Municipal waste disposal in Perth and its impact on groundwater quality

by

K-J. B. Hirschberg

Abstract

There are 99 known abandoned or operating municipal landfill sites in Perth. In order to assess their impact on the groundwater, the Geological Survey of Western Australia investigated groundwater quality near 50 of these sites. Several hundred field tests for ammonia expressed as nitrogen (NH_4–N) were carried out on private garden reticulation bores and monitoring bores near the selected landfill sites, and about 40 water samples were taken for detailed analysis. Elevated NH_4–N values were found near many of the sites. Concentrations of heavy metals were, however, very low or below detection level. Results from pesticide analyses by the Chemistry Centre (W.A.) for the Health Department in 1991 indicate that the concentration of these substances in monitoring bores is several orders of magnitude lower than the maximum permissible levels. From a human health risk perspective, it appears that Perth's landfill sites have generally performed well, although many of the sites are in hydrogeologically unfavourable locations. The major ammonia plumes delineated coincide with former liquid-waste disposal areas. It is concluded that there is apparently minimal threat to human health from groundwater contamination by landfill leachate. However, the potential impact on the environment through increased nutrient input cannot be disregarded. Continued groundwater-quality monitoring is recommended

KEYWORDS: Groundwater, contamination, waste disposal, Perth Basin.

Introduction

The volume of domestic waste created in Perth has increased considerably over the past few decades. This has resulted from rapid population expansion, increase in garden waste due to restrictions on burning, and changes in product packaging combined with less recycling in a more affluent society. The traditional waste-disposal method has been by landfill, and local government authorities have had the responsibility for collection and disposal of municipal waste. As a result a large number of landfill sites are distributed over the metropolitan region.

Many of the now-abandoned waste-disposal sites were merely dumps; new sites have been planned, and are managed in a more environmentally acceptable way. Nevertheless, the potentially adverse impact of municipal waste disposal on human health and the environment in general through groundwater contamination has become the subject of mounting public concern.

More than 50% of Perth's total water supply is met from shallow groundwater resources. The main public water-supply borefields draw from the Gnangara Mound in the north, and the Jandakot Mound in the south. The maintenance of groundwater quality in these areas is achieved by strict controls over development, and by prohibiting certain activities (such as waste disposal). There are also more than 80 000 private and municipal bores in the metropolitan region. The water from most of these is used for reticulation of private gardens and public open space, and for industrial purposes. Only very few are used for private domestic consumption.

Following a request by the State Government Senior Officers Committee on Waste Management in 1990, the Geological Survey of Western Australia (GSWA) undertook to assess the risk to human health from groundwater contamination associated with landfills, by investigating a number of operating and abandoned landfill sites in the Perth Metropolitan Region.

History of landfill site selection

Prior to about 1970, the selection of landfill sites was largely governed by the availability of cheap land within the respective local authority boundaries. Transport distances had to be short to keep costs down, and because the collection and transport of rubbish was initially by horse and cart. Wetlands, consisting of lakes, swamps, and river foreshores, were deemed useless land and were considered to present a health hazard by providing breeding grounds for mosquitoes. Consequently, many of Perth's old landfill sites are found in, or near, such wetlands (Fig. 1) and the dumping was called 'land improvement'. Co-disposal of solid waste with liquid waste, such as night soil, was also common practice. Other targets for waste disposal were abandoned limestone quarries and sand and clay pits. No consideration was given to any potential impact on the environment, including groundwater. Waste disposal into wetlands was

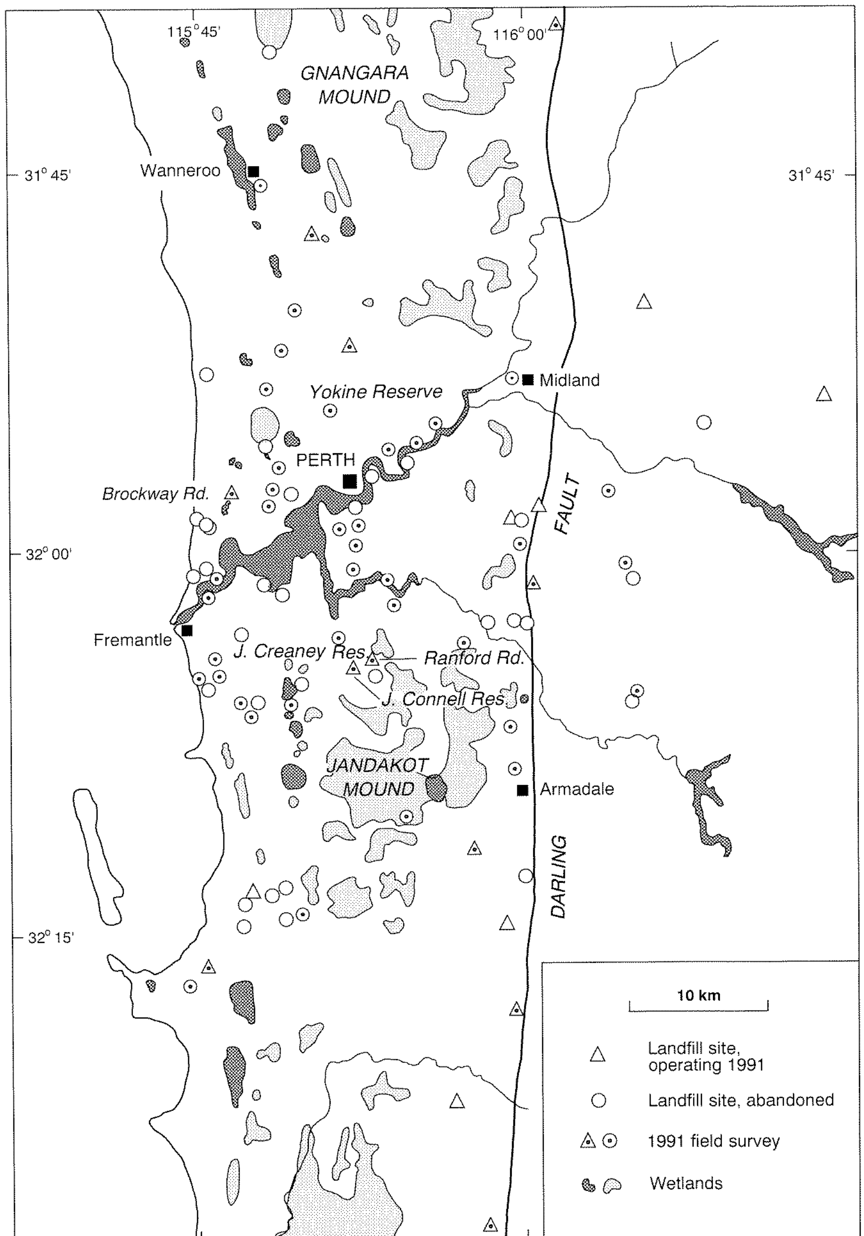


Figure 1. Location plan, landfill sites and wetlands

still practised in the early 1980s at Lake Pinjar and Hertha Road.

The change of waste disposal and management from poorly controlled dumping to sanitary landfill, incorporating compaction and regular cover of the waste, was completed by about 1962. Site selection and site management have also improved considerably since about 1970. The growing awareness of the potentially deleterious effects of waste disposal on the environment resulted in the exclusion of certain types of waste and, eventually, in the installation of groundwater monitoring bores at all operating sites.

Rapidly increasing amounts of waste required the establishment of more and more disposal sites by local authorities. This dispersal of waste over numerous sites, however, was considered undesirable by the Health Department of Western Australia, which instigated the formation of waste-disposal zones and, eventually, of regional councils consisting of several local government authorities. The aim was to create a small number of large, well-managed landfill sites, preferably centrally located within the regional council boundaries. The criteria for acceptance of existing sites, formulated by the Health Department and to be issued in a revised form in the near future, will result in some site closures. Concurrently, the establishment of regional landfill facilities within the area of each regional council will be accelerated.

Type of waste

The early tips received any waste, both domestic and industrial, created within their intake area. The material is presumed to have consisted of putrescent domestic waste, tree loppings, lawn clippings, paints and thinners, acids and alkalis, car bodies, tyres and batteries, and in later years pesticides and their containers. Over the last few decades, the amount of plastic waste has increased dramatically, as has the number of car bodies and tyres. The disposal of toxic waste such as pesticides and some industrial wastes is no longer permitted; thus leachate from a modern landfill site is potentially less harmful than that from an old disposal site. Some intractable materials, however, are still being disposed of at the present landfill sites. Among these are small amounts of PCBs contained in old fluorescent light fittings, and large numbers of batteries containing lead, cadmium, mercury, and other toxic heavy metals.

Hydrogeology

Most of the Perth Metropolitan Region lies on the Swan Coastal Plain, which is underlain by a sequence of mainly permeable sediments. From west to east, they consist of the Safety Bay Sand; the Tamala Limestone and its leached sandy facies; the Bassendean Sand; and the Guildford Formation (Fig. 2). These formations are mainly sands or sandy limestone, and only the Guildford Formation consists mostly of clay. Collectively, these sediments are known as the 'superficial formations' (Allen, 1975). They range from 20 to 40 m in thickness and contain unconfined groundwater, with a watertable generally at shallow depth.

The sandy nature of the sediments, in conjunction with the shallow watertable, makes the unconfined aquifer particularly vulnerable to contamination.

Procedures of investigation

Site selection

Ninety-nine landfill sites had previously been identified in the metropolitan area (Hirschberg, 1988). In order to reduce this number to a more manageable group for investigation, the following sites were excluded:

1. those which were closed more than about 30 years ago;
2. some operating sites, because they were already the subject of detailed studies (e.g. Yirrigan and Red Hill sites);
3. most of the small landfill sites near the outer margin of the metropolitan region (e.g. Yanchep, Wooroloo, and Wundowie sites).

A representative cross section of 50 sites was selected on the basis of regional distribution, hydrogeological setting, and size of landfill. These are listed in Table 1.

Methods of study

After a study of bore records held by the GSWA, a detailed bore census was carried out around each site. Water samples from all private reticulation and monitoring bores within a radius of about 500 m were tested in the field for ammonia expressed as nitrogen (NH_4–N). This parameter is commonly used as a pollution indicator at landfill sites, with values of NH_4–N above 0.5 mg/L generally considered to indicate human influence. The ammonia is generated during the anaerobic decomposition of organic matter such as putrescent household waste, lawn clippings, and tree prunings. It is also a major breakdown product of septic waste.

The field test is based on an ion-specific test solution (Aquamerck) which, after appropriate reaction time with the sample, is analysed colorimetrically. The readings obtained with the field test kits were not considered to be quantitatively accurate. However, they were found to be generally in good agreement with the chemical analyses.

Whenever positive field readings were obtained, the area of the census was widened until zero values were obtained. Where possible, concentrations of NH_4–N were contoured; however, at many sites there were insufficient bores and data points to achieve this.

Samples for chemical analysis were taken from a number of bores, generally where field NH_4–N readings had been 10 mg/L or higher. Analyses for pesticides and other potentially harmful organic compounds were not carried out; however, the results of previous analyses for these substances were reviewed and taken into consideration.

Results of investigation

Field NH_4–N readings

Table 1 lists the numbers, in each of the selected sensitivity brackets, of both field tests and samples taken for analysis by the Chemistry Centre of W.A. (CCWA).

The bore census failed to locate any bores near nine of the 50 sites; at a further eleven sites, only one or two bores were found, and limited field testing and sampling was carried out. Most of the 276 field tests, however, were undertaken on private or monitoring bores close to the remaining 30 sites.

Thirty-four samples from 16 sites were submitted for chemical analysis, the results of which are presented in Table 2. Full analyses (including heavy metals) were carried out on 17 of the samples, while analyses of fewer parameters were made on the remainder.

Only five sites had a sufficient number of data points in the various sensitivity ranges to allow contouring of

Table 1. Details of field investigations

Local authority	*Landfill site*	*Lithology (a)*	*(Formation)*	*Number of field NH_4–N tests* Total	*<0.5*	*0.5–3*	*3–5*	*5–10*	*>10*	*No. of CCWA analysis*
							mg/L			
Armadale	Hopkinson Rd, Armadale	Cl	(GF)	2	1	-	1	-	-	4
	Springdale Rd, Karragullen	Cl	(Gr)	3	2	1	-	-	-	-
	Third Avenue, Kelmscott	Cl	(GF)	7	4	2	-	-	1	-
	Nicholson Rd, Jandakot	Sd	(DS)	(b)	-	-	-	-	-	-
Bassendean	Ashfield Res., Ashfield	Cl–Sd	(BS)	7	4	2	-	1	-	1
Bayswater	Slade Street, Bayswater	Cl	(Al)	2	2	-	-	-	-	-
Canning	Centenary Ave, Wilson	Sd	(BS)	12	8	4	-	-	-	-
	Adenia Res., Willetton	Sd	(BS)	8	4	4	-	-	-	-
	Ranford Rd, Willetton	Sd	(BS)	27	7	11	1	1	7	2
Cockburn	Howson Way, Bibra Lake	L/s	(TL)	1	1	-	-	-	-	-
	Dixon Res., Hamilton Hill	L/s	(TL)	2	2	-	-	-	-	-
	Dubove Pk, Spearwood	L/s	(TL)	2	2	-	-	-	-	-
	Bibra Lake, Bibra Lake	L/s	(TL)	2	2	-	-	-	-	-
East Fremantle	Preston Point, East Fremantle	L/s	(TL)	6	6	-	-	-	-	-
Fremantle	Daly St, South Fremantle	L/s	(TL)	5	2					
	Mather Rd, Beaconsfield	L/s	(TL)	2	2	-	-	-	-	-
Gosnells	Walter Padbury Pk, Thornlie	Cl	(GF)	9	6	1	1	1	-	1
	Bickley Rd, Orange Grove	Cl	(GF)	4	4	-	-	-	-	-
	Carole/Church Rds, Maddington	Cl	(GF)	1	1	-	-	-	-	-
	Kelvin Road, Orange Grove	Cl	(LF)	11	9	2	-	-	-	2
Kalamunda	Hartfield Pk, Forrestfield	Cl	(GF)	3	3	-	-	-	-	-
	Lawnbrook Road, Bickley	Cl	(GF)	(b)	-	-	-	-	-	-
	Ledger Rd, Gooseberry Hill	Cl	(Gr)	(b)	-	-	-	-	-	-
	Kent Rd, Maida Vale	Cl	(GF)	(b)	-	-	-	-	-	-
Kwinana	Durrant Ave, Kwinana	L/s	(TL)	1	-	1	-	-	-	-
Melville	John Connell Res., Leeming	Sd	(BS)	30	6	5	2	2	15	2
	John Creaney Res., Bull Creek	Sd	(BS)	19	9	3	2	2	3	2
Mosman Park	Fairbairn St, Mosman Park	L/s	(TL)	2	2	-	-	-	-	-
Nedlands	Brockway Rd, Mt Claremont	L/s	(TL)	29	6	3	11	2	7	7
Rockingham	Ennis Ave, Rockingham	L/s	(TL)	4	-	1	-	1	2	2
	Old Golf Course, Rockingham	L/s	(TL)	6	6	-	-	-	-	1
Serpentine–Jarrahdale	Elliot Rd, Keysbrook	Cl	(GF)	3	1	2	-	-	-	-
	Karnup Rd, Serpentine	Cl	(GF)	(b)	-	-	-	-	-	-
	Cardup Siding Rd, Cardup	Cl	(GF)	(b)	-	-	-	-	-	-
South Perth	Morris Mundy Oval, Kensington	Sd	(BS)	2	2	-	-	-	-	-
	Ernest Johnson Oval, South Perth	L/s	(TL)	4	4	-	-	-	-	-
	Manning Rd, Manning	Sd	(BS)	13	5	3	3	2	-	3
	Thelma St, Como	Sd	(BS)	4	2	-	1	-	1	2
Stirling	Gibney Res., Maylands	Cl	(BS–GF)	3	3	-	-	-	-	-
	Delawney St, Balcatta	L/s	(TL)	5	2	3	-	-	-	-
	Hertha Rd, Osborne Park	L/s	(TL)	5	3	-	-	-	2	1
	Yokine Res., Coolbinia	L/s	(TL)	11	2	4				
Subiaco	Shenton Pk Lake, Shenton Park	L/s	(TL)	(b)	-	-	-	-	-	-
	Mabel Talbot Pk, Jolimont	L/s	(TL)	(b)	-	-	-	-	-	-
	Rosalie Park, Subiaco	L/s	(TL)	(b)	-	-	-	-	-	-
Swan	Blackadder Creek, Midland	Cl	(GF)	4	4	-	-	-	-	-
	Morrison Rd, Bullsbrook	Cl	(Col)	5	1	4	-	-	-	1

Table 1. *(continued)*

Local authority	*Landfill site*	*Lithology (a) (Formation)*		*Number of field NH_4–N tests*						*No. of CCWA analysis*
				Total	*<0.5*	*0.5–3*	*3–5*	*5–10*	*>10*	
						mg/L				
Wanneroo	Badgerup Rd, Wangara	L/s	(TL)	3	1	2	-	-	-	-
	Hudson Res.,Girrawheen	L/s	(TL)	3	3	-	-	-	-	-
	Ariti Ave, Wanneroo	L/s	(TL)	4	3	1	-	-	-	-
		Total:		**276**	**137**	**60**	**23**	**12**	**44**	**34**

Note: (a) L/s = limestone/resid. sand; Sd = sand; Cl = clay

(TL) = Tamala Limestone; (GF) = Guildford Formation; (Al) = alluvium

(BS) = Bassendean Sand; (Gr) = weathered granite; (Col) = colluvium

concentrations. The Ranford Road (Fig. 3) and John Connell Reserve (Fig. 4) sites are large operating landfills, while the Brockway Road site (Fig. 5) at Mount Claremont, a large regional landfill, was closed in early 1992. John Creaney Reserve (Fig. 6) and Yokine Reserve (Fig. 7) sites closed in the 1970s.

All five sites have extensive plumes of NH_4–N extending downgradient in the direction of the regional groundwater flow. The plume length generally ranges from 500 to 1500 m, and the width from 400 to 700 m; the Brockway Road plume is the largest found during the investigation, with a length of about 2000 m, and a width of about 1000 m.

Chemical analyses

All groundwaters sampled are sodium–chloride waters, usually with a near-neutral pH, a highly variable hardness depending on the hydrogeological environment, and a salinity (Table 2) ranging from 200 to 1000 mg/L total dissolved solids (TDS).

Ammonia–N analyses (Table 3) confirmed that the field tests yield semi-quantitative results useful for an initial screening of an area. The major cause of variability appears to have been due to a differing test-strip interpretation by individual field staff.

The chemical analyses confirmed the existence of the extensive plumes of NH_4–N, with maxima in the plume centres up to 100 mg/L and averages of between 20 and 40 mg/L. These concentrations greatly exceed the level of 0.5 mg/L, commonly used as a contamination indicator. However, the risk to human health from the ingestion of ammonia is generally considered to be small. Nitrate levels are well below the maximum permissible level of 10 mg/L nitrate–N, apart from one sample from the Kelvin Road tip. The chemical analyses suggest that denitrification may not play a major role at depth in the aquifer, and that the reducing conditions allow the ammonia to persist in high concentrations up to several hundred metres from the source.

The analyses of heavy metals were expected to yield levels of at least noticeable concentrations. However, nearly all of those analysed (Cd, Pb, Cu, Cr, Ni, and Zn) produced values below the respective maximum permissible levels, and 57% of all heavy metal analyses were below detection level. The exceptions were one value for cadmium (Manning Road) of 0.035 mg/L, which exceeded the maximum limit of 0.01 mg/L; and one value for zinc (Ashfield Reserve) of 32 mg/L, more than twice the current desirable level of 15 mg/L. The latter high level was probably due to industrial activities some distance upgradient. Manganese concentrations were also high in several samples; however, as with high iron values, these are quite common in Perth groundwater and are considered more a nuisance than a health or environmental risk.

Pesticides

Owing to the specialized sampling required and the high cost of analysis, the samples were not analysed for residual pesticides or other artificial organic compounds. In an earlier study of the Hertha Road landfill site (Bestow, 1977), water samples were analysed for HCB, DDT, dieldrin, and organophosphorus pesticides. It was found that the concentrations for these pesticides were all several orders of magnitude lower than the maximum permissible levels.

In 1991, the Health Department sampled all landfill monitoring bores for organochlorine and organophosphorus pesticides, total aliphatic and aromatic hydrocarbons, polyaromatic hydrocarbons, and PCBs and atrazine. The analyses were carried out by the CCWA. Several samples showed values above detection level for aromatic and polyaromatic hydrocarbons and organochlorines, and one sample had a higher than desirable PCB concentration. All these samples were from bores within the landfill sites. Pesticide levels and other organic constituents are consequently expected to be very much lower at short distances from the landfill. The CCWA concluded in its comments on the chemical analyses that 'widespread pollution of groundwater is not indicated', although continued monitoring was advisable.

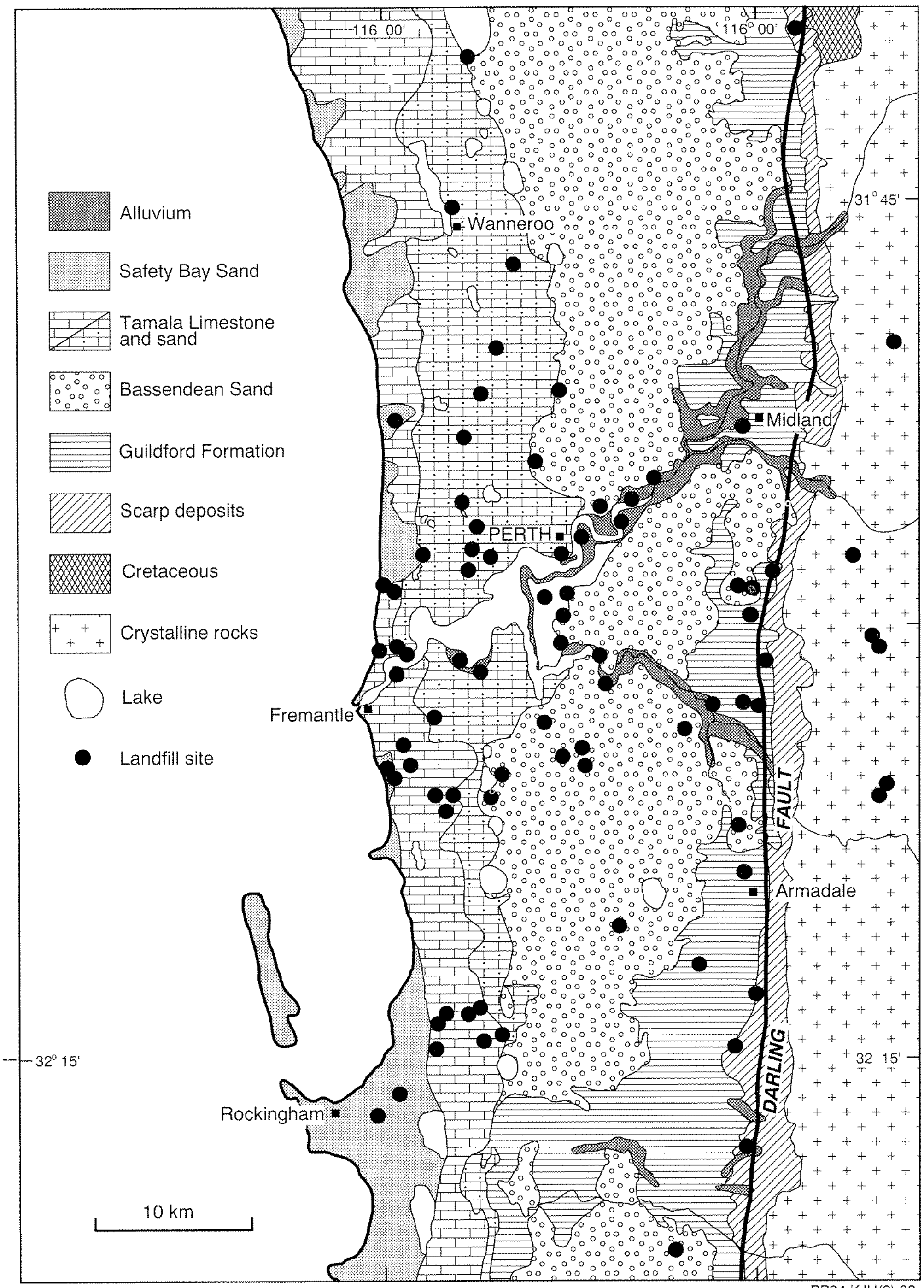


Figure 2. Generalized geology

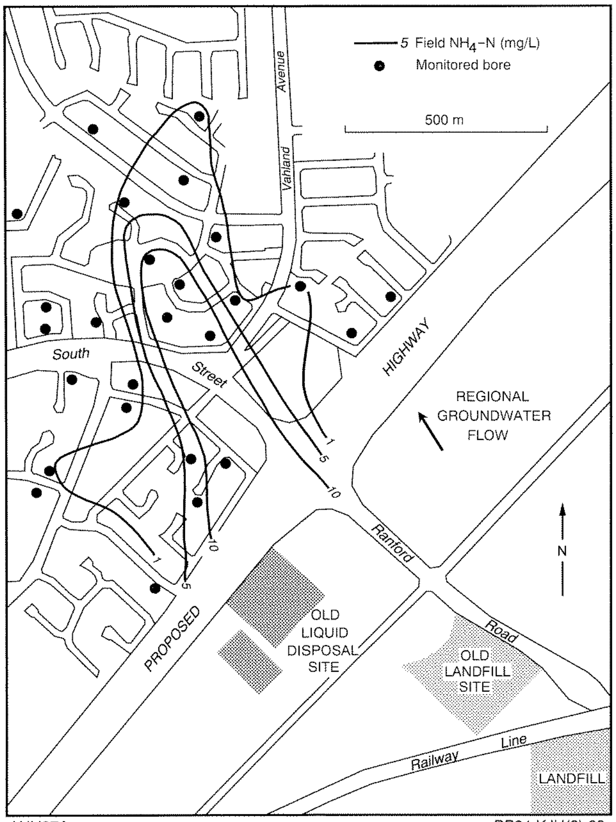
Other potential sources of ammonia

Septic systems

Large parts of Perth are not deep-sewered (Fig. 8), and the potential NH_4–N input from septic tanks can be considerable (Whelan et al., 1981; Appleyard and Bawden, 1986; Appleyard, 1992). However, this input is generally diffuse and concentrations cannot therefore easily be contoured. The input of nutrients from septic systems is at present not quantifiable, and may not be significant when compared with concentrations in pollution plumes from landfill sites.

Fertilizer application

Large amounts of fertilizers are applied annually to Perth's gardens, parks, ovals, and golf courses. Most of this fertilizer is in the form of superphosphate, which contains about 50% ammonium sulfate. Many of the abandoned landfill sites have been converted to sportsgrounds, with consequent high fertilizer use.



KJH27A PP34 KJH(2) 03

Figure 3. Ranford Road disposal site

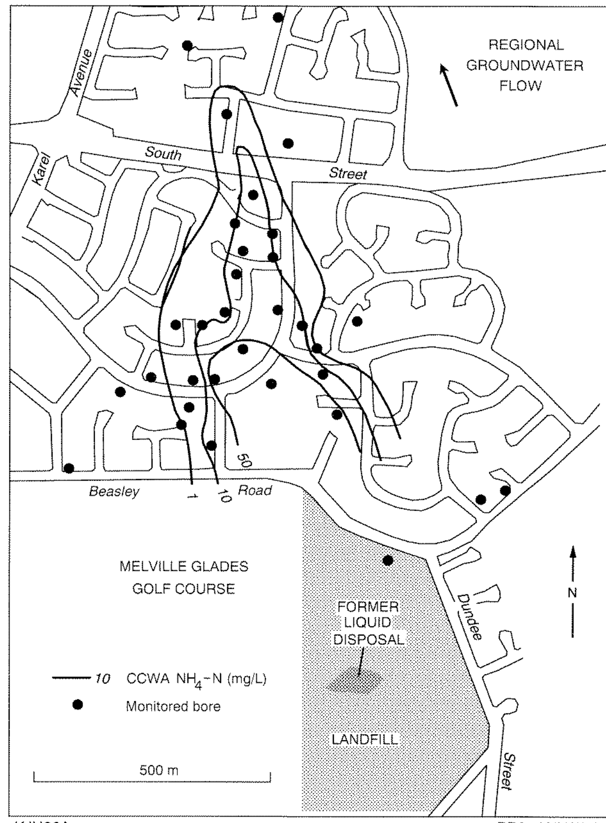


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Figure 4. John Connell Reserve disposal site

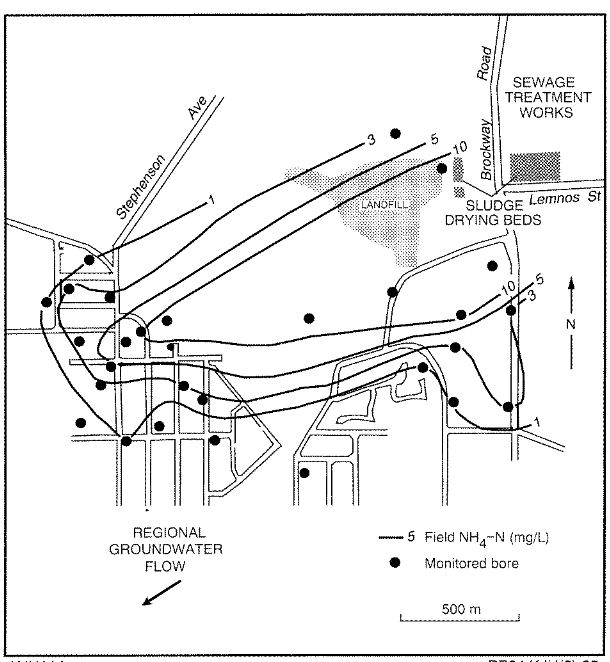

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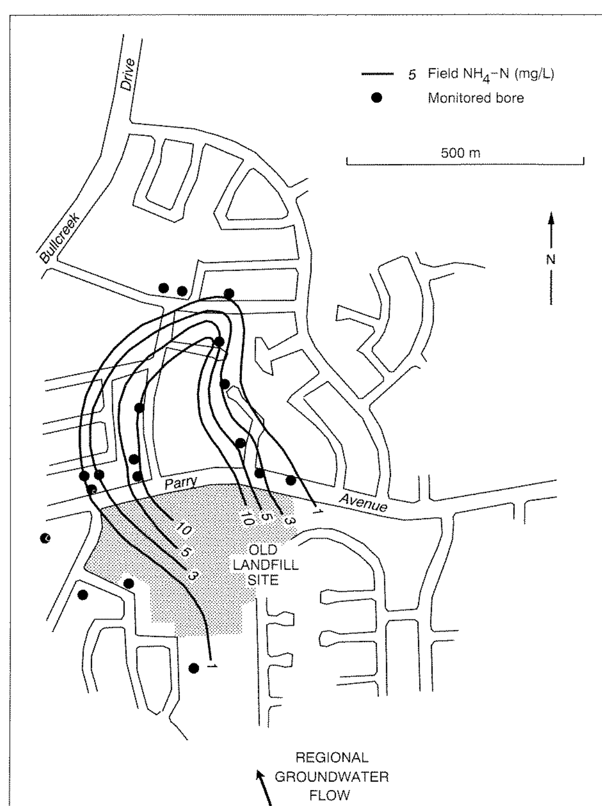
Figure 5. Brockway Road disposal site



KJH28A PP34 KJH(2) 06

Figure 6. John Creaney Reserve disposal site

Table 2. Results of chemical analyses

Local authority / *GSWA no.*	*Site* / *Sample locality*	*pH*	*Colour (TCU)*	*Conductivity (mS/m at 25°C)*	*Total dissolved solids (calc. at 180°C)*	*Total hardness (as $CaCO_3$)*	*Total alkalinity (as $CaCO_3$)*	*Ca*	*Mg*	*Na*	*K*	*HCO_3*	*Cl*	*SO_4*	*NO_3*	*SiO_2*	*Cd*	*Pb*	*Mn*	*Cu*	*Cr*	*NO_3–N*	*NH_4–N*	*Ni*	*Zn*
Armadale	**Hopkinson Rd**																								
111229(a)	MPB red 10 m	5.4	-	603	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	0.05	0.88	-	
111230(a)	MPB yellow 15 m	5.9	-	173	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	<0.02	0.06	-	
111231(a)	MPB green 21 m	5.9	-	190	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	<0.02	0.23	-	
111232(a)	MPB blue 26 m	5.9	-	194	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	<0.02	0.59	-	
Bassendean	**Ashfield Res.**																								
103064	45 Haig Street	4.0	120	185	1 380	580	<2	112	73	178	15	<2	167	817	<1	16	0.004	0.02	2.3	0.02	0.02	<0.02	2.7	0.08	3
Canning	**Ranford Rd**																								
103059	37 Trident Tce	5.6	55	39.4	200	26	16	4	4	48	5	20	65	55	<1	7	<0.001	0.01	-	0.04	<0.02	0.02	9.3	-	<0.0
103060	27 Merrifield Circ.	6.8	120	65.9	380	220	79	74	11	33	8	96	54	159	<1	1	<0.001	0.02	-	0.05	<0.02	0.03	8.5	-	<0.0
Fremantle	**Daly St**																								
111217	33 Douro Street	7.2	-	140	770	-	-	-	-	-	<1	-	-	-	-	-	<0.001	<0.01	-	0.05	0.05	0.20	13	-	<0.0
Gosnells	**Walter Padbury Pk**																								
103067	30 Rushbrook Way	7.9	-	131	-	-	266	57	30	182	12	-	-	-	-	-	<0.001	0.02	0.24	0.05	<0.02	0.09	9.3	<0.05	0.0
Gosnells	**Kelvin Rd**																								
103065	Lot 331 Kelvin Rd	7.9	20	59.9	310	110	95	8	22	80	2	116	117	19	<1	7	<0.001	<0.01	0.16	<0.02	<0.02	0.04	0.06	<0.05	0.0
103066	Lot 249 Victoria Rd	6.7	-	46.2	-	69	-	3	15	61	2	-	-	-	-	-	<0.001	<0.01	<0.02	0.02	<0.02	11	0.07	<0.05	0.0
Melville	**John Connell Res.**																								
103061	41 Gracechurch Cr	7.1	180	205	920	281	689	65	29	128	70	840	201	9	<1	1	<0.001	0.02	-	0.04	0.02	<0.02	97	-	<0.0
103062	73 Gracechurch Cr.	5.9	60	66.9	350	101	39	11	18	84	8	47	142	41	16	6	<0.001	0.02	-	0.05	<0.02	3.5	5.1	-	0.0
Melville	**John Creaney Res.**																								
111218	91 Perry Ave	6.7	-	78.2	430	-	-	-	-	-	34	-	-	-	-	-	<0.001	<0.01	-	<0.02	<0.02	0.02	15	-	0.0
111221	1 Litic Way	6.5	-	84.5	460	-	-	-	-	-	21	-	-	-	-	-	<0.001	<0.01	-	<0.02	<0.02	<0.02	22	-	<0.0
Nedlands	**Brockway Rd**																								
111222	100 Rochedale Rd	7.6	15	156	880	451	457	138	26	159	17	557	231	12	<1	22	-	-	-	-	-	0.04	3.6	-	
111223	John XXIII College	7.7	15	156	720	320	361	92	22	116	27	440	154	51	29	11	<0.001	<0.01	-	0.02	0.02	0.26	27	-	<0.0
111224	Tip gatehouse	7.6	20	159	650	251	361	71	18	91	25	440	151	46	11	18	0.001	0.02	-	0.41	<0.02	0.07	34	-	
111225	7 Whitney Cres.	7.5	10	115	660	352	344	113	17	101	12	420	161	26	<1	15	-	-	-	-	-	0.02	2.4	-	

Table 2. (*continued*)

Local authority *GSWA no.*	*Site* *Sample locality*	*pH*	*Colour (TCU)*	*Conductivity (mS/m at 25°C)*	*Total dissolved solids (calc. at 180°C)*	*Total hardness (as $CaCO_3$)*	*Total alkalinity (as $CaCO_3$)*	*Ca*	*Mg*	*Na*	*K*	*HCO_3*	*Cl*	*SO_4*	*NO_3*	*SiO_2*	*Cd*	*Pb*	*Mn*	*Cu*	*Cr*	*NO_3–N*	*NH_4–N*	*Ni*	*Zn*
Nedlands (cont.)																									
111226	Adderley St	7.8	5	93.9	520	246	221	74	15	89	12	270	130	52	<1	15	<0.001	<0.01	-	0.02	<0.02	0.09	4.9	-	0.0
111227	Hamilton Lane	7.8	10	175	880	358	362	99	27	173	28	442	243	54	18	16	<0.001	0.01	-	0.02	<0.02	4.0	34	-	0.0
111228	101 Rochedale Rd	7.8	5	140	760	354	330	109	20	144	15	403	220	29	2	18	<0.001	0.01	-	0.02	<0.02	0.42	2.2	-	0.0
Rockingham	**Ennis Ave**																								
103068(a)	MPB red 10 m	7.6	-	194	-	-	-	-	-	-	49	-	-	-	-	-	0.004	<0.01	<0.02	<0.02	<0.02	0.05	29	<0.05	<0.0
103069(a)	MPB blue 27 m	8.4	-	87.9	-	-	-	-	-	-	16	-	-	-	-	-	0.004	<0.01	<0.02	0.03	<0.02	0.26	9.6	<0.05	0.0
Rockingham	**Old Golf Course**																								
103070	Wallaroo Rugby Club	8.1	-	62.4	-	-	-	-	-	-	2	-	-	-	-	-	0.001	<0.01	<0.02	<0.02	<0.02	1.6	0.76	<0.05	0.0
South Perth	**Manning Rd**																								
111236(a)	MPB black 5 m	8.3	-	99.8	-	-	-	-	-	-	61	-	-	-	-	-	0.035	0.02	0.04	0.06	<0.02	<0.02	3.1	<0.05	0.2
111237(a)	MPB green 16.5 m	6.0	-	28.3	-	-	-	-	-	-	2	-	-	-	-	-	0.003	0.01	<0.02	0.04	<0.02	0.11	0.13	<0.05	0.0
111240	Trinity Playing Fld	6.6	-	65.2	-	-	-	-	-	-	34	-	-	-	-	-	<0.001	<0.01	0.02	<0.02	<0.02	<0.02	4.7	<0.05	0.1
South Perth	**Thelma St**																								
111238(a)	MPB black 6.3 m	7.7	-	270	-	-	-	-	-	-	14	-	-	-	-	-	0.001	<0.01	0.41	<0.02	<0.02	0.02	69	<0.05	0.0
111239(a)	MPB blue 35.9 m	4.8	-	20.6	-	-	-	-	-	-	0	-	-	-	-	-	0.004	<0.01	<0.02	<0.02	<0.02	0.35	0.28	<0.05	0.0
Stirling	**Hertha Rd**																								
111233	Lot 7 Hertha Rd	7.6	30	152	810	458	200	134	30	100	32	244	160	195	10	24	<0.001	<0.01	0.10	<0.02	0.02	<0.02	22	<0.05	0.0
Stirling	**Yokine Res.**																								
111234	Sir D. Brand Sch.	5.2	80	77.4	300	63	10	7	11	72	18	12	129	44	1	10	<0.001	<0.01	<0.02	0.02	<0.02	<0.02	22	<0.05	0.0
111235	Coolbinia Prim. Sch.	7.5	15	71.8	380	138	60	19	22	77	8	73	132	81	<1	8	<0.001	<0.01	0.02	0.02	<0.02	0.03	4.7	<0.05	<0.0
Swan	**Morrison Rd Bullsbrook**																								
103063	Darling Ra. Saddl.	6.2	5	102	590	111	50	15	18	152	15	61	260	30	<1	72	<0.001	<0.01	-	0.02	<0.02	<0.02	0.18	-	0.0

Note: All values in mg/L except for pH, colour, and conductivity
(a) denotes multi-port monitoring bore

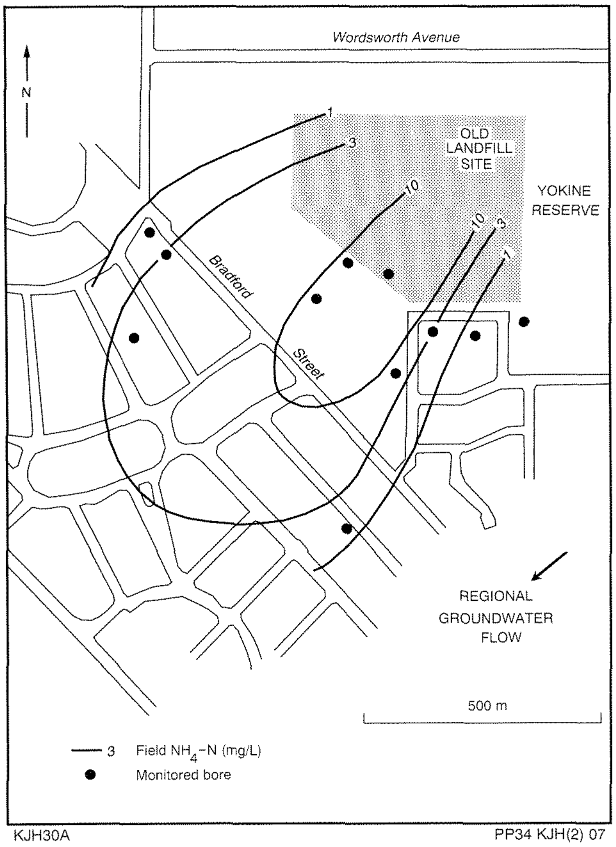


Figure 7. Yokine Reserve disposal site

Table 3. Comparison of ammonia—N determinations

Landfill site	*Bore location*	*NH_4-N (mg/L) CCWA*	*NH_4-N (mg/L) Field*
Hopkinson Road	MPB blue	0.59	3.0
Ashfield Reserve	45 Haig Street	2.7	5–10
Ranford Road	37 Trident Terrace	9.3	>10
	27 Merrifield Circle	8.5	>10
Daly Street	33 Douro Street	13	10
Walter Padbury Park	30 Rushbrook Way	9.3	5–10
Kelvin Road	Lot 331 Kelvin Road	0.06	1–3
	Lot 249 Victoria Road	0.07	0
John Connell Reserve	41 Gracechurch Crescent	97	>10
	73 Gracechurch Crescent	5.1	10
John Creaney Reserve	91 Perry Avenue	15	10
	1 Litic Way	22	10
Brockway Road	100 Rochdale Road	3.6	5–10
	John XXIII College	27	>10
	Tip gatehouse	34	>10
	7 Whitney Crescent	2.4	10
	Adderley Street	4.9	>10
	Hamilton Lane	34	>10
	101 Rochdale Road	2.2	5
Ennis Avenue	MPB red	29	>10
	MPB blue	9.6	>10
Old Golf Course	Wallaroo Rugby Club	0.76	0–0.5
Manning Road	MPB black	3.1	5–10
Thelma Street	MPB black	69	10
Hertha Road	Lot 7 Hertha Road	22	10
Yokine Reserve	near Sir D. Brand School	22	10
	Coolbinia Primary School	4.7	10
Morrison Road	Darling Range Saddlery	0.18	1–3

Superimposed on the plumes resulting from municipal landfill, this is certain to have some impact on NH_4–N concentrations in groundwater.

Liquid domestic -waste disposal

Bulk liquid (including septic) wastes have a greater potential than solid waste to pollute groundwater. They are applied as a 'shock load' in liquid form (Hirschberg, 1984), whereas leachate from solid waste has to be generated first by interaction between waste and water. The three most extensive and concentrated NH_4–N plumes are all associated with sites where large amounts of septic wastes have been disposed (Figs 3, 4 and 5), and probably result more from the liquid waste than the landfill.

Role of hydrogeological setting

The hydrogeological setting, in particular the lithology of sediments beneath a site and depth to watertable, was expected to have a major influence on the size and severity of any contamination plume. Of the 50 landfill sites investigated, 22 are underlain by Tamala Limestone (including its predominantly sandy facies); nine are in Bassendean Sand; and 19 are in a predominantly clayey environment, incluing three sites in clay derived from the weathering of granite (Table 1).

As expected, the predominant factor in plume development appears to be the permeability of the strata. The low infiltration of rainwater and leachate in a clay environment, combined with much higher adsorptive capacities of clays than those of sands, appears to restrict the development of leachate plumes in clay. Only two of the NH_4–N field tests which gave readings above 5 mg/L, were from sites predominantly in clay.

The main contamination plumes have developed in the Bassendean Sand and the Tamala Limestone, both of which have high permeabilities and generally low adsorptivities.

Depth to watertable appears to play a lesser role than lithology in the development of contamination plumes. The watertable was found to be generally shallower in clay than in sand or limestone; however, no extensive plumes were found in clay, and the NH_4–N concentrations were also generally very much lower than those in sand or limestone.

Limitations and merits of method

The investigation was designed to determine the degree of risk to human health from groundwater contamination by leachate from landfills, by attempting to define the extent of contamination plumes. The approach was to

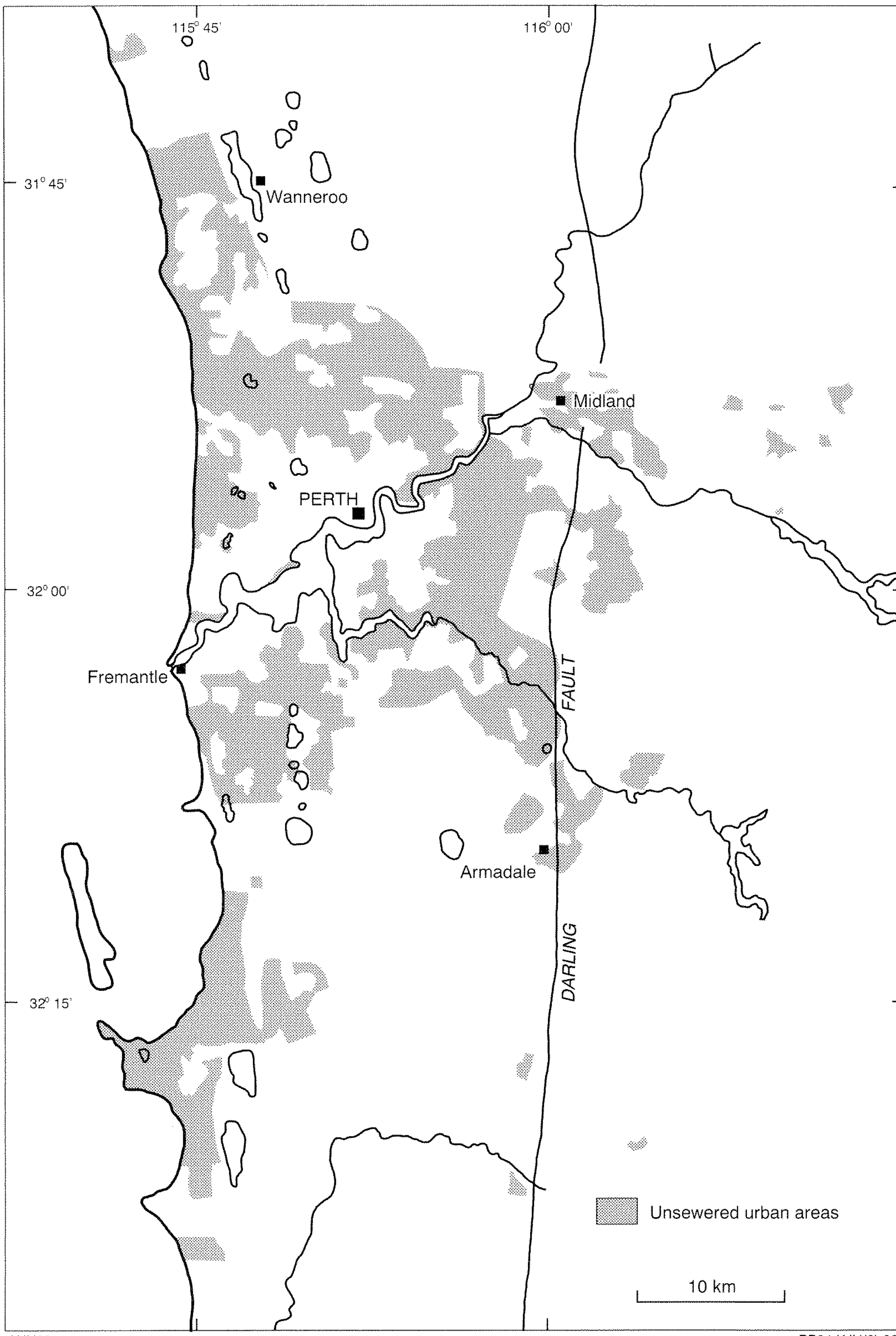


Figure 8. Unsewered urban areas, Perth

analyse water from bores in the vicinity of a number of sites. This approach has inherent limitations. For example, these bores may not all be in hydrogeologically suitable positions, and they may also be completed in different horizons of the respective aquifer. Any attempt at contouring of particular contaminant concentrations can, therefore, only be an approximation of the true extent and shape of a contamination plume, and also cannot reflect a three-dimensional picture. For the determination of the latter, multiple monitoring points at different locations and to different depths are required.

Apart from some limited studies (Bestow, 1977; Barber et al., 1991) no detailed study of the size and shape of

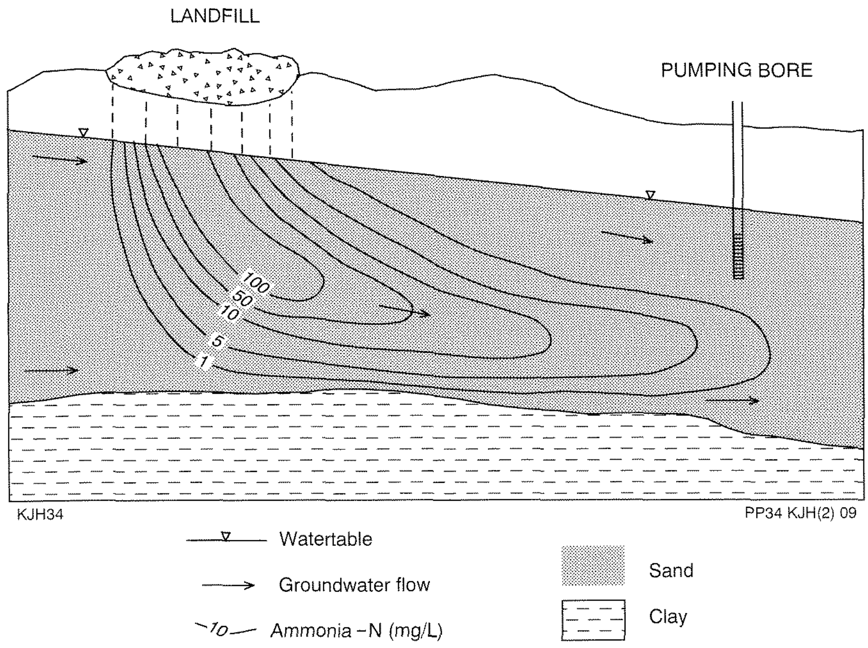


Figure 9. Schematic cross section through a contamination plume

groundwater contamination plumes associated with landfill sites has been undertaken in Perth. Overseas studies have found that pollution plumes emanating from landfill sites typically have a boot-shaped configuration due to gravity differences between leachate and groundwater, and subsequent movement with the general groundwater flow (Fig. 9). Consequently, a shallow bore near the toe of a plume may not intercept any of the contamination which lies beneath it.

During its travel with the groundwater, the strength of the contamination plume is reduced, to varying degrees, by each of the processes of dilution, dispersion, diffusion, adsorption, biodegradation, and chemical reactions.

Despite the above limitations, the results of the investigation showed the merits of this approach. The field-screening of private and monitoring bores for NH_4–N proved to be a fast and reliable indicator to determine the presence of groundwater contamination, as confirmed by chemical analyses. The field measurements were readily and cheaply obtainable and, as long as over-interpretation is avoided, a qualitative assessment of the groundwater quality near landfill sites can be achieved.

Conclusions

Provided inherent limitations are not ignored, field testing for NH_4–N in water from bores in the vicinity of landfill sites has proved to be useful for the determination of the extent of leachate pollution plumes.

Groundwater contamination was found near 21 of 50 investigated sites. However, the contamination appears to consist almost exclusively of elevated levels of ammonia, and increased salinity. Ammonia appears to persist over long distances and periods of time. Analyses for the major ions were generally in the range of normally expected background values, and heavy metals were orders of magnitude below maximum permissible levels. Other studies have shown that pesticides and hydrocarbon compounds were usually well below permissible residual limits, or below detection level. Several large plumes of NH_4–N in groundwater were delineated, and it appears that most of these may be at least partly due to co-disposal of domestic liquid waste.

The development of groundwater contamination plumes appears highly dependent on the permeability and nature of the strata below a site, and to a lesser extent on the depth to the watertable. The development of leachate plumes in predominantly clayey sediments appears largely restricted by the low permeabilities of clays, combined with generally high adsorptive capacities. The main leachate plumes were found to emanate from landfill sites located on Bassendean Sand and Tamala Limestone, both with high permeabilities and generally low adsorptive capacities.

From a human health risk perspective, Perth's landfills have performed quite well; especially when considering that many of the sites are in hydrogeologically unfavourable positions. The potential impact on human health due to leachate production from landfill sites is considered to be very low, as only a small number of irrigation bores in the vicinity of the sites appears to be affected. Furthermore, very few, if any, of these bores are used as a source of drinking water. The Water Authority's borefields are under no threat of contamination from landfill sites, as the latter are all hydraulically downgradient from the borefields.

The potential threat of nutrient input from waste disposal into wetlands needs to be considered in the management of the wetlands.

To ensure continued protection of the groundwater resources and the environment, a high standard of landfill site selection, construction, and management (including groundwater monitoring) is required. Wherever possible, sites should be selected in areas of clay, preferably with a watertable at several metres depth, although this situation is rarely achievable on the Swan Coastal Plain. The requirements for lining and leachate interception should be adressed on a case-by-case basis, with due consideration of all hydrogeological aspects.

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