Making decentralised systems viable: a guide to managing decentralised assets and risks

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Abstract Decentralised systems have the potential to provide a viable option for long term sustainable management of household wastewater. Yet, at present, such systems hold an uncertain status and are frequently omitted from consideration. Their potential can only be realised with improved approaches to their management, and improved methods to decision-making in planning of wastewater systems. The aim of this paper is to demonstrate the value of a novel framework to guide the planning of decentralised systems so that asset management and risk management are explicitly considered. The framework was developed through a detailed synthesis of literature and practice in the area of asset management of centralised water and wastewater systems, and risk management in the context of decentralised systems. Key aspects of the framework are attention to socio-economic risks as well as engineering, public health and ecological risks, the central place of communication with multiple stakeholders and establishing a shared asset information system. A case study is used to demonstrate how the framework can guide a different approach and lead to different, more sustainable outcomes, by explicitly considering the needs and perspectives of homeowners, water authorities, relevant government agencies and society as a whole.

Keywords Asset management; decentralised wastewater systems; risk management; socio-economic risk; wastewater planning

Introduction

The need for new approaches to risk management
Practitioners in the decentralised wastewater sector recognise the need for new frameworks and tools to enable effective long-term management of, and decision-making, for decentralised infrastructure. Risk management is the most appropriate focus for such frameworks and tools (Willetts et al., 2005). Centralised wastewater systems have benefitted from extensive development of asset management approaches to manage risk (Etnier et al., 2005). However, the characteristics (ownership, management, regulatory performance responsibility, technical purpose [treatment or transport]) of assets and their risks differ markedly between centralised and decentralised wastewater systems, so centralised asset management tools are not immediately transferable to the decentralised context. There are two potential paths for managing risks to facilitate improved acceptance and performance of decentralised systems (Willetts et al., 2005): (i) make decentralised more like centralised, e.g. through centralised management of decentralised systems, and (ii) develop new tools for improved management of decentralised systems. The work described in this paper addresses both these aims.

The paper introduces asset management and risk concepts, then outlines a new framework that operationalises these in the decentralised context. The value of the framework for producing qualitatively different, more sustainable outcomes is highlighted in a fictional case study focusing on responses to the failure of existing on-site systems.
Central elements of asset management

“Asset management is a means of managing infrastructure to minimize the cost of owning and operating it while delivering the service levels that customers desire.” (AMSA, 2002). Within the diverse approaches to asset management, four aspects are pivotal to asset management in centralized systems (Fane et al., 2005) and are critically different for decentralized systems. These aspects and their relationship to centralized systems are explained below:

- **Clear performance standards**: regulators play a crucial role in setting performance standards and in defining who is responsible for meeting performance standards. Performance-based regulations align with asset management strategies by providing latitude for choice between a range of technical and management solutions to meet a defined performance goal.

- **A functional asset information system**: contains information about the assets of concern, including an asset inventory (system type, age, location, capacity/scale/design flow, maintenance history), ongoing performance information, data on expected reliability of systems and components, and cost data for capital works and operations (Babovic et al., 2002).

- **Explicit consideration of the organisational and regulatory structures**: these structures define how and by whom the risks and costs of wastewater management will be borne. In the centralized sector, a corporate model is the norm, with ownership and operation usually vested in the same organization. This promotes the cost-optimisation central to asset management approaches.

- **Accessible reliability and costing tools**: reliability and costing tools are needed to translate the data contained in the asset information system into predictions about system performance and failure risk, together with the likely cost of responding to failures versus proactive maintenance and management (Ostfeld, 2001).

These aspects differ markedly in decentralized systems because the range of stakeholders is broader: responsibilities are therefore distributed, diffuse and often lack clarity and accountability processes, and data availability and management are typically partial and/or inadequate (Beal et al., 2003; NOWRA, 2004; Willetts et al., 2005). The framework we developed to operationalize these central aspects of asset management for decentralized wastewater systems deals with these differences by being explicit about stakeholders, information requirements and the need to account for broader risk types.

**Decentralised systems have multiple risk types**

Risk, for wastewater infrastructure, is of multiple types: engineering, public health, ecological, and socioeconomic (ORNL, 2003). For decentralized systems, these risk types exhibit strong, almost causal, interactions, e.g. the engineering risk of (a set of) systems (the probability and consequence of system “failure” at a local or larger catchment scale) largely defines the public health and ecological risks posed, which in turn define many of the socio-economic risks. However, the local geography influences the engineering risks (e.g. through a high groundwater table), and the socio-economic conditions also influence the engineering risk (e.g. through ability to pay).

Engineering, public health and ecological risks are often explicitly considered in wastewater management and planning (Beal et al., 2003). Socio-economic risks, however, are often given little explicit attention, so here we explain the most important dimensions. A systematic approach to risk assessment defines receptors of risks and stressors that generate risk (ORNL, 2003). In this model, socio-economic risk receptors include a wide range of stakeholders affected: individuals (such as property owners or occupants), vulnerable subgroups, adjacent populations, the water authority, the local council,
the environmental agency and the public health agency. Stressors occur at the micro (household) and macro (community or catchment) scale and vary from tangible to intangible. Tangible stressors include costs (e.g. expenditure on design, installation or maintenance of a system and regulatory compliance costs); changes in property values; the time households spend to maintain a system. Intangible stressors include, for example, issues around privacy and access to inspect systems, perceived inequities between recipients of centralised and decentralised wastewater services, restrictions in use of particular products (e.g. certain soap products), aesthetic impacts such as noise or smell, socio-economic impacts regarding ecological or public health effects and organisational risk factors (e.g. for a water authority). Dealing with socio-economic risk is demonstrably complex. It requires consideration of multiple perspectives and attention to spatial and temporal boundaries of analysis and setting up a consistent basis for comparison between potential options. It also requires appropriate communication with stakeholders and would likely benefit from deliberative processes to inform decision-making. The need for a systematic, participatory planning process is clear. The framework presented here is intended to enable such a process as a means of explicitly considering and managing socio-economic risk, alongside engineering, public health and environmental risks in wastewater planning. This focus on the various stakeholders or “actors” aligns with the latest thinking on analysis for planning investments in sanitation worldwide (IWA, 2006).

Methods
The National Decentralised Water Resources Capacity Development Program, under the auspices of the USEPA, commissioned a project on “Reliability and Life Cycle Costing of Decentralised Wastewater Systems” which was carried out by the Institute for Sustainable Futures, UTS and Stone Environmental, USA. As a part of this project, the ideas and concepts integral to centralised asset management and concepts and tools used in the field of reliability, risk assessment and risk management were comprehensively investigated and synthesised into a novel conceptual framework that operationalises them in a systematic planning process (Etnier et al., 2005). This initial framework is developed further in this paper to better represent how regulatory, policy and institutional issues impinge on wastewater planning processes. In addition, economic principles from Integrated Resources Planning (IRP), a key emerging to sustainability in water resource planning (Atkinson and Buckland, 2002), were integrated into the framework. In particular, the requirement to aim for solutions that have a “least cost to society”, and explicitly examine the risk and cost perspectives of different stakeholders as part of the decision-making process have been included (Herrington, 2005). We utilise a case study to demonstrate the use of our framework, which was supported by an economic model to provide estimates of net present value (NPV) for different options under consideration in the case study.

Results: a framework to manage assets and risks
The framework is intended as a thinking tool for both managers and regulators. The framework (see Figure 1) follows a six step cyclic planning process to guide decisions towards cost-effective management strategies. Figure 1 shows how the actions in the planning cycle are bounded by the local environmental, or bio-physical, context. It also shows that at the core of the planning process is the regulatory, policy, institutional and social context, key aspects of which include communication with stakeholders and an asset management information system. We argue that explicit recognition of, and engagement with, the biophysical boundary and communication with the institutional landscape are necessary at every step of the planning process.
The planning cycle starts with situational assessment, then goal setting, and moves to developing possible responses and criteria for their assessment. The next step is to choose and then enact a particular response and, most importantly, a final step to check back to see how the response worked in practice, before moving around the cycle again.

Case study application of the framework in Johnsonville, Australia

The following hypothetical case study draws on a range of real projects and situations that have taken place in Australia in recent years. It uses a combination of elements extracted from these experiences to illustrate how the framework might be used, and how it would help provide different outcomes compared to other approaches.

Setting the scene

The local oyster industry has been closed down by the State Health Department for 3 months and now summer visitors are being warned about the potential dangers of swimming in the river estuary. Failing onsite systems have been branded as the cause. With tourist operators joining the oyster farmers’ call for action, and an increasing community interest in sustainable development, the councillors of Port Johnson meet and decide that the time for a more sustainable wastewater solution to be developed is now.

Port Johnson is a (fictitious) regional locality in Australia, that has a rural estate (Johnsonville) of some 2,500 houses released 10 years ago that utilises septic systems for management of domestic wastewater. The rural estate consists of a hill with larger blocks (and houses) (upper Johnsonville) and smaller sub-divisions at the foot of this hill (lower Johnsonville). A major tidal creek enters the estuary at the foot of the hill. The local council environmental officer (EO) knows that poor management is usually the reason why septic systems fail, and the EO also knows there are other options besides sewering.

At the national EOs’ conference earlier in the year, the EO heard about a new framework for planning and managing on-site systems. Historically, the water authority steps in and sewers “problem” areas. Instead, Council agrees to trial the framework because it seems...
to have the potential to deliver more sustainable, lower cost outcomes with community support.

**Analyse existing situation.** There is little information available on the existing systems and their impact, and so the EO carries out a high-level risk assessment across the four primary dimensions of risk. The EO conducts a survey of 10% of systems checking for surfaced effluent as well as perspectives and level of knowledge of and maintenance by homeowners. The EO also talks widely with other stakeholders. The EO obtains help to set up a new database as the beginning of a simple asset information system. Brief results:

- **Engineering risk** – roughly 40% of septic systems could be classified as failing.
- **Public health risk** – a quarter of households divert greywater to relieve failing septic systems. Untreated greywater is generally reused for surface irrigation. Despite the warnings, many locals and visitors are still swimming in the estuary and there are some reports of illegal oyster harvesting.
- **Environmental risk** – a nitrate level of over 18 mg/L is measured at several points in the waterway.
- **Socio-economic risks** – Residents in upper Johnsonville are against having the area sewered as they believe this would open up the area for development, and people in lower Johnsonville already cannot afford charges and are afraid it will get worse. The oyster farmers face bankruptcy if the ban on sale of their product continues. As the mainstay of the local economy, any impact on the tourist industry affects the whole economy of the region.

Already the process is looking complicated so the EO sets up a steering committee including members of council, the local water authority, some innovative engineering consultants, the environment agency, public health agency, representative of the local business chamber and a selection of five homeowners.

**Define goals or performance standards.** The steering committee meets and deliberates on a set of goals. There is much discussion and argument and eventually they agree on a set of three performance goals related to each of the risks of concern. The steering committee decides that the engineering performance goal is implicit in the other performance goal. The agreed goals are:

- **Performance goal 1**: Level of nitrate in the waterway below WHO guideline of 10 mg/L and *E. coli* occurrence must drop below Health Agency requirement for the oyster farms to reopen.
- **Performance goal 2**: All wastewaters, including greywater, with a potential for human contact must be treated.
- **Performance goal 3**: Costs should be minimised in line with sustainability principles i.e. the least cost to society should be sought.

**Design a range of responses to meet goals.** Sewering was going to cost around $45,000 per lot, and both residents and councillors are concerned with that figure. The EO engages innovative engineering consultants to consult with homeowners and devise a set of alternative responses. The final set of options accepted by the steering committee for further investigation are:

- **Response 1**: Council enforced homeowner control. Council inspects all systems and issues orders for improvement for suspect systems (failing or situated too close to the creek). Homeowners must either replace with AWTS or revamp these systems. Septic revamp involves replacement of the absorption trench with a subsurface irrigation
system and the addition of a septic filter. All remaining septic tanks have filters added. Homeowners trained in monitoring and maintenance.

- Response 2: Local water authority takes on the on-site systems, to manage and maintain. Water authority inspects all the systems and replaces the suspect ones with aerated water treatment systems (AWTS). All remaining septic tanks have septic filters added.

- Response 3: Local water authority takes on the on-site systems, to manage and maintain. Water authority replaces all with AWTS with telemetric monitoring.

- Response 4: Local water authority takes on systems and using the existing septic tanks installs three STEP (septic tank effluent pump) small-bore cluster wastewater systems and package wastewater treatment plants for the 1,500 houses on the smaller blocks. Elsewhere the septic systems are retained with filters added and fully revamped if failing.

- Response 5: Local water authority takes on systems and installs a total of five cluster systems.

**Balance risk and cost to decide on best response.** Balancing the four risk types and cost is a complex exercise in trade-offs and necessarily involves a transparent participatory process of relevant stakeholders and citizens to inform decision-making (Clark, 2004; Lundie et al., 2006). In this case, the EO first asks for a cost analysis of the five responses conducted from multiple perspectives (society and the three main stakeholders) utilising the life cycle cost (net present value at a real discount rate of 7% over 50 year period of analysis) (see results in Table 1). The life cycle cost estimates include both the capital and operational costs for installation and maintenance of systems, as well as replacement and regulatory compliance. Only actual expenditures are included, for instance the time cost of homeowners in system maintenance in Response 1 is excluded. Costs are based on estimates verified by five separate water authorities and from a published wastewater management study (Geolink, 2002).

The EO organises a participatory process involving the entire steering committee, as well as a set of five randomly selected representative citizens from the locality (since they may be implicated through rising council or water authority rates etc.). A facilitator is hired to run the process and a form of multi-criteria assessment (MCA) (White et al., 2006) is used to deliberate on the costs and risks. This process involves participants considering the cost analysis for whole of society and each cost perspective, and then choosing and discussing priority risks and the resulting risk level within socio-economic, environmental and public health dimensions (summarised in Table 2).

After much debate, Response 4 is nominated as the preferred response. All agree that low public health risk, with its strong linkage to socio-economic risk to the oyster and tourist industry, is critical. While Response 5 has the lowest ecological and public health risk, Response 4 showed a 20% lower life cycle cost. The decrease in risk of nitrogen pollution entering the estuary is not deemed to be worth $7.6 million dollars in life cycle terms.

<table>
<thead>
<tr>
<th>Response</th>
<th>Total life cycle cost (NPV)</th>
<th>Water authority</th>
<th>Council</th>
<th>Homeowner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response 1</td>
<td>$20,610,000</td>
<td>$0</td>
<td>$5,350,000</td>
<td>$15,270,000</td>
</tr>
<tr>
<td>Response 2</td>
<td>$28,880,000</td>
<td>$26,520,000</td>
<td>$450,000</td>
<td>$1,920,000</td>
</tr>
<tr>
<td>Response 3</td>
<td>$39,780,000</td>
<td>$35,650,000</td>
<td>$450,000</td>
<td>$3,700,000</td>
</tr>
<tr>
<td>Response 4</td>
<td>$28,950,000</td>
<td>$27,390,000</td>
<td>$450,000</td>
<td>$1,110,000</td>
</tr>
<tr>
<td>Response 5</td>
<td>$36,580,000</td>
<td>$35,030,000</td>
<td>$450,000</td>
<td>$1,110,000</td>
</tr>
</tbody>
</table>
Table 2 Perceived risk levels for each potential response

<table>
<thead>
<tr>
<th>Response</th>
<th>Socio-economic risk (to society)</th>
<th>Socio-economic risk (to homeowners)</th>
<th>Socio-economic risk (to water authority)</th>
<th>Ecological risk</th>
<th>Public health risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High public health risks due to heavy reliance on homeowners for maintenance</td>
</tr>
<tr>
<td></td>
<td>Potential for conflict over compliance, high economic (oyster business) and recreational costs</td>
<td>Extremely high cost, resulting in inequity with other citizens</td>
<td>Not implicated</td>
<td>Ecosystem health potentially compromised due to heavy reliance on homeowners for maintenance</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Some health risk depending on AWTS system reliability</td>
</tr>
<tr>
<td></td>
<td>Concerns for oyster and tourism business</td>
<td>Medium cost</td>
<td>Institutional changes needed for centralised control of disperse assets</td>
<td>High public health risks due to heavy reliance on homeowners for maintenance</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low public health and ecological risk</td>
</tr>
<tr>
<td></td>
<td>Concerns for oyster and tourism business, citizen concern about rising land and water rates</td>
<td>High cost resulting in inequity with other citizens</td>
<td>High cost, institutional changes needed</td>
<td>Minimal risk since quality ensured through telemetric control</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>All wastewater collected</td>
</tr>
<tr>
<td></td>
<td>Minimal public health risk</td>
<td>Low cost, large blocks have responsibility for septic systems</td>
<td>Institutional changes needed</td>
<td>Minimal risk since quality ensured through telemetric control</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>All wastewater collected</td>
</tr>
<tr>
<td></td>
<td>Low public health and ecological risk</td>
<td>Low cost, no responsibilities</td>
<td>High</td>
<td>Minimal risk since quality ensured through telemetric control</td>
<td></td>
</tr>
</tbody>
</table>

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Enact response. It takes 18 months for Response 4 to be implemented. The water authority and council come to an agreement to jointly fund the asset information system since they both require similar data.

Monitor and evaluate extent to which goals met. Given the debate that takes place about the choice of response and the lack of information available about costs and reliability of different types of system, the monitoring system is taken very seriously and appropriate data is captured and input to the asset management system. Actual performance against all three performance goals is monitored:

- Performance goal 1: The goal to maintain pollutant levels in the waterway below acceptable levels is assigned $30,000 in the council’s budget and is monitored through weekly testing for nitrogen and E. coli by council officers.
- Performance goal 2: The goal of treating all wastewaters with potential for human contact is met through system design and inspection of remaining onsite systems for surfacing effluent, telemetry for cluster systems managed by water authority.
- Performance goal 3: On-going costs to each party monitored and input to asset management system to inform future decisions in the region.

Next steps, moving to a second cycle of management actions
Information from the new asset management system is used to refine or redefine the performance standards after 1 year and provide input to another cycle of the planning process to fine-tune management of the systems and identify any further issues which required resolution. The inevitable changes in policies, costs, climate and regulations mean that the planning and management process is in constant evolution and the framework provides a means to proactively manage that situation.

Conclusions
The framework presented in this paper provides a systematic process to guide incorporation of risk and asset management into planning and management processes for decentralised systems. The framework moves people to the centre of the process rather than the technology, which is essential in achieving workable and sustainable solutions that are accepted by the various stakeholders. This focus on people also means that cooperation and partnership are promoted (for example, between water authority and local government). The case study demonstrates how a broad range of options could be compared on equal grounds through a robust cost analysis from multiple perspectives and a deliberative participatory process engaging stakeholders and citizens to decide on the chosen risk trade-offs and cost-sharing arrangements. The process supported by the framework results in the choice of most sustainable solution in the long-term through the explicit integration of social, economic, institutional and environmental dimensions in decision-making.

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