Paper presented at 1st International Conference on Onsite Wastewater Treatment and Recycling (NOWRA/NOSSIG/OnSiteNZ) / 6th Specialist Conference on Small Water and Wastewater Systems (IWA/AWA) in Fremantle, Australia, February 11-13, 2004

Evaluating Reliability and Life-Cycle Cost for Decentralized Wastewater within the Context of Asset Management

S. Fane*, J. Willetts*, K. Abeysuriya*, C. Mitchell*, C. Etnier**, and S. Johnstone**

* Institute for Sustainable Futures, University of Technology, Sydney, PO Box 123, Broadway, NSW, 2007 Australia (E-mail: Simon.Fane@uts.edu.au)
**Stone Environmental Inc. 535 Stonecutters way, Montpelier, Vermont, 05602, USA

Abstract
This paper describes the findings of the initial stages of a project that aims to review and develop tools for asset management of decentralized wastewater systems. The work is being conducted for the NDWRCDP (National Decentralized wastewater Research and Capacity Development Project) in the United States. Here we provide a description of what reliability analysis and an asset management approach mean for decentralized wastewater. The key facets of centralized urban water asset management are first summarized. Strong parallels can be drawn from these, however important differences exist between centralized and decentralized systems and their management. These differences stem from the distinctive characteristics of decentralized wastewater assets and the large spectrum of management, regulatory, and policy scenarios confronting decentralized asset managers. In addition, for decentralized wastewater, we argue that system reliability must be interpreted broadly, and include the analysis and evaluation of technical, ecological, public health, and socio-economic risks. Such differences mean that an adapted asset management framework is necessary for decentralized wastewater. Finally, although some of the necessary tools already exist, our framework and outline of tool groupings shows that potential remains for development of further reliability analysis and life-cycle costing tools to aid asset management of decentralized wastewater systems.

Keywords
Decentralised wastewater, on-site wastewater, operations and maintenance, risk assessment

INTRODUCTION

About a quarter of residences in the United States rely on decentralized treatment of wastewater and both the number of systems and percentage of users are growing (USEPA 1997). Unfortunately, many decentralized wastewater treatment systems have been poorly designed and installed and receive little or no effective management. Where systems are not properly managed, they have a higher rate of failure (Hoover 2002).

It is only relatively recently that decentralized wastewater has been truly accepted as a permanent part of the wastewater infrastructure in the US (USEPA, 1997). It is increasingly being recognized that sound management is a key requirement for the functioning of decentralized wastewater treatment systems at a level of reliability that protects public health and the environment. There are now trends toward improving the management of decentralized systems in the US. For example many States, counties and municipalities are now regulating systems and requiring regular inspections and system upgrades where necessary. Efforts are also being made at a federal level to improve decentralized wastewater performance by providing the tools to system managers so they can administer decentralized assets in a manner that can parallel centralized wastewater. To this end the U.S. Environmental Protection Agency has developed voluntary guidelines for introducing five alternative models of management for decentralized wastewater (USEPA, 2003a). These models aim to increase the level of management as environmental sensitivity and/or system complexity increases, for configurations ranging from individual onsite systems to cluster systems serving dozens or hundreds of residences and businesses (USEPA, 2003b).

The review and synthesis presented in this paper represents the findings of the first phase of an on-going US federally funded project. The larger project is aimed at developing a framework for asset management and reliability analysis of decentralized wastewater systems and reviewing the methods, tools and data available and required. This work is being conducted for the NDWRCDP, which is a cooperative effort funded by the USEPA through a Cooperative Agreement with Washington University in St. Louis. The project is considering asset management and reliability analysis of decentralized wastewater systems under various management, regulatory, and policy scenarios. In developing the framework and identifying tools, each of the five models of management for decentralized systems as described in the voluntary guidelines (US EPA 2003a) are to be considered. Likewise various levels of system complexity will be taken into account.

The principal outcome from this work will be a handbook (due in 2005) that aims to illustrate the usefulness of these approaches for decentralized wastewater to service-providers, regulators and other workers in the field. The handbook will characterize the approaches available within the framework being developed. It will allow appropriate methods and tools to be selected for specific decentralized management situations and highlight the data needs and recommend processes for gathering data for the particular methods. The finalized framework(s) will also be used within the project to characterize the methods and tools requiring further research and development.

This paper first considers asset management in centralized urban water. Key differences between centralized and decentralized wastewater management that need to be accounted for are then outlined. Finally, a discussion of the application of asset management to decentralized wastewater systems is presented. The types of life-cycle costing and reliability analysis methods and tools that will be needed for asset management in the decentralized wastewater sector are also highlighted.

ASSET MANAGEMENT IN CENTRALIZED URBAN WATER

Asset management has been used in centralized water and wastewater utilities for over fifteen years in Australia, New Zealand, and the United Kingdom, and more recently in the United States. Asset management is based on a fairly simple idea: Find out what assets you have, where they are, what condition they are in, and how they affect your ability to meet performance requirements, use this information to make decisions on investing in new assets and maintaining the existing ones.

The Association of Metropolitan Sewerage Agencies (AMSA) handbook describes asset management as "*An integrative optimization process that enables a utility to determine how to minimize the total life-cycle cost of owning and operating infrastructure assets while continuously delivering the service levels that customers desire*" (AMSA 2002). Asset management for centralized urban water will involve an information system that is used to characterize the risks associated with failure to repair or replace particular infrastructure components and a decision-making approach that uses risk assessment to measure the benefits of alternative approaches to infrastructure maintenance, rehabilitation and replacement (USEPA, 2003c).

Drawing on the experience of centralized water and wastewater utilities with asset management this project identifies four key elements that make up the framework of asset management. These elements are:

1. The setting/regulating of service and performance standards;
2. A regulatory and organizational structure conducive to least cost optimization;
3. The use of asset information systems, asset inventories, data-bases, asset monitoring and GIS;
4. The use of tools for reliability analysis and life-cycle costing including estimates of asset condition, useful-life and the cost of asset operation, maintenance, rehabilitation and replacement.

Each the key elements will now be discussed in turn.

Performance goals and standards

Performance goals and standards answer the question, "What are we trying to achieve by managing these assets?" They are largely driven by the service expectations of customers and other stakeholders and dependents on the organizational structure. In the ASMA handbook performance standards and goal are discussed in terms of 'strategy' and in terms of a utility developing objectives and policies in consultation with customers that then frame performance standards for assets. For example a standard may be set for the maximum number and duration of water shutoffs that customers can expect to experience during a year. Alternatively the policy may be one of continuous improvement in service continuity or maintaining asset condition (Young, 2002). In other jurisdictions, regulators mandate performance standards in operating licenses (Young and Blez, 1999). The regulator, acting as a proxy for other stakeholders, can play a strong role in asset management by setting unambiguous performance standards that the utility must meet. Asset performance standards may be set for environmental outcomes (Ashley and Hopkinson, 2002) as well as the more commonly considered: potable water quality, service provision (supply continuity and avoidance of on-property sewer overflows) and level of customer service.

Organizational and regulatory structures

The classic form of asset management occurs within a regulated corporation that owns and manages its own assets. Motivated by financial interest and applying a corporate accounting standard, the corporation should manage it's assets to meet agreed performance standards at the least life cycle cost to the corporation. This will involve balancing the operation, maintenance, rehabilitation and replacement costs of assets together with the risk and consequence of not meeting performance standards (Young and Blez, 1999). The Australian urban water sector is an example of the importance of regulatory and organizational structures in promoting asset management. Asset management came to the fore in the water industry in Australia after the commercialization of utilities and clear delineation of the role of independent regulators. Where other organizational structures exist in urban water, asset management remains possible; some business process redesign will however be needed to promote the least cost optimization of managed assets (ASMA, 2002).

Asset information systems

Asset management requires an information system that tracks assets, how they are being managed, their costs and reliability under that management (USEPA, 2003c). Central to the information system will be an inventory of assets, which covers at least the location, condition, and criticality of assets. An accurate asset inventory sets the stage for effective management (WERF, 2002). Monitoring will important in keeping an information system and inventory updated. Monitoring can be made through periodic inspections, or continuously, through telemetry.

Reliability analysis and life-cycle cost tools

Reliability analysis for centralized systems has a primary focus on technical or engineering reliability related to pipe networks. This is because in terms of risk, pipe breakage represents a risk of significant consequence and pipes for water distribution and sewage conveyance represent centralized utilities' principal assets. The potential for pipe failure can be assessed through both technical reliability analysis and asset inventory analysis. Ostfield (2001) describes stochastic simulation for reliability analysis of distribution assets. Fenner *et al*, (2000), Babovic *et al* (2002) and Silinis and Frank (2003) describe various approaches to the analyses of asset inventory information (and in the case of Silinis and Frank biophysical data such as soil type) in order to group asset into classes and make assessments of failure risk based on previous experience.

Various cost-risk models such as those described by Young and Bletz (1999) have and CSIRO Urban Water (2003) been developed for asset management in centralized water and wastewater. These models identify optimal pipe maintenance and replacement strategies based on life cycle cost with reliability analyses used to estimate the risk of pipe burst under various management scenarios. A corporate utility will decide to replace a pipe before it bursts if this avoids the risk of expensive consequences. Alternatively the corporation may calculate that it makes financial sense not to replace some aging pipes and that performance goals can be meet at least cost by waiting for pipes to burst before they are replaced.

DIFFERENCES BETWEEN CENTRALIZED AND DECENTRALIZED WASTEWATER MANAGEMENT

Water distribution and collection costs dominate of the life cycle cost of a centralized system (AWWA, 2001). Asset management in the urban water sector has therefore focused on the question of how best to manage the pipe infrastructures. In comparison, for decentralized wastewater management, the treatment process itself is of much greater importance to total cost and system risk and for on-site systems disposal becomes the major factor.

Together with the differences in relative importance of pipes to system performance, managing decentralized wastewater systems involves special challenges not found in centralized wastewater collection and treatment. The complexities of managing decentralized systems include the issues of siting, the impacts of varying usage, the usual lack of effluent data, and the multi-faceted nature of the risks from system failure. Like the systems themselves, ownership of the systems is generally dispersed. It is usual that no single organization coordinates investment decisions for decentralized wastewater infrastructure, though local regulators and policy makers may use financial incentives, regulations and penalties to encourage system owners to manage their systems in specific ways. While management (and possibly ownership) of decentralized systems by responsible management entities (RME) would increase the parallels to the management of centralized systems, (USEPA, 2003b) few systems today are controlled by such entities. Table 1 below highlights some of the important differences between centralized and decentralized wastewater systems from the perspective of asset management.

Table 1 Relevant management issues for centralized and decentralized wastewater

Management Issue	**Relevant to centralized systems?**	**Relevant to decentralized systems?**
Quality of site is critical	Unusual	Normal
Performance of pipe assets critical	Normal	Occasional
Performance of treatment assets critical	Normal	Normal
Performance of wastewater disposal assets critical	Occasional	Normal
High flow variability a concern (seasonality or other)	Occasional	Normal
Lack of effluent data	Unusual	Normal
Dispersed ownership and operational responsibility	Unusual	Normal
Poor understanding of maintenance requirements from asset owner	Unusual	Normal
Probability that individual asset failure will go undetected	Unusual	Occasional
Potentially high consequence individual technical failure	Normal	Unusual

Thirdly, another key difference between decentralized and centralized wastewater systems is the complexity with regard to risk, which is a key determinant of the required level of technical reliability of a decentralized system and its various components. As mentioned earlier, centralized systems have the risk of pipe breakage as the primary risk and this risk is normally acute with sudden high consequence. In contrast, decentralized systems have a wider range of critical modes of failure with an even larger range of possible consequences ranging from low to high impact. Many of the impacts of decentralized asset failure are more chronic in nature, and cumulative over time, although acute impacts are also possible. As Jones *et al* (2000) state, there are four types of risks associated with decentralized systems, these being engineering, public health, and ecological and socio-economic risks. This all serves to make asset management more complex for decentralized systems and means that it involves a greater understanding of risk. Reliability analysis tools for decentralized systems therefore need to include various types of risk and impact assessment tools. In addition, since decentralized systems are often operated and even maintained by homeowners, reliability analysis needs to account for their probable actions and ways of influencing their actions.

ASSET MANAGEMENT FOR DECENTRALIZED WASTEWATER SYSTEMS

The four key elements of asset management in centralized urban water are now discussed in relation to how they might be applied for decentralized wastewater, taking into account the differences described above. In addition to these four elements, a further element regarding 'communication with stakeholders' has been added to account for the need for strong communication between various parties involved in decentralized systems.

Performance goals and standards.

In industries currently using asset management, regulation plays a crucial role both in setting the performance standards and in defining who is responsible for meeting the performance standards. In decentralized wastewater treatment, the greater part of regulation is prescriptive, rather than performance based and an asset management framework is less easily adapted to prescriptive regulations. Current efforts by the National Onsite Wastewater Recycling Association (NOWRA) to develop a model performance-based code (NOWRA Model Performance Code Committee, 2003) should leads to greater use of performance standards by state and local jurisdictions. This development would significantly increase the applicability of asset management to decentralized wastewater in the United States. Other authors have also expressed the value of risk-based performance standards to replace existing prescriptive and often unnecessarily conservative regulations (Hoover *et al,* 1998).

The goals and performance standards need to address the four types of risks associated with decentralized systems (engineering, public health, ecological and socio-economic risks) and also account for the regulatory and policy context, the organizational context, the current and projected performance of the systems, and the views of the various stakeholders. Agreement needs to be reached with stakeholders on performance standards for catchments and customer service in the areas of engineering, environment, public health, and socio-economic factors. The goals and performance standards may also need to be made at various levels, including for individual wastewater system, a set of systems (defined, for example, by location or time of construction), and the management organization. It is clear that for decentralized wastewater the definition of the performance standards will differ substantially as compared with the centralized urban water field.

Organizational and regulatory structures

As discussed above, organizational and regulatory structure plays a significant role in wastewater asset management. The reason for this is that the structure defines how and by whom the risks and costs of wastewater management will be borne. The voluntary guidelines set out by the US EPA describe five management models for decentralized wastewater management (USEPA, 2003a). The alternatives are: 1) a homeowner awareness model, 2) a maintenance contract model, 3) an operating permit model, 3) a responsible management entity (RME) operation and maintenance model, and 5) a RME ownership model. Of these, the RME ownership model most strongly parallels utility management of centralized urban water. Least cost optimization of managed assets becomes slightly more complicated for the other four management models where no single entity owns and manages all assets. However, even with the RME ownership model decentralized wastewater management decisions are not purely in the hands of the RME. Indoor plumbing and fixtures are an important part of the decentralized wastewater system and changes made indoors by customers (e.g., low-flow fixtures, separate paths for black-water and grey-water) can have significant effects on the rest of a decentralized system. This means that with all management models least cost optimization of decentralized wastewater assets will involve the negotiated interests of multiple parties. For example, with permit based models some of the roles of the asset owner/manager and the regulator may be consolidated in a local regulatory body such as a 'board of public works'. Such a body will manage collective assets through permits, with its decisions about asset maintenance, rehabilitation or replacement enforced on the actual owners.

Asset information systems

The information system necessary for decentralized systems will need to contain a much larger variety of information than is necessary for centralized systems. Depending on the USEPA management model the detail and diversity of information stored in such a system would be expected to vary considerably. A database might be expected to include information such as:

- an asset inventory (system type, age, location, capacity/scale/design flow, maintenance history),
- on-going performance information (site condition assessments, monitoring, loading rates),
- bio-physical information (planning/land use, lot size/density soil, wetness, slope, water courses, vegetation, catchment characteristics), and
- cost data for capital works and operations (historical cost of capital, operations & maintenance).

Reliability analysis and life-cycle cost tools

We consider four types of tools to be necessary to perform the analyses to inform decision-making regarding asset operation, maintenance, and replacement for decentralized systems. These are: inventory analysis tools, technical reliability analyses tools, impact assessment tools and investment decision-making tools. These tool types are also used in centralized system asset management, however the specific tools within these groups are likely to differ between the two contexts. Further detail is provided below describing each of these tools types in the context of decentralized systems. These will be further developed in ensuing stages of the project.

Inventory analysis tools. Tools that use information directly from the asset inventory and predict or infer life expectancy and performance of individual assets. Examples include data mining of the inventory, cohort analysis, condition tracking and monitoring and GIS/soil type analysis. These are also sometimes known as 'Inventory Condition Assessment tools' (WERF, 2002).

Technical reliability analyses. These are tools for determining or predicting the probability, mode, and location of asset failure. Mechanical, structural and system reliability tools feature in this group, as failure may occur due to breakage or dysfunction of components, or may be related to the treatment process itself. Examples include probability assessments, predictive models, fault tree analysis, failure modes and effect analysis, critical component analysis. Human factors must also be taken into account in such analyses due to the important effects of actions of homeowners. Particular methods such as FACTSS (failure analysis chart for troubleshooting septic systems (Adams, 1998) help provide systematic methods to evaluate the causes of failure. Both quantitative and qualitative tools will be useful. Quantitative tools suffer from the need for data that is often unavailable. Qualitative tools are limited to comparative analyses.

Impact assessment tools. This group of tools is for predicting the consequences of poor performance with regard to public health, ecological and socio-economic impacts. Monitoring, modelling and risk assessment tools for emissions feature here. Tools to determine and predict both the impact of individual assets and the collective impact of multiple assets are needed. Such tools might be based on particular emissions (e.g. Nitrogen, phosphorus, pathogens), or might be based on assets with assumed performance levels. A good example is the OSRAS (On-site Sewage Risk Assessment System) tool developed in Australia that integrates spatial, natural resource, infrastructure, and operational data to create a cumulative spatial assessment of risks (Irvine and Kenway, 2003).

Investment decision tools. Once the consequences of various management strategies are understood, asset management calls for a process to decide on the preferred management strategy. When performance standards are sufficiently clear and comprehensive, and organizational structures allow true least cost optimization, then the management strategy with the least financial cost which meets the standards may be chosen. When clear performance standards cover only a small part of the impacts of the managed asset, or multiple stakeholders and cost perspective need to be considered, then different tools are needed. These tools are likely to include risk management, economic analyses, multi-criteria assessment, use of sustainability criteria, and participatory and deliberative approaches.

Stakeholder communication

The disaggregated nature of decentralized systems presents challenges because many different parties are involved in their use and operation. Homeowners, installers, managers, inspectors, and regulators all play a role. In addition, since impacts from such systems directly affect other parties such as neighbors or other community members, the circle of stakeholders for such systems further widens. There is therefore a need for communication with the relevant stakeholders at virtually all steps of the asset management process.

DISCUSSION AND CONCLUSIONS

This paper has described the initial findings from the first phase of a project aimed at reviewing and developing the methods, tools and data required for asset management and reliability analysis of decentralized wastewater systems.

It is apparent that while some strong parallels for decentralized systems can be drawn to centralized urban water asset management, important differences also exist. These differences mean that a novel framework of asset management and reliability analysis, which can be used to help make decisions about least-cost ways to deliver agreed-upon performance, is justified for decentralized wastewater treatment systems. A number of tools used in centralized system asset management are applicable to decentralized system. In addition, existing management tools already in use for decentralized system management can be seen to have application within an asset management, reliability analysis framework. The differences however mean that significant potential for tool development in the decentralized wastewater asset management area remains.

In conclusion, this review and synthesis represents an initial output from a larger project, from which the principal outcome will be a handbook. The paper has provided an introduction to the topics of asset management and reliability analysis from the perspective of decentralized wastewater. The handbook will guide the use of methods and tools for service-providers, regulators and other workers in decentralized wastewater management.

ACKNOWLEDGEMENT

The authors wish to thank the NDWRCDP for their support of this project and acknowledge discussions with and the input from other members of our project team: Richard Pinkham, George Tchobanoglous and Steve Moddemeyer.

REFERENCES

Adams A, Hoover M, Arrington B and Young G (1998) Failure Analysis Chart for Troubleshooting Septic Systems, Proceedings of Onsite Wastewater Treatment, *Eighth National Symposium on Individual and Small Community Sewage Systems*, Orlando, Florida, ASAE, Society for engineering in agriculture, food and biological systems

AMSA 2002. *Managing public infrastructure assets to minimize cost and maximize performance,* Association of Metropolitan Sewerage Agencies, Washington, DC.

Ashley R., and P. Hopkinson. 2002. Sewer systems and performance indicators—into the 21st century, *Urban Water* **4**:123-135.

AWWA (2001) *Dawn of the Replacement Era: Reinvesting in Drinking Water Infrastructure*, American Water Works Association, Denver, CO

Babovic V., J-P Decount, M. Keijzer, and P-F Hansen (2002) A data mining approach to modelling of water supply assets, *Urban Water* **4**:401-414.

CSIRO Urban Water (2003) Management and operation of urban water systems, accessed in 2003 at *http:// www.cmit.csiro.au/reseach/urbanwater/mouws*.

Fenner, R., and L. Sweeting. 1999. A decision support model for the rehabilitation of "non-critical" sewers, *Wat. Sci. Tech*., **39**(9).

Hoover M, Arenovski A, Daly D, and Lindbo D (1998) A risk-based approach to on-site siting, design and management, Proceedings of Onsite Wastewater Treatment, *Eighth National Symposium on Individual and Small Community Sewage Systems,* Orlando, Florida, ASAE, Society for engineering in agriculture, food and biological systems

Hoover, M. (2002) Performance standards for wastewater pretreatment, *Northeast On-site Wastewater Short Course and Equipment Exhibition*; 25-26 March 2002, Oral presentation; Newport, Rhode Island.

Irvine, R., S. Kenway, et al. (2003). Implementing an On-site Sewage Risk Assessment System (OSRAS) in the Hawkesbury Lower Nepean Basin. *Proceedings of Onsite '03 Conference,* Armidale, Australia.

Jones D, A. Armstrong, M. Muhlheim, and B. Sorensen, (2000) Integrated Risk Assessment and Risk Management as applied to Decentralized Wastewater: A High-Level Framework, in *National Research Needs Conference Proceedings: Risk-Based Decision Making for Onsite Wastewater Treatment,* EPRI, Palo Alto, CA, U.S. Environmental Protection Agency, and NDWRCD 2001. 1001446.

NOWRA Model Performance Code Committee (2003) Model Performance Code: Pre-conference Workshop. NOWRA: Edgewater, Maryland

Ostfeld (2001). Reliability Analysis of regional water distribution systems. *Urban Water* **3**: 253-260.

Silinis, P. and S. Franks(2003) Development of a diagnostic index to guide maintenance. *Journal AWWA* **95**(5):105-111

US EPA (1997) *Response to Congress on use of decentralized wastewater treatment systems*, U.S. Environmental Protection Agency, Office of Water and Office of Wastewater Management, Washington DC

US EPA (2003a) *Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems,* U.S. Environmental Protection Agency, Washington, DC.

US EPA, (2003b) *Draft Handbook for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems*, U.S. Environmental Protection Agency, Washington, DC.

US EPA, (2003c) Summary of Water Infrastructure Forum from the Closing the Gap: Innovative Solutions for America's Water Infrastructure Forum January 31, 2003, accessed in 2003 at *http://www.epa.gov/water/ infrastructure/forum_summary.html*.

WERF. 2002. *Research Priorities for Successful Asset Management: A Workshop*, Water Environment Research Foundation workshop held on March 21-22, 2002 in Alexandria U.S

Young, K., and P. Belz. (1999) A Whole of Life Approach to Management of Water Mains, accessed in 2003 at http://www.masterplumbers.com/plumbwatch/pipes99/wholeoflife.doc.

Young, K (2002), Setting Service Levels- A simple task or a major challenge in Asset Management? A power point presentation accessed in 2003 at www.bcwaternews.com/socalh2onews/ asset/service_levels.ppt