IDEAS AND TOOLS TO SHAPE LONG-TERM MANAGEMENT OF AND INVESTMENT IN DECENTRALISED INFRASTRUCTURE

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Abstract

More and more, decentralised systems are considered a permanent part of the wastewater infrastructure. Information, tools and processes that enable us to improve the long-term reliability and performance of these systems are therefore critical to allocating capital and management resources now and in the future. In centralised wastewater systems, asset management systems meet this need. Since asset management is uncommon in the decentralised field, this research project focused on elucidating how asset management might be applied in the decentralised context, and exploring the tools and data likely to be useful or necessary to facilitate improved long-term management of decentralised systems. The project resulted in the 'Decentralized Wastewater System Reliability Analysis Handbook', now posted on the National Decentralized Water Resources Capacity Development web site at http://www.ndwrcdp.org/publications.cfm. This paper focuses on tools, which is one aspect of the project's outcomes. In close alignment with the key theme of this conference, we present tools both to monitor system operation and performance and to cost and qualitatively compare different investment scenarios for their ability to reduce real and perceived risks of on-site systems. The key to using tools is data availability. In the USA, similar to Australia, there is a paucity of data. Therefore, a key feature of the handbook is how to make best use of existing data, and how to best focus further data gathering. Thus, in the reliability and costing tools we examine here (failure curves, failure modes and effects analysis, and life cycle costing), we use synthesized data that reflection of experience in the USA.

Keywords

Asset management, Life cycle costing, On-site systems, Reliability tools, Risk management

1 Introduction

A new paradigm has arisen challenging the conventional, minimal methods of managing on-site systems. The status of decentralised infrastructure is gradually rising, to become an accepted, long-term solution to domestic wastewater issues (US EPA, 1997). There is widespread recognition of the need to proactively manage on-site systems so that precious resources are invested wisely to avoid the dispersed risks that might cause harm to human health and the environment. This recognition is reflected in the USEPA's identification of increasing levels of management and intervention (USEPA 2003). In this project, the goal was to produce a manual that would assist regulators, system managers, and practitioners, working at all management levels, to make effective use of the resources and information at their disposal to deliver improved outcomes from distributed wastewater treatment systems.

2 A strategic framework based on risk and asset management

To improve long-term management and investment in on-site systems, a strategic decision making process is necessary. Thereafter, systematic steps can be taken from an existing, problematic situation toward one where performance standards are met, and trade-offs between risks and costs to different stakeholders are made consciously and explicitly. To do this, a combination of ideas adapted from integrated risk management and asset management approaches is required. Integrated risk management denotes the concurrent consideration of different types of risk. Asset management is: "a means of managing infrastructure to minimise the cost of owning and operating it while delivering the service levels that customers desire" (AMSA, 2002). The details of this combined approach are provided in the handbook (Etnier et al, 2005). Here, we outline the central elements as a backdrop and context for the reliability and costing tools that we present. The tools need to sit within this strategic-level framework, as it is this that defines both the choice of tool and the depth or detail of its usage. The critical elements of a combined risk management–asset management approach are set out below.

Firstly, asset management approaches rely on the use of an "asset information system" as a critical and integral part of the approach (WERF, 2002). Data collection and information management is extremely important to gain any kind of an understanding of the trends within existing sets of systems, or to use any of the more advanced tools suggested in this paper. Targeted data collection is therefore key to effective investment.

Secondly, with multiple and diverse stakeholders involved in distributed systems, explicit initiatives to enable appropriate participation in decision making are crucial. In Australia, at a minimum, the homeowner, local community, local council, local water authority, state environmental protection agency, and the relevant public health authority are implicated.

Thirdly, contextual factors (environmental, regulatory and organisational) play an important role in defining and informing a combined risk management–asset management approach. Such factors determine the feasibility of achieving a given performance standard and define which stakeholders shall bear the various costs and risks.

A fourth element to the decision making process is to consider not only the risk of one or more systems failing (that is, engineering risk), but also to consider public health and environmental risks (impact risk assessment), and the large, complex realm of socio-economic risks (ORNL, 2003). Omitting the latter element means that an identified solution that is acceptable to one of the stakeholders may be unacceptable to another. This could compromise its overall validity and constrains its effectiveness in the long run.

The fifth and final aspect is a cyclical planning process that works through the following steps, employing appropriate tools at each stage:

1. Assess current performance
2. Identify performance standards
3. Develop responses/scenarios/options
4. Balance risk and cost
5. Enact response
6. Monitor and evaluate

Below we outline the value and process of technical reliability tools (failure curves, and failure modes and effect analysis) and costing (life cycle costing) tools. Reliability tools might be applied in the "assess performance" step to inform responses or options. Costing tools are useful in the "balance risk and cost" step, where decisions between responses occur.

3 Reliability Tools

A wide spectrum of reliability tools is available for decentralised wastewater practitioners to adopt. We see the most easily applied and useful tools as being **failure curves** in conjunction with cohort analysis, and **failure modes and effects analysis**. Other reliability tools include process reliability analysis, probability assessments, critical component analysis, field sampling of system performance and systematic troubleshooting (see Etnier *et al.*, 2005).

3.1 Failure curves in conjunction with cohort analysis

Performance standards can be categorized as either hydraulic (e.g. surcharging effluent) or treatment performance (e.g. poor effluent quality). Insights into both can be gained by analysing failure curves. They are a simple actuarial tool comprising plots of the frequency of failure of systems or components over time, such as typical pumps, septic tanks, filters and entire systems, using local or industry-wide data. This tool allows us to predict when certain elements are likely to fail and to plan accordingly. Strategic application of this tool has the potential to lower overall costs and reduce system failures.

A “cohort” is a group of systems sharing one or more common properties. Hudson (1986) recommends establishing on-site sewage system cohorts on the basis of the regulations in force at the time of system construction. Geographical information systems (GIS) offer the possibility of defining cohorts according to, for instance, soil types, location, and/or proximity to groundwater and surface water.

A “failure curve” illustrates the number of systems in a given population failing at any given point in the lifetime of that population (Moubray, 1997). At a minimum, the data required to construct a failure curve is, for each past failure, information about when the unit was installed, when it failed (if ever) and when it was last known to be performing adequately. Whilst this kind of data is historically sporadic, at best, legislative changes forcing annual inspections provide an opportunity to change that. Constructing different failure curves for different cohorts of systems gives the analysis increased predictive power. Hudson’s view (1986) is that soil type and system age are the key cohort variables: further additional parameters increase the complexity of the analysis with little gain in predictive power.

Failure curves have characteristic shapes that reflect systemic weaknesses (Moubray, 1997). A high number of failures near the beginning of a system’s life (called infant mortality) could reflect poor installation practices. High numbers of failures after a long period of good performance could reflect the impending end of life (“wear-out” period) of a particular component, for example, a pump. A constant failure rate could reflect the constant probability of inappropriate homeowner behaviour, or a constantly increasing failure rate could reflect continuing solids carryover into the distribution box. Wherever possible, care should be taken to include data about adequate numbers of systems in order to predict the shape of the failure curve with defensible statistical significance.

Example application of the failure curve tool: As noted, data is as scarce in the USA as it is here in Australia. Here, we present hypothetical data to illustrate the idea. We assume a cohort of 240 systems, representing a small town. The systems are all septic tanks with absorption trenches in similar soil types, installed under similar Council rules. Records are a bit sporadic – some years there are reports of failures, some years there are no reports. The failure curve shows relatively more failures immediately after installation, suggesting, for example, some settling in the distribution box leading to partial overload of the trench. Then, the systems seem to perform well for 15 or so years, after which the failure rate increases and remains high, suggesting some shared feature of failure. From this data, the following table and corresponding failure curve (Figure 1) were constructed. Using a null hypothesis that the failure rate remained the same throughout the period, a student t-test was used to test whether significant differences were evident between various periods of the systems’ lives. In this example, the failure rate was statistically higher in the first year than the following years, and again in years 17-21. This would suggest a need for close inspection following installation, and appropriate maintenance at around 15 years to ensure continued performance.

Year	Performing Systems	Failures	Failure rate (%)
1	240	8	3.3
3	232	3	1.3
4	229	0	0.0
6	229	1	0.4
7	228	2	0.9
9	226	0	0.0
12	226	3	1.3
13	223	1	0.4
14	222	1	0.5
15	221	3	1.4
16	218	5	2.3
17	213	8	3.8
18	205	6	2.9
20	199	11	5.5
21	188	12	6.4

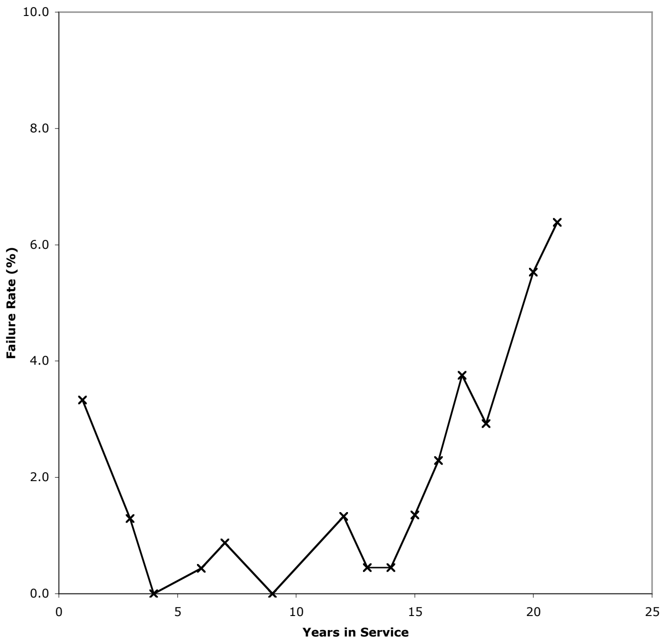

Figure 1: Hypothetical failure curve

3.2 Failure modes and effects analysis

Failure modes and effects analysis (FMEA) uses a simple, structured process to ensure that future decisions are informed by experience. It can be performed simply or in a very detailed test environment. FMEA involves thinking through and documenting all the potential ways failure can occur in a component or system, and what the effects of that failure would be. The simplest form of FMEA identifies potential failure modes, potential causes of each failure mode and a qualitative rating of the severity of the effect of this failure. More complex forms include quantitative measurements or calculations of severity and probability of each failure mode (ORNL, 2003). In this way, maintenance procedures can be directed towards reducing or eliminating potential failures. In addition, decision making is facilitated and made more transparent as to how the costs of the maintenance action balance the failure effects.

This tool can be used to troubleshoot existing problems (as would be done in the "assess performance" step) in a similar way to other tools such as HAZOP (Diaper *et al.*, 2001) and FACTS (Adams, 1998). Equally, it can strategically inform useful options for preventative maintenance techniques (in the "balance risk and cost" step). A related on-going management activity would be to track the maintenance performed, actual failure modes and their effects, in an asset management database, so this information can be analysed to inform how operation and maintenance costs might be reduced.

Example application of FMEA: If surcharging effluent were apparent for a large number of the systems, FMEA could identify the failure modes and causes that might have contributed to it. Table 1 shows the possible failure modes and causes related to the tank, the distribution system and the drainage field (adapted from ORNL, 2003):

Component	**Failure mode**	**Failure cause**
		Tank too small
		Tank too shallow
		Filter blockage
		Leaky tank

		Velocity of liquid through tank too fast
		Too much liquid
	No settling	Leaking taps overloading system
		High concentration of suspended solids and/or BOD
	Leak/rupture	Baffle failure in septic tank
		Crack in tank
Distribution system	Too much flow	Poor initial construction or installation
		System too small
		Heavy use causes back-up
	Leak/rupture	Leaky septic tank
	Improper installation	Tree root invasion
Drainage system	Plugged/blocked	Settling causes imbalance and unequal flows
		Encroachment over drainage field (e.g. deck, plants, drive)
		Vehicle compacts soil
	Too much flow	Transport of particles to drainage field causing blockage
		Heavy use causes backup
		Leaky septic tank
	Improper installation	Storm-water run-off overloads field
		Soil not permeable enough
		Poor placement
		Poor construction
	Flooding	Inadequate trench length
		Poor grading of field
		Erosion

Table 1: Potential failure modes for surcharging effluent (adapted from ORNL, 2003)

The risk analysis following this identification stage focuses on determining the likely effects of the failure by assigning estimates of frequency and severity. A qualitative analysis is often sufficient at the ‘assess performance’ stage to shed light on appropriate performance standards. For example, a ‘high’ frequency might reflect a situation where half the systems in a given location were found to be failing after 10 years in operation. If the blocks are relatively large and the climate is quite dry, then the severity might be ‘low or moderate’, reflecting the consequences for public health and environment, in this particular instance. If the blocks were quite small, or the local water table was quite high, or the local soils were a bit sandy, or the catchment was generally low in nutrients, then the severity might be ‘high’.

4 Costing Tools

Costing tools help translate information about system reliability into projections about costs of system performance or failure under different operational and maintenance practices. Cost is only one criterion of many to be considered in the associated decision making process, but it often takes precedence. Unfortunately, costing processes often lack transparency and consistency, which limits the basis for comparison between options. Therefore, best practice costing tools will make assumptions transparent. Here, we outline fundamental kinds of assumptions and present life cycle costing, the most relevant and useful costing tool.

Four pivotal assumptions need to be transparent and consistent. They are: 1. The time value of money. 2. Whose and which costs are included and excluded. 3. How uncertainty and risk are managed, and 4. Temporal and spatial boundaries and scales. In cost projections into the future, taking into account the time value of money is important, and requires choosing an appropriate discount rate. In Australia, an appropriate discount rate for wastewater infrastructure is 7%. In terms of whose and which costs are included or excluded, it is important to make sure that system boundaries for the calculation are constant (that is, the time dimension and the stages in the life cycle of a system, and the set of stakeholders whose costs and benefits are included).

4.1 Life cycle costing

This tool is used and studied widely, and therefore, we focus solely on its capabilities for decentralised management decision making, and present a hypothetical demonstration synthesised from cost and maintenance information from several villages in the USA.

Life cycle costing relies upon accurately predicting all the costs involved with an activity, and thus is supported by using a process called "activity based costing". In this method, an organisation tracks costs by *activity* rather than by typical listings such as capital expenditure, labour and materials. For example the real cost to "inspect" a system would include the labour time as well as indirect costs like use of a vehicle, travel costs, required data management infrastructure, report-writing time etc.

Some instances where life cycle costing adds value in on-site wastewater systems include:

1. Comparing several possible wastewater solutions
2. Comparing different operation and maintenance regimes
3. Decisions about building in redundancy (extra capacity), which means higher capital costs but potentially reduced risk of failure or lower maintenance requirements
4. Examining the effects of reducing household water use (and therefore hydraulic load)
5. Decisions about upgrading a system versus keeping the status quo, and
6. Choosing between disinfection options with capital and operating costs

Example application of life cycle costing: In this example, we compare mandatory pump-outs with inspection and 'pump out as needed' maintenance regimes. In Regime 1, the septic system is pumped out automatically every two years. In Regime 2, a "sludge judge" is procured and all systems are checked annually. The costs associated with the resultant pump-out frequencies for this regime are considered. In Regime 3, risers and inspection ports are installed to facilitate system inspections, and costs are considered for two pump-out frequencies (five and ten years). The following assumptions are used:

- The checked tank may need pumping out at 3, 4, 5 or 10-year intervals[1].
- The planning period is 30 years.
- A "sludge judge" costs $500. One "sludge judge" is sufficient for the community, which has 184 systems. The distributed cost is $3 per household in the first year.
- The cost of inspections is 1.5 hours labour per system, including travel to the site ($60)[2].
- If risers and inspection ports are installed, the cost of inspection per system is reduced to 1 hour labor, including travel to the site ($40).
- Installation of a riser costs $500.
- The cost of administration per system is $5.
- Training costs $200 for the person who uses the sludge judge.
- No regime leads to a greater or lesser probability of failure of the septic system.
- The discount rate is 7%[3].

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[1] The range of pump-out frequencies is based on US EPA(2002): "If systems are not inspected, septic tanks should be pumped every 3 to 5 years depending on tank size, the number of building occupants, and household appliances and habits..."

[2] This time and cost estimate can be customised for the local travel, soil, and site conditions and may be significantly longer in some cases; particularly for the first visit when the tank must be located.

- Costs that are consistent across options are not shown.

The results of the analysis are summarised in Table 3.

Maintenance Regime	Action(s) Taken in This Regime	Predicted Pump-out Frequency	Sensitivity Analysis	
			NPV over 30 Years for $255 Pump-out	NPV over 30 Years for $300 Pump-out
Regime 1	Pump-out automatically	Every 2 years	1,560	1,830
Regime 2a	Check sludge level yearly	Every 3 years	1,980	1,970
Regime 2b	Check sludge level yearly	Every 4 years	1,690	1,630
Regime 2c	Check sludge level yearly	Every 5 years	1,550	1,460
Regime 2d	Check sludge level yearly	Every 10 years	1,230	1,080
Regime 3a	Install riser, check sludge level yearly	Every 5 years	1,770	1,740
Regime 3b	Install riser, check sludge level yearly	Every 10 years	1,440	1,360

Table 3: Life cycle cost (Net Present Value or NPV) for different maintenance regimes

The cost of automatically pumping every two years is comparable to the cost of inspecting annually and pumping out every five years (with or without riser installation), a frequency consistent with expectations for monitored systems. However, there are significant non-monetary benefits to incorporating regular inspections. Monitoring systems regularly reduces risk of failure. Automatic pump-out of a system is unrelated to inspection, so a system that is pumped out on a regular schedule but not inspected could suffer unnoticed chronic or even acute failure. Riser installation allows a greater opportunity for practitioners (and enthusiastic homeowners!) to be aware of the system's state, thus reducing probability of its failure. Adding unnecessarily to the volume of sludge to be treated is undesirable – sludge pumping is by volume, not need. In addition, sludge treatment is an issue in areas where existing sewage treatment plants are at or near capacity. Finally, a performance record is created through the annual monitoring process that can be used to target maintenance actions. For example, households with frequent pump-outs can be identified and given education to improve their use of the septic system and reduce pump-out frequencies and risks. Such information is also useful for directing long-term efforts toward improving on-site system reliability.

The results also show that, should pump-out frequency fall to as low as every 10 years (a possible scenario for lower occupancy or water-conserving households), in addition to the substantial improvements in risk outlined above, there is a small cost saving attached to regular inspection, of about $330 per system over a 30-year period compared with automatic 2-year pump-outs. Such small cost savings on a household scale become significant if we start to think about a set of systems and their cost to society. This community comprising 184 systems might save $60,000 that could be invested elsewhere.

A sensitivity analysis was conducted to examine the effect of the cost of pump-out in this hypothetical example. To do this, the cost of a pump-out was raised from $255 to $300 and the same analysis conducted. Although the two costs differ by only $45, the impact on the analysis results is significant. Whilst the change in pump-out cost did not materially affect the relative order of the life-cycle costs for different regimes, it more than doubled the possible savings. This sensitivity analysis shows small changes can make a considerable difference over the life of a system.

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[3] Labour costs sometimes increase at a higher rate than inflation. If this is expected, then it should be reflected in the calculation. Such an escalation of labour costs has not been taken into account in this example.

The most important lesson from this life cycle costing example is that the same investment can enable qualitatively different outcomes in terms of potential risks to public health and environment.

5 Conclusions

Through example, we have demonstrated the value and new insights that come through applying a selection of reliability and costing tools to inform the management and investment decisions for proactively managing on-site systems. Such tools can be utilised at varying levels of detail, depending on the data available, the time resources available to conduct the analysis and the decision that the analysis is intended to inform. Use of the strategic-level combined risk management–asset management approach described will direct efforts at using these tools most effectively.

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