TOWARDS A BETTER UNDERSTANDING OF SUSTAINABLE LOT DENSITY - EVIDENCE FROM FIVE AUSTRALIAN CASE STUDIES

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Abstract

A large number of Australian studies have demonstrated that a substantial proportion of domestic on-site wastewater management systems perform poorly or fail. Few, if any, of these studies have demonstrated direct linkages between failing systems and adverse impacts on receiving waters. The figure of 15 systems per square kilometre has been quoted as one at which on-site wastewater management system density is likely to have catchment scale impacts yet this is based on very limited data.

Studies of on-site system density and surface and groundwater quality in five sensitive coastal catchments in New South Wales (Allworth, Coomba Park, North Arm Cove, Pindimar) and Tasmania (Dodges Ferry) demonstrate some direct linkages between on-site system performance, system density and receiving water quality. However, these studies also demonstrate that in many Australian catchments, on-site system densities exceeding 15 systems per square kilometre, even of poorly performing systems, might not significantly impact on receiving water quality.

This evidence suggests that more detailed investigation of effluent contaminant pathways, clearer distinction between contaminants derived from on-site systems and other potential sources and contaminant attenuation are required to adequately determine sustainable lot densities for on-site systems.

Keywords

On-site system performance, receiving water contamination, sustainable system density.

1 Introduction

Surveys undertaken in a number of Local Government areas throughout Australia (Geary 1992, 1993, O'Neill *et al*. 1993, Beard *et al*. 1994, Jelliffe 1995a, Martens & Warner 1995) identify a high proportion of on-site wastewater management systems which perform poorly or fail. It is widely assumed that such systems are contributory to contamination of receiving waters by nutrients and bacterial contaminants. There is, however, relatively little published literature which demonstrates direct linkages between the performance of on-site wastewater management systems and specific incidence of contamination of receiving waters (Geary & Gardner 1998, Whitehead & Geary 2000). Catchment scale impacts of on-site wastewater management systems have been demonstrated by Hoxley & Dudding (1994), Ivkovic *et al*. (1998) and Whitehead & Associates (1998).

A project undertaken for the Rural Water Corporation in Victoria investigated the impact of septic tank effluent on groundwater receptors in the Murray Basin (HydroTechnology 1993). This study identified septic tank effluent as the cause of groundwater nitrate-nitrogen (nitrate-N) levels in excess of the World Health Organisation and U.S. drinking water standard. In this study, based on studies in the United States (Yates 1985), a septic tank density of 15 tanks per km^2 was cited as the primary cause for the high levels of contamination. Other attempts have been made to determine sustainable on-site system density on the basis of potential contaminant loads (Jelliffe 1995b, Martens & Warner 1995) but few published Australian studies investigate sustainable system density in the light of on-site system performance and receiving water contamination.

2 Study Methodology

Since 1998 five studies of on-site system density and surface and groundwater quality have been conducted in sensitive coastal settlements in New South Wales (Allworth, Coomba Park, North Arm Cove, Pindimar) and Tasmania (Dodges Ferry). In each case small scale catchments have been defined and surface water and groundwater samples analysed for a number of physical, chemical and bacterial parameters.

2.1 Catchment analysis

To determine system density and identify pathways for potential pollutant migration, small-scale subcatchments have been delineated on the basis of the topography, natural and constructed drainage lines and the subsurface geology. The small-scale catchments were delineated by a combination of desktop interpretation of existing mapping and by field mapping.

As no more detailed contour mapping was available, contours at 10 metre intervals were transposed from published 1:25 000 topographic maps of each settlement onto more detailed cadastral maps drawn from the Council Geographic Information System. Small-scale drainage catchments, of the order of a few tens of domestic properties in size, were interpolated and transferred to field mapping sheets. Ground truthing of these small-scale drainage catchment boundaries was conducted at an early stage of each investigation. The field mapping was undertaken during rainfall events to ensure that all drainage lines, discharges, sinks and seeps were recorded within each catchment and that subtle breaks in slope and drainage could be accurately mapped and appropriate surface water sampling points determined.

2.2 Sampling and water quality analysis

A surface water sampling program was established for each study area and sampling was undertaken following both drier periods and rainfall events. Samples were tested in the field and laboratory for a range of physical, chemical and bacterial parameters including temperature, turbidity, pH, dissolved oxygen, electrical conductivity, phosphorus, nitrate-N, ammonia-N, total Kjeldahl nitrogen, iron, faecal coliforms, faecal streptococci and *E.coli*. Not all analytes were tested for in each case. Water quality data is presented in Table 1.

Records of all on-site wastewater treatment systems installed within each township were obtained from the relevant authority and mapped directly onto each of the small-scale drainage catchment maps. Surface water sampling points and groundwater sampling points from existing spear points, bores and wells were similarly located on the maps.

2.3 On-site system density

The area of each small-scale drainage catchment was calculated and the number of on-site systems in each catchment determined. Where possible, on-site systems were further subdivided by type into traditional septic systems with trenches, aerated wastewater treatment systems with surface or occasionally subsurface irrigation, pumpout systems and others including composting and chemical toilets. From the small-scale subcatchment areas and on-site system numbers, on-site system densities were determined. These are shown in Table 1.

An example of the resultant mapping is shown in Figure 1.

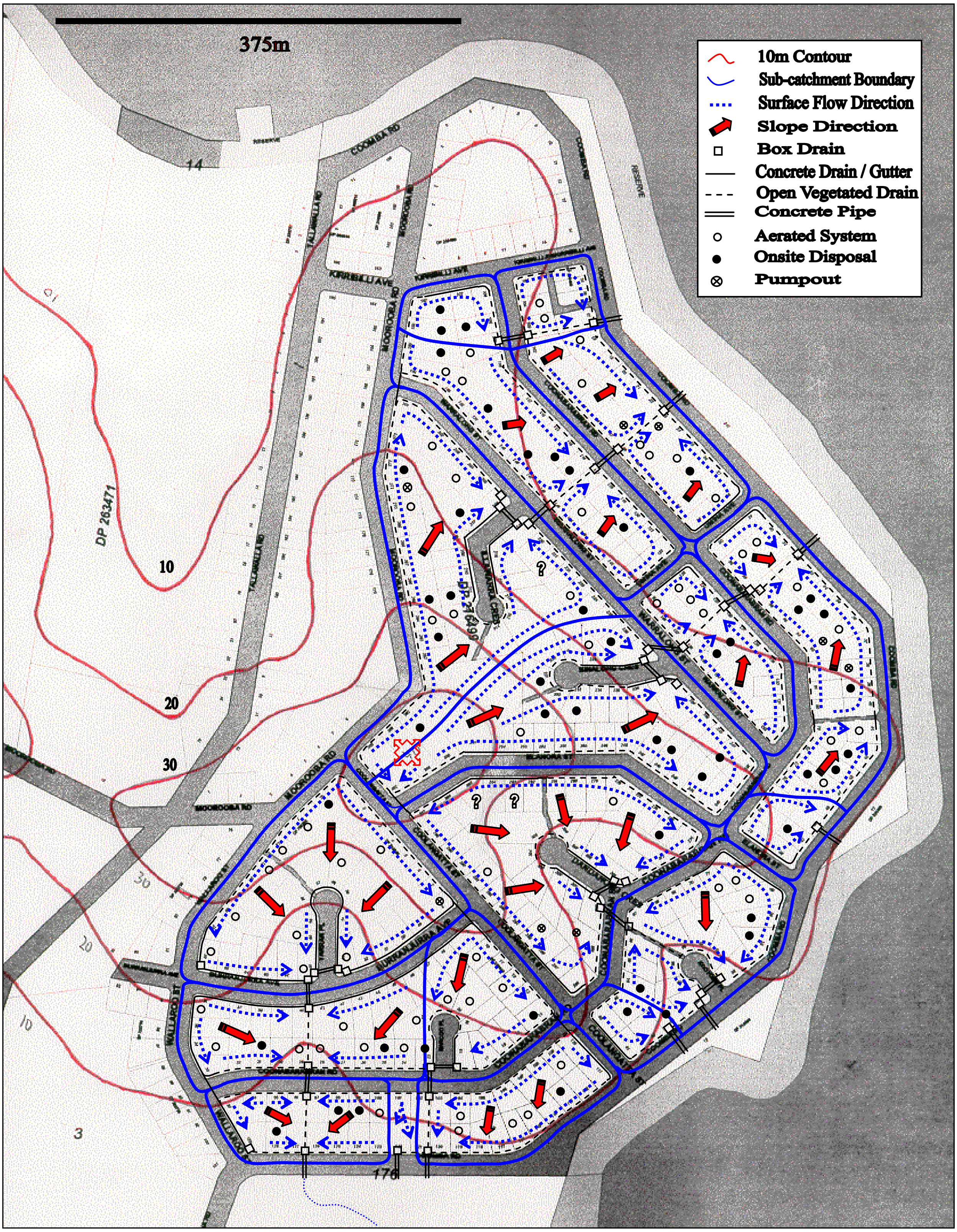

Figure 1. Small-scale subcatchment mapping and on-site systems at Coomba Park.

STUDY AREA	CATCHMENT SAMPLE SITE	CATCHMENT AREA (m^2)	ON-SITE SYSTEMS WITHIN SUB-CATCHMENT					SYSTEM DENSITY (SYSTEMS /km^2)	SAMPLE DATE	ANALYTICAL PARAMETERS (mg/L)					BACTERIA (cfu/100mL)			
			S	**P**	**A**	**O**	**Total**			**NO_3-N**	**NH_3-N**	**TKN**	**PO_4**	**Fe**	**FC**	**FS**	**E.coli**	**Enterococci**
AL	Surface water																	
	Ala AL1	14812	3	--	2	--	5	338	31/01/01	--	--	--	--	--	--	--	--	--
	Alb AL2	25200	7	--	3	--	10	397	31/01/01	--	--	--	--	--	--	--	--	--
	Alc AL3	16441	5	--	2	--	7	426	31/01/01	1.10	--	--	--	--	1637	1546	--	--
	Ald AL4	41798	10	1	4	--	15	359	31/01/01	4.60	--	--	--	--	12000	11000	--	--
	AL5	--	--	--	--	--	--	--	31/01/01	1.00	--	--	--	--	8000	6800	--	--
	Ala AL1	--	3	--	2	--	5	338	25/03/01	1.90	--	--	--	--	70000	28000	60000	--
	Alb AL2	25200	7	--	3	--	10	397	25/03/01	2.50	--	--	--	--	30000	38000	30000	--
	Alc AL3	16441	5	--	2	--	7	426	25/03/01	6.70	--	--	--	--	36000	38000	36000	--
	Ald AL4	41798	10	1	4	--	15	359	25/03/01	4.50	--	--	--	--	65000	84000	65000	--
	AL5	--	--	--	--	--	--	--	25/03/01	6.30	--	--	--	--	40000	22000	20000	--
	AL6	--	--	--	--	--	--	--	25/03/01	4.30	--	--	--	--	30000	15000	30000	--
	AL7	--	--	--	--	--	--	--	25/03/01	4.20	--	--	--	--	29000	24000	22000	--
CP	Surface water																	
	Cpa CP1	34010	1	1	10	--	12	353	31/01/01	0.80	--	--	--	--	32000	10000	--	--
	CPb CP2	20061	3	--	8	--	11	548	31/01/01	0.80	--	--	--	--	42000	120000	--	--
	CPc CP3	11451	3	--	1	--	4	349	31/01/01	0.80	--	--	--	--	75000	92000	--	--
	CPd CP4	33436	1	2	2	2	7	209	31/01/01	0.40	--	--	--	--	35000	103000	--	--
	Cpe CP5	18942	4	--	3	--	7	370	31/01/01	0.44	--	--	--	--	89000	89000	--	--
	CPf CP6	35551	8	--	2	--	10	281	31/01/01	0.50	--	--	--	--	31000	240000	--	--
	CPg CP7	14634	2	--	4	--	6	410	31/01/01	1.50	--	--	--	--	39000	124000	--	--
	CPh CP8	31140	4	2	4	--	10	321	31/01/01	0.76	--	--	--	--	77000	360000	--	--
	Cpi CP9	39460	8	1	6	1	16	405	31/01/01	0.40	--	--	--	--	54000	118000	--	--
	CPj CP10	24252	6	--	4	--	10	412	31/01/01	0.30	--	--	--	--	45000	102000	--	--
	CPk CP11	18799	1	2	6	--	9	479	31/01/01	0.60	--	--	--	--	38000	240000	--	--
NAC	Surface water																	
	N1a	106288	42	7	11	--	60	565	30/08/99	0.16	--	--	0.61	--	--	--	--	--
	N2a	248005	30	4	15	--	49	198	30/08/99	0.12	--	--	--	--	--	--	--	--
	N3	127107	19	7	1	--	27	212	30/08/99	0.09	--	--	0.09	--	--	--	--	--
	N4a	14537	4	--	5	--	9	619	30/08/99	0.61	--	--	0.02	--	--	--	--	--
	N5	150483	12	7	19	--	38	253	30/08/99	0.39	--	--	0.13	--	--	--	--	--
	N1	248005	30	4	15	--	49	198	26/10/99	0.06	0.06	1.61	0.20	--	~1637	--	~1237	--
	N2	124915	--	--	--	--	0	0	26/10/99	0.03	0.06	1.64	0.14	--	2800	--	2800	--
	N3	150483	12	7	19	--	38	253	26/10/99	0.18	<0.05	1.00	<0.01	--	~1546	--	~1546	--

PDM	Surface water																	
	P1	1488750	9	--	--	--	9	6	26/10/99	0.04	0.06	1.25	0.19	--	260	--	260	--
	P2	372188	13	3	3	--	19	51	26/10/99	0.03	0.06	1.94	0.33	--	440	--	440	--
	P3	620310	24	1	7	4	36	58	26/10/99	0.11	<0.05	1.70	0.16	--	~6600	--	~6600	--
	P4	5004500	37	8	7	7	59	12	26/10/99	0.02	0.06	0.96	0.05	--	~73	--	~73	--
	P5	--	--	--	--	--	--	--	26/10/99	0.45	0.31	2.08	1.38	--	220	--	220	--
PDM	Groundwater																	
	GP1	372188	13	3	3	--	19	51	15/11/99	0.05	--	--	0.10	1.57	0	--	0	--
	GP2	372188	13	3	3	--	19	51	15/11/99	0.02	--	--	0.09	0.25	0	--	0	--
	GP3	1488750	9	--	--	--	9	6	15/11/99	0.04	--	--	0.51	2.75	0	--	0	--
	GP4	1488750	9	--	--	--	9	6	15/11/99	0.01	--	--	0.17	1.05	0	--	0	--
	GP5	620310	24	1	7	4	36	58	15/11/99	0.06	--	--	0.13	5.94	0	--	0	--
	GP6	5004500	37	8	7	7	59	12	15/11/99	--	--	--	1.34	3.04	1	--	1	--
DF	Groundwater																	
	5	31500	--	--	--	--	18	571	02/98	57.50	--	--	--	--	<2	--	<2	--
	6	6500	--	--	--	--	6	923	08/94	13.00	--	--	--	0.84	--	--	--	--
	6	6500	--	--	--	--	6	923	09/94	6.20	--	--	--	--	<2	--	<2	--
	6	6500	--	--	--	--	6	923	02/98	11.50	--	--	--	--	<2	--	<2	--
	6	6500	--	--	--	--	6	923	01/99	7.82	--	--	--	0.11	<1	--	<1	420
	6	6500	--	--	--	--	6	923	12/99	23.64	0.03	--	0.021	--	--	--	--	--
	9	13100	--	--	--	--	9	687	08/94	2.00	--	--	--	2.5	--	--	--	--
	9	13100	--	--	--	--	9	687	09/94	0.10	--	--	--	--	<2	--	<2	--
	9	13100	--	--	--	--	9	687	02/98	7.00	--	--	--	--	<2	--	<2	--
	9	13100	--	--	--	--	9	687	01/99	2.59	--	--	--	0.72	<1	--	<1	<1
	9	13100	--	--	--	--	9	687	12/99	7.43	0.05	--	<0.002	--	--	--	--	--
	23	8900	--	--	--	--	8	899	02/98	0.30	--	--	--	--	<2	--	<2	--
	23	8900	--	--	--	--	8	899	12/99	0.90	--	--	--	9.5	<1	--	<1	<1
	31	11800	--	--	--	--	10	847	12/97	0.10	--	--	--	22	--	--	--	--
	31	11800	--	--	--	--	10	847	12/99	1.41	--	--	--	14.3	<1	--	<1	180est
	31	11800	--	--	--	--	10	847	12/99	0.41	0.12	--	<0.002	--	--	--	--	--
	38/46 seep	9200	--	--	--	--	8	870	01/99	10.18	0.01	--	--	--	<1	--	<1	1
	38/46 seep	9200	--	--	--	--	8	870	12/99	6.73	0.06	--	0.019	--	--	--	--	--
	48 seep	9200	--	--	--	--	8	870	12/99	9.86	0.03	--	<0.002	--	--	--	--	--
DF	Surface water																	
	A 9 First Ave	25100	--	--	--	--	15	597	10/99	0.10	0.107	--	0.043	--	100(est)	--	--	46000
	A 9 First Ave	25100	--	--	--	--	15	597	10/99	0.21	0.105	--	0.035	--	<10	--	--	6500
	B 11 Jetty Rd	13100	--	--	--	--	8	611	10/99	0.58	0.664	--	0.003	--	17000(est)	--	--	18000(est)
	B 11 Jetty Rd	13100	--	--	--	--	8	611	10/99	0.13	0.443	--	0.031	--	5900	--	--	14000(est)
	C Jetty Rd W	27600	--	--	--	--	12	435	10/99	0.23	0.029	--	0.636	--	5200	--	--	13000(est)
	C Jetty Rd W	27600	--	--	--	--	12	435	10/99	0.05	0.015	--	0.233	--	7400	--	--	12000(est)

A = Allworth   CP = Coomba Park   NAC = North Arm Cove   P =DM = Pindimar (all NSW)   DF = Dodges Ferry (TAS)

S = Septic System   P = Pumpout System   A = Aerated Wastewater Treatment System   O = Other System   FC = Faecal coliforms   FS = Faecal streptococci

Table 1. Catchment size, system density, surface water and groundwater quality data.

2.4 Review of water quality data

The village of Allworth sits on low permeability, seasonally waterlogged clay soils in the Karuah Valley. The Karuah Valley drains into Port Stephens on the NSW coast. System densities range from 338/km^2 to 426/km^2. Slightly elevated nitrate-N levels were identified at most surface water sample points. These correlate closely with high bacterial indicator levels.

Coomba Park lies on the western shore of Wallis Lake. Slopes range from 5-26% and descend in all directions from the settlement to the lake. Soils are relatively thin and are a sandier than those at Allworth. System densities range from 209/km^2 to 548/km^2. Bacterial indicator levels were high at all surface water sample points but nitrate-N levels were generally lower than at Allworth.

Development at North Arm Cove is again on slopes (up to 15%) descending to the shores of the inner part of Port Stephens, the estuary into which the Karuah River flows. Soils are moderately deep (50-150 cm) light sandy clay loams which are highly permeable. System densities range from 0/km^2 to 619/km^2. Both nitrate-N and bacterial indicator levels were generally low at surface water sample points.

Pindimar sits on poorly drained, flat lying sands at elevations only just above sea level on the outer shores of Port Stephens. The developed areas experience a permanently high water table and periodic inundation. System densities range from 6/km^2 to 58/km^2. At all surface water sample points, nitrate-N levels were low and so too, with one exception, were bacterial indicator levels. A number of spear points and bores were sampled. In these, nitrate-N levels were low and bacterial indicators were below detectable levels. In one bore and also nearby at one surface water sampling point, phosphorus levels significantly higher than the ANZECC estuarine water quality guideline level of 0.005 - 0.015 mg/L (ANZECC 1999) were found.

Dodges Ferry lies on the eastern shore of Frederick Henry Bay to the west of Hobart. The soils are predominantly sands, with some horizons of sandy clay supporting perched water tables in the upper few metres. These sandy clays give rise to seeps from unconfined aquifers in the sand cliffs along the shoreline at Tiger Head Bay. System densities range from 435/km^2 to 923/km^2. Surface water samples generally exhibited low nitrate-N levels and some modest level of bacterial indicators. Groundwater samples show varying levels of nitrate-N ranging up to one sample which contained 57.5 mg/L, very high by any standards, and both this and one other sample exceeded the NH&MRC Drinking Water Guideline of 11.3 mg/L (NH&MRC 1996), though in all cases bacterial indicators were not detected.

2.5 Tracing groundwater contaminant migration

In the case of Dodges Ferry, impacts to groundwater have been studied in greater depth with samples taken on a number of occasions over a period of several years, from a number of spear points and bores along a transect which extends some 800 metres east from the shore at the northern end of Tiger Head Bay. The location of bores and the geology and hydrogeology of the transect are shown in Figure 2. The geological cross-section demonstrates the position of the perched water table aquifer supported by a horizon of sandy clay which gives rise to a seep in the beachfront sand cliffs. Bathing water quality at Tiger Head Bay has given cause for concern in the past and this study has been undertaken to attempt to ascertain the possible contribution of failing on-site systems and to provide the local council with guidance as to the possible impact of further residential development in the area.

Whilst some bores are contaminated by high levels of nitrate-N others yield water of a much higher quality, even where on-site system densities are very high (>800/km^2). In this case it appears that contamination is generally localised and that whilst a nitrate contamination plume appears to be slowly migrating towards the coast from bores 5 and 6 in particular, there is no evidence of any bacterial contamination any distance down gradient of failing systems. It is assumed that failures of on-site systems in the catchment, with the possible exception of systems located immediately behind the seeps at the beach cliffs, are not contributory to reduced bathing water quality.

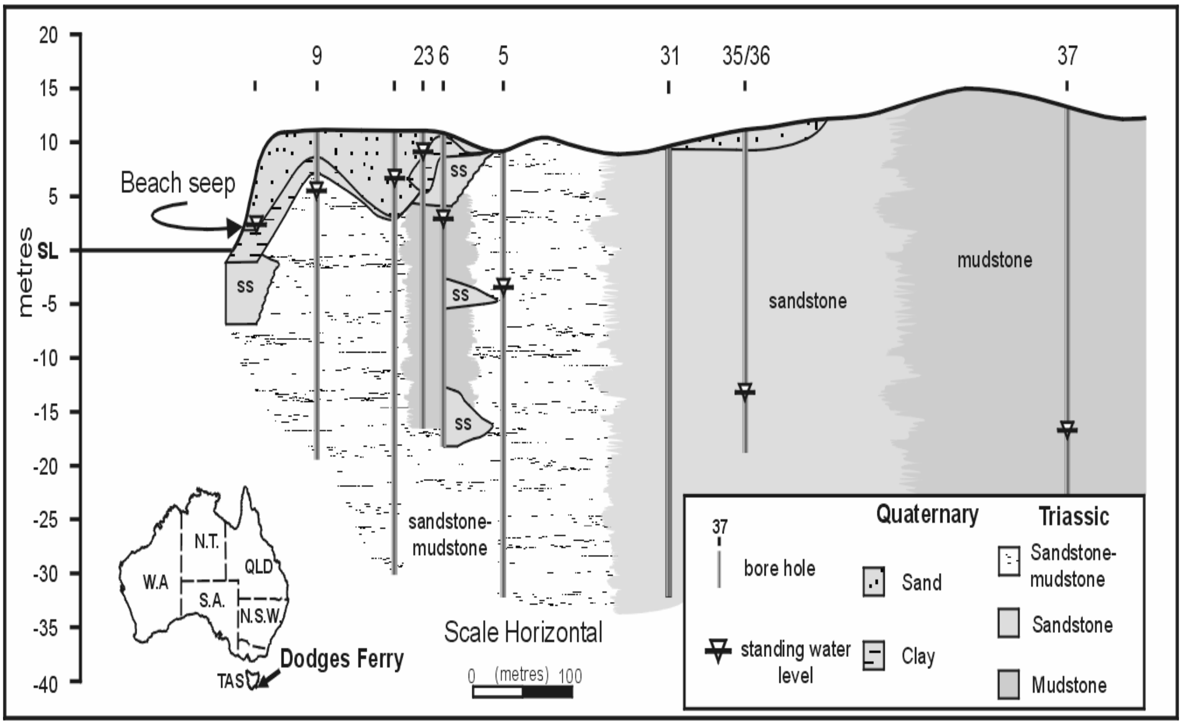

Figure 2. Dodges Ferry geological and hydrogeological transect. (Geary & Whitehead 2001).

3 Conclusions

In each of the study areas there is a variety of types of on-site systems, performing at a range of levels from satisfactorily to poorly. In each area performance of systems has historically been both problematic and linked to contamination of receiving waters. This study has identified both nitrate and bacterial contamination of surface water and groundwater and demonstrated linkages with high on-site system densities.

The study has, however, demonstrated no consistent association between nitrate and bacterial contamination in either surface water or groundwater, nor has it demonstrated a clear correlation between level of contamination and on-site system density. Indeed, in some areas of very high system density, even where cases of individual failing systems have been identified, impacts to receiving waters are negligible or not evident.

It would appear from the study that high on-site system densities need not necessarily adversely impact receiving water quality, even where poorly performing systems are suspected or even identified.

Whilst some risk still remains with poorly performing systems, it is clear that more detailed investigation of effluent contaminant pathways should be undertaken and attempts made to differentiate between on-site system and other potential contaminant sources.

A number of emerging tracer techniques offer potential in this regard and should help in the more accurate determination of sustainable lot densities for on-site systems.

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