

# The location and significance of point sources of groundwater contamination in the Perth Basin

by

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## Abstract

Over 1100 point sources of groundwater contamination have been identified in the Perth Basin. Of these, some 700 are in the Perth metropolitan area, while about 400 are located in the remainder of the basin. A risk ranking has been assigned to major waste-creating activities. Most of the point sources of a high-, or moderate to high-risk ranking are within the Perth region and concentrated mainly in zoned industrial areas. The predominantly sandy sediments of the Swan Coastal Plain, which has a generally shallow watertable, are most at risk from groundwater contamination. The groundwater resources in the Perth Basin beyond the metropolitan area are presently at little risk from point sources in the high-risk categories, due to the concentration of both population and secondary industry in the Perth area. The major impact on groundwater quality in the rural parts of the Perth Basin is likely to be from non-point sources, e.g. fertilizer, herbicide and pesticide application in agriculture and horticulture. Non-point sources are also suspected to be major contributors to groundwater contamination in the Perth metropolitan area.

**KEYWORDS:** Groundwater, contamination, point sources, Perth Basin.

## Introduction

### Background

The Perth Basin contains large amounts of usable groundwater, often at shallow depth and therefore susceptible to contamination. More than 80% of Western Australia's population reside on the basin and, in many areas, groundwater is the only water supply. Total abstraction of groundwater from the Perth Basin is estimated to be about  $300 \times 10^6 \text{ m}^3/\text{year}$ , most of it from the shallow, unconfined aquifers (Australian Water Resources Council, 1987). For the Perth area, annual abstraction from the unconfined aquifers is about  $220 \times 10^6 \text{ m}^3$ , or about 75% of the total groundwater usage for the basin. Contamination of groundwater is almost unavoidably connected with many human activities, be it industrial development, agriculture, residential development, or outdoor sporting and recreational facilities. An increase in awareness of the hazards and consequences of such contamination has raised public concern over the last few years about the threat to valuable groundwater resources.

The Geological Survey of Western Australia (GSWA) has been involved in groundwater contamination studies since the early 1970s, principally in the role of advisers in hydrogeological matters to various other government agencies, including the former Effluent Licensing Advisory Panel responsible for the licensing of industrial waste discharges until the mid-1980s. Data from past

investigations into numerous groundwater contamination problems have been collected and held by a variety of government and local government bodies, and individual industries and consultants. It was also found that, in many cases, the mode of data collection and storage differed from agency to agency, often making the interpretation and comparison of different data sets difficult and, in some cases, almost impossible.

### Purpose and scope

In the mid-1980s, the GSWA began the task of incorporating the existing data on point sources of groundwater contamination in Western Australia into one readily accessible file with a uniform classification system. Non-point sources of contamination, e.g. fertilizer, herbicide and pesticide application in agriculture, roadside spraying, and areas serviced by septic tanks were omitted from this compilation. Also excluded were accidental spills, and leaking underground storage tanks.

It was recognized that the compilation of such an inventory would constitute a major task and would best be approached in several stages. The first stage was centred on Perth, where the majority of Western Australia's population (about 70%) resides, and where most secondary industry is situated. This study extended from Two Rocks in the north to Mandurah in the south, and eastward to just beyond Wundowie. Two maps and a computer listing presenting the results of this investigation were published by the GSWA (Hirschberg, 1988), and the results of the investigation were reviewed by Hirschberg (1989).

The second phase of the investigation extended the coverage to the remainder of the Perth Basin (Hirschberg, 1991). The onshore Perth Basin extends from Northampton in the north, to Augusta in the south, and from the coast in the west to the Darling Scarp in the east (Fig. 1). It forms a long and narrow coastal strip of approximately 1000 km in length, and an average width of about 45 km, covering an area of about 45 000 km<sup>2</sup>.

This paper reviews the results of the two investigations, and complements the groundwater contamination vulnerability maps of the Perth Basin, currently being prepared by the GSWA.

### Previous work

Previous studies of point sources of groundwater contamination in the Perth region have been detailed by Hirschberg (1986, 1989). Outside the Perth metropolitan area there have been few such investigations apart from a few local assessments of waste-disposal licence applications. Regionally, several maps at various scales have been published showing at least some aspects of groundwater contamination. The GSWA has produced several 1:50 000 environmental geology maps of selected areas of the basin, and these include comments on waste-disposal aspects. Land-suitability maps, at the scale of 1:1 000 000, were prepared by D. P. Commander of the GSWA and published by the Department of Agriculture (Ryan and Payne, 1989). These maps assessed the potential impact of piggeries, and assist in their improved siting in the future.

### Climate

The Perth Basin has a mediterranean-type climate, with warm, dry summers and cool, wet winters. The annual rainfall decreases from about 1200 mm in the far south to less than 400 mm in the north. The average annual pan evaporation increases from about 1000 mm in the south to about 2600 mm in the north and, for most of the basin, greatly exceeds the annual rainfall.

### Population

The population distribution for the Perth Basin is shown in Figure 2 (Commonwealth Bureau of Statistics figures for 1990). Approximately 1.33 million people, or about 81% of the population of Western Australia, live on the basin. About 70% of the total population (1.19 million) live in the Perth metropolitan area. Apart from Perth and its surroundings, there are only four population centres with more than 10 000 inhabitants—Geraldton, Mandurah, Bunbury and Busselton. South of Perth there are a number of small to medium-sized settlements, but to the north of Perth the population is sparse with only Dongara and Moora of any notable size. This pattern is also reflected in the density of the rural population, with 100–500 people per 100 km<sup>2</sup> in the southern part of the basin, and 5–20 people per 100 km<sup>2</sup> in the northern part. The population distribution can be expected to influence the locations and density of point sources of groundwater contamination.

### Physiography

The physiography of the onshore Perth Basin has been described by Playford et al. (1976) who divided the basin into a number of physiographic regions (Fig. 3) which can

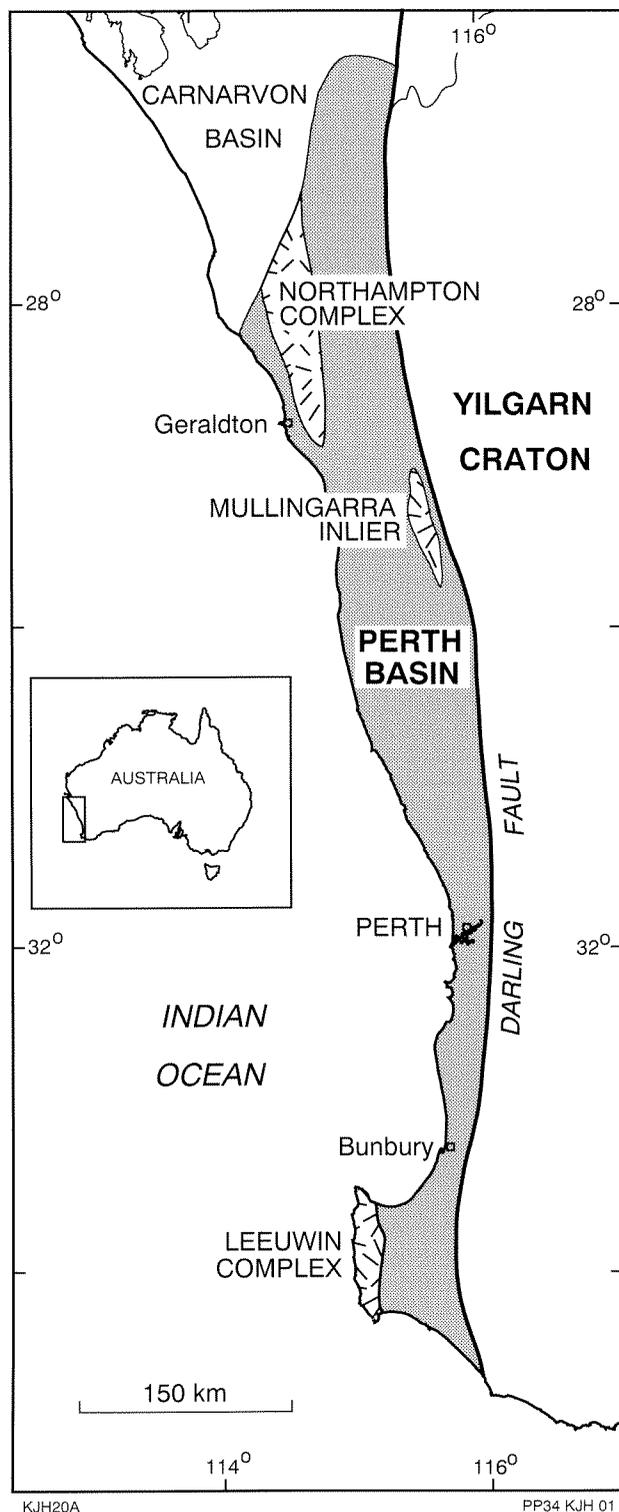


Figure 1. Location plan, Perth Basin

Plain, which stretches from near Geraldton in the north to Busselton in the south.

## Hydrogeology

The Perth Basin is an elongate sedimentary trough, bounded in the east by the Darling Fault, which separates the sedimentary sequence of the basin from the mainly crystalline rocks of the Archaean Yilgarn Craton. Several inliers of Proterozoic rocks (Northampton Complex, Mullingar Inlier, and Leeuwin Complex) are located within its boundaries (Fig. 1). The basin contains up to 15 000 m of sedimentary rocks which range in age from Silurian to Quaternary. The pre-Quaternary sediments consist predominantly of formations of interbedded sandstone and shale of varying thickness and proportions, and occur in a number of structurally controlled subdivisions. The pre-Quaternary sediments outcrop on the upland plateaus where they are generally heavily lateritized whereas, on the coastal plains, they are blanketed by the Quaternary sediments collectively referred to as 'superficial formations' which consist mainly of sand, silt, clay, and limestone.

The Perth Basin contains a number of major confined and unconfined aquifers (Allen, 1990; Commander et al., 1990). Groundwater in the pre-Quaternary aquifers is mostly confined, although beneath the upland plateaus which form the main intake areas, the shallow groundwater is unconfined. The depth to watertable in these areas is usually more than 20 m. The Quaternary superficial formations constitute a major aquifer and contain unconfined groundwater, with the watertable usually at shallow depth. This shallow groundwater is particularly vulnerable to contamination.

## Point sources of groundwater contamination

### Definitions

'Contamination' and 'pollution' are used in most dictionaries as synonyms. The Western Australian Environmental Protection Act of 1986 defines both terms as 'any direct or indirect alteration of the environment to its detriment or degradation or to the detriment of any beneficial use'. This definition is adopted here; however, only the term 'contamination' is used.

Point sources of contamination are known or inferred localized sites of waste production or disposal. Non-point sources, however, generally cover larger areas over which diffuse groundwater contamination occurs.

### Data sources

The data for the Perth metropolitan region were obtained in 1987 from a number of Western Australian government agencies, the major ones being the Water

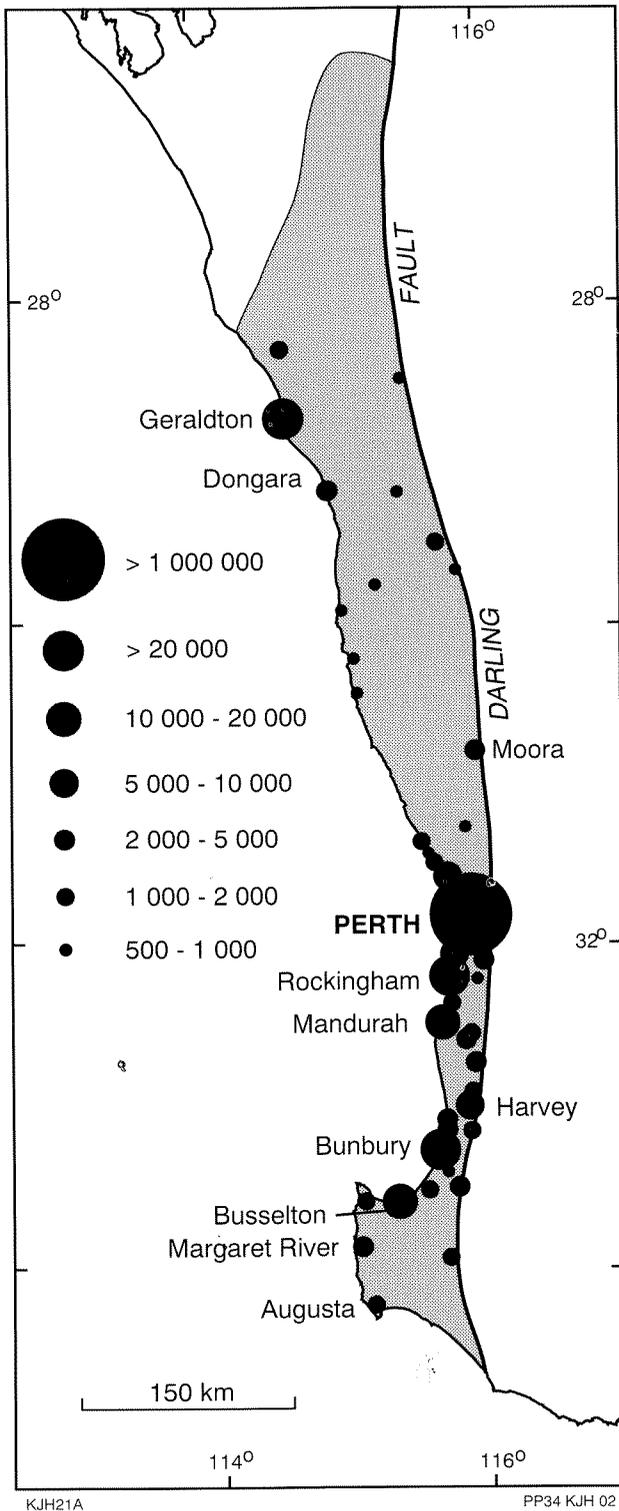
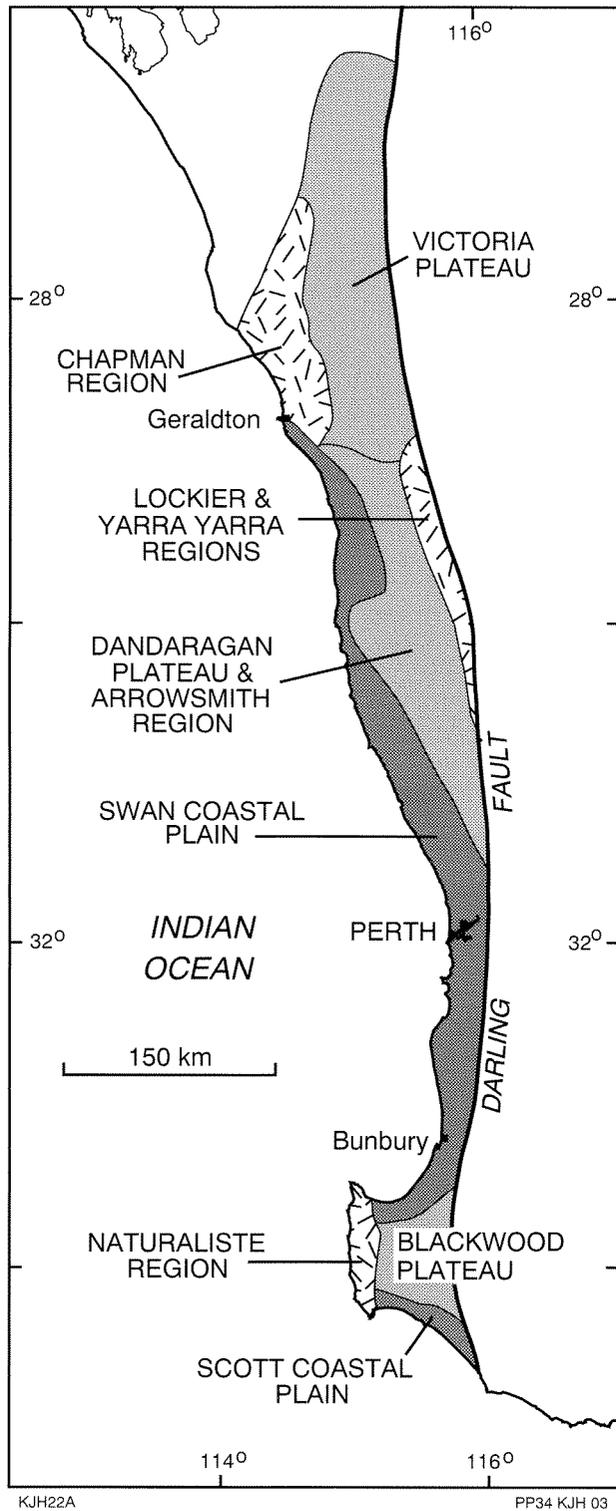


Figure 2. Perth Basin — population distribution 1990

be broadly grouped into coastal plains (Swan and Scott Coastal Plains), upland plateaus (Victoria, Dandaragan and Blackwood Plateaus), and miscellaneous regions (Chapman, Lockier, Yarra-Yarra, Arrowsmith and Naturaliste Regions). The most important region in the context of groundwater contamination is the Swan Coastal



**Figure 3. Perth Basin — physiographic subdivisions**

Authority, the Health Department, the Chemistry Centre (W.A.), the Department of Agriculture, and the GSWA. Data were also collected by interviewing all local government authorities and a number of other organizations, and this information was supplemented by numerous site visits and data supplied by individual companies. The data for the remainder of the Perth Basin

were obtained in 1990/91 through interviews with all local government authorities, and inspections of a limited number of sites. It is estimated that about 95% of all point sources in the Perth area were recorded during the 1987 survey. However, there has been intensive industrial development since then, especially in Kwinana and Canning Vale, and the data file does not include most of these new sites. These industrial areas probably require update surveys every few years. It is considered that almost 100% of all sources outside the metropolitan area have been recorded.

The information collected usually consisted of the names and addresses of companies and industries, the local government authority, the location and type of activity, the type of waste produced, and sometimes the major contaminants. A computer data base has been established which also includes grid coordinates, and data on existing monitoring and remedial measures where applicable.

### Grouping of contamination sources

There is a very wide range of industrial and other human activities, and they can be assigned to broad groupings according to the major contaminants they are expected to produce. Following discussions with officers of the Chemistry Centre, seven main groups were defined by Hirschberg (1989) for the Perth area investigation. These main groups, and their predominant activities, are given in Table 1.

### Risk ranking

Some contaminants pose a greater threat to the environment, including human health, than others. Once the main contaminants from each activity are known, the anticipated severity of groundwater contamination can be assessed. In a report of the Kwinana Industries Co-ordinating Committee in 1987, three categories of contamination risk were defined. In the present paper, the number of categories has been expanded to five, as follows.

- Category 1 - high risk to the environment or population due to toxicity, volume of material, or location. Requires careful management, regulation, and rehabilitation.
- Category 2 - moderate to high risk due to toxicity, volume of material, or location. Requires careful management and regulation.
- Category 3 - moderate risk due to type, volume, or location of material. Requires regular monitoring and assessment.
- Category 4 - moderate to low risk due to type, volume, or location of material. Requires regular assessment, and often also monitoring.
- Category 5 - low risk due to type, volume, or location of material. Should be recognized and recorded; no monitoring or control required.

**Table 1. Grouping and risk ranking of contamination sources**

Contamination Group	Major Activities	Risk category	Number of Sources		Total
			Perth metropolitan area	Outside metropolitan area	
Industrial-waste sources	metal-finishing shops	1	44	4	48
	metal prod., foundries, casting sand disposal, power stations	2	48	34	82
	mech. workshops, battery recycling	2	65	5	70
	prod. of cement, bitumen, fibreglass, paper etc	3	57	5	62
	laboratories, photo proc.	3	28	0	28
	laundries, drycleaners	3	8	2	10
Chemical-based waste sources	production of all chemicals and pesticides	1	42	-3	39
	prod. of paints, glues, solvents	1	11	1	12
	prod. of fertilizers	2	7	2	9
	Sub-total		310	50	360
Landfill sites	domestic-waste disposal	3	96	96	192
Liquid-disposal sites	domestic-liquid disposal, sewage-treatment plants, large septic systems	3	57	126	183
		Sub-total	153	222	375
Animal-based waste sources	woolscourers	1	7	0	7
	tanneries	1	16	1	17
	piggeries	3	106	42	148
	meat rendering, packing, processing	3	27	10	37
	abattoirs, feedlots	3	20	28	48
Food-production waste sources	prod. of starch/gluten, bakeries	4	16	1	17
	dairies, cheese factories	4	10	5	15
	fruit/veg. producers, wineries, breweries, soft-drink production	4	21	4	25
Sites for disposal of bodies	cemeteries	5	16	43	59
	burial sites for animals	5	4	0	4
	Sub-total		243	134	377
		<b>Total</b>	<b>706</b>	<b>406</b>	<b>1 112</b>

In general, heavy metals, cyanide, arsenic, and all herbicides, pesticides, hydrocarbons, and phenolic compounds would fall into categories 1 and 2; high levels of nutrients and surfactants into categories 3 and 4; and moderate nutrient levels, and increased salinity, into category 5.

The risk categories for the various activities in the seven contamination groups used in this paper are given in Table 1. Most industrial activities, including chemicals production, woolscouring and skin tanning have a high-risk ranking and are in category 1; battery recycling and fertilizer production are in category 2 of high to moderate risk; most animal-based activities (other than woolscouring and tanning), waste from food production, and also domestic waste disposal, are of moderate risk and are in category 3; waste from food production is in the moderate-to low-risk category 4; and cemeteries and disposal sites for animal carcasses constitute the low-risk

category 5. Owing to the great variety of activities, most contamination groups contain more than one risk category.

## Distribution of contamination sources

A total of 1112 point sources of groundwater contamination have been identified in the Perth Basin. Of these, 706 (63%) are located in the Perth metropolitan area (Hirschberg, 1989).

For convenience, the seven contamination groups have been combined into three more general classifications: the first (Fig. 4) comprises all sources of industrial and chemical waste production; the second (Fig. 5) contains all landfill sites and domestic liquid-waste disposal sites; and the third (Fig. 6) is made up of all sources of animal-based waste, waste from food production, and also cemeteries and sites for the burial of animal carcasses.

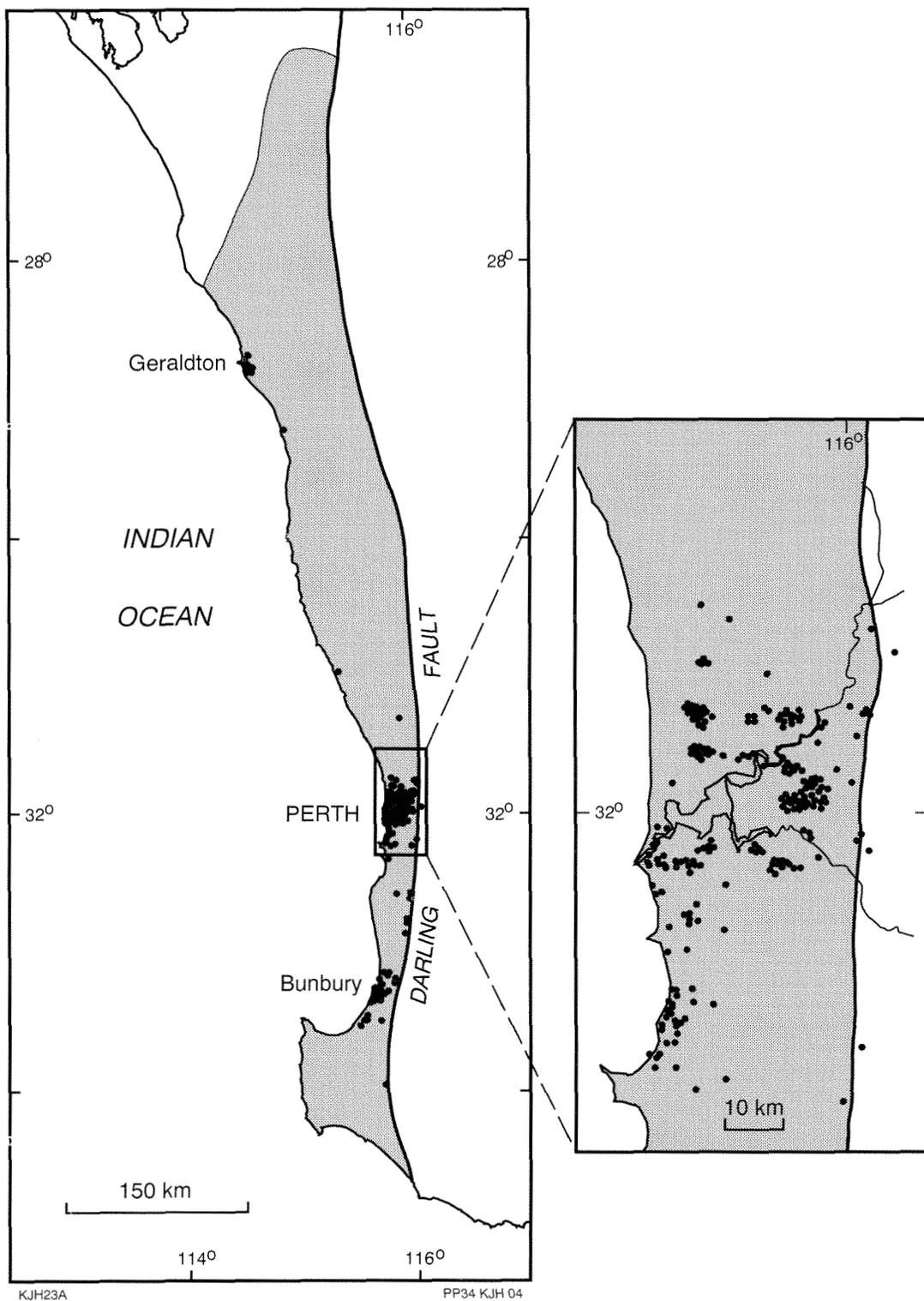


Figure 4. Sources of industrial and chemical waste

### Industrial and chemical-based waste sources

Figure 4 shows the locations of the point sources of industrial and chemical waste production, with those for the Perth metropolitan area shown in the inset. In Perth, 310 industrial and chemical point sources were identified. These sources are concentrated mostly in zoned

industrial areas, particularly in Kwinana. It is here, and also in Canning Vale, O'Connor, Osborne Park, and Welshpool-Kewdale that most of the cases of severe groundwater contamination in Perth are located. Only 50 additional sites of this kind occur in the remainder of the Perth Basin, and there are only two other locations where sources of industrial and chemical waste are

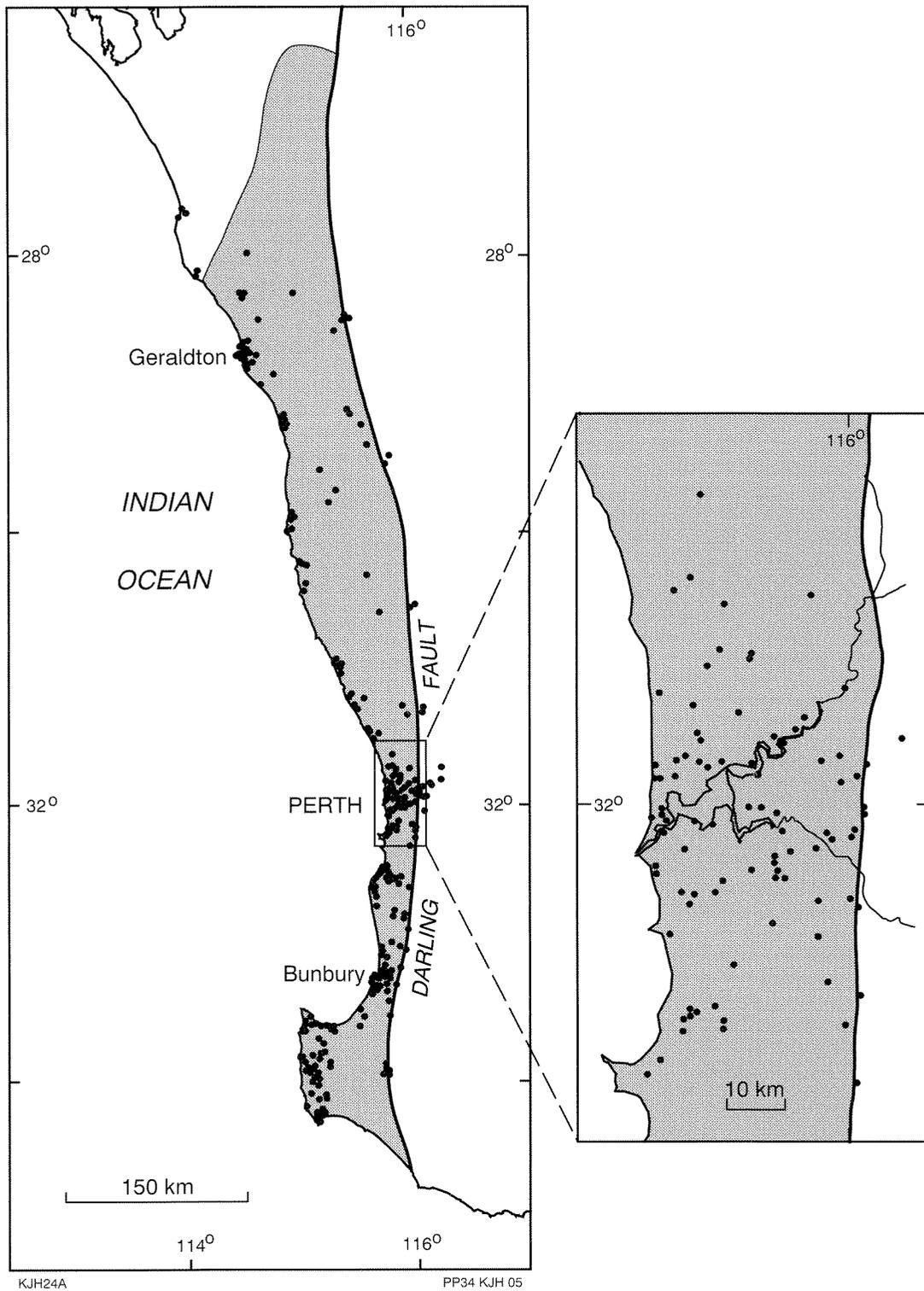


Figure 5. Landfill sites and liquid-disposal sites

concentrated, namely the Bunbury–Kemerton area, and the Geraldton–Narngulu area. The few remaining sites of this type are scattered along the Darling Scarp between Pinjarra and Harvey. Of the total of 360 such sources, 260 have the high- or moderately high-risk ranking of 1 or 2, while the remaining 100 sources are in the moderate-risk category 3.

### Landfill sites and liquid-disposal sites

Figure 5 shows the distribution of landfill sites and liquid-disposal sites which are in the moderate-risk category 3. In the Perth metropolitan area, 153 such sites were identified, but a further 222 sites occur in the remainder of the Perth Basin. Compared with the

distribution of industrial and chemical waste sources (Fig. 4), these sites are more evenly distributed over the basin, with noticeable concentrations at the major population centres of Geraldton, Dongara, Mandurah, Bunbury, and Busselton. Leachate production can be expected to be much less in the northern parts of the basin, owing to the decrease in the annual rainfall and the increase in evaporation reducing the impact of contamination from landfill sites in these areas.

Approximately one-third of all sites in this group outside the Perth metropolitan region are septic systems for caravan parks and tourist developments. They occur in smaller clusters, predominantly along the coast, where most holiday resort centres are located. A surprising feature in the southern part of the basin is the relatively dense distribution of landfill sites on the western part of the Blackwood Plateau, and on the Leeuwin Complex. Most of these sites have never been gazetted, and they are comparatively small. The Shire of Augusta–Margaret River is at present undertaking to close most of these uncontrolled waste-disposal sites and to replace them with a small number of properly approved and managed landfill sites.

### Animal-based and food production waste sources, and cemeteries

The contamination sources related to animal-based waste, waste from the food industry, and cemeteries and sites for the disposal of animal carcasses, are shown in Figure 6. The animal-based waste sources have a moderate-risk ranking of 3, with the exception of tanning and woolscouring which have a high-risk ranking of 1. All sources of food production waste have a moderate- to low-risk ranking of 4, and cemeteries and sites for animal carcass burial are of the low-risk category 5.

In the Perth inventory, 176 animal-based sources, 47 sources related to food industry, and 20 cemeteries and four sites for the burial of animal carcasses were identified. An additional 81 animal-based sources, 10 food-industry sources, and 43 cemeteries are located in the remainder of the Perth Basin. Within the Perth area the sites are evenly distributed, with the only major concentration of tanneries, fellmongers, and related industries, in the Coogee area. Outside the Perth area the sources consist mostly of piggeries and dairies and are concentrated mainly in the Geraldton, Moora–Gingin, and Harvey–Bunbury areas. Cemeteries are found at or near all settlements of any size. Outside Perth, animal carcasses are generally buried at the municipal waste-disposal sites.

### Threat to groundwater resources

The seriousness of existing or potential groundwater contamination from point sources can be assessed from both quantitative and qualitative aspects: by determining firstly the number and locations of such sources; and secondly, where the majority of sources in the higher risk categories are situated (Table 2).

**Table 2. Contamination risk ranking**

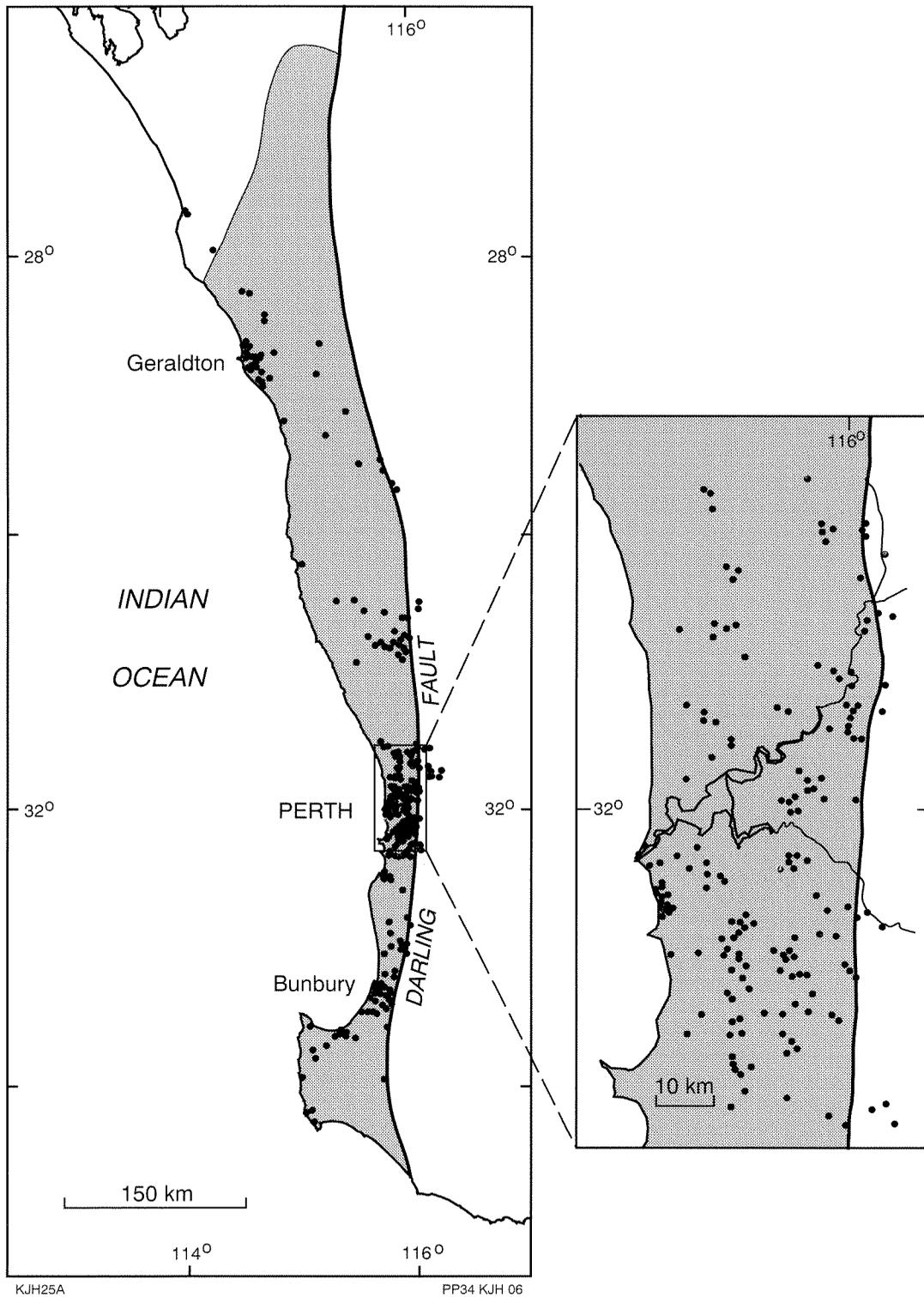
<i>Risk category</i>	<i>Perth Basin total</i>	<i>Perth metropolitan area</i> <i>(percentage of total)</i>	<i>Perth Basin outside metropolitan area</i>
1	123	120 (98)	3 (2)
2	161	120 (75)	41 (25)
3	708	399 (56)	309 (44)
4	57	47 (82)	10 (18)
5	63	20 (32)	43 (68)
Total	1 112	706 (63)	406 (37)

Of the total of 1112 point sources of groundwater contamination identified in the Perth Basin, 706 (about 63%) are located in the Perth metropolitan region, as was expected from the distribution of the population. The remaining 406 sources (37%) are spread over the wider area of the Perth Basin, with noticeable concentrations in the Geraldton and Bunbury regions.

The sources in the high- and moderate to high-risk categories 1 and 2 originate mainly from secondary industry and the production of chemicals, but also include tanneries and woolscourers (Table 1). Table 2 shows that 98% of all sources with a risk ranking of 1, and 75% of those with a ranking of 2, are located in the Perth metropolitan area. The remainder are located mostly in the industrial areas of Narngulu and Kemerton, with a few scattered over the remaining area of the basin. Point sources in these categories pose the greatest threat to groundwater quality should contamination occur.

The moderate-risk category 3 comprises landfill and domestic liquid-disposal sites, and waste from piggeries and other animal-based industry. The Perth area contains 56% of these sources. The remaining 44% are scattered over the basin and include about 60% of all landfill and liquid-disposal sites.

Compared with a typical metropolitan landfill site, the country waste-disposal sites are generally quite small although, due to the general lack of supervision and control, the risk of some local groundwater contamination cannot be discounted. The liquid-disposal sites include septic/leach drain systems of larger than domestic size. These service country hospitals, schools, and caravan parks: the latter are mostly located along the ocean foreshore, at the outflow end of the groundwater flow systems. This category can therefore generally be considered to pose only a minor threat to groundwater resources.



**Figure 6. Sources of animal-based waste, food industry waste, and cemeteries**

Category 4 sources, with a moderate to low-risk ranking, consist of waste from food production: 82% are within the Perth area. Category 5, with a low-risk ranking, comprises cemeteries and sites for animal carcass disposal. The Perth area contains 32% of these. The threat of

groundwater contamination from these sources is considered to be minimal.

Analysis of these data indicates that the unconfined aquifers of the Swan Coastal Plain, particularly in the

metropolitan region, are most at risk of contamination from point sources. Contributing factors include the predominantly sandy sediments, a generally shallow watertable, population concentration, and the location of secondary industry. Careful planning in particularly sensitive areas is essential to avoid problems in the future.

The Perth Basin outside the metropolitan area is to date relatively unaffected by groundwater contamination from point sources. The normally shallow unconfined groundwater in the Quaternary sediments of the coastal plains is so far largely unaffected because contamination sources with a high- or moderate to high-risk ranking are scarce. Moreover, many of the sources in the moderate- and low-risk categories are located along the ocean foreshore at the outflow end of the groundwater systems. The unconfined groundwater beneath the upland plateaus is to a large extent protected from groundwater contamination by a depth to the watertable commonly in excess of 20 m. The groundwater in the pre-Quaternary confined aquifers is least at risk, because overlying extensive clay formations largely retard downward movement of groundwater and contaminants. As the clays also usually have good adsorptive capacity, the risk of contamination of the confined aquifers is considered minimal.

The major impact on groundwater quality in the Perth Basin outside the metropolitan area is considered more likely to come from non-point sources such as fertilizer, herbicide and pesticide application in agriculture, and urban areas with septic systems. The non-point sources are also suspected of being major contributors to groundwater contamination within the Perth metropolitan area. Large parts of urban Perth are still unsewered; many local government authorities apply large amounts of weedicides during roadside spraying; fertilizer application in horticulture and viticulture is extensive; and fertilizers and pesticides are also applied regularly and extensively on the numerous parks, playgrounds, sportsgrounds, and golf courses. The impact of these non-point sources warrants special study.

## Conclusions

Over 1100 point sources of groundwater contamination have been identified in the Perth Basin. Of these, some 700 are in the Perth metropolitan area, and about 400 have been identified in the remainder of the Perth Basin.

Of the major aquifers in the Perth Basin, the groundwater resources in the predominantly sandy Quaternary sediments of the Swan Coastal Plain, with a generally shallow watertable, are most at risk from groundwater contamination. The risk to the groundwater in the unconfined aquifers in areas where the watertable is deep, and to the confined aquifers in the pre-Quaternary sediments, is considered to be small.

Ninety-eight percent of all point sources of groundwater contamination of a high-risk ranking, and the majority of the sources with a moderate to high-risk ranking, are in the Perth metropolitan region and

predominantly in areas which are zoned industrial. Of these, the Kwinana area is the worst affected and contains the majority of serious cases of groundwater contamination known in Perth. Elsewhere on the Perth Basin, the groundwater resources can generally be considered under only minor threat from point sources in the high-risk categories, with the exception of local concentrations of such sources in the Narngulu and Bunbury areas. Owing to rapid industrial development in some areas, update surveys may be required every few years.

Sources in the categories with a moderate to low-risk ranking are more widely scattered over the whole of the Perth Basin. However, the risk of groundwater contamination from these sources is considered small for most of the basin.

The major impact on groundwater quality in the rural parts of the Perth Basin is likely to be from non-point sources, e.g. fertilizer, herbicide and pesticide application in agriculture and horticulture. Non-point sources are also suspected of being major contributors to groundwater contamination within Perth. These sources should be studied in detail.

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