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# Why do residential recycled water schemes fail? A comprehensive review of risk factors and impact on objectives

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A B S T R A C T

In Australia, recycled water schemes have been implemented in residential developments to contribute to sustainable urban development, improve water supply security and reduce pollutant discharges to the environment. A proportion of these schemes, however, have been decommissioned well before the end of their design life which raises questions about the adequacy of the risk assessment and management practices adopted for recycled water schemes. Through a detailed literature review, an investigation of 21 residential recycled water schemes and in-depth interviews with nine scheme stakeholders, we identified 34 risk factors arising from six sources which have the potential to impact the long-term viability of residential recycled water schemes. Of the 34 risk factors identified, 17 were reported to have occurred during the development and implementation of the 21 schemes investigated. The overall risk rating of the 17 factors was qualitatively defined on the basis of the likelihood of occurrence and the impact of the risk factors on the scheme objectives. The outcomes of the assessment indicate that the critical risks to the long-term viability of residential recycled water schemes are 1. unanticipated operational costs, 2. legal and contractual arrangements, 3. regulatory requirements and approval process and 4. customer complaints and expectations not met. To date, public health risks associated with the provision of recycled water have been of primary concern, though the outcomes of this study indicate that the impact to public health has been low. Evidently there is a need for improved assessment and management practices which address the range of critical risk factors, in addition to the routine consideration of public health risks.



## 1. Introduction

The provision of water and wastewater services in Australia has changed significantly over the past two decades in response to water supply security concerns, environmental degradation and a drive to facilitate sustainable urban development (Marlow et al., 2013). Since the first residential recycled water scheme was implemented in the Rouse Hill development, Sydney, New South Wales, in 1994 (Law, 1996), numerous schemes have been developed including Mawson Lakes residential recycled water scheme in South Australia (Leonard et al., 2013) and Pimpama Coomera residential recycled water scheme in Queensland (Davis and Farrelly, 2009).

Despite the construction of desalination plants in major cities of Australia, residential recycled water schemes are continuing to be progressed in some states of Australia. In Melbourne, Victoria, water utilities have the authority to mandate dual piping in areas where additional water supply is required, as has been undertaken for the Fishermans Bend Urban Renewal Area in Melbourne's inner city region (South East Water, 2015) and Greenvale and Beveridge in north Melbourne (Yarra Valley Water, 2015). In New South Wales, City of Sydney is continuing to implement the Sydney Decentralised Water Master Plan with the support of private water utilities, such as Flow Systems, who are progressing sustainable urban development in the region (City of Sydney, 2012).

While residential recycled water schemes have become an important component of the water supply portfolio in Victoria and New South Wales, in other states of Australia, specifically Queensland, the prudency of such schemes has been questioned (Taylor et al., 2011). Public health risks of residential recycled water

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schemes have been of primary concern, while the high cost of construction and operation of residential recycled water schemes has become evident, particularly since the provision of Government grants has declined (Marsden Jacob Associates, 2013). As a result, residential recycled water schemes have been prematurely decommissioned and approval of the business case for schemes has not been granted in some cases (Mukheibir et al., 2015).

During the Millennium Drought (2001–2009) when several residential recycled water schemes were in development, a plethora of studies were undertaken to investigate risk perceptions and the potential impacts of residential recycled water schemes. The perceptions of risk focused predominately on public health (Cook et al., 2008), community acceptance (Hurlimann, 2007) and financial viability (ACIL Tasman 2005). In addition, numerous case study investigations were undertaken to provide detail on the development process and the successes and challenges of residential recycled water schemes (Chapman, 2006; Davis and Farrelly, 2009; Farrelly and Davis, 2009a, b; Goddard, 2006).

While this body of work provided vital information to support scheme development during the Millennium Drought, the contextual environment of residential recycled water schemes has since changed. In addition to climatic (physical) changes, the political and regulatory, social, financial and economic and legal and contractual environment of schemes has diverged since the height of the drought (Institute for Sustainable Futures, 2013c). Few studies have been undertaken to assess current risk factors of residential recycled water schemes or to document impacts of risk factors, with the exception of work undertaken by the Institute for Sustainable Futures (Institute for Sustainable Futures, 2013c). In a review of eight recycled water schemes, the Institute for Sustainable Futures identified that changes in the contextual landscape of a scheme may bring about significant risk and uncertainty which has not been adequately addressed to date. The authors suggest that a thorough consideration of risks is required to facilitate improved decision making and the equitable allocation of risks, costs and benefits for future recycled water schemes.

In order to improve the long-term viability of residential recycled water schemes, it is essential that learnings from schemes are disseminated and that, to the extent possible, information required to assess the likelihood of occurrence of risk factors and the associated impact on objectives is made available (Marsden Jacob Associates, 2013). The development of a comprehensive and holistic understanding of risks will enable effective risk management approaches to be identified and implemented throughout the lifecycle of a scheme (Institute for Sustainable Futures, 2013d).

Consequently, this paper aims to comprehensively identify and characterize risks to the long-term viability of residential recycled water schemes. Through investigation of residential recycled water schemes implemented to date in Australia, we have qualitatively assessed the impact of risk factors on the objectives of schemes and have identified critical risk factors which require enhanced attention. The outcomes of this paper further highlight the deviation between the risk factors which have gained focus to date, predominately public health risk, and those factors which are negatively impacting residential recycled water schemes.

## 2. Materials and methods

A qualitative risk assessment was undertaken in accordance with the Australian and International risk management standard, ISO 31000:2009 (Standards Australia, 2009), in order to ensure a consistent and industry standard approach to identifying and characterizing the risk factors and their associated likelihood and impact on the long-term viability of residential recycled water schemes. The assessment was undertaken in two phases: 1. identification and characterization of risk factors and 2. specification of critical risk factors.

### 2.1. Identification and characterization of risk factors

An exploratory approach, comprising discussions with experienced personnel and a literature review, was adopted for the identification and characterization of risks to the long-term viability of residential recycled water schemes. For the purpose of this study, residential recycled water scheme is defined as the application of dual piping for the supply of treated stormwater, greywater and/or wastewater for non-potable residential use comprising toilet flushing, cold washing machine, garden watering and/or other outdoor use.

Exploratory discussions with 17 personnel who had been involved in the development and/or implementation of a residential recycled water scheme were conducted in order to generate a list of residential recycled water schemes for further analysis and an extensive and comprehensive list of the risks to the long-term viability of residential recycled water schemes. The experienced personnel represented water utilities, urban development, local Government and consultancies. The discussions enabled the development of a long-list of risk factors which was refined on the basis of information gathered through a detailed literature review.

The literature review was undertaken to ensure that the risk factors were accurately defined and to refine the long-list of factors to a short-list which effectively addressed all risk factors initially identified. The literature review also enabled the identification of additional residential recycled water schemes which had not been identified through the exploratory discussions with experienced personnel. The reviewed literature is listed in the Supplementary Material.

### 2.2. Specification of critical risk factors

In order to define critical risks to the long-term viability of residential recycled water schemes, in-depth interviews were conducted with scheme stakeholders and a case study literature review was undertaken. The collated information was analysed in accordance with the ISO 31000:2009 (Standards Australia, 2009) in order to specify the critical risk factors.

#### 2.2.1. In-depth interviews

The stakeholders of each residential recycled water scheme identified in phase 1 of the study were contacted to ascertain their ability and/or willingness to participate in an in-depth interview. Consented interviews were conducted with eight stakeholders representing nine residential recycled water schemes. The stakeholders were affiliated with public water utilities, private water utilities and local Government. The in-depth interviews were conducted to gather information pertaining to each residential recycled water scheme as follows:

1. Objective/s of the residential recycled water scheme – where available the business case for the scheme was collected and reviewed;
2. Risk factor occurrence – the short-list of risk factors developed in phase 1 was addressed with respect to the residential recycled water scheme and the relevant risk factors were documented;
3. Risk factor impact – the impact of each risk factor on the objectives of the residential recycled water scheme was addressed either qualitatively or quantitatively. If qualitatively addressed, a linguistic description of the impact was provided by the scheme stakeholder i.e. low, medium, high. Where available, historical

data, including water supply rates, energy usage and financial information, were provided to enable the quantitative definition of the impact of the risk factors.

### 2.2.2. Case study literature review

Information pertaining specifically to each residential recycled water scheme was gathered from five sources: 1. grey literature, 2. academic papers, 3. research reports, 4. government websites and 5. newspaper articles. The literature was reviewed for reference to each of the risk factors and to the impact of specific risk factors on scheme objectives. The Supplementary Material lists the case study literature reviewed.

### 2.2.3. Risk analysis

The information obtained from the in-depth interviews and the case study literature review was collated to enable the definition of the likelihood of occurrence of each risk factor, the impact of the risk factor on the objectives of the residential recycled water scheme and the overall risk rating of each factor.

*2.2.3.1. Likelihood of occurrence of risk factors.* The likelihood of occurrence of each risk factor, as illustrated in Fig. 3, was calculated as follows:

1. The occurrence of each risk factor was documented for each scheme (1 = present, 0 = absent), and the total number of occurrences of each risk factor was counted;
2. The percentage occurrence of each risk factor was calculated by dividing the total number of occurrences of each risk factor by the total number of schemes; and
3. The percentage occurrence of each risk factor was referenced to the definition of likelihood of occurrence, as specified in Table 1, to obtain a rating for the likelihood of occurrence from 1 = rare (<10%), 2 = unlikely (10–20%), 3 = possible (20–40%), 4 = likely (40–60%) or 5 = almost certain (>60%).

*2.2.3.2. Impact of risk factors on objectives.* The impact of each risk factor on each objective was calculated as follows:

4. For each risk factor reported for each scheme, the objective/s impacted by the risk factor were identified and an impact score was defined on the basis of the definitions specified in Table 1. For example, the impact to the recycled water supply target of a scheme, as a result of a delay in the regulatory approval process, was defined on the basis of the variance between the forecast and actual water supply rates of the scheme;
5. For each scheme, the impact all risk factors on each objective was rated as follows:
   - Where the impact score was qualitatively defined, the maximum impact score for the objective was retained e.g. if an impact to community satisfaction occurred as a result of two risk factors, one with a low impact rating (score of 2) and one with a moderate impact rating (score of 3), the overall impact to community satisfaction was rated as moderate (score of 3); or
   - Where the impact score was quantitatively defined, the impact score for the objective was calculated on the basis of the total impact to the objective e.g. if an impact to capital costs occurred as a result of two risk factors, both with a low impact rating (score of 2) on the basis of the increase in capital costs ($4M of $50M additional capital cost as a result of risk factor 1 and $9M of $50M additional capital cost as a result of risk factor 2), the overall impact to capital cost was defined as moderate (score of 3) on the basis of the total impact to capital costs ($13M of $50M additional capital cost as a result of risk factor 1 and 2);
6. The impact score for each objective was summed for all schemes and divided by the total number of schemes in which the impact was reported in order to obtain an average impact score for each objective, as illustrated in Fig. 4; and
7. For each risk factor, the impact score for each objective impacted by the risk factor was summed and divided by the total number of objectives impacted in order to obtain an average impact score for each risk factor, as illustrated in Fig. 5.

*2.2.3.3. Evaluation and ranking of risk factors.* The overall rating of each risk factor was quantitatively defined as:

$$\text{Risk rating} = \text{likelihood of occurrence} \times \text{average impact score} \quad (1)$$

where the likelihood of occurrence, derived as detailed in step 3 above, and the average impact factor, derived as detailed in step 7 above, were rated from 1 to 5.

The quantitative risk rating was rounded to the nearest integer and referenced to a linguistic rating, as defined in Table 1, where a rating of 1 to 3 = very low risk, 4 to 6 = low risk, 7 to 9 = medium risk, 10 to 12 = high risk and 13 to 25 = very high risk. The factors rated as medium to very high risk were defined as critical risk factors.

## 3. Results

### 3.1. Risk factors specific to residential recycled water schemes

Risk factors with the potential to impact the long-term viability of residential recycled water schemes, were found to arise from six risk sources: physical, social, political and regulatory, implementation and operation, financial and economic and legal and contractual. A total of 34 risk factors were identified and are defined in Table 2.

The risk factors were found to occur at varying stages of development and implementation of a residential recycled water scheme, as illustrated in Fig. 1. The risk factors and sources exhibit strong and complex interactions where one risk factor may influence another, potentially resulting in feedback loops and delay between risk occurrence and impact on objective. For example, an error occurring in the construction stage may result in an impact to public health in the operational stage, which may in turn influence regulatory requirements for future residential recycled water schemes. Of the identified risk factors, those arising from political and regulatory sources have the potential to impact the long-term viability of a residential recycled water scheme at any stage of development and implementation. It should be noted that, while the risk factors addressed in this paper are discussed in a negative manner, some risk factors may be either negative or positive depending on the specifics of the risk factor and the resulting impact on objectives.

### 3.2. Critical risk factors

#### 3.2.1. Status and objectives of residential recycled water schemes

A total of 21 residential recycled water schemes were identified and reviewed, as listed in Table 3. The design number of dwellings to be serviced by the schemes ranged from 30 to 65,000. Majority of the schemes are, or are planned to be, owned by water utilities, though three are owned and managed by a corporation of residents

**Table 1**
Risk matrix for residential recycled water schemes (developed through detailed literature review and stakeholder interviews).

| | Criteria | Impact on objective | | | | |
|---|---|---|---|---|---|---|
| | | **Insignificant (1)** | **Low (2)** | **Moderate (3)** | **Major (4)** | **Severe (5)** |
| | *Design target - financial, recycled water supply, pollutant discharge reduction* | Less than 5% variance from target | 5 - 20% variance from target | 20 - 40% variance from target | 40 - 50% variance from target | Greater than 50% variance from target |
| | *Level of service* | Scheme delayed or offline for negligible period | Scheme delayed or offline for less than 6 months | Scheme delayed or offline for 6 - 12 months | Scheme delayed or offline for more than 12 months | Scheme delayed indefinitely or decommissioned |
| | *Regulatory compliance* | No breach of regulation | Minor breach of regulation | Moderate breach of regulation | Major breach of regulation | Breach incurring significant prosecution |
| | *Environmental / public health* | Minor and reversible impact | Minor, short-term impact | Moderate, short-term impact or minor, long-term impact | Serious, short to medium-term impact | Serious, long-term impact |
| **Likelihood of occurrence** | *Stakeholder confidence, customer satisfaction, reputation* | No adverse publicity or customer complaints | Some adverse publicity and minor loss of stakeholder confidence | Moderate adverse publicity and some loss of stakeholder confidence | Significant adverse publicity and loss of stakeholder confidence | Intense public, political and media criticism and complete loss of stakeholder confidence |
| **Almost Certain (5)** | The event is expected to occur in most circumstances (>60%) | Low (5) | High (10) | Very high (15) | Very high (20) | Very high (25) |
| **Likely (4)** | The event will probably occur in most circumstances (40 - 60%) | Low (4) | Medium (8) | High (12) | Very high (16) | Very high (20) |
| **Possible (3)** | The event might occur at some time (20 - 40%) | Very low (3) | Low (6) | Medium (9) | High (12) | Very high (15) |
| **Unlikely (2)** | The event is not expected to occur in most circumstances (10 - 20%) | Very low (2) | Low (4) | Low (6) | Medium (8) | High (10) |
| **Rare (1)** | The event will only occur in exceptional circumstances <10% | Very low (1) | Very low (2) | Very low (3) | Low (4) | Low (5) |

Very high risk rating
High risk rating
Medium risk rating
Low risk rating
Very low risk rating

(body corporate). Fig. 2 illustrates the status of the residential recycled water schemes in each state of Australia.

Of the 21 schemes reviewed, three schemes with a total of 1809 dwellings to be serviced were delayed in commissioning at the time of writing this paper. Three schemes, with a total of 68,736 dwellings to be serviced, have been prematurely decommissioned, while 15 schemes with a total of 148,286 dwellings to be serviced are operational. In New South Wales, all reviewed schemes are operational while in Queensland, two of the four schemes have been delayed in commissioning and two have been prematurely decommissioned.

The 21 residential recycled water schemes, listed in Table 3, were developed predominately to meet three main objectives: contribute to sustainable urban development (12 schemes), improve water supply security by diversifying water sources (seven schemes) and reduce treated wastewater effluent discharge and pollutant load to waterways (two schemes). In addition, the recycled water schemes were designed to meet

**Table 2**
Risk factors with potential to impact the long-term viability of residential recycled water schemes.

| No. | Risk factor | Definition |
|---|---|---|
| *Physical risk source* | | |
| 1 | Change in catchment characteristics | Change in catchment size, land use, drainage pathways etc. resulting in change in quantity and/or quality of influent water to treatment plant |
| 2 | Climate change/climate variability | Impacts to influent water quality and quantity and/or impacts to treatment infrastructure due to flooding, rising or declining groundwater levels/quality, reduced or increased stormwater quantity and quality, variable temperatures etc. |
| *Social risk source* | | |
| 3 | Community risk perception | Public risk perception resulting in delayed scheme commissioning or reduction in non-potable water use |
| 4 | Customer complaints | Water quality concerns, aesthetic concerns and/or price concerns resulting in customer complaints |
| 5 | Customer expectations not met | Inability to deliver recycled water scheme to the standard, or within the required timeframe, expected by customers |
| 6 | Equity of access | Residential recycled water schemes are deemed to be inequitable as only a portion of the community is serviced |
| *Political and regulatory risk source* | | |
| 7 | Change in Government | Change in Government and/or Government agenda resulting in reduced support for recycled water schemes |
| 8 | Regulatory requirements | Overly onerous regulatory requirements or inhibitory policy due to perceived risks associated with recycled water schemes (includes change in regulation) |
| 9 | Approval process | Poorly defined regulatory requirements and/or lengthy approval process with subsequent challenges to implementation of recycled water schemes |
| 10 | Regulatory pricing policy | Regulatory pricing policies limit viable innovation and viable competition with conventional infrastructure |
| *Implementation and operation risk source* | | |
| 11 | Optimism bias | Selection of recycled water scheme is based on stakeholder opinion rather than sound assessment processes |
| 12 | Organisational risk perception | Organisational decisions regarding recycled water schemes are based on perceived risks rather than true risks |
| 13 | Organisational change | Organisational change resulting in reduced support or guidance/leadership for recycled water scheme |
| 14 | Assessment and design error | Assessment and design methodology is unsatisfactory, consultant lacks experience, "corner cutting" to reduce time requirements, uncertainty not considered etc. |
| 15 | Construction error | Construction challenges/errors resulting from lack of qualification, experience and/or poor performance |
| 16 | Technology risk | Adopted technology is not mature or able to deliver output specifications reliably |
| 17 | Fall in demand | A decline in water demand as a result of climate variability, economic decline, demographic changes, water price, risk perception, technological innovation etc. |
| 18 | Asset condition uncertainty | Uncertainty regarding the lifespan of technical components as a result of lack of information, immature technology or lack of experience |
| 19 | Operation error | Poor operational performance resulting from lack of qualification, experience and/or motivation |
| 20 | Management and maintenance error | Recycled water scheme is poorly managed and maintained resulting in technical component failure |
| 21 | Impacts to conventional infrastructure | Recycled water scheme results in impacts to conventional infrastructure (i.e. sewer network blockages) and subsequent increase in operational costs |
| 22 | Environmental health risk - compliance related | Unintended discharge from recycled water scheme resulting in environmental health risk |
| 23 | Environmental value risk - stormwater related | Unintended risk of recycled water scheme on environmental values i.e. hydrological/hydrogeological characteristics |
| 24 | Environmental value risk - greywater/wastewater related | Unintended risk of recycled water scheme on environmental values i.e. greenhouse gas emissions |
| 25 | Public health risk | Poor treatment, incorrect use, cross-connection etc. resulting in public health risk |
| 26 | Perceived benefits do not materialise | Perceived environmental, social and/or financial benefits do not materialise or are difficult to measure |
| *Financial and economic risk source* | | |
| 27 | Inability to demonstrate incontestable business case | Economic viability of recycled water scheme is unable to be proven |
| 28 | Unanticipated capital costs | Poor understanding of capital costs at the assessment stage due to lack of information, lack of experience or change in contextual environment of scheme |
| 29 | Reduction in developer charges | Reduction in developer charges resulting in reduced revenue |
| 30 | Reduction in non-potable water price | Reduction in non-potable water price resulting in reduced revenue |
| 31 | Unanticipated operational costs | Poor understanding of operational costs at the assessment stage due to lack of information, lack of experience or change in contextual environment of scheme |
| *Legal and contractual risk source* | | |
| 32 | Inability to agree on contractual terms | Lack of agreeance on contractual terms, or inability to contract a long-term owner and operator |
| 33 | Poorly defined contractual arrangements | Poorly defined contractual arrangements including risk allocation mechanism, financial arrangements, commitment of partners etc. |
| 34 | Conflict between stakeholders | Strained relationships with impacts to recycled water scheme implementation and operation |

environmental and public health regulations, maintain viable life cycle costs and maintain community satisfaction and stakeholder confidence.

### 3.2.2. Likelihood of occurrence

The review of 21 residential recycled water schemes identified 17 reported risk factors arising from the six risk sources listed in Table 2 and illustrated in Fig. 1. Fig. 3 shows the number of risk factors reported for each scheme type: delayed commissioning, operational and decommissioned.

*3.2.2.1. Schemes delayed in commissioning.* Of the three schemes delayed in commissioning, each scheme reported risk factors arising from legal and contractual arrangements, namely inability to agree on contractual terms (risk factor 32), poorly defined contractual arrangements (risk factor 33) and conflict between stakeholders (risk factor 34). These risk factors were found to delay scheme commissioning by one to six years (Economic Development Queensland, 2014; Leonard et al., 2013). Unanticipated capital costs (risk factor 28) and poorly defined regulatory requirements and lengthy approval process (risk factor 9) were reported for one scheme.

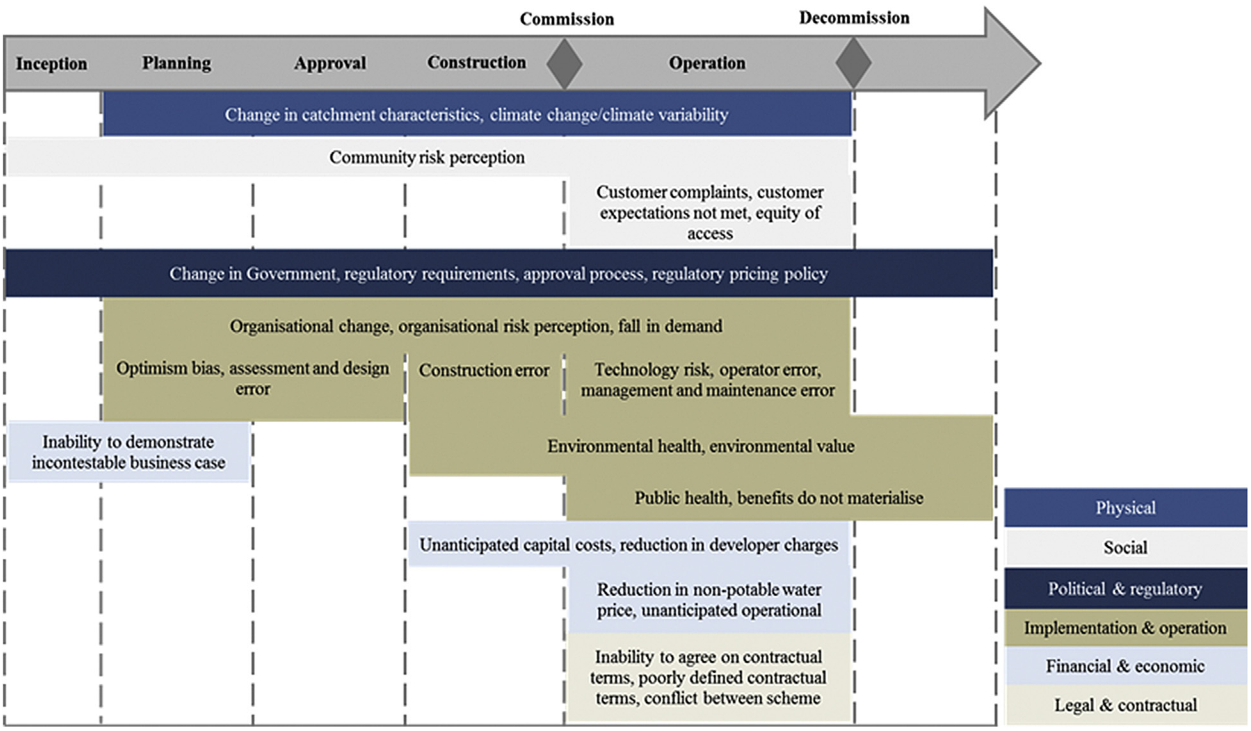


**Fig. 1.** Risk factors at each stage of a residential recycled water scheme.

Customer complaints and customer expectations not met (risk factor 4 and 5) were reported regarding the delay in commissioning and the proposed non-potable water price (Leonard et al., 2013).

*3.2.2.2. Operational schemes.* Risk factors arising from five of the six risk sources were reported for operational residential recycled water schemes. Climate variability (risk factor 2) was found to affect

**Table 3**
Residential recycled water schemes (reviewed sub-set).

| No. | Water type | | | Treatment location | | | Treatment process | | Design no. of dwellings to service[a] |
|---|---|---|---|---|---|---|---|---|---|
| | Stormwater | Greywater | Wastewater | Development | Suburb/district | Centralised | Tertiary[b] | Advanced or other | |
| **Victoria** | | | | | | | | | |
| 1 | | ✓ | | ✓ | | | ✓ | Membrane bioreactor | 236 |
| 2 | | | ✓ | | ✓ | | ✓ | Ultrafiltration | 8500 |
| 3 | | | ✓ | | ✓ | | ✓ | – | 14,800 |
| 4 | | | ✓ | | | ✓ | ✓ | Ozone injection | 19,800 |
| 5 | | | ✓ | | ✓ | | ✓ | Microfiltration | 20,000 |
| 6 | ✓ | | | | ✓ | | ✓ | – | 58 |
| 7 | | ✓ | | ✓ | | | ✓ | Ultrafiltration | 30 |
| 8 | | | ✓ | | ✓ | | ✓ | Ultrafiltration & reverse osmosis | 25,000 |
| **South Australia** | | | | | | | | | |
| 9 | ✓ | | ✓ | ✓ | | | ✓ | – | 58 |
| 10 | ✓ | | | ✓ | | | | Wetland & aquifer storage and recovery | 109 |
| 11 | ✓ | | ✓ | ✓ | | | ✓ | Wetland & aquifer storage and recovery (stormwater) | 4000 |
| 12 | | | ✓ | | | ✓ | ✓ | Ultrafiltration | 8000 |
| **New South Wales** | | | | | | | | | |
| 13 | | | ✓ | | | ✓ | ✓ | – | 36,000 |
| 14 | ✓ | | ✓ | ✓ | | | ✓ | Microfiltration & reverse osmosis | 2400 |
| 15 | | | ✓ | ✓ | | | ✓ | Membrane bioreactor & reverse osmosis | 940 |
| 16 | | | ✓ | ✓ | | | ✓ | Membrane bioreactor & reverse osmosis | 1800 |
| 17 | | | ✓ | ✓ | | | ✓ | Membrane bioreactor & reverse osmosis | 7500 |
| **Queensland** | | | | | | | | | |
| 18 | | | ✓ | | | ✓ | ✓ | Microfiltration, reverse osmosis & advanced oxidation | 400 |
| 19 | ✓ | | | ✓ | | | ✓ | – | 1300 |
| 20 | | | ✓ | ✓ | | | ✓ | Ultrafiltration | 65,000 |
| 21 | | | ✓ | ✓ | | | ✓ | Membrane bioreactor & ozonation | 3500 |

[a] May not currently be servicing design number.
[b] Coagulation, flocculation, clarification, prefiltration, chlorination and/or ultraviolet disinfection.

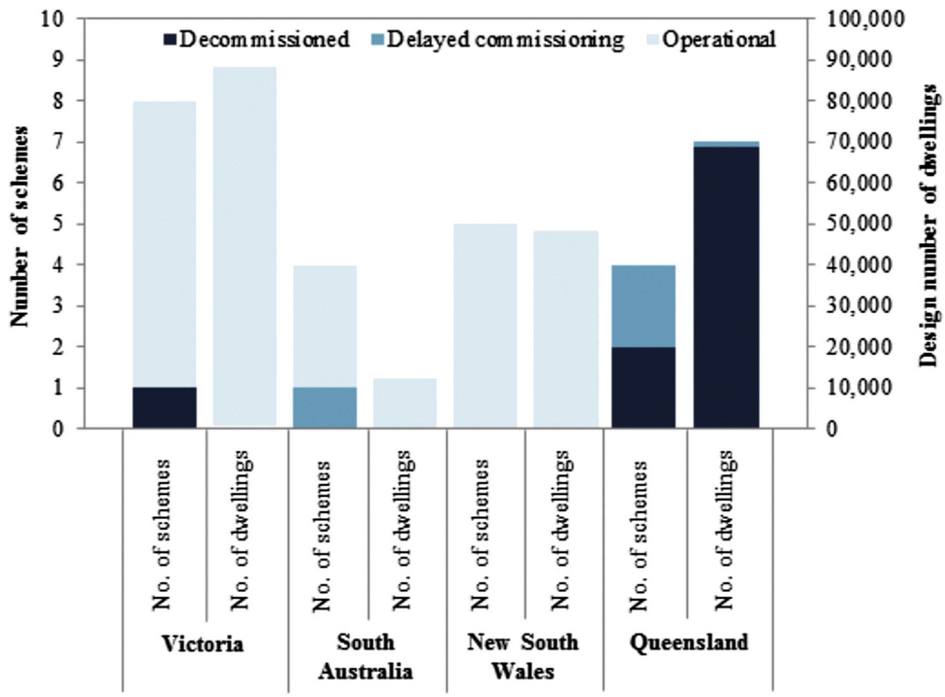


**Fig. 2.** Status of residential recycled water schemes in four Australian states (reviewed sub-set).

influent water quality in two stormwater harvesting and reuse schemes and customer complaints pertaining to aesthetic characteristics of recycled water were reported for two operational residential recycled water schemes (Leonard et al., 2013; Marks et al., 2003; Page et al., 2013). Regulatory risks (risk factor 8 and 9) were also reported for two operational schemes, namely a poorly defined and lengthy approval process and increased monitoring requirements with impacts to operational costs (Institute for Sustainable Futures, 2013a).

Implementation and operation risks were the highest reported with a total of ten schemes reporting risk events arising from this source. Public health risk (risk factor 25) was the highest reported risk factor in operational schemes with four schemes reporting cross-connections between recycled water and potable water pipes. Technology risk (risk factor 16) was the second highest reported risk factor in operational schemes, along with unanticipated operational costs (risk factor 31). Three operational schemes reported technology risks pertaining to premature fouling of

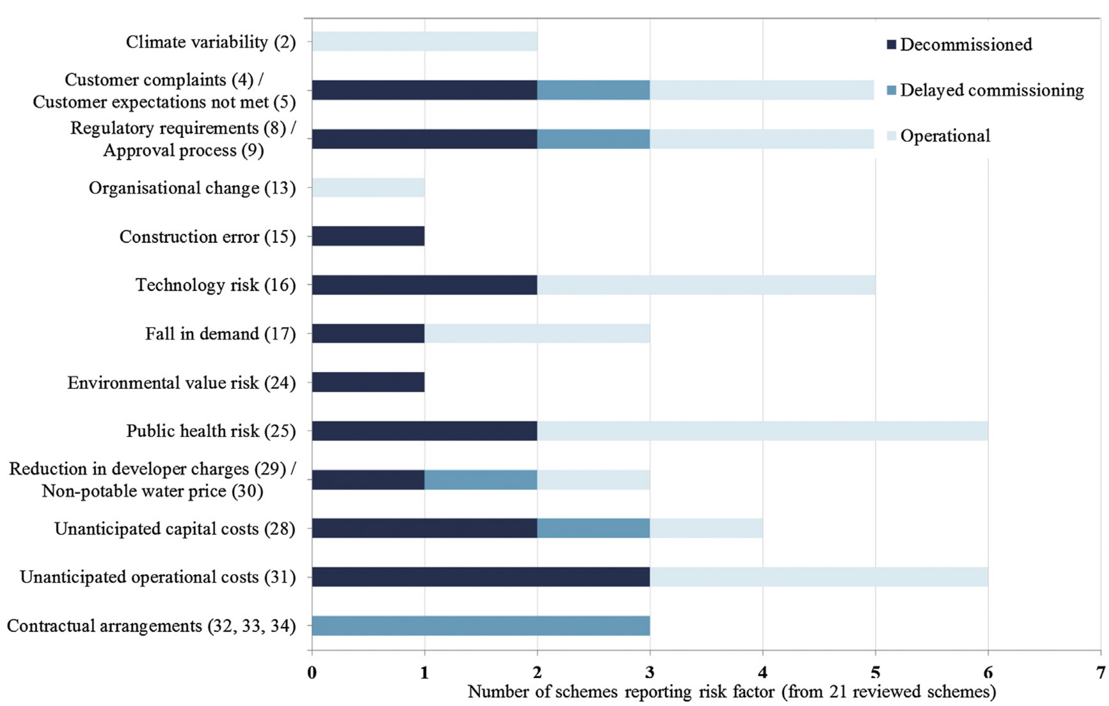


**Fig. 3.** Number of residential recycled water schemes reporting risk factors (bracketed numbers correspond to risk factors in Table 2).

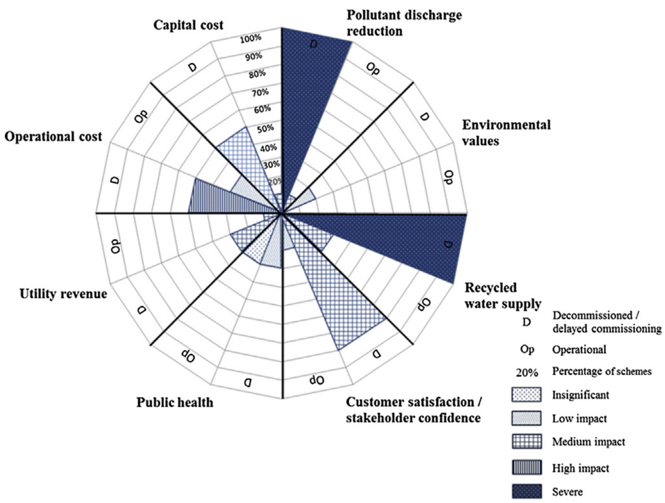


**Fig. 4.** Average impact of risk factors on objectives of residential recycled water schemes.

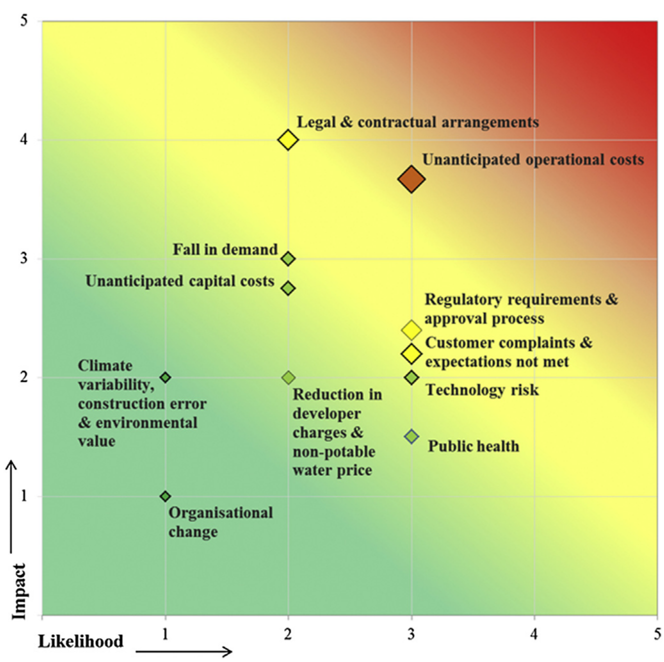


**Fig. 5.** Overall rating of risks to the long-term viability of residential recycled water schemes.

membranes and challenges with ultra-violet lamps, programming control and chemical dosing.

Fall in demand (risk factor 17) with subsequent commissioning and operational challenges were reported for two operational schemes. A variance in forecast and actual demand was shown to impact all components of a recycled water scheme including treatment, storage and distribution. In the treatment system, low flows have been shown to cause aeration issues (Suggate, 2009), excessive growth of filamentous bacteria and premature membrane failure. Treated water has been required to be stored for longer periods of time prior to distribution, resulting in reduced water quality and the requirement for additional chlorine disinfection at storage locations (Taylor et al., 2011). In the distribution network, low flows may result in inadequate pressure, sediment build-up and blockages, stagnation and biological growth and inadequate water quality at extremities due to long hydraulic residence times (Taylor et al., 2011). A variance in forecast and actual demand was found to arise as a result of changing climatic conditions, slow lot sales due to economic decline, customer concern and optimistic demand forecasting (Institute for Sustainable Futures, 2013a, b; Taylor et al., 2011).

Financial and economic risks for operational schemes pertained to a reduction in developer charges (risk factor 29), unanticipated capital costs (risk factor 28) and unanticipated operational costs (risk factor 31). Reduction in developer charges occurred when capped infrastructure charges were introduced, with one operational scheme reporting the occurrence of this risk factor. Unanticipated capital costs were reported for one operational scheme and unanticipated operational costs were reported for three operational schemes. An increase in capital and operational expenditure was found to occur as a result of technology risks, a variance in forecast and actual demand and the challenge of estimating costs at the planning stage with limited financial data available to support estimation (Institute for Sustainable Futures, 2013a; Leonard et al., 2013).

*3.2.2.3. Decommissioned schemes.* Risk factors reported in decommissioned schemes arose from social, political and regulatory, implementation and operation and financial and economic risk sources. Customer complaints and customer expectations not met (risk factor 4 and 5) were reported for two decommissioned schemes and pertained to the high cost of treatment plant maintenance, which in turn resulted in scheme decommissioning, and the dissatisfaction of the community due to the premature decommissioning of the residential recycled water scheme (Smith, 2013). Regulatory risks (risk factor 8 and 9) were reported for two decommissioned schemes, namely a poorly defined and lengthy approval process and increased monitoring requirements with impacts to operational costs.

Implementation and operation risks included public health risk (risk factor 25), technology risk (risk factor 16), fall in demand (risk factor 17), construction error (risk factor 15) and environmental value risk (risk factor 24). Cross-connection errors were reported in two decommissioned schemes, with one scheme also reporting construction errors as a result of the fast pace in which the scheme was constructed (Suggate, 2009). Technology risks were reported in two decommissioned schemes and pertained to membrane failure, loss of the plant control system and challenges with chemical dosing (Suggate, 2009). A deviance in forecast and actual demand was reported in one decommissioned scheme while the requirement to re-treat a significant portion of treated water resulted in an energy increase nearly double that of other wastewater treatment plants in the region (Taylor et al., 2011).

A reduction in developer charges (risk factor 29) was reported to have occurred during the construction of one scheme (Taylor et al., 2011), while an increase in capital costs (risk factor 28) was reported in an additional scheme as a result of regulatory requirements to install additional treatment infrastructure and replace the non-potable water pipe (Farrelly and Davis, 2009a). Unanticipated operational costs (risk factor 31) were reported for all three decommissioned residential recycled water schemes (City of Gold Coast, 2014; Goddard, 2006; Smith, 2013).

### 3.2.3. Impact of risk factors on scheme objectives

The impact of the risk factors on the objectives of residential recycled water schemes are qualitatively illustrated in Fig. 4. Schemes that are delayed in commissioning or were prematurely decommissioned have not met the recycled water supply target or pollutant discharge reduction target for which they were designed, thereby having a severe impact on these objectives based on the criteria specified in Table 1. Operational schemes which were offline for periods of time due to technology risks, fall in demand and water quality variability, have also impacted the recycled water supply target and pollutant discharge reduction target, though to a lesser extent (30% and 10% of operational schemes respectively).

In 80% of schemes classified as delayed commissioning and decommissioned, medium impacts to customer satisfaction and stakeholder confidence were reported. Reduced customer satisfaction and stakeholder confidence arose as a result of cross-connection incidents and as a direct result of delayed scheme commissioning and premature decommissioning. While cross-connection incidents were reported for 30% of decommissioned schemes and 30% of operational schemes, public health impacts, on average, were reported as low and insignificant respectively (Smith, 2013; Storey et al., 2007; Taylor et al., 2011).

Water utility revenue suffered medium impact in 30% of decommissioned schemes and low impact in 10% of operational schemes, while high impact to capital cost was reported for 50% of decommissioned or delayed commissioning schemes and low impact to capital cost was reported for 10% of operational schemes. For 50% of decommissioned schemes, impacts to operational costs were high, on average, and were reported as the main reason for premature scheme decommissioning (City of Gold Coast, 2014; Smith, 2013). 30% of operational schemes reported low impact on operational cost as a result of specific risk factors. It should be noted that while schemes reported high operational costs as the primary reasoning for decommissioning, impacts on operational costs occurred as a result of multiple risk factors. Fig. 3 shows that 13 different risk factors were reported for decommissioned schemes, with each risk factor having the potential to impact operational cost.

#### 3.2.4. Evaluation and ranking of risk factors

Fig. 5 illustrates the overall rating of each risk factor based on the likelihood of occurrence and impact of the risk factor on objectives. Four factors were rated as very low risk: climate change/climate variability (risk factor 2), organisational change (risk factor 13), construction error (risk factor 15) and environmental value risk (risk factor 24). Six factors were rated low risk: technology risk (risk factor 16), fall in demand (risk factor 17), public health risk (risk factor 25), unanticipated capital costs (risk factor 28), reduction in developer charges (risk factor 29) and reduction in non-potable water price (risk factor 30). Eight factors were rated as medium risk: customer complaints (risk factor 4), customer expectations not met (5), regulatory requirements (risk factor 8), approval process (risk factor 9), construction error (risk factor 15), technology risk (risk factor 16), fall in demand (risk factor 17), inability to agree on contractual terms (risk factor 32), poorly defined contractual arrangements (risk factor 33) and conflict between partners (risk factor 34). Unanticipated operational cost (risk factor 31) was rated as high risk due to the likelihood of occurrence and the impact on objectives.

## 4. Discussion

This research has demonstrated that the long-term viability of residential recycled water schemes is impacted by a broad range of risks which can arise from multiple sources and at various stages of development and implementation of a scheme. Effectively addressing the range of risk factors throughout the life-cycle of a scheme, and implementing management measures for critical risk factors, is essential for enabling the scheme objectives to be met.

### 4.1. Risk assessment for future schemes

To date, residential recycled water scheme risk assessments have focused primarily on public health risks. While management of these risk factors is essential given the likelihood of occurrence of cross-connections between recycled water and potable water supply pipelines, the broader range of risks require attention. Furthermore, the focus on public health risks may have indirectly enhanced specific risks, such as financial risks, by unintentionally encouraging a cautious approach to the setting of treatment levels for recycled water schemes (Institute for Sustainable Futures, 2013d).

Consequently, we recommend that an integrated risk assessment approach is adopted for future schemes, whereby the risks arising from all six sources - physical, social, political and regulatory, implementation and operation, financial and economic and legal and contractual, are addressed. Whereas traditional risk assessment practices in the water sector have focused on hard, quantitative risks, the outcomes of this study illustrate that an enhanced attention to soft risks, namely legal and contractual arrangements, regulatory requirements and approval process and customer complaints and expectations not met, is required. Managing soft risks in projects requires the adoption of sense-making and value management; where sense-making comprises the continual review and understanding of stakeholder needs and expectations throughout the project life-cycle and value management focuses on achieving a balance between meeting those needs and expectations and the magnitude of resources required to do so (Thiry, 2002).

When adopting management measures for specific risk factors, the associated trade-offs between costs, benefits and risks should be considered (Haimes, 2009). Specifically, the influence of risk management measures adopted for one risk factor, i.e. public health, should be considered with respect to the range of risk factors, and primarily to the critical risk factors, identified through this research.

### 4.2. Managing critical risk factors

The risk factors identified as critical to the long-term viability of residential recycled water schemes are 1. unanticipated operational costs, 2. legal and contractual arrangements, 3. regulatory requirements and approval process and 4. customer complaints and expectations not met.

In order to minimize the likelihood of incurring unanticipated operational costs, a sound basis for estimation of operational costs at the planning stage of a residential recycled water scheme is required. Stakeholder interviews, however, identified challenges associated with estimating costs at the planning stage due to the limited financial data available to support estimation. For some utilities, the financial data associated with non-potable water supply is not retained separately to that of the potable water supply, and hence, a sound understanding of the operational costs associated with a recycled water scheme has not been attained.

Additionally, the impact of multiple risk factors on the operational costs of a scheme is not well understood. While operational costs were the predominant reason for premature scheme decommissioning, multiple risk factors were present during the implementation and operation of these schemes, leading to the operational costs far exceeding that which were forecast. Management of the risk factors with the potential to impact operational costs, specifically technology risk (16) and fall in demand (risk factor 17), will aid in reducing the overall impact to operational costs of a scheme and the likelihood of incurring unanticipated operational costs.

For schemes which are developed by multiple stakeholders, managing the stakeholder relations throughout the duration of the scheme life-cycle is imperative. As identified from this study, poorly defined stakeholder arrangements, strained relationships and lack of agreeance on contractual terms can lead to the indefinite delay in commissioning of a scheme with subsequent impact to customer satisfaction and stakeholder confidence. Stakeholder interviews identified that where all stakeholders were involved from the commencement of the scheme planning, the implementation and operation of schemes was significantly improved. Whereas significant challenges arose for those schemes in which an additional stakeholder, predominately a public water utility, was brought on board later in the implementation phase of a scheme. Given the drive for increased private participation in the provision of water infrastructure (Water Services Association of Australia and Infrastructure Partnerships Australia, 2015), review of legal and contractual arrangements associated with residential recycled water schemes is required, in addition to a fundamental understanding of what facilitates successful stakeholder relations.

Managing customer expectations and customer complaints associated with residential recycled water schemes requires enhanced attention given the critical nature of these risk factors. The impact to customer satisfaction and stakeholder confidence as a result of delayed commissioning or decommissioned recycled water schemes has not been adequately addressed or quantified to date. Aside from newspaper articles, no literature was identified which addressed these impacts. This is a fundamental gap in knowledge given the social objectives of residential recycled water schemes.

Stakeholder interviews identified that while the regulatory environment of recycled water schemes has become easier to navigate, the approval process remains a lengthy and challenging endeavor, with one interviewee stating that the length of time required for approval has increased, rather than decreased, with the increased number of residential recycled water schemes. In numerous infrastructure development projects, political and regulatory risks have been identified as critical risk factors and are a significant deterrent to private investment and the adoption of public private partnerships (World Economic Forum, 2015).

### 4.3. Study limitations

The qualitative risk assessment presented in this study is based on a detailed literature review, case study investigation and expert guidance, though limited information was available for some schemes and risk factors. A detailed investigation of additional schemes, where stakeholder consent was provided, and/or a survey of water industry practitioners pertaining to the 34 risk factors identified in this study would provide additional information to validate or refine the risk ratings presented in this study.

## 5. Conclusions

Through a detailed literature review, interviews with industry practitioners and a review of 21 residential recycled water schemes, we draw the following conclusions:

- Current risk assessment and management guidelines effectively address environmental and public health risks, though the broader range of risks to the objectives of residential recycled water schemes have not been adequately addressed to date;
- Although 30% of both decommissioned and operational schemes reported cross-connection incidents, the impact to public health, on average, was classified as low and insignificant respectively;
- The long-term viability of residential recycled water schemes is impacted by 34 risk factors arising from multiple sources and at various stages of development and implementation of a scheme;
- Unanticipated operational costs, legal and contractual arrangements, regulatory requirements and approval process and customer complaints and expectations not met are critical risks to the long-term viability of residential recycled water schemes;
- Delayed commissioning of a scheme occurred primarily a result of challenges associated with the legal and contractual arrangements between scheme stakeholders, while unanticipated operational costs were reported as the main reason for premature decommissioning of three schemes; and
- Limited quantitative data is available to accurately assess the likelihood of occurrence and impact of risk factors on scheme objectives. In particular, quantification of the financial impact of risk factors is required and an investigation into the impacts of delayed commissioning or decommissioned schemes on customer satisfaction and stakeholder confidence.

The outcomes of this study provide a basis for further investigation through the qualitative definition of critical risks to the long-term viability of residential recycled water schemes. Additional works are required to quantitatively define the impact of critical risk factors on objectives of schemes and to facilitate the development of improved assessment methodologies and management approaches to be implemented throughout the life-cycle of a residential recycled water scheme.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.watres.2016.06.044.

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