Author version of paper published as:
Carroll, Steven, Goonetilleke, Ashantha and Thomas, Evan (2006) Onsite Wastewater Treatment: Implementation of a region-wide Integrated Risk Framework
Proceedings of the International Conference on Small Water and Wastewater Systems, Mexico City, Mexico

Onsite Wastewater Treatment: Implementation of a region-wide Integrated Risk Framework

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Abstract
Onsite wastewater treatment systems are becoming more widely accepted as long term wastewater treatment systems in areas not serviced by centralised sewerage systems. However, the current means of assessing site and soil conditions to provide adequate treatment and dispersal of domestic wastewater has been a major drawback in achieving specific performance outcomes. In Australia, it is the responsibility of local governments to assess and approve the use of onsite systems, and appreciable variations in standards and codes exist between different jurisdictions. The main aim of this research was to develop a scientific framework for assessing onsite systems, based on risk assessment and management principles thereby allowing more appropriate integration across local government boundaries. A case study illustrating the implementation of the risk framework is also presented.

Introduction

Onsite wastewater treatment systems (OWTS) are essential for the treatment and dispersal of effluent in areas that are not serviced by a centralised wastewater collection system. Unfortunately, poor performance, of OWTS is a common scenario. The consequences associated with poorly performing systems have come to the fore in recent years (Harris 1995). A report to the US congress in 1997 noted that failing onsite wastewater treatment systems, mostly septic tank-soil absorption systems, were the second leading cause of contamination of water sources in the United States (US EPA 1997). Geary (1992) highlights several studies undertaken in Australia relating to the contamination of water resources as a result of onsite treatment systems. They attributed the poor performance to inadequate site and soil assessment and characterisation, prior to the installation of the system. Similar observations relating to inadequate site and soil investigations were also noted by Dawes and Goonetilleke (2003) and Carroll et al (2004).

With increasing concerns relating to poor OWTS performance and the contamination of the surrounding environment, the current performance based standards and codes are coming under scrutiny as to whether they can ensure adequate treatment performance. There is a lack of standardised procedures which have led to many inconsistencies in siting and design and consequently, performance (Whitehead and Geary 2000). In Australia, it is the responsibility of the local governments to administer the necessary standards and codes, and consequently many have developed their own guidelines and requirements with wide variations between different jurisdictions. This has been a major drawback to the nation-wide acceptance of AS/NZS 1547:2000, the national standard for performance based assessment of onsite systems, and the adoption of standardised management strategies. Similar attitudes to siting, design and management of OWTS are evident internationally (USEPA 1997, Jones et al 2000).

This paper presents an integrated framework for onsite wastewater treatment, with the aim of developing a generic risk assessment process suitable for developing standardised assessment

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procedures and its application to the Gold Coast region, Queensland State, Australia as a case study. Issues related to poorly performing onsite wastewater treatment systems is singularly evident in the Gold Coast region with approximately 90% of septic systems failing to meet stipulated standards (Goonetilleke et al 2002). Due to the Gold Coast region being a major tourist destination and home to numerous environmentally sensitive areas including World Heritage sites, Ramsar wetlands, and estuaries and watercourses, better management of onsite systems was deemed crucial.

METHODS & MATERIALS

Study Location

The Gold Coast region is currently undergoing rapid development along the urban fringe, without any centralised wastewater treatment facilities in place to treat the increased wastewater load. This lack of centralised treatment facilities has led to an increased demand for onsite system use. The region (Figure 1) currently has over 15,000 onsite systems in use with the majority being septic tank-soil adsorption systems, although over the past few years an increase in the use of aerobic wastewater treatment systems (AWTS) has become evident. Several areas in the region already have substantial failure rates due to inadequate soil and site conditions (Carroll and Goonetilleke 2004). In order to prevent adverse environmental and public health impacts that may result due to failing systems, the local government considered it necessary to develop a more robust methodology for site assessment.

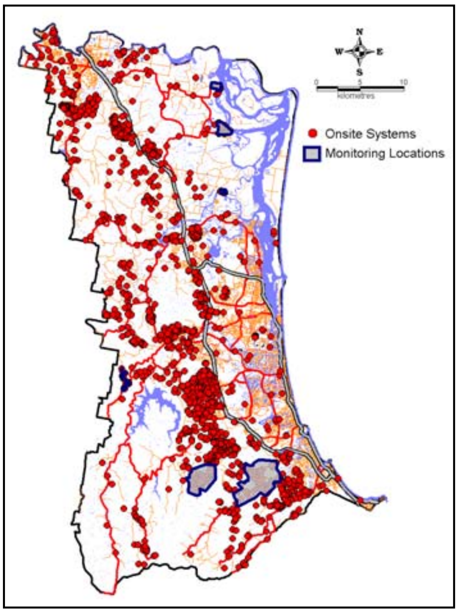

Figure 1: Study area showing monitoring locations

Risk Assessment Elements

The development of the risk framework was based on the Australian Standard AS4360:1999 Risk Management. This approach entails the following four major steps in the generic risk process; 1) Problem formulation, 2) Hazard identification, 3) Risk Assessment and 4) Risk Management and mitigation. Each of these steps was undertaken in a logical progression. In addition, the overall risk process was iterative, with continual review and revisions of the major outcomes as the research developed.

Problem formulation and development

The first stage in implementing the OWTS risk framework entailed the following; (i) identification of relevant stakeholders, (ii) identification of highly sensitive areas within the Gold Coast region, and (iii) identification of hazards associated with OWTS that are critical for the region. These issues were resolved through several stakeholder workshops. Stakeholders included local government officers, developers, contractors, regulators and community. The inclusion of stakeholders was fundamental for the development of the framework with their involvement throughout the process and also allowed the transfer of knowledge created.

The initial identification of sensitive areas in relation to OWTS was undertaken in discussions with the stakeholders. Several areas as shown in Figure 1 were identified as highly sensitive due to both, environmental and public health issues. The identification of sensitive areas was achieved through the assessment of several factors including unsatisfactory soil and site characteristics, potential for contamination of water resources, currently failing systems or high densities of OWTS. These areas formed the basis for field investigations undertaken. The identification of the key hazards involved in siting and design, operation and long term use and management and environmental and public health, was also undertaken.

Hazard Identification and Characterisation

The identification of key hazards was a crucial step in the development of the risk framework and subsequent risk assessment. The identification of hazards that are the most significant in relation to wastewater treatment allowed the focus of the research to be directed towards the main concerns in the study area. The key hazards identified are described in Table 1. From the identification of the hazards, several initial criteria, including soil suitability and planning and setback distances that were related to these hazards were selected. An initial risk map for the region was developed based on a preliminary risk assessment. This enabled the identification of other potentially sensitive areas in addition to those already identified by stakeholders. These additional areas were then targeted for more detailed investigations. Through the sequential development of the risk framework, the risk map was refined regularly as the research progressed and additional scientific information became available.

Table 1: Key hazards and contributing factors related to OWTS

Item	Key Hazard	Contributing Factors
OWTS (Treatment system and disposal area)	Release of contaminants due to *'failure'* of Onsite wastewater treatment system	1. Soil 2. Planning (Lot size) 3. Environmental Sensitivity 4. Flooding 5. Topography 6. Loading rates 7. Operation and maintenance
Surrounding Soil	Inability to renovate effluent and prevent contaminants from reaching groundwater and/or surface water.	1. Soil Type & Horizon Depth 2. Physical characteristics 3. Chemical characteristics 4. Water table depth
Public Health	Contamination of water/surrounding environment such that a considerable health risk is evident due to the release of contaminant (namely pathogens).	1. Surface exposure 2. Water resources 3. Aerosols 4. Pests (mosquitoes etc)
Environmental	Release of contaminants into the receiving environment (ground/surface waters) causing environmental degradation (such as eutrophication).	1. Surface runoff 2. Groundwater discharge 3. Flooding 4. Water table

Integrated Risk Framework

The key hazards were then utilised in developing the integrated risk assessment process. The risk framework consisted of three stages as shown in Figure 2; *Stage 1* – Integrated risk assessment and Risk mapping; *Stage 2* – Detailed assessment of at risk areas; and (iii) *Stage 3* – Risk Management and Mitigation.

Stage 1 forms the backbone of the risk framework and was used to assess the risks related three main risk assessment processes; (1) OWTS siting and design risk; (2) Environmental Risk; and (3) Public Health Risk. The integrated risk assessment utilised in the first stage provided an indication of the resulting risk from OWTS on two levels. Firstly, the current level of risk as a result of existing onsite systems and their impact, including cumulative risk was established. Secondly, using the identified hazards that lead to these risks, an assessment of the potential risks that will arise due to new systems or upgrades to existing systems was undertaken. These two levels of risk were incorporated into a GIS database allowing the visual identification of low, medium and high risk areas. Determining the OWTS siting and design risk involved characterisation of several identified hazards, including soils' renovation ability, lot size of the development, slope, setback distances from water sources such as groundwater wells and surface water and development within a floodplain. The assessment itself evaluated the inherent risks resulting from discharged effluent from the system, rather than being based on the risk associated with specific design principles and system technology. Acceptable risk levels for these identified hazards were defined through investigation as part of the research undertaken, or based on published research. Additionally, the adoption of acceptable risk levels was also discussed with the stakeholders. The acceptable risk criteria for each of the identified hazards are provided in Table 2. The processes in determining the acceptable risk levels and their assessment are discussed below.

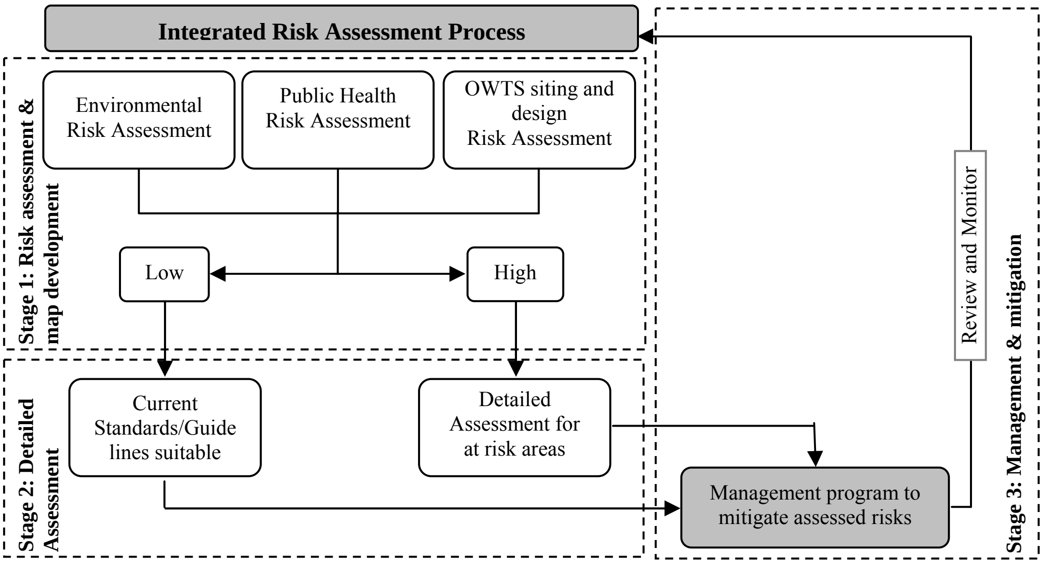

Figure 2: Integrated Risk Assessment Framework for OWTS, Gold Coast City.

Table 2: Risk resistance or concentrations threshold values used for risk assessment

Issue	Parameter	Response	Guideline values (thresholds)	Reference
Environmental	NO_3^{-}N	General Water Quality	10mg/L	ANZECC (2000)
		Eutrophication*	≤ 40µg/L – Freshwater Rivers ≤ 15µg/L – Estuaries	ANZECC (2000)
	PO_4^{3-}- P	General Water Quality	No Guidelines	
		Eutrophication[a]	≤ 50µg/L – Freshwater Rivers ≤ 30µg/L – Estuaries	ANZECC (2000)
Public Health	Faecal Coliforms and E.coli	Drinking water	0 cfu/100mL	NHMRC (1996) ANZECC (2000)
		Primary Contact (recreation, swimming)	≤ 150 cfu/100mL	
		Secondary Contact irrigation, boating	≤ 1000 cfu/100mL	
	NO_3^{-}N	Drinking (ingestion)	10mg/L	NHMRC (1996) ANZECC (2000)

[a] - Indicated values are general guidelines only

Stage 1: Integrated Risk Assessment and Risk Mapping

The assessment of both, environmental and public health risk was established based on the risk of contamination at monitored locations. This was developed around an engineering risk analysis approach as outlined by Ganoulis (1994). The risk established through this process is determined by the probability of failure of contaminant concentrations failing acceptable threshold concentrations and is equivalent to:

$$Risk = probabilty\,of\;\,failure = P_f = P(L > R) = \int_0^{\infty}\left\{\int_0^{L} f_{LR}(L,R)dR\right\}dL \qquad (1)$$

where L = pollutant loading or concentration and R = resistance or prescribed water quality standard or threshold. The specified water quality parameters for environmental (focusing on nutrients of nitrate and phosphate) and public health (faecal coliforms and *E. coli*) risk assessment were obtained from monitored groundwater and surface water locations throughout Gold Coast region. Water samples were collected on a fortnightly basis over a four month period for analysis. The monitoring locations are shown in Figure 1. The risk (probability) of monitored contaminants failing to meet the specified water quality guidelines for both drinking water (NHMRC 1996) and recreational water and aesthetics (recreational, primary and secondary contact) (ANZECC 2000) was determined and compared to values given in Table 2. Respective probabilities were established according to fitted probability distribution functions. For an area to have a low environmental or public health risk, the arithmetic mean of the assessed contaminants had to be lower than the stipulated guideline level 100% of the time. The area is considered at risk whenever the guideline is exceeded. For establishing the environmental risk, nitrogen and phosphorus were the main pollutants considered. The thresholds adopted for assessing the risks are those set out in the ANZECC guidelines (2000) (Table 2). The determination of environmental risk is equivalent to the probability of the pollutant concentration exceeding the water quality standards specified.

In relation to public health risk assessment, levels of fecal coliforms, in particular *E. coli,* were assessed against drinking water and the recreational water quality guidelines listed in Table 2. Although there is debate whether fecal coliforms accurately represent the human pathogenic organisms within the water sample (Parveen et al 1999, Meays et al 2004), it was decided to utilise *E. coli* for two reasons. Firstly, it is the most widely used predictor of fecal contamination. Secondly, to use actual pathogenic organisms is resource intensive. However, in order to determine whether the source of *E. coli* was actually from onsite systems, the antibiotic resistance patterning technique was used for bacterial source tracking. This allowed the estimation of human origin *E. coli* present and separate from other (animal) sources, and a more accurate assessment of public health risk (Carroll et al 2005). The resulting data were input into the GIS database to provide another thematic layer for developing the risk map.

Stage 2: Detailed Assessment of 'at risk' areas

Stage 2 of the risk assessment framework involved deciphering the level of assessment required based on the outcomes of the risk assessment conducted through *Stage 1* and subsequent risk mapping. Where the area of assessment falls within a low risk area, the current standards and codes already available for assessing location suitability and for designing OWTS can be adopted. In Australia, this generally implies AS/NZS 1547:2000, the Australian Standard for Onsite Sewage Systems, as well as the locally adopted codes and guidelines. However, if the site of interest falls within an 'at risk' area (all areas that have either a medium or high risk), then a more detailed assessment is necessary. What is involved in the detailed assessment phase is at the discretion of the stakeholders, particularly the regulators. However, in general, it will be necessary to undertake a more detailed soil and site assessment in order to collect the requisite information to suitably assess the risks.

Stage 3: Risk Management and Mitigation

Stage 3 entails the development of a suitable management program in order to mitigate the risks identified. Through the process of assessing the level of risks in *Stage 1*, the areas with the highest levels of risk will have already been identified. The continual monitoring and review process that is part of the risk management process allows a means of assessing whether the risk framework and management process is effective in providing suitable risk mitigation, and initiate appropriate data collection practices for reviewing the assessed risks and further refining the defined risk areas.

The management of the inherent risks characterised through the integrated risk framework for the Gold Coast region involved two main processes. Firstly, management of OWTS was achieved by developing new and more appropriate assessment guidelines. This was effectively aimed at mitigating the possible risk inherent in the use of OWTS in areas that are unsatisfactory in meeting the specified requirements set out in the standards and guidelines. Secondly, a critical point monitoring (CPM) program to allow the local government to monitor the 'at risk' areas for identified critical parameters was established. In a risk management context, CPM identifies the critical points within a management system that should be monitored to provide suitable mitigation of identified risks. Figure 3 illustrates a generic CPM program. The first three steps in the CPM program were already completed during the integrated risk assessment for OWTS (Stage 1). The final three steps form part of the ongoing management of OWTS to be conducted by the local government. Monitoring and verification of the critical parameters at the identified critical points throughout the Gold Coast region will remain an ongoing process necessary to minimise the identified hazards. The intermediate step is the key to achieving a successful management process. This required the development of suitable procedures to collect monitoring data at critical points, and for assessing the critical parameters to allow the mitigation of identified risks.

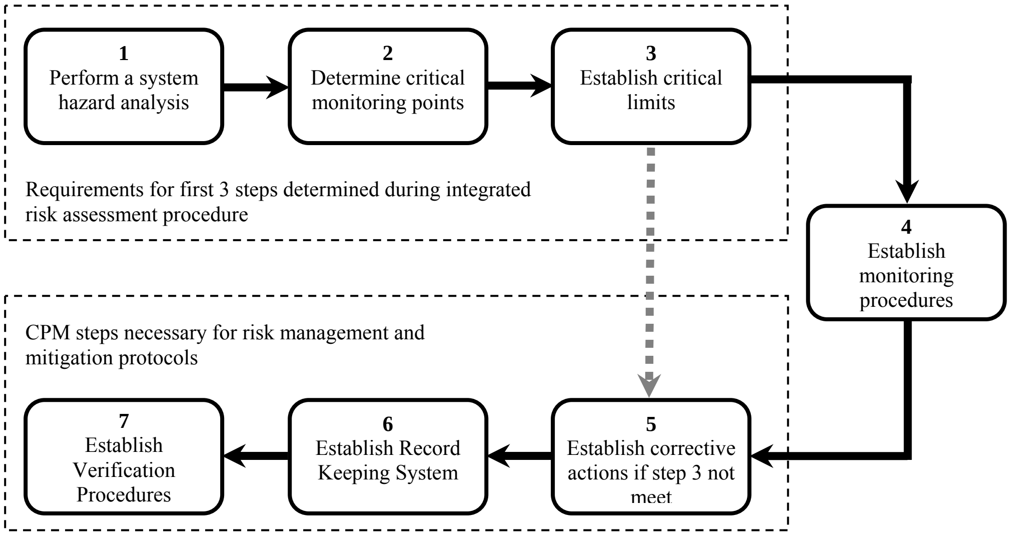

Figure 3: Critical Point Monitoring Process (adapted from Eliasson et al 2001)

Results and Discussion

Integrated Risk Framework

The integrated risk assessment framework, as shown in its generic form in Figure 2, was utilised to assess the hazards related to OWTS for the Gold Coast region. Each of the identified hazards were assessed based on quantitative information established through scientific research conducted as part of this project, or assessed using information available in published research literature. The developed risk assessment framework has been integrated into the Gold Coast region's Planning Scheme, thus contributing to more scientifically robust management of OWTS.

Development of Integrated Risk Maps

Development of the final integrated risk map for the Gold Coast region involved several procedures developed through the use of GIS technology. The technology included MAPINFO version 7.0, a vector based GIS, and ARCVIEW version 8.0, a raster based GIS. The procedure for developing the integrated risk map involved overlaying each individual layer obtained through the assessment of the various risks. The individual GIS layers included (1) soil; (2) planning (Lot size); (3) setback distances; (4) slope; (5) flooding; (6) public health

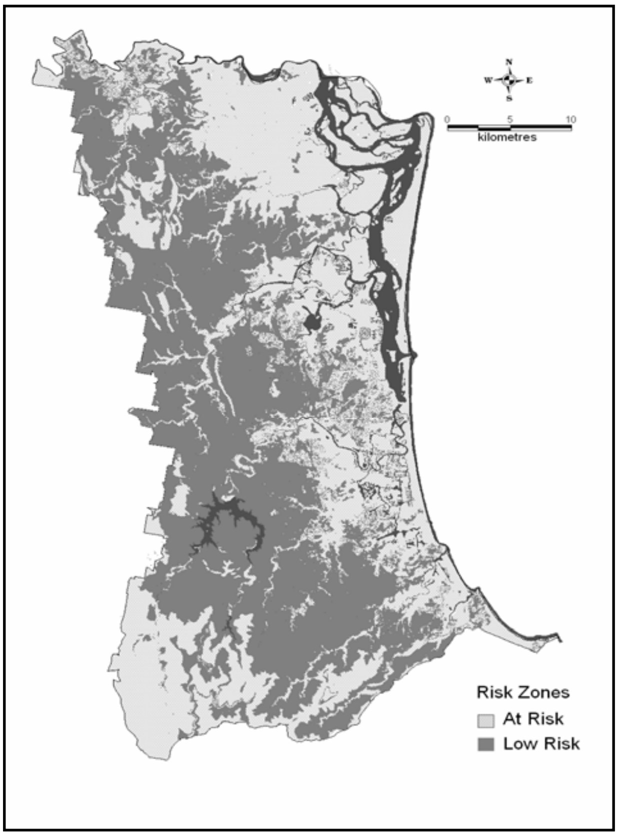

Figure 4: Map developed through Integrated Risk framework indicating 'at risk' areas for OWTS for Gold Coast.

risk; and (7) environmental risk. Layers (1) to (5) were first combined using boolean overlays to produce the risk map for OWTS siting and design risks. This was then overlayed with the public health and environmental risk maps to produce the final risk map, as shown in Figure 4. The algorithm used in establishing the final risk map had to be developed specifically for this task. With the development of this algorithm, the process became more automated, thereby allowing for easier manipulation of the GIS layers, which is highly beneficial for future upgrades of the risk map following revisions of the established risk assessment. This map, along with the risk assessment criteria was implemented as part of the local government's planning scheme.

Risk Management and Critical Point Monitoring

In constructing the integrated risk framework, the critical points associated with the 'at risk' areas were already identified. Therefore, the incorporation of the CPM program was easily integrated into the overall framework. The critical parameters used for the CPM program were identified through the research undertaken and included parameters focusing on soil and site requirements and environmental and public health issues. Essentially, these were based on the limiting factors isolated through the risk assessment stage for the different 'at risk' areas. Ongoing assessment of these critical parameters at the identified critical points allows a re-evaluation of the established risks, providing an overview of the suitability of the management and mitigation of identified risks through the risk framework.

Conclusions

Though the integrated risk assessment framework for onsite wastewater treatment systems was developed for a specific regional area within the Queensland State, Australia, the framework and concomitant procedures and assessments have been developed as a generic approach. This will allow the framework to be utilised in other areas wanting to implement a risk based approach to the siting, design and management of OWTS. The risk framework developed for Gold Coast City has enabled the local government authority to implement a more scientifically robust means of assessing and managing OWTS. This approach will ensure that the environmental and public health concerns related to poor OWTS performance are mitigated, and the siting, design and performance of OWTS are appropriately managed.

This information was subsequently used for the development of a GIS based map to allow visual identification of regions throughout the Gold Coast region most susceptible to the assessed risks. The established risk map highlights areas within the region that are at risk of developing potential environmental and public health impacts resulting from poor OWTS performance. *Stage 2* of the risk framework indicates the level of assessment needed in order to allow the use of OWTS. This stage indicates areas identified as low risk to be assessed according to available standards and guidelines used by the regulatory authority. However, areas indicated as being 'at risk' require further detailed assessment to provide the most suitable treatment system alternative that will not lead to adverse impacts. Finally, *Stage 3* involves employing suitable management and mitigation measures to ensure that the characterised risks are suitably managed. For the Gold Coast case study, a critical point monitoring program was implemented to allow identification and monitoring of critical point locations to allow suitable management strategies to be established.

Incorporation of the developed integrated risk framework and risk maps to the Gold Coast City Planning Scheme will enable the Gold Coast City Council to determine which regions within their jurisdictional area are 'at risk' of causing detrimental environmental and public health impacts. This will enable them to incorporate best management practices efficiently manner specifically targeting these regions, thereby mitigating the inherent risks. The generic process incorporated into the developed integrated risk assessment framework will ultimately provide the ability for the framework to be used across different local authorities, minimising the differences typically associated with currently adopted standards and codes.

References

ANZECC 2000. Australian and New Zealand guidelines for fresh and marine water quality, volume 1, the guidelines (chapters 1-7). Canberra: Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ).

AS/NZS 1547. 2000. AS/NZS 1547:2000 Onsite domestic-wastewater management, Standards Australia/New Zealand, Strathfield

AS/NZS 4360. 1999. AS/NZS 4360:1999 Risk Management, Standards Australia and Standards New Zealand, Sydney and Wellington

Carroll, S., Hargreaves, M. and Goonetilleke, A. (2005) Sourcing faecal pollution from onsite wastewater treatment systems in surface waters using antibiotic resistance analysis. *Journal of Applied Microbiology* **99:** 471–482

Carroll, S., Goonetilleke, A., and Dawes, L. 2004. Framework for soil suitability evaluation for sewage effluent renovation. *Environmental Geology* **46(2):** 195-208.

Carroll, S.P., and Goonetilleke, A. 2004. Assessment of high density of onsite wastewater treatment systems on a shallow groundwater aquifer. *Environmetrics* **99:** 257-274

Dawes, L. and Goonetilleke, A. 2003. An Investigation into the role of site and soil characteristics in onsite sewage treatment. *Environmental Geology* **44(4):** 467-77.

Eliasson, J.M., Lenning, D.A., and Wecker, S.C. 2001. Critical point monitoring - a new framework for monitoring on-site wastewater systems. In Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems. Mancl, K. (ed). Fort Worth, Texas: ASAE, pp. 461-469.

Ganoulis, J. 1994. Engineering risk analysis of water pollution: Probabilities and fuzzy sets. VCH Publishers, New York.

Geary, P. M. 1992. Diffuse Pollution from Wastewater Disposal in Small Unsewered Communities. *Australian Journal of Soil and Water Conservation* **5(1):** 28-33.

Goonetilleke, A., Dawes, L. and Biddel, D. 2002. Performance Evaluation of Septic Tanks in the Gold Coast Region. Environmental Studies, Gold Coast City Council Research Unit, Volume 8, Gold Coast, Australia.

Harris, P. J. (1995). Water quality impacts from on-site waste disposal systems to coastal areas through groundwater discharge. *Environmental Geology* **26(4):** 262-268.

Jones, D. S., Armstrong, A. Q. and Muhlheim, M. D. 2000. Integrated Risk Assessment/Risk Management as Applied to Decentralised Wastewater Treatment: A High-Level Framework. Proceedings of the National Research Needs Conference: Risk-Based Decision Making for Onsite Wastewater Treatment, Palo Alto, CA.

Meays, C. L., Broersma, K., Nordin, R. and Mazumder, A. (2004). Source tracking fecal bacteria in water: a critical review of current methods. *Journal of Environmental Management* **73(1)**: 71-79.

Parveen, S., Portier, K.M., Robinson, K., Edmiston, L. and Tamplin, M.L. 1999. Discriminant analysis of ribotype profiles of *Escherichia Coli* for differentiating human and nonhuman sources of fecal pollution. *Applied and Environmental Microbiology* **65(7):** 3142-3147.

NH&MRC 1996. Australian drinking water guidelines. National Health and Medical Research Council, Canberra, Australia

US EPA. 1997. Response to Congress on Use of Decentralized Wastewater Treatment Systems. United States Environmental Protection Agency. EPA 832-R-97-001b.

Whitehead, J. H. and Geary, P. M. 2000. Geotechnical Aspects of Domestic Onsite Effluent Management Systems. *Australian Journal of Earth Sciences* **47**: 75-82.