

Author version of paper published as:

Carroll, Steven, Goonetilleke, Ashantha, Thomas, Evan, Hargreaves, Megan, Frost, Ray and Dawes, Les (2006)

Integrated risk framework for onsite wastewater treatment systems. *Environmental Management*, Vol. 38(2): pp. 286-303.

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## **Integrated Risk Framework for Onsite Wastewater Treatment Systems**

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## **Abstract**

Onsite wastewater treatment systems (OWTS) are becoming increasingly important for the treatment and dispersal of effluent in new urbanised developments that are not serviced by centralised wastewater collection and treatment systems. However, the current standards and guidelines adopted by many local authorities for assessing suitable site and soil conditions for OWTS are increasingly coming under scrutiny due to the public health and environmental impacts caused by poorly performing systems, in particular septic tank-soil adsorption systems. In order to achieve sustainable onsite wastewater treatment with minimal impacts on the environment and public health, more appropriate means of assessment are required. This paper highlights an integrated risk based approach for assessing the inherent hazards associated with OWTS in order to manage and mitigate the environmental and public health risks inherent with onsite wastewater treatment. In developing a sound and cohesive integrated risk framework for OWTS, several key issues must be recognised. These include the inclusion of relevant stakeholders throughout framework development, the integration of scientific knowledge, data and analysis with risk assessment and management ideals, and identification of the appropriate performance goals for successful management and mitigation of associated risks. These issues were addressed in the development of the risk framework to provide a generic approach to assessing risk from OWTS. The utilisation of the developed risk framework for achieving more appropriate assessment and management techniques for OWTS is presented in a case study for the Gold Coast region, Queensland State, Australia.

**Keywords:** Integrated risk assessment, Onsite wastewater treatment, Water pollution, Effluent irrigation, Septic tanks

## **Introduction**

The impacts associated with onsite wastewater treatment systems (OWTS) has come to the fore in recent years in order to protect public health and the environment from the consequences of poorly performing systems, in particular septic tanks (Harris 1995, Scandura and Sobsey 1997, Geary and Whitehead 2001, Lipp and others 2001). 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 country (US EPA 1997). Numerous studies have described the consequences of failing onsite systems. Borchart and others (2003) found that the incidence of human enteric viruses in private drinking water wells in the US, adjacent to onsite adsorption trenches was in the order of 8-11%. They further estimated that with incidence rates of this magnitude, approximately 1.2 million US households may be exposed to contaminated water sources resulting from inadequate treatment of effluent from onsite systems. 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 construction of the systems. Similar observations relating to inadequate site and soil investigations were also noted by Dawes and Goonetilleke (2003).

The soil plays one of the most important roles in the onsite system treatment train. It essentially forms the 'last line of defence' between subsurface treatment systems and underlying the groundwater (Dawes and Goonetilleke 2003), and depending on the type of soil, can also influence surface irrigation of effluent as well. Understanding a soil's ability to accept, treat and disperse applied effluent is crucial in the management of onsite wastewater treatment systems. Traditionally, assessment of siting and design requirements for onsite

systems is typically achieved by a simple soil permeability test and an evaluation of soil structure and texture characteristics. This information is used to provide an overall soil category describing the soil's infiltration and permeability characteristics, which is subsequently used for determining the soil's long term acceptance rate (LTAR) or design effluent loading rate (DLR – as used in AS1547: 2000). The DLR is used in the design stage of onsite systems for determining applicable land areas for effluent application. More detailed soil assessment techniques can be implemented where a substantial public health or environmental impact is expected to occur. However, most local authorities only require basic soil information (soil permeability and classification) in order to meet the minimum requirements specified in the standards and locally adopted codes and guidelines. This is essentially due to the lack of knowledge and scientific information required for undertaking more detailed evaluations. A simple soil percolation test or basic classification through assessment of soil texture, although indicating a soil's potential for accepting effluent, will not indicate whether the soil will remove effluent pollutants prior to entering the groundwater system (Carroll and others 2004). Consequently, the risk of pollution to groundwater and surface water as a result of inappropriate soil conditions for effluent renovation needs to be adequately assessed. Failing septic systems are the most frequently reported cause of groundwater contamination (Nicosia et al 2001, US EPA 1997, Hoxley and Dudding 1994, Yates 1985, Perkins 1984).

Numerous cases of public health issues and environmental contamination have been reported throughout the research literature. Yates (1985) noted that approximately 50% of waterborne disease outbreaks in the USA were a result of consumption of contaminated groundwater, with septic tanks reported as the most frequent cause of contamination. The most significant case in Australia relating to public health attributed to failing onsite systems was that of a

viral Hepatitis A outbreak at Wallis Lakes in the State of New South Wales (NSW) (Ryan 1999). 444 local residents fell ill with Hepatitis A after consuming shellfish from the lake which was contaminated with sewage effluent. Poorly maintained and failing septic tank-soil absorption systems within the lake's vicinity were found to contribute to the contamination. As a result of the consequences due to the failure of OWTS, regulatory authorities worldwide are becoming actively involved in implementing more stringent strategies for managing onsite wastewater treatment systems.

With increasing concerns relating to poor OWTS performance and the contamination of surrounding environments, 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 local authorities to assess and manage OWTS, under the guidance of the current standard for onsite wastewater treatment systems, AS/NZS 1547:2000 Onsite Domestic Wastewater Management (AS/NZS 1547. 2000). This standard is performance based and guides system design based on site and soil assessment, with the aim of achieving sustainable performance. As a national standard, AS/NZS 1547:2000 should provide adequate OWTS assessment and management procedures to achieve the requisite performance requirements and sustainable outcomes. However, 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. Unfortunately, these variations between region specific codes and guidelines have been a major drawback in meeting the specified performance requirements of AS/NZS1547:2000 and the adoption of standardised management strategies. In order for management strategies

for onsite treatment systems to be effective, a strong regulatory framework is necessary (Beavers 1999). As a result, the utilisation of risk assessment and management procedures is becoming more widely adopted. The incorporation of risk techniques will help to remove the variations in assessment codes and guidelines adopted by local authorities and provide a more standardised approach towards the assessment and management of onsite systems. Siegrist and others (2000), Cliver (2000) and Gold and Sims (2000) in their whitepapers at *The National Research Needs Conference: Risk-Based Decision Making for Onsite Wastewater Treatment* (EPRI 2000), highlighted several key areas in which further research is necessary in order to achieve adequate environmental and public health safeguards. These include more acceptable universal standards and codes to reduce environmental pollution, with a major focus towards risk-based approaches to OWTS. Over the past years, numerous risk based approaches to OWTS have been developed.

Under the Septic✓Safe program implemented in the State of New South Wales (NSW), Australia, following the Wallis Lake Hepatitis A outbreak, a risk based model, the Onsite Sewage Risk Assessment System (OSRAS) was developed (Brown and Root Services 2001, Kenway 2001). The OSRAS model was developed to utilise existing databases to determine the risk posed by onsite treatment systems on the surrounding environment and the cumulative impacts of systems on downstream environments. Another similar model, the Development Assessment Module (DAM), has been developed by the Sydney Catchment Authority, NSW State, Australia (McGuinness and Martens, 2003). DAM was developed in order to reduce the impacts on Sydney City's water supply from new housing developments in areas relying on onsite systems for sewage treatment. DAM also utilises existing databases to predict the extent and direction of an effluent plume originating from a treatment system in order to assess its potential impact on water quality (McGuinness and Martens, 2003). This

predicted plume can then be utilised in assessments to determine the level of risk associated with installing an onsite system in a particular area. Similar models have also been developed internationally, such as Trench<sup>TM</sup> 3.0 (Cromer 1999) which aids in the assessment and suitability of sites for septic absorption trenches; WARMF (Kirkland 2001), *Watershed Analysis Risk Management Framework*, which has been modified to incorporate effluent infiltration into the soil layer below the land surface to account for cumulative effects of systems as non-point source pollutant loads (Chen and others 2001); and MANAGE (Joubert and others 1996) or *Method for Assessment, Nutrient-loading, and Geographic Evaluation of Watersheds*, a model used to identify groundwater pollution sources and future risks and to evaluate the impacts of alternative onsite wastewater treatment systems. However, though these models are able to determine the level of risk if an onsite system is installed at a particular location, the accuracy of the risk model is singularly dependant on the amount and type of data available to the user. Additionally, the complexity of some of these models reduces them to ‘black box’ approaches, whereby the user inputs data and receives an answer without any guidance as to how this was derived.

Another important limitation of these models is that they are unable to assess the level of risk currently present in an area due to existing onsite treatment systems. The cumulative impact approach, which assesses the impact on the environment and public health from incremental changes in the risk resulting from additional onsite systems, is assessed from a background or zero risk level. This may be misleading if the assessed area is already at high risk due to the presence of onsite treatment systems for many years.

This paper presents an integrated risk assessment framework for onsite wastewater treatment systems, and provides a case study of the development and utilisation of the framework for the Gold Coast region, Queensland State, Australia. Issues related to poorly performing onsite

wastewater treatment systems is singularly evident in the region (Goonetilleke and others 2002). This led to the development of an integrated risk assessment approach for assessing and managing onsite wastewater treatment systems. Although developed for the assessment of OWTS at a regional or catchment scale, the generic concepts of risk, and the sequential processes developed for assessing risk related to OWTS, provides the ability to utilise this framework at any level. The framework is envisaged to be utilised by regulatory authorities for the assessment and management of onsite systems.

## **Materials and Methods**

### **Study Area**

Though the integrated risk assessment framework for onsite wastewater treatment systems was developed for the Gold Coast region, 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 for other regions, provided appropriate data is available. Gold Coast region 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) employing surface irrigation has become evident. Due to numerous environmentally sensitive areas located throughout the region, including World Heritage sites, Ramsar wetlands, numerous estuaries and watercourses, and the region being a major tourist destination, better management of onsite systems was deemed crucial. A recent study on the treatment performance of septic tank-soil adsorption systems conducted in the Gold Coast region showed that approximately 90% of audited septic systems were not meeting the appropriate standards adopted by the Local Government (Goonetilleke and others 2002). Consequently, the Local Government

considered it necessary to develop a more robust methodology for site assessment in order to mitigate the resulting adverse impacts.

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 subsequently led to an increased demand for onsite system use. With the current procedures of assessing site suitability for onsite systems proving to be inadequate, the inherent environmental and public health risk resulting from poorly functioning systems could increase significantly. Several areas in the region already have substantial failure rates due to inadequate soil and site conditions (Carroll and Goonetilleke 2004). Gold Coast has a range of soil types, as classified under the Australian Soil Classification (Isbell 2002), from Podsol soils on the sandy coastal plains in the northeast, to Ferrosol and Dermosol soils in the hilly and mountainous regions in the south-west. Most of the residential areas developed on the coastline are situated on Hydrosol (seasonally or permanently saturated) soil which has effectively limited treatment capacity for assimilating effluent from onsite systems. The soil group which makes up a major part of the Gold Coast region is Kurosol or highly acidic soils. These have been described as soils which are generally not suitable for effluent treatment and dispersal under the previous soil classification (Noble 1996, Stace and others 1968). However, based on the outcomes of recent research, Kurosol soils have been found to be suitable for effluent renovation provided their permeability and drainage characteristics are satisfactory (Carroll and others 2004). Due to the inherent issues resulting from poorly performing OWTS, and the various site and soil characteristics throughout the Gold Coast, the development of a risk assessment framework for OWTS was considered more suitable than currently adopted standards.

### **Basis for Risk Assessment Process**

The development of the risk framework was based on the Australian Standard AS4360:1999 Risk Management (AS/NZS 4630. 1999). This approach entails the following four major steps; 1) Problem formulation, 2) Hazard identification, 3) Risk Assessment and 4) Risk Management and mitigation, as shown in Figure 1. Additionally, it was also considered necessary to undertake continuous communication and consultation with the relevant stakeholders who will be affected by the implementation of the risk procedure. The inclusion of appropriate stakeholders who have an essential role in the development of the risk assessment and management process is one of the essential elements that should form part of any risk management process (AS/NZS 4630. 1999).

### **Problem Formulation and Logic Model Development**

For the process of developing the risk framework, numerous stakeholder groups including regulators, developers, plumbers, planners and community groups were identified and invited to be involved in the development of the framework. In order to facilitate problem formulation and the development of an acceptable management solution to the inherent risk associated with OWTS, several workshops were conducted to consult with the identified stakeholders. This was to ensure that they formed part of the overall development of the risk framework. From these workshops, important aspects of the framework were derived, including data identification, hazard identification and characterisation, as well as the identification of the necessary outcomes, for the framework to be effective. To formulate the overall process of progressing from the data collection phase to achieving the final outcomes, as well as to maintain adequate consultation and communication with the relevant stakeholders, a logic model as shown in Figure 2 was developed. This was based on the

procedures described by McLaughlin and Jordan (1999). Essentially, the logic model was used to identify the required outcomes from the project and the steps and processes to be followed to successfully to achieve these outcomes. As highlighted by Jones and others (2000), planning and utilising sound risk assessment and management techniques depends on the successful integration of scientific knowledge, data and analysis, with risk assessment and management ideals. The utilisation of the logic model process becomes particularly useful for identifying the short-term outcomes from the various stages of the project to the overall long-term outcome. The development of the logic model also helped to identify the necessary stakeholder groups needed at the various stages of the risk framework development.

### **Risk Framework Elements**

The task of identifying the inherent hazards related to OWTS can be complex. Table 1 gives the important hazards and their contributing factors. Hazards related to environmental and public health issues are more easily identified as their impacts on the relevant receptors are relatively more obvious. For example, contamination of surface water from excess nutrients can be identified with routine sampling and testing. However, the identification of hazards resulting from OWTS siting and design is far less clear. The primary difficulty is to separate the hazards resulting from poor treatment performance with those from the contributing factors. In order to achieve this separation, it is necessary to initially understand the various failure modes that can occur in an onsite wastewater treatment system.

The term ‘failure’ associated with OWTS has been broadly used in literature to describe major faults associated with these systems, including effluent surfacing, odour or mechanical malfunctions. However, it is important to note that the failure of an OWTS occurs when any stage of the treatment train fails, including those located within the subsurface and not visible.

This includes the treatment system, effluent dispersal area and the underlying groundwater system, as depicted in Figure 3. Failure of many onsite systems is generally not due to inherent flaws in system technology, but rather due to inappropriate siting and design issues or their operation and management (Otis and Anderson 1994). Therefore, with the current move towards the inclusion of risk based assessment of OWTS, the definition of ‘failure’ needs to be clearly defined in terms of the resultant hazards and exposure scenarios. The overall definition of failure relates to several key scenarios that result in hazards as listed in Table 2. After identifying the various hazards associated with OWTS and the environmental and public health risks, the subsequent phase in the risk paradigm is risk analysis and assessment. This stage determines the level of risk associated with the respective hazard. The hazards associated with the failure scenarios of onsite systems, as well as the inherent environmental and public health hazards are directly related to the risk of failure, where:

$$\text{Risk} = \text{probability of failure} = P(L > R) \quad (1)$$

with L = load on the system (such as pollutant loading) and R = system’s resistance to that load (amount of pollutant that the system can withstand before failure occurs) (Ganoulis 1994).

In the case of the risk of failure in relation to water quality, R is equivalent to the stressor endpoints or water quality standards threshold values to be utilised in the overall risk assessment. This was the fundamental approach used in the formulation of the risk framework.

The final stage of the risk framework process includes the management and mitigation of the assessed risks. This involves adopting suitable methods to reduce the overall effect that the identified risks from onsite systems have on the environment and public health. In developing suitable risk management protocols for onsite systems, the design and operation of OWTS has to be based on a set of performance goals that will allow successful mitigation of the explicit risk to an acceptable level (Siegrist and others 2000). In the past, the main focus of the management stage was to develop more suitable technology to reduce the level or concentration of pollutants prior to releasing the effluent to the surface or subsurface environment. Unfortunately, although technology is improving over time, the already identified problems still commonly occur. As such, the need to assess the site and soil conditions, rather than relying solely on technology is clear. The final stage in the risk management process is to regularly monitor and review the identified hazards and assessed risks to determine if the appropriate management techniques have been successful in mitigating the characterised risks. In doing so, the overall effectiveness of the risk framework process can be monitored and subsequent review and updating of the risk assessment and management protocols can be maintained.

### **Implementation of the Risk Assessment Framework**

The integrated risk based framework for OWTS, developed consisted of three major stages as shown in Figure 4. *Stage 1* was used to assess the risks related to OWTS siting and design (assessment of the contributing hazards related to site and soil characteristics, landscape positioning and planning issues), environmental and public health risks and the development of a GIS based map to provide visual identification of these risks. *Stage 2* of the risk framework indicates the level of assessment needed in order to allow the use of OWTS. This stage required areas that are indicated as being ‘at risk’ to subsequently undergo further

detailed assessment to establish the most suitable treatment system which will not lead to adverse impacts. *Stage 3* involves employing suitable management and mitigation measures to ensure that the characterised risks are suitably managed.

The risk assessment framework developed is based around a semi-qualitative risk process. This involved the use of both quantitative and semi-qualitative assessments, depending on the type of data available. Quantitative risk assessment utilises statistical analysis of collected scientific data to provide the probability of the hazard occurring. Outcomes from the statistical analysis provide a means of ranking the respective levels of risk assessed. Semi-quantitative assessments use the same principles as quantitative risk assessments. However, no explicit statistical analysis is used to provide the probability of occurrence. Collected data was used to rank the hazards on a numerical scale to provide a likelihood of the hazards occurring and to provide an appropriate rank which was used for assessment purposes. Both, quantitative and semi-qualitative risk assessments were undertaken for developing stage 1 of the risk framework in order to establish the required GIS based risk map. This included quantitative assessments for environmental and public health risks, and the soil assessment stage of the OWTS siting and design risk. The remaining steps in the risk assessment were developed based on semi-qualitative assessments. This involved identifying appropriate risk index scales to apply to the appropriate data in order to establish the level of risk involved.

### ***Stage 1: Integrated Risk Assessment***

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 existing impact, including their cumulative risk was established. Secondly, by utilising the identified hazards that led to these risks, an assessment of the potential risks

that will arise in developments utilising new systems or upgrades to existing systems was undertaken. These two levels of risk were developed into a GIS database allowing the visual identification of low, medium and high risk areas.

Assessment of OWTS siting and design risk is based around the major contributing hazards that will cause potential risks to occur. The hazards assessed through this stage were identified through the stakeholder workshops. The major factors identified as contributing to the OWTS siting and design risks included the soils' renovation ability, planning and lot size of the development, slope, suitable separation or setback distances from adjacent water resources (groundwater wells and surface water) and development within the identified floodplain. The risk 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 technology for the type of system used. The type of data used to assess OWTS siting and design risk contained both quantitative data (for soil renovation suitability assessment (Carroll and others 2004) and semi-quantitative data (for lot size, slope, set back distances and development in the floodplain). Subsequently, due to the different types of data formats available for risk assessment, a semi-quantitative approach was adopted to allow a more suitable means of integrating the various data formats.

The assessment of both environmental and public health risk was established based on assessing the risk of contamination exceeding adopted threshold levels. This was developed around an engineering risk analysis approached as outlined by Ganoulis (1994). The risk established through this process is equivalent to:

$$Risk = \text{probability of failure} = P_f = P(L > R) = \int_0^{\infty} \left\{ \int_0^L f_{LR}(L, R) dR \right\} dL \quad (2)$$

where L = pollutant loading or concentration and R = resistance or prescribed water quality standard or threshold.

Essentially, specified water quality parameters for environmental (nitrate and phosphate) and public health (fecal coliforms and *E. coli*) risk assessment were obtained from monitored groundwater and surface water sites. The probabilities of these parameters exceeding the specified water quality thresholds were then determined. For establishing the environmental risk, assessment of nitrogen and phosphorus were the main pollutants considered, as these are the primary water quality indicators utilised for assessing nutrient input into water courses. The adopted thresholds used for assessing the risks are those set out in the ANZECC (2000) guidelines. Therefore, the determination of environmental risk is equivalent to the probability of the pollutant concentration exceeding the water quality standards. Table 3 provides the guidelines and subsequent thresholds adopted to establish the environmental risk.

In relation to public health risk assessment, levels of fecal coliforms, in particular *E. coli*, were assessed against both the ANZECC (2000) and NHMRC (1996) drinking water and the recreational water quality guidelines, as listed in Table 3. Although there is debate whether fecal coliforms accurately represent the human pathogenic organisms within the water sample (Parveen and others 1999, Lipp and others 2001, Meays and others 2004), it was decided to utilise *E. coli* for two reasons. Firstly, it is the most widely used predictor of fecal pollution and pathogenic organisms. Secondly, to utilise actual pathogenic organisms is both costly and time consuming. However, in order to determine whether the source of *E. coli* was actually from onsite systems, the antibiotic resistance patterning technique, as described by Whitlock and others (2002), was used for bacterial source tracking. This allowed the estimation of the percentages of human origin *E. coli* present, and a more accurate level of public health risk

from onsite systems to be developed. This added an extra level of accuracy to the determination of public health risk by determining the percentage of fecal coliforms of human origin present, and consequently from onsite systems as compared to other (animal) sources. The resulting risks were input into the GIS database to provide another thematic layer for developing the risk map.

### ***Stage 2: Detailed Assessment***

Where the area of assessment falls within a low risk area, then the current standards and codes already available for assessing suitable locations and for designing OWTS can be utilised. 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. This requires flexibility in the risk framework to permit further assessment in addition to what the existing prescriptive standards and codes allow. 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 and analysis in order to collect the requisite information to suitably assess the risks.

### ***Stage 3: Risk Management and Mitigation***

*Stage 3* revolves around the development of a suitable management program to be implemented in order to mitigate the risks developed. 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. Consequently, more appropriate management techniques can be implemented to provide improved mitigation in these high priority areas. 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 suitable data collection techniques for reviewing the assessed risks and further refining the defined risk areas.

### **Data Requirements**

In developing a risk assessment and management framework, the necessary data requirements for undertaking the risk assessment needed to be addressed. The developed logic model (see Figure 2), allowed the data requirements for each of the individual stages of the risk assessment framework to be identified. This was then followed up with the collection of appropriate data for each of the individual risks through field investigations as well as identifying appropriate existing data. To obtain appropriate scientific data for risk assessment, several areas within the Gold Coast region were selected to allow adequate representation of both the 'at risk' and 'low risk' regions. Figure 5 and Table 4 provides the locations of selected sites and characteristics used for their selection, respectively.

Assessment of appropriate soil conditions for effluent renovation was based on the framework developed by Carroll and others (2004). This required the collection of multiple soils samples located through the Gold Coast region. This framework takes into account the soil's physico-chemical characteristics, permeability and drainage to establish its overall ability to treat and disperse discharged effluent. Soil characteristics including pH, electrical conductivity (EC), chloride (Cl<sup>-</sup>), organic matter content (OM%), cation exchange capacity (CEC), permeability (k) and nutrients (nitrogen and phosphorus) were assessed for the soil samples collected. This was followed by multivariate statistical techniques to assess the soil's ability to remove

effluent pollutants. The overall soil renovation suitability is measured based on a semi-quantitative approach, similar to risk indexing

The environmental and public health risks were established based on data collected from several ground and surface water monitoring sites. Some of these sites were previously identified by stakeholders as high risk areas. Monitored groundwater and surface water sites were located in areas with high densities of OWTS, poor soil renovation ability, proximity to nearby water courses and shallow groundwater conditions. Monitoring sites were also located in control areas that were not as highly impacted by onsite systems, or were in areas that indicated suitable conditions for onsite wastewater treatment.

## **Results and Discussions**

### **Integrated Risk Assessment Framework**

The resulting integrated risk assessment framework for OWTS is shown in Figure 6. This framework, although following the same generic processes as previously discussed, highlights in more detail the steps in which the various stages have been extended to meet the specific needs of the Gold Coast City Council (GCCC). Firstly, the stages for OWTS siting and design have been extended to incorporate the necessary assessment factors. Secondly, the detailed assessment of the ‘at risk’ regions has been described to highlight how GCCC aims to assess and manage these regions when assessing onsite systems. 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.

### ***OWTS siting & design, Environmental and Public Health Risk Assessments and GIS risk map development***

The determination of risks from identified environmental and public health hazards was based on specific water quality parameters exceeding threshold values as given in Table 3. The environmental risk assessment was based on nitrogen and phosphorus contamination of ground and surface water resources and was assessed for the risk of exceeding the threshold values. To provide adequate sample representation of the monitoring sites, sampling continued over a period of four months to allow suitable seasonal and climatic variations to be investigated. Once determined, the subsequent risk levels were developed into a GIS database layer for integration into the risk map.

Public health risk was assessed by determining the risk of exceeding the required water quality guidelines for fecal coliforms and *E. coli* as indicated in Table 3. Antibiotic Resistance Patterns (ARP) were utilised for bacterial source tracking to provide a more accurate picture of human fecal contamination from onsite systems. In assessing the risk of failing the required threshold values, the percentage of human fecal coliforms and *E. coli* only were assessed against the respective guidelines.

For OWTS siting and design risk, an assessment of the cumulative risk was developed based on several key hazards related to site and soil characteristics (see Figure 6) including soil suitability, lot size, set back distances, slope and location within flood prone areas. The process for determining the soil risk for OWTS involved determining respective risk indices for the different soil types located throughout the Gold Coast region based on the framework developed by Carroll and others (2004). The resulting indices developed for each soil type through this framework were calculated based on the respective soil physico-chemical attributes and input into a GIS database. This was subsequently used to develop a soil risk layer.

The remaining data necessary for determining OWTS siting and design risk were established from existing GIS database information, with semi-quantitative risk indices applied to establish the corresponding risks. These risks included: (1) planning or appropriate lot size suitable for OWTS; (2) setback distances from water resources; (3) slope; and (4) areas below flood inundation boundaries. The lot sizes in potential developments which will use OWTS are under the jurisdiction of the local authority via the planning scheme. This information can be used to identify areas which have small lot sizes and consequently higher densities of OWTS. The risk framework utilises this information by developing another GIS database layer indicating high, medium and low risk areas based on the lot sizes. Lot sizes greater than four hectares were considered to have a low risk, with areas smaller than this as areas being 'at risk' (4000m<sup>2</sup> to 4.0Ha medium risk, <4000m<sup>2</sup> high risk). Lot sizes less than 4000m<sup>2</sup> were considered to have the highest risk, due to the high density of OWTS.

Ensuring appropriate separation or setback distances between the onsite system and nearby water resources such as groundwater wells and surface water, is a crucial issue. Setback distances are included in current standards and guidelines to ensure adequate distance between water resources and the onsite system. This implicitly includes risk-based management ideals into the current performance standards. The current setback distances stipulated in AS1547:2000 recommends that 50m between the onsite system and adjacent water resources be used. This value was adopted for assessing the risk of pollution of nearby water resources. Once assessed, the analysed setback distances were applied to a GIS map layer as part of the onsite risk map.

Slope was included in the framework essentially for surface disposal systems, although it can also have an impact on subsurface disposal systems. The slope of the land plays a major role in relation to runoff, with steeper slopes more likely to increase the runoff potential. Consequently, the risk of pollutants from surface disposal systems will increase with higher slope. In addition to higher pollution risks, issues relating to construction as well as slope stability were also considered. Typically, slopes in the range of 6-10% were viewed as suitable for surface irrigation systems, with steeper slopes contributing to higher runoff volumes and hence higher risks of pollution (Wells 2001, Kleene and others 1993, AS1547:2000). For subsurface dispersal systems, slope is a concern if the dispersal field is not adequately level. This will cause ponding and surfacing of effluent from the absorption bed, causing both an immediate public health risk as well as environmental risk due to pollution caused by runoff from the site. Additionally, in areas that are prone to slope instability, subsurface systems can lead to extra water flowing through the substratum which may cause slope instability. Slope is generally included in most landscape assessments for subsurface systems, with slopes of 10-20% accepted as the norm (Brouwer 1983, US EPA 2002, AS1547:2000). The threshold value adopted to assess the risk of pollution was taken as 10%. Slopes less than 10% were deemed as low risk, with steeper slopes classified as high risk.

Onsite system siting within a floodplain is considered inappropriate. The main concern is flooding of the dispersal area, preventing effluent renovation and allowing untreated effluent to flow into a waterway. GCCC uses the 100 year average recurrence interval (ARI) flood boundary as the reference level for building approvals. In the case of a 100 year ARI flood event, dilution of the effluent and high flows would remove untreated effluent away with the flood water. Additionally, people are more likely to be evacuated during this period of high

flood. Hence, for the framework, the 100 year ARI level was adopted, with systems below the flood boundary considered at high risk.

### **GIS Database and Risk Map Development**

The main purpose of the risk map developed as part of this framework was to indicate areas which are at risk as a result of the use of OWTS. This process has a two-fold purpose. Firstly, with the identification of ‘at risk’ areas, the local authority can actively develop appropriate management guidelines to manage and mitigate the characterised risk. Secondly, it identifies areas that either should not have the density of onsite systems increased or where more appropriate assessment techniques need to be implemented to ascertain the most suitable onsite system to use. The risk mapping process essentially utilises all of the developed risk layers obtained through the risk framework for each of the environmental, public health and OWTS siting and design risks. These were combined to develop the integrated risk map for the Gold Coast region as depicted in Figure 7. The integrated risk map indicates the respective ‘at risk’ regions which will require further site investigation and assessment to be undertaken.

### **Assessing the use of OWTS in high risk areas**

Although the current standards and codes are satisfactory for low risk areas, ‘at risk’ regions will need more thorough investigations to ensure that the use of OWTS in these areas will not significantly increase environmental and public health risks. The developed assessment procedure requires more rigorous site and soil investigation to ensure that the most appropriate system is utilised. In the case of soil requirements, this may include additional chemical testing to be undertaken to assess the overall soils renovation ability, similar to those undertaken by Carroll and others (2004) and Khalil and others (2004). Similarly, more thorough investigations relating to siting conditions, such as slope, setback distances and

flood conditions will also need to be considered. For example, in the case of flooding, is it possible to provide a higher building level above the predicted flood boundary by using fill, and if so, can an OWTS be used under these conditions? These queries will need to be investigated and an appropriate level of risk assessment undertaken prior to selecting the most suitable system type.

## **Conclusions**

The rapid increase in urbanisation along the coastal fringes of southeast Queensland, Australia has increased the need for onsite wastewater treatment systems due to the absence of centralised wastewater treatment in newly developed regions. Consequently, with the increasing number of OWTS, the inherent environmental and public health hazards associated with these systems are becoming a major concern. This is mostly in relation to inappropriate soil and siting characteristics, leading to increased failure scenarios and subsequent contamination of water resources. In order to obtain sustainable wastewater treatment through OWTS, more scientifically robust methods of assessing sites is needed. The incorporation of risk assessment techniques will minimise the variations in assessment codes and guidelines utilised by local authorities and provide a more standardised approach towards the assessment and management of onsite systems.

The risk based framework discussed in this paper highlights a means of assessing and managing the different levels of risk related to OWTS, based on the integration of siting and design, environmental and public health risk assessment processes. Furthermore it facilitates the identification of regions unsuitable for common OWTS systems. These unsuitable or ‘at risk’ areas can then be investigated on a more rigorous basis to determine the most favourable type of OWTS suited to the specific site under investigation.

Throughout the development of the integrated risk framework, several important processes needed to be established. Firstly, it was necessary to identify the stakeholders who had a prominent role through the development and utilisation of the risk framework. This provided a means of identifying the critical parameters that were required to be assessed and removed any uncertainty in how the framework and risk assessments were to be utilised for the assessment of OWTS. Secondly, with the diverse nature of the inherent risks, it was important to assess the cumulative effect of the various risk facets, and not focus solely on an individual hazard. The risk based approach, as highlighted by the case study, showed that by developing the risk framework around the assessment processes and relevant stakeholders, a more suitable framework can be developed allowing it to successfully implemented into the current standards and guidelines.

### **Acknowledgements**

The authors would like to thank Gold Coast City Council and Queensland University of Technology for funding this research project.

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## **Figure Captions**

**Figure 1:** Risk Management Process (adapted from AS4360:1999 Risk Management)

**Figure 2:** Logic Model developed to highlight process of utilising identified resources, activities and outputs to achieve the necessary outcomes for the risk framework development.

**Figure 3:** Onsite Wastewater Treatment processors and pathways

**Figure 4:** Integrated Risk Assessment Framework for OWTS

**Figure 5:** Study site locations used in developing the risk framework.

**Figure 6:** Integrated Risk Framework developed for Gold Coast City Council

**Figure 7:** Map developed through Integrated Risk framework indicating ‘at risk’ areas for OWTS for Gold Coast.

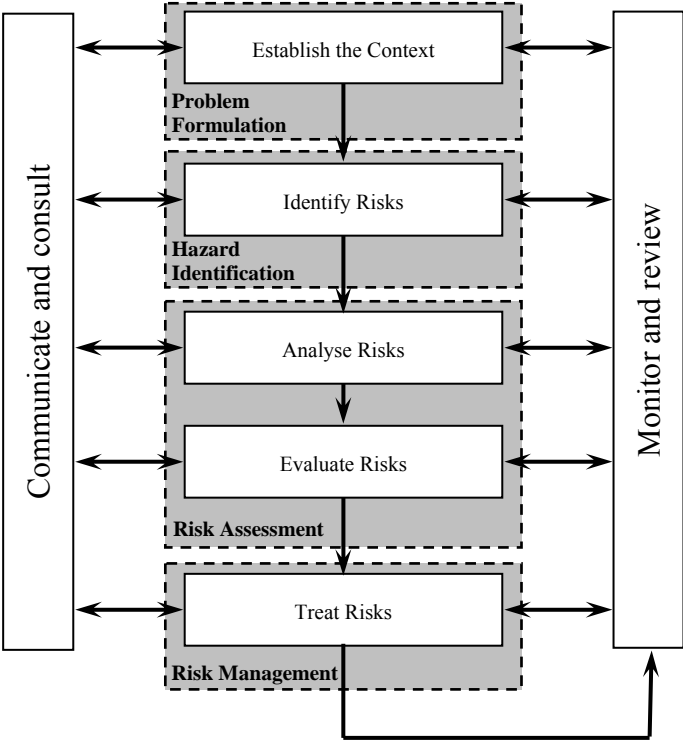


Figure 1

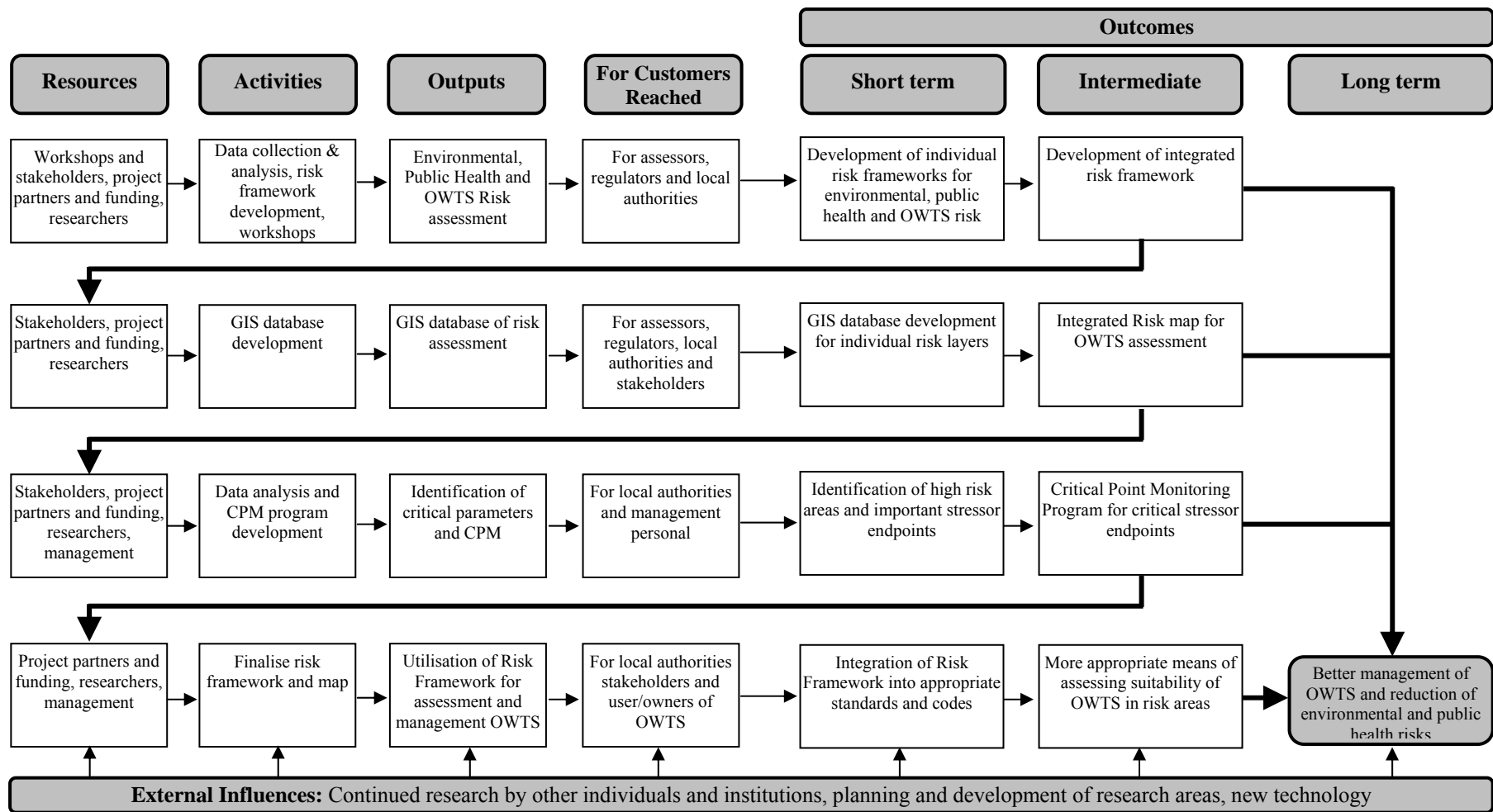


Figure 2

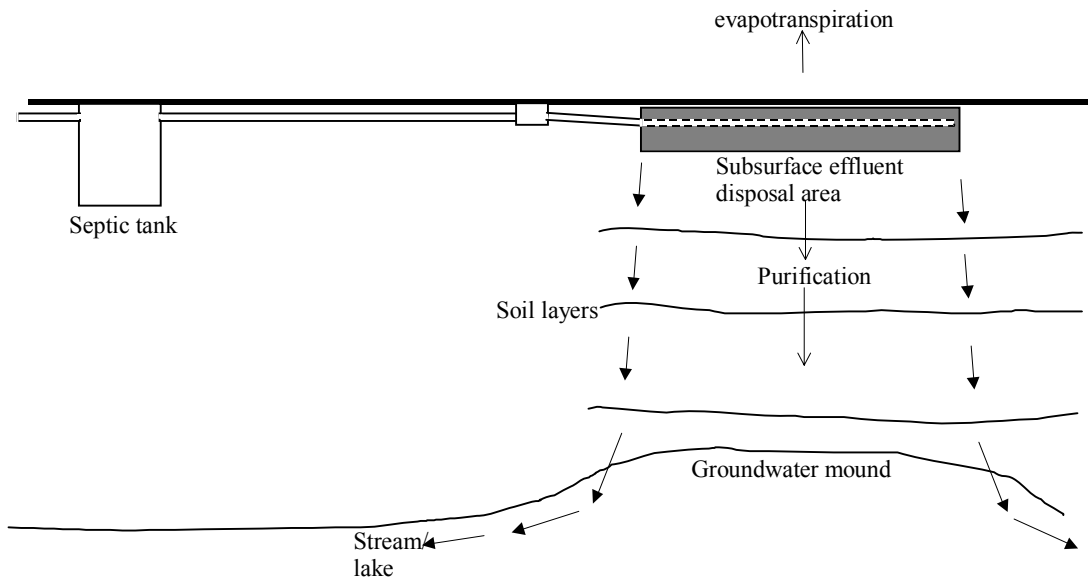


Figure 3

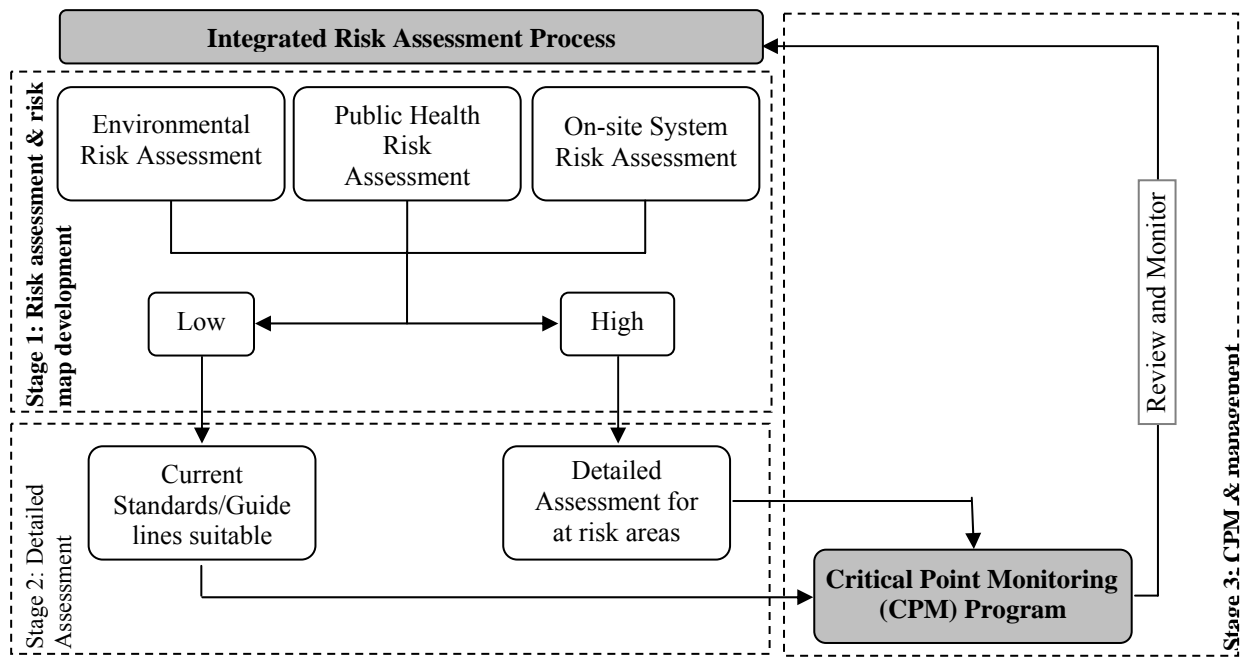


Figure 4

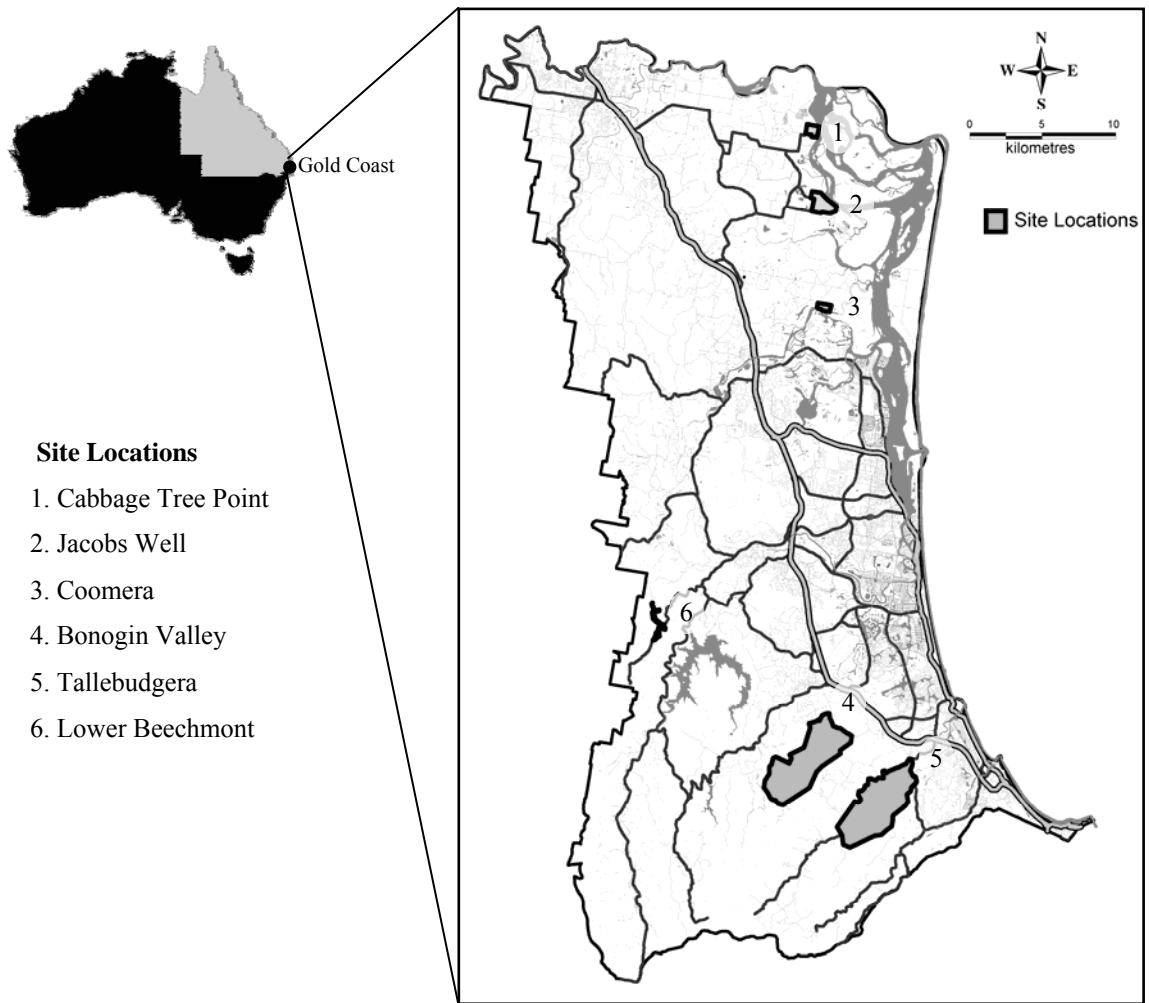


Figure 5

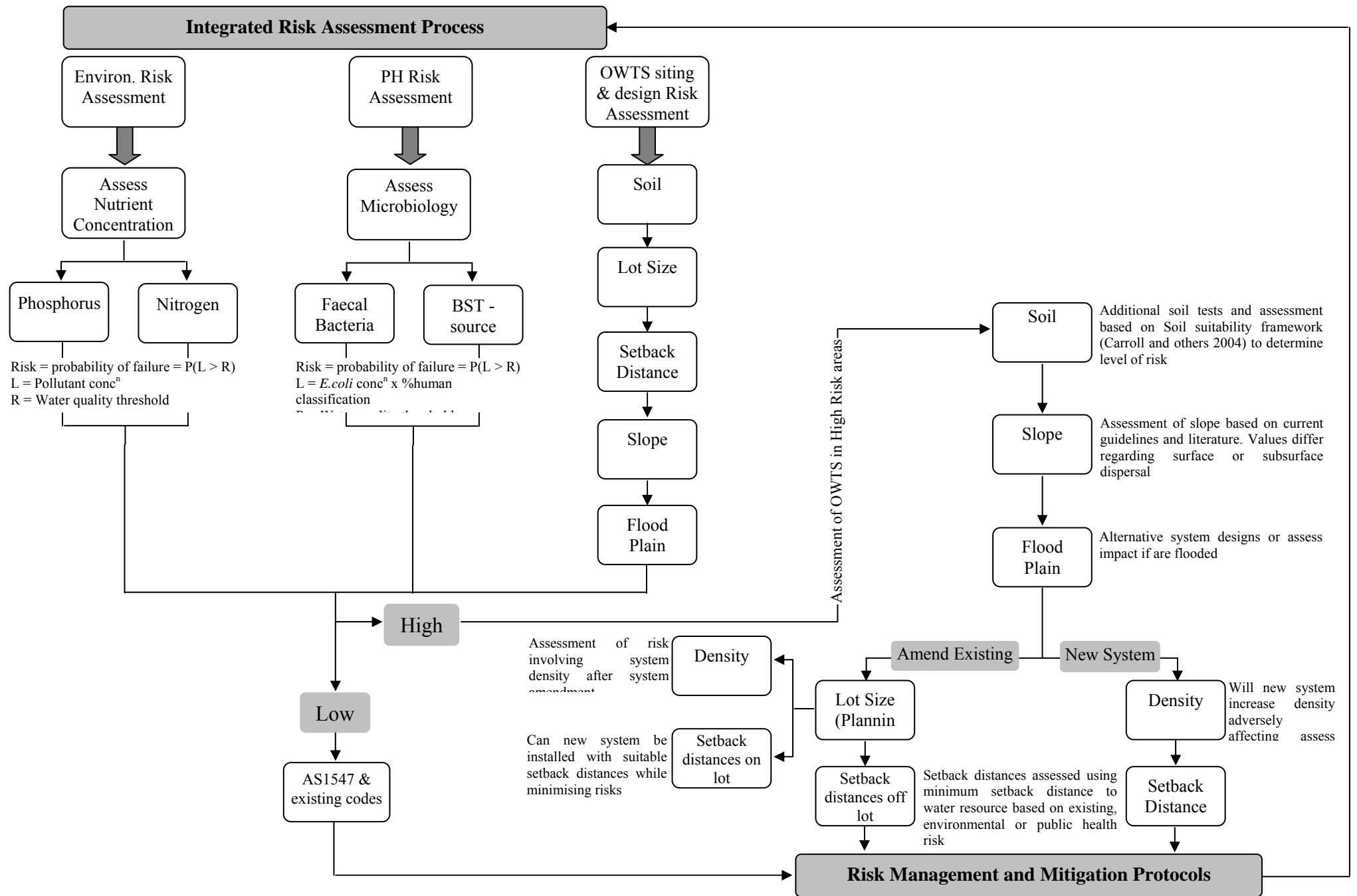


Figure 6

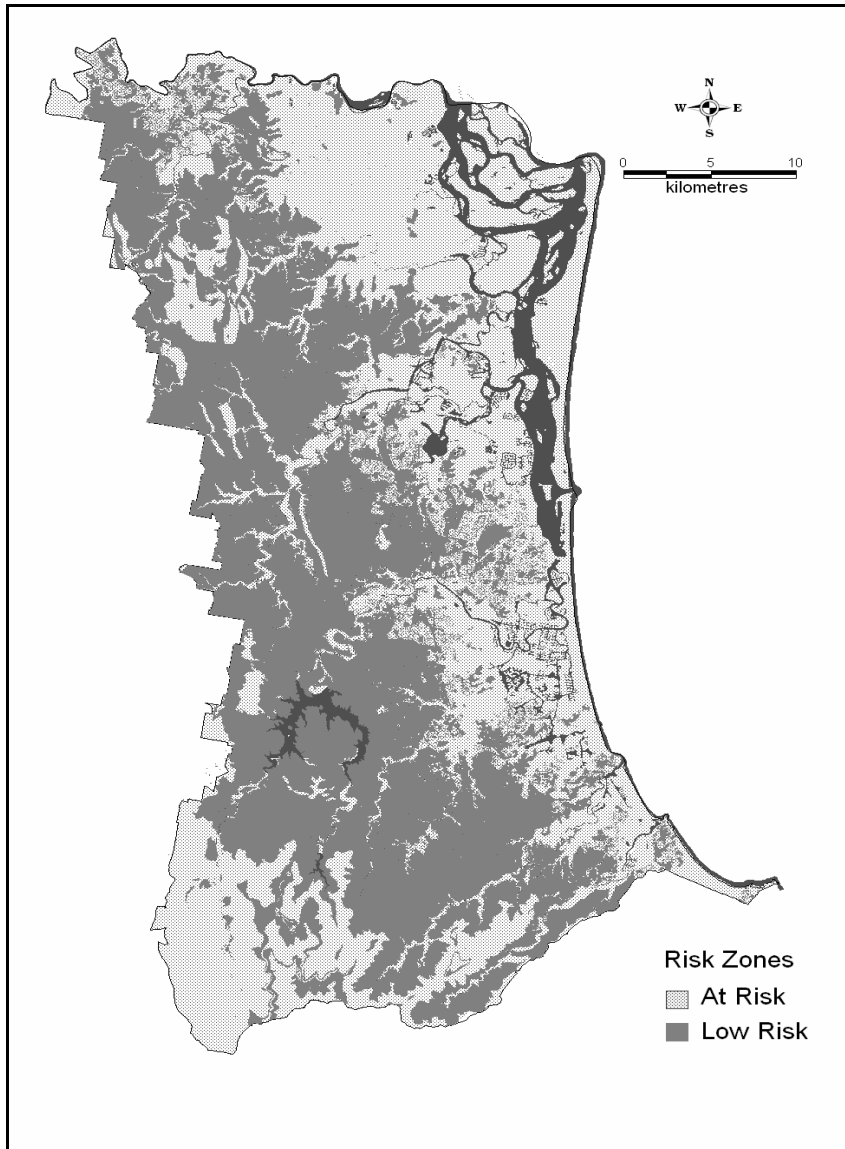


Figure 7

Table 1: Hazards and contributing factors related to OWTS

Item	Key Hazard	Contributing Factors
<b>OWTS (Treatment system and disposal area)</b>	Release of contaminants due to <i>'failure'</i> of Onsite wastewater treatment system	<ol style="list-style-type: none"> <li>1. Soil</li> <li>2. Planning (Lot size)</li> <li>3. Environmental Sensitivity</li> <li>4. Flooding</li> <li>5. Topography</li> <li>6. Loading rates</li> <li>7. Operation and maintenance practices</li> </ol>
<b>Surrounding Soil</b>	Inability to renovate effluent and prevent contaminants from reaching groundwater and/or surface water	<ol style="list-style-type: none"> <li>1. Soil Type</li> <li>2. Depth of soil horizons</li> <li>3. Physical characteristics</li> <li>4. Chemical characteristics</li> <li>5. Water table depth</li> </ol>
<b>Public Health</b>	Contamination of water/surrounding environment such that a considerable health risk is evident due to the release of contaminant (namely pathogens) which have an impact on human health	<ol style="list-style-type: none"> <li>1. Surface exposure</li> <li>2. Water supply (ground/surface)</li> <li>3. Aerosols</li> <li>4. Pests (mosquitoes etc)</li> </ol>
<b>Environmental</b>	Release of contaminants into the receiving environment (ground/surface waters) causing environmental degradation (such as eutrophication) causing the environment to be unsuitable.	<ol style="list-style-type: none"> <li>1. Surface runoff</li> <li>2. Groundwater discharge</li> <li>3. Flooding</li> <li>4. Water table</li> </ol>

Table 2: Failure Scenarios related to OWTS

Failure Scenario	Resulting Consequences
Hydraulic Failure of OWTS	Sewage ponding on ground surface near subsurface system or leakage on slopes; sewage pipe blockage and backup into pipes and fixtures;
Groundwater and surface water contamination with chemical pollutants	Elevated nitrate levels in drinking water sources; taste or odour problems in drinking water caused by untreated, poorly treated, or partially treated wastewater; presence of toxic substances (e.g., solvents, cleaners) in water source  Algal blooms, high aquatic plant productivity, low dissolved oxygen concentrations in nearby freshwater and marine water bodies
Microbial contamination of ground and surface water	Shellfish bed bacterial contamination; recreational areas contaminated due to high bacterial levels; contamination of down-gradient drinking water wells with fecal bacteria or viruses

Table 3: Risk resistance or concentrations threshold values used for risk assessment

Issue	Parameter	Response	Guideline values (thresholds)	Reference
Environmental	NO <sub>3</sub> <sup>-</sup> -N	General Water Quality	10mg/L	ANZECC (2000)
		Eutrophication*	≤ 40µg/L – Freshwater Rivers ≤ 15µg/L – Estuaries	ANZECC (2000)
	PO <sub>4</sub> <sup>3-</sup> -P	General Water Quality	No Guidelines	
		Eutrophication <sup>a</sup>	≤ 50µg/L – Freshwater Rivers ≤ 30µg/L – Estuaries	ANZECC (2000)
Public Health	<i>E. coli</i>	Drinking water	0 cfu/100mL	NHMRC (1996) ANZECC (2000)
		Primary Contact (recreation, swimming)	≤ 150 cfu/100mL	ANZECC (2000)
		Secondary Contact irrigation, boating	≤ 1000 cfu/100mL	ANZECC (2000)
	NO <sub>3</sub> <sup>-</sup> -N	Drinking (ingestion)	10mg/L	NHMRC (1996) ANZECC (2000)

<sup>a</sup> Indicated values are general guidelines only

Table 4: Site Locations and characteristics used for their selection

Site Location	Risk Classification <sup>a</sup>	Major Soil Classification <sup>b</sup>	Soil Renovation Suitability	Landscape	Depth to Groundwater <sup>c</sup>	OWTS Density <sup>d</sup> sys/km <sup>2</sup>	System Usage % <sup>e</sup>	
							Septic	Aerobic
1. Cabbage Tree Point	High	Intertidal Hydrosol, Mixture of Brown Dermosol and Arenic Rudosol soil groups	Low renovation ability with rapid permeability in permanently saturated conditions	Flat coastal plains	0.5m	1150	68%	32%
2. Jacobs Well	High	Supertidal Hydrosol, Pockets of Arenic Rudosols	Low renovation ability with rapid permeability in permanently saturated conditions	Flat coastal plains	0.5m	740	75%	25%
3. Coomera	Medium to High	Mixture of Intertidal Hydrosol, Arenic Rudosol, Grey Dermosol, Red and Brown Kurosols	Low - medium renovation ability with moderate to high permeability and poor to moderately well drained soil	Hilly terrain, leading into flat coastal plains	0.75 - 10m	1520	76%	24%
4. Bonogin Valley	Medium	Red, Yellow and Brown Kurosols, with patches of Brown Dermosol	Medium renovation ability with moderate permeability and well drained soils.	Undulating hilly terrain, leading into mountainous areas	0.4 - 4.5m	90-260	38%	62%
5. Tallebudgera	Medium	Red, Yellow and Brown Kurosols, with patches of Brown Dermosol, Yellow Kandosol and Red Ferrosol soils	Good renovation ability with moderate permeability and well drained soils.	Undulating hilly terrain, leading into mountainous areas	Groundwater not monitored	85-150	72%	28%
6. Lower Beechmont	Low	Red and Brown Ferrosols surrounded by Red and Yellow Kurosols	Good renovation ability with moderate permeability and well drained soil	Mountainous area	9.25m	557	74%	26%

<sup>a</sup> Risk classification derived through developed Integrated Risk Framework

<sup>b</sup> Soil Classification bas on Australian Soil Classification (Isbell 2002)

<sup>c</sup> Depth to groundwater is average depth to groundwater at monitored site locations

<sup>d</sup> Onsite system density derived through number of existing systems over a unit area (km<sup>2</sup>)

<sup>e</sup> System usage separated based on primary treatment systems (septics) and secondary treatment (aerobic) systems