

# THE USE OF TRACERS IN ASSESSING ON-SITE SYSTEM FAILURE IN PORT STEPHENS

Phillip M Geary

*School of Environmental and Life Sciences, The University of Newcastle NSW*

## Abstract

The Port Stephens Council area contains 4200 on-site sewage management systems. Many of these are close to sensitive estuarine areas and along drainage channels that feed into Port Stephens, a major oyster-producing estuary worth \$2.4 million annually and a breeding ground for marine life. Recent surveys of drainage channels have detected high numbers of faecal coliforms, particularly following heavy rainfall. The contamination is attributed to urban runoff, animal wastes and failing on-site systems.

As part of the NSW *SepticSafe* Program, funding was obtained to examine the contribution that failing on-site systems are making to stream and estuarine water quality. Part of the project involved an examination of the use of chemical and biological tracers to establish whether individual septic systems are linked to water contamination. Tracers such as fluorescein, lithium and bromide were evaluated and used on individual properties in the Salt Ash area at Port Stephens. The properties near Tilligerry Creek were instrumented with suction lysimeters and piezometers and monitoring was undertaken during dry and wet weather periods in 2001 and 2002. The results of some of the dye and chemical tracing work in 2001 are presented in this paper. A project report on this study is available on the Department of Local Government *SepticSafe* Website (Geary, 2003).

## Keywords

Bromide, fluorescein, groundwater contamination, lithium, septic systems, tracers

## 1 Introduction

The movement of subsurface aqueous contaminants from individual on-site wastewater systems is highly dependent on a number of site factors including soil type, soil hydraulic capacity, geology, topography and rainfall. With an inadequate unsaturated separation distance between a disposal field and the water table, contaminants present in domestic wastewaters may be only partially treated and enter the groundwater. Surface contamination of water systems may also occur if effluent moves off-site in situations where the hydraulic load exceeds the capacity of the soil to assimilate effluent. Domestic wastewater may on these occasions contribute to significant human health or environmental risks if not treated effectively before being released to the receiving environment.

Regular inspections and maintenance are necessary in managing on-site wastewater treatment systems to ensure that individual and cumulative environmental impacts are not realised. An on-site facility (including the land application area) has failed if it releases an unacceptable level of contaminants via groundwater or surface water pathways to the natural environment (Brown & Root Services, 2001). Apart from examining the status and integrity of the installed on-site system components for leaks, determining the fate of surface and particularly subsurface contaminants is very difficult. In this paper a number of chemical indicators of septic effluent are described, along with those dyes and chemicals that may be added to septic system effluent as tracers. The results of studies at two individual properties are described.

## 2 Dye and Chemical Methods

### 2.1 Chemical Indicators in Septic Effluent

Chemical indicators are natural by-products of human metabolism and or activity. Both caffeine and human pharmaceuticals have been used to indicate that particular sources of contamination in surface and groundwaters were human (Chen *et al*, 2002; Seiler *et al*, 1999), while detergent chemicals have also been extensively studied. Seiler *et al* (1999) reported that the usefulness of these indicators is limited because caffeine is non-conservative and the presence of prescription pharmaceuticals is unpredictable.

There has however been a substantial amount of work done which has examined the fate of detergent chemicals in septic systems. Studies on individual systems have specifically examined the fate of washing products and detergents containing individual chemicals such as tripolyphosphate (Close *et al*, 1989), linear alkylbenzene sulphonate (Shimp *et al*, 1994) or the individual salts of sodium or chloride which are present in detergent compounds in domestic wastewaters (Alhajjar *et al*, 1990). There are a variety of chemicals which are normally part of daily household use and which may be used as leak indicators and which may be used to delineate septic system plumes in land application areas.

Perhaps the most work on the fate of effluent from septic systems has been undertaken using the fluorescing property of optical brighteners, which are added to household washing products. Close *et al* (1989) have successfully used these whitening agents as indicators to identify septic tank contamination in New Zealand, while groups in Massachusetts and Washington in the USA have also used this effluent property in sanitary surveys to identify failing on-site systems. The Massachusetts group has developed an Optical Brightener Handbook which explains the test methodology which uses cotton pads to absorb the optical brighteners in effluent. Alhajjar *et al* (1990) however have concluded that other indicators are better than optical brighteners. This is because natural substances such as humic and fulvic acids are also sources of fluorescence in groundwaters and that optical brighteners do not necessarily pass through septic drainfields.

Another potentially useful indicator of faecal pollution is the presence of coprostanol, a faecal sterol present in faeces of humans and higher mammals. Attributes that make coprostanol a good chemical indicator of human pollution are that it is the primary sterol in domestic wastes and that it is unaffected by physical factors such as temperature and salinity (Sargeant, 1999).

### 2.2 Added Dye and Chemical Tracers

Dyes and chemical compounds may be added as tracers to septic systems to determine if there are leaks present in the system or to monitor the fate of the treated effluent off-site. Tracers have also been used to model nitrate, bacteria, and virus movement away from soil absorption systems. In general terms, ideal tracers should be non-toxic, inexpensive, easy to detect, chemically stable, not present in large amounts already and not be filtered or sorbed by the solid medium through which they move (Davis *et al*, 1980).

Radioactive isotopes such as tritium have also been added in various projects to track the movement of septic effluent (Brandes, 1975) and enriched nitrogen isotopes added as indicators to differentiate between sewage derived nitrate sources and nitrate originating from agricultural sources in groundwaters (Aravena and Robertson, 1998; Chen and Harkin, 1998). Stable isotopes of carbon, oxygen and sulphur have been used successfully (with nitrogen) to track septic system plumes and study chemical transformations along the flow path.

Fluorescing dyes such as fluorescein, rhodamine or eosin are more commonly added to detect surface system leaks, however, their usefulness for subsurface work is limited because most are rather easily sorbed on solid materials and there are confounding effects from humic and fulvic acids in the soil. These tracers are best adapted to tests having travel distances of several metres only. One other aspect that needs consideration is the determination of the presence or absence of the fluorescing dye in a water sample. For low concentrations a visual assessment is often not adequate and there may be a need for an expensive field fluorometer or access to a laboratory with a fluorescing spectrophotometer.

An application of the use of fluorescein dye to determine whether septic systems were failing in sensitive shellfish growing areas in Puget Sound, Washington is described by Hofstad and Davis (1995). This sanitary survey method relied on the placement of activated carbon packets at various locations adjacent to a system where surface failures were suspected. The packets were collected after a period of time and the sorbed fluorescein (if present) eluted from the packets and the solution either visually assessed (using the naked eye or under an ultraviolet lamp) or spectrophotometrically determined. Proof of failure was confirmed where dye was present from the packets and faecal coliforms were also detected in water samples. The monitoring of over 1600 sites in a similar manner revealed that approximately 12% of waterfront homes (in Thurston County) had failing septic systems and that these were potentially impacting upon waters in Puget Sound used for shellfish growing. Geary (2003) describes the methodology associated with the use of activated carbon packets.

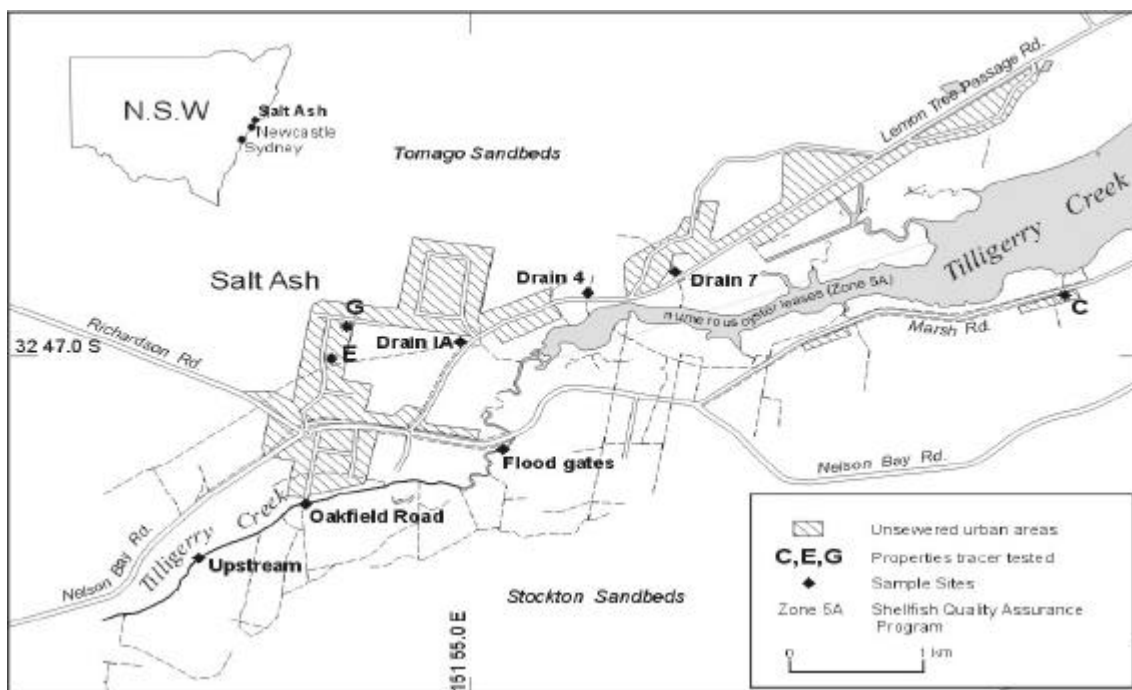
There are a number of inorganic salts that have been used successfully in various groundwater-tracing studies with lithium, chloride and bromide being the most popular. In septic system work, lithium chloride is commonly used while bromide, which is also only usually present in background concentrations, not generally sorbed and stable towards microbiological activities, is usually added as sodium bromide or potassium bromide. Bromide is one of the best tracers because it moves as fast as water in soil and is of low toxicity. Both McNellie *et al* (1994) and Gerritse *et al* (1995) provide excellent examples of the application of bromide to an on-site system to monitor the travel time and movement of effluent towards receiving watercourses.

Ion ratios have proved useful in distinguishing between groundwaters and those impacted by septic contaminants, as has the extreme consistency of non-reactive solute ions such as sodium and chloride in septic system groundwater plumes (Robertson & Cherry, 1992). Robertson *et al* (1989) for example, report that sodium was the best indicator of an impact from a septic system because it occurs in the plume at 10-20 times the background levels.

### **3 Study Area and Methods**

#### **3.1 Study Area**

The study area is located in and adjacent to the estuarine inter-barrier depression known as the Tilligerry Valley which separates the Tomago and Stockton sand ridges (Woolley *et al*, 1995), approximately 30 kilometres north of Newcastle, NSW. Tilligerry Creek, which drains towards Port Stephens, is the most prominent drainage feature of the area and is flanked by mangrove flats. It is a narrow, poorly flushed estuary where part of the Port's oyster industry is located. In the unsewered communities in and around Tilligerry Creek and in the small community of Salt Ash there are 330 residences, 53 along Marsh Road, Bob's Farm (Figure 1) at a density of about 70/km<sup>2</sup>. Within Salt Ash the system density is closer to 55-60/km<sup>2</sup>.



**Figure 1 Tilligerry Creek catchment showing sampling site locations**

An audit of the performance of on-site systems undertaken in 1998 (Hunter, 1999), part of the Port Stephens Catchment Assessment Program in the Salt Ash/Marsh Road area, revealed that many of the systems inspected had some problems and that a number were considered to be in high risk areas adjacent to waterways and drainage lines. In many locations the seasonal watertable is within one metre of the ground surface and many disposal areas within 100 m of a permanent waterway and within 40 m of a drainage channel. The audit of the performance of on-site systems in Salt Ash revealed that about 66% of the 331 systems inspected had some problems and that 11% were considered to be in high risk areas adjacent to waterways and drainage lines. While many of these problems have subsequently been remedied, there are still major concerns with the environmental performance of on-site systems in this area.

The monitoring which was undertaken as part of the Catchment Assessment Program involved faecal indicator bacteria sampling of surface waters at a number of locations around the Tilligerry estuary (major drains 1A, 4 and 7; Tilligerry Creek Floodgates, Oakfield Road and Upstream and two drains (not shown on figure) along Marsh Road). The bacterial data collected indicated wide variability in terms of faecal coliform numbers and was considered reflective of the diversity in landuse activities (mixed agriculture and low density unsewered urban development) existing in the Tilligerry catchment. Hunter (1999) concluded that the sources for the high numbers of faecal coliform bacteria regularly present in surface waters in the Salt Ash area were considered to be septic tank contamination of surface waters, rural runoff from grazing activities along the channel, and runoff from bushland areas.

### 3.2 Methods

The monitoring at two of the properties selected for tracer testing in the latter half of 2001 is reported here. One property (G) was located within the small community at Salt Ash (a “high risk” area described by Hunter, 1999). Further testing to examine the suitability of one of the tracing methods under different conditions was undertaken at Property K (outside the area shown in Figure 1). Testing was to determine which of the failing systems on adjoining properties was responsible for the observed effluent seepage observed at Property K. The hydraulic and site characteristics of the properties investigated are described below:

**Property K** (outside catchment): large 3-4 bedroom house in rural/residential estate; two adults and two older children; reticulated water supply with high use; septic tank and on-site wastewater disposal; large in-ground swimming pool; shallow, thin soils on bedrock shelf; effluent seepage from adjoining properties. At this property effluent from unidentified adjacent properties was seeping in the bank above the swimming pool and contributing to odours and unsanitary conditions. The method was used to determine if the “suspect” septic system on the selected property was failing and responsible for the seeping effluent.

The tracing method used at this property involved the use of activated carbon packets (previously described) and the dosing of sodium fluorescein dye to a “suspect” septic tank at an adjoining property. The activated carbon packets were placed strategically at a number of locations within the property boundary along drainage lines and low points downslope from the neighbouring disposal area. After the placement and removal of the control packets, a solution of approximately 20 g/L fluorescein was added to the “suspect” septic tank and the activated carbon packets replaced at weekly intervals for a period of one month.

**Property G:** two older adults in large 3-4 bedroom house on large lot approximately one hectare; dishwasher; two toilets and two showers; rainwater tank for potable use; spear point for garden watering; one 2300 L septic tank with 9 m tunnel trench approximately 9 m from an open drain; clothes washing 3 times per week; water use metered for duration of study – average daily use 301 L/day with effluent loading to trench approximately 55 L/m<sup>2</sup>/day; large in-ground swimming pool; economical use of water in house; site located in free draining Tomago sands, Salt Ash; high groundwater table.

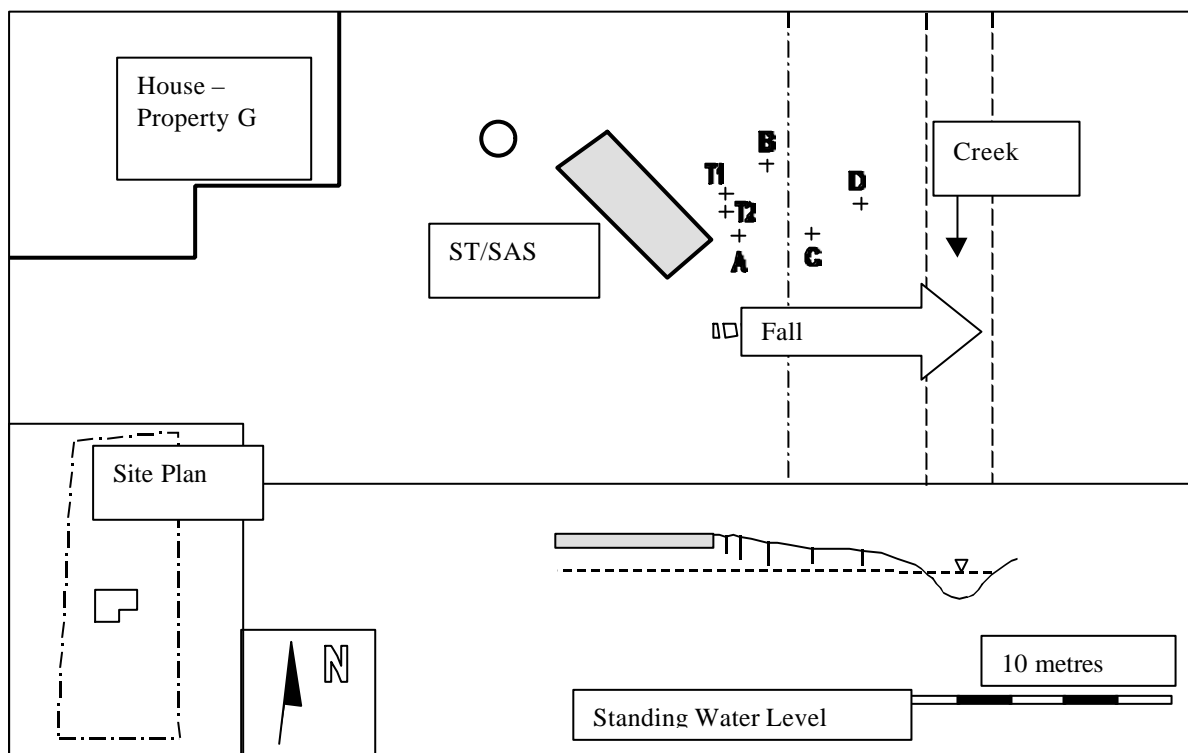


Figure 2 Instrumentation - Property G

At Property G suction lysimeters (A, B, C, D) and tensiometers (T1, T2) were installed in July 2001 (Figure 2) and chemical tracers added to the system to determine the fate of effluent in the subsurface and see whether effluent was leaving the property. Excavations using augers were to determine the direction of flow and measure the hydraulic gradient at the site.

Pore water samples were regularly collected from the suction lysimeters between 4/08/2001 and 4/12/2001 at this property and analysed in the field for pH and electrical conductivity using a Horiba (D24) meter. They were also analysed in the laboratory for nitrate-nitrogen (Hach DR2000 Spectrophotometer - Cadmium Reduction Method), which can be a useful indicator of nitrified septic effluent in sandy soils. After the pore water samples had been collected for at least one month, solutions of lithium chloride (11/09/2001) and potassium bromide (9/10/2001) at concentrations of approximately 50 g/L were introduced into the on-site system after the septic tank via an access port but before the effluent disposal area. Sodium fluorescein at a similar concentration was also added on 6/11/2001. The pore water samples were regularly collected at each site and the fate of each of the tracers monitored.

## 4 Tracing Results

### 4.1 Activated Carbon Packets with Fluorescein – Property K

Using the method outlined, five activated carbon packets were placed at strategic locations inside the boundary of the affected property and the “suspect” septic tank dosed with fluorescein and lithium chloride. The collected activated carbon packets were eluted with potassium hydroxide and solutions analysed using fluorescing and atomic absorption spectrophotometers for fluorescein and lithium respectively. A visual assessment for fluorescein was carried out. At this location there were shallow soils on bedrock and a small, shallow hole was excavated where there was an obvious surface seep. The results of the analyses of water samples from the hole and the activated carbon packets (B1-B5) are shown in Table 1.

**Table 1 Borehole Tracing Results (upper) and Activated Carbon Packet Fluorescein Concentration (lower) – Property K**

(Tracer Added 22-10-01; ND - Not Detected in Analysis)

Date	Lithium (mg/L)	Fluorescein (mg/L)
22-10-01	0.02	ND
25-10-01	1.64	3.56
05-11-01	1.12	1.86
14-11-01	0.57	1.02

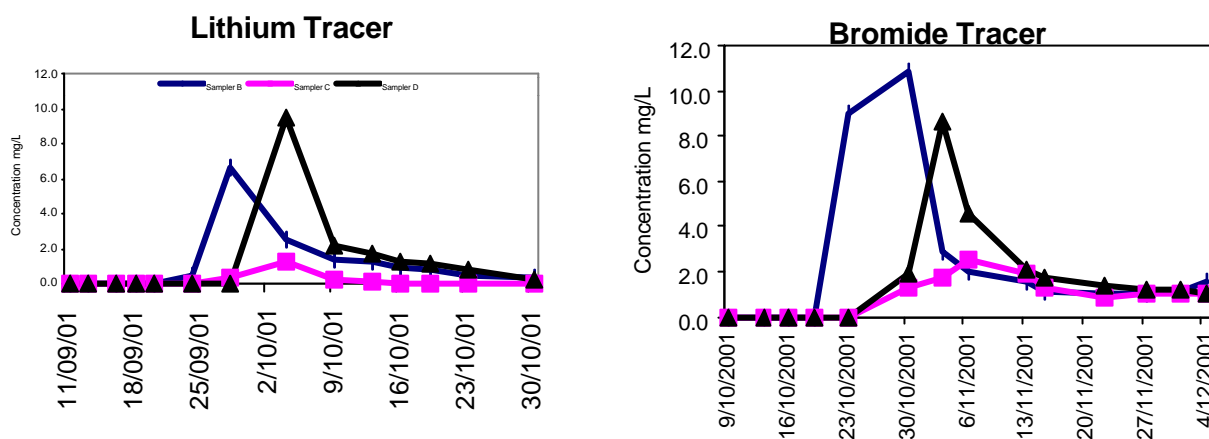
  

Date	B1	B2	B3	B4	B5
22-10-01	ND	ND	ND	ND	ND
29-10-01	1.10	0.49	0.71	ND	ND
05-11-01	2.12	1.82	0.63	ND	ND
12-11-01	2.67	0.96	0.43	1.10	ND

The results in Table 1 provide conclusive evidence that the dosed system was failing and contributing to the effluent problems being experienced at Property K. Background analyses indicated that fluorescein was not detectable. However, shortly after tracer dosing (three days), measurable concentrations were obtained from the shallow bore. The solution obtained was clearly coloured by fluorescein dye, confirmed by instrumental results. The presence of lithium in water samples confirmed that the effluent source was the adjoining property. The results of testing eluted solutions from the activated carbon packets showed the presence of fluorescein, indicating that the technique is successful provided solutions are not highly coloured by organic materials. In this case, the method was cheap to administer and need not have relied upon instrumental methods to confirm the presence or absence of fluorescein. Care is always needed in the visual analysis and identification of fluorescein in water samples, as it is well known that fluorescein may be sorbed in subsurface transport and highly coloured soils can interfere with its visual and sometimes instrumental identification.

## 4.2 Suction Lysimeter Results with Lithium and Bromide – Property G

Figure 3 shows the travel time of the lithium tracer between monitoring points B, C and D at Property G. The tracer peaks are well defined and dispersion of the lithium between samplers has occurred. The result for bromide, also shown in Figure 3, indicates marginally higher concentrations in soil water than lithium and the peak at Sampler B has been missed. One reason for the higher concentrations of bromide relative to lithium in the tracing work relates to retardation of tracer. The bromide retardation factor is usually assumed to be approximately one (the tracer moves at the same velocity as groundwater, along with chloride for example), while lithium is assumed to be a little slower. Over the short horizontal distance considered, both tracers moved at similar velocities (approximately six days travel time between peaks at Samplers B and D). Sampler B has a higher peak than Sampler D and lower concentrations are again recorded at Sampler C. Using the extrapolated peak-to-peak travel time between Samplers B and D (3.5 m apart) gives an average tracer velocity of 0.58 m/day. Fluorescein, which was added to the on-site system on 6/11/01, was not recorded in any of the suction lysimeter samples collected thereafter during the monitoring period.



**Figure 3 Tracer Curves for Lithium and Bromide – Property G**

One interesting observation made at Property G was that on occasions some of the soil water samples that were collected in the sandy soils were clear and coloured bright blue. After further investigation it became apparent that the colour was derived from a common commercial product used in the household. The householders had purchased a bluing rim block (Duck Bluey) and placed this in the toilet cistern. The blue colour in the soil water was derived from the degradation of this product and movement through the septic tank, soil absorption system and land application area. The Material Safety Data Sheet for this product did not reveal its chemical composition but it is classified as non-hazardous, a blue solid with characteristic odour and colour. It appears it could also be a suitable tracer in sandy soils.

## 5 Conclusions

Lithium chloride and potassium bromide salts are suitable for on-site system tracing because of the usually low background concentrations of lithium and bromide ions. They are cheap, easy to detect using instrumental methods, and stable in the subsurface environment. Unless a selective ion electrode for bromide is calibrated for field use, laboratory determinations are necessary. Retardation of lithium relative to bromide suggests that some is sorbed in the soil and groundwater, making bromide preferable as a tracer in on-site wastewater applications.

Fluorescein was used as a tracer as it is readily available and commonly used in plumbing and leak detection work. Both inorganic salts used were much better than the fluorescein that disappeared after addition to the on-site system. Fluorescein appears unsuitable in subsurface work, even in sandy soils, because of its sorption to soil particles and the organic colour in soil water samples that may be present in estuarine locations. Using fluorescein with activated carbon packets (with a confirmatory tracer) was successful in detecting on-site wastewater systems that were failing and contributing to unsanitary conditions. Both tracing methods appear suitable in assessing on-site system failures under specific conditions.

## Acknowledgements

Financial support provided by NSW Department of Local Government under the *SepticSafe* Program.

## References

- Alhajjar BJ, Chesters G & Harkin JM (1990) Indicators of chemical pollution from septic systems, *Ground Wat.* 28(2):559-568
- Aravena, R. and Robertson, W.D. (1998) Use of multiple isotope tracers to evaluate denitrification in ground water: study of nitrate from a large-flux septic system plume, *Ground Wat.*, 36(6):975-982.
- Brandes, M. (1975). Studies on Subsurface Movement of Effluent from Private Sewage Disposal Systems using Radioactive and Dye Tracers, Pollution Control Branch Applied Sciences, Ontario Ministry of the Environment.
- Brown and Root Services (2001). *On-site Sewage Risk Assessment System*. Report prepared for NSW Department of Local Government, Bankstown NSW by Brown and Root Services Asia Pacific Pty. Ltd.
- Chen, C-P. and Harkin, J.M. (1998) Transformations and transport of <sup>15</sup>N-based nitrogen from septic tanks in soil absorption systems and underlying aquifers, *8th National Symposium on Individual and Small Community Sewage Systems*, American Society of Agricultural Engineers, St. Joseph, Michigan. 293-305.
- Chen Z, Pavelic P, Dillon P & Naidu R. (2002) Determination of caffeine as a tracer of sewage effluent in natural waters by on-line solid-phase extraction and liquid chromatography with diode-array detection, *Wat. Res.* 36(19):1343-1354.
- Close ME, Hodgson LR & Tod G. (1989) Field evaluation of fluorescent whitening agents & triphosphosphate as indicators of septic tank contamination in domestic wells, *NZ. J. Marine Freshwater Res.* 23:563-568.
- Davis SN, Thompson GM, Bentley HW & Stiles G. (1980) Groundwater tracers - a short review, *Ground Wat.* 18:14-23.
- Geary, P.M. (2003) On-site Treatment System Failure and Shellfish Contamination in Port Stephens, NSW, NSW Department of Local Government SepticSafe Enhancement Grant Project Report E08.
- Gerritse, R. G., Adeney, J.A. and Hosking, J. (1995) Nitrogen Losses from a Domestic Septic Tank System on the Darling Plateau in Western Australia, *Wat. Res.* 29(9):2055-2058.
- Hofstad RS & Davis S. (1995) Thurston County intensive dye-tracing method for on-site sewage system evaluations, *8th Northwest On-Site Wastewater Treatment Short Course*, Seattle WA, Univ. Washington & Dept Health.
- Hunter, M. (1999) *The Karuah River/Port Stephens Catchment Assessment Program*, Final report prepared for Port Stephens Council, Raymond Terrace, NSW.
- McNellie JI, Anderson DL & Belanger TV. (1994) Investigation of the surface water contamination potential from on-site wastewater treatment systems (OWTS) in the Indian River Lagoon Basin. *7th International Symposium on Individual and Small Community Sewage Systems*, Atlanta, GA, American Society of Agricultural Engineers. pp154-163.
- Robertson, W.D. and Cherry, J.A. (1992) Hydrogeology of an Unconfined Aquifer and its Effect on the Behaviour of Nitrogen from a Large-Flux Septic System, *Applied Hydrogeology*, 0/92, 32-44.
- Robertson WD, Cherry JA, Sudicky EA, Rapaport RA & Shimp RJ (1989) Impact of a domestic septic system on an unconfined sand aquifer, *in* Kobus HE & Kinzelbach W (eds) *Contaminant Transport in Groundwater*, A.A.Balkema, Rotterdam, 105-112.
- Sargeant, D. (1999) *Fecal Contamination Source Identification Methods in Surface Water*, Washington State Department of Ecology Report #99-345, Olympia, WA.
- Seiler, R.L., Zaugg, S.D., Thomas, J.M. and Howcroft, D.L. (1999) Caffeine and Pharmaceuticals as Indicators of Wastewater Contamination in Wells, *Ground Wat.* May-June, 37, 3, 405-410.
- Shimp RJ, Lapsins, EV & Ventullo, RM. (1994) Chemical fate and transport in a domestic septic system: biodegradation of linear alkylbenzene sulphonate (las) and nitritotriacetic acid (NTA), *Environ.Toxicol.Chem.*, 13(2):205-212.
- Woolley D, Mount T & Gill J. (1995) *Tomago Tomaree Stockton Groundwater Technical Review*, NSW Dept Water Resources, Parramatta.