, the consideration of externalities could be incorporated as a requirement in the development approvals process. Other suggestions included: encouraging uptake through financial mechanisms such as greater transfer and sharing of costs between stakeholders associated with implementing a water sensitive approach to developments; collecting, documenting and reporting life cycle cost data of WSUD systems, particularly O&M, from technology manufacturers, maintenance providers and other stakeholders; and documenting and disseminating information on the costs and benefits of WSUD.

System operation and maintenance

Unfamiliarity with system O&M requirements and the concern of a higher maintenance burden was seen by many survey participants and stakeholders interviewed as a current impediment to WSU developments. Also, the lack of data on the long-term performance and on new technologies...
and/or their limited diffusion was perceived as a barrier to WSU development uptake.

Suggestions to address the operational issues included: identifying the agency responsible for ongoing O&M during the planning and design of WSUD features for consultation; development of best practices for operation and management of WSUD systems and their incorporation into guidelines; defining and clarifying responsibilities and roles for long-term O&M of WSU developments through regulation and policy; exploring the feasibility of a centralised regulatory authority, such as a water utility or State government agency, and overseeing the management of decentralised water and wastewater systems in each jurisdiction.

**Sustainability and broader system impacts**

The difficulty in accounting for externalities, such as the environmental and broader system impacts of different water servicing options, was identified in discussions with stakeholders of existing WSU developments as a major barrier, as it obscures the true value of WSUD features in improving the sustainability of urban developments. In one case study, the water retailer thought that despite the alternative water servicing approaches being more expensive to implement than conventional water services that the investment could be justified due to the wider community benefits exceeding the costs.

Research into the impacts of WSU development outside of the development boundary is essential to understand the overall impact of WSUD features. This research would feed into improving decision making tools that evaluate the broader system impact of a WSU development. It was also suggested that economic models should be developed to account for externalities, which can then be adopted into guidelines and regulations. Furthermore, the impact of climate change on the design of WSU features and systems, including changes to rainfall patterns and volumes affecting the achievement of WSUD stormwater design objectives for water quality, should also be considered.

**CONCLUSIONS**

This study was conducted to investigate the impediments and constraints in the uptake of WSU developments as a mainstream practice. The investigation methodology included: a critical review of existing literature; an investigation of existing WSU developments in Australia to define issues faced in their planning, design, implementation, operation and maintenance; site inspections of nine WSU developments, which represented a range of contexts and development scales; discussions with developers, planners, consultants, operators and utilities; and a survey of water professionals, consultants, regulators, and water utilities. As WSUD approaches are new, wide knowledge gaps in their planning, design and implementation were identified.

The key impediments identified for the mainstream adoption of WSU development were grouped in eight themes: governance, regulations and guidelines; community acceptance and social impacts; skills and knowledge; public health; system evaluation, performance, and monitoring; financial incentives for WSUD; system operation and maintenance; and sustainability and broader system impacts. The recommendations to overcome the impediments were organised based on suggestions provided by survey participants and water professionals for these eight themes. It is hoped that this investigation will build the resolve of planners, developers, policy makers, academia, and other stakeholders to address identified knowledge gaps that would promote uptake of WSU developments. Although, this study is based on WSU developments in Australia, the knowledge gaps identified through this investigation will be useful to water professionals across the globe.

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