

Hydrogeology Report No. 1995/7

**GROUNDWATER QUALITY IN THE
COCKBURN GROUNDWATER MANAGEMENT
AREA, PERTH METROPOLITAN REGION**

by

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NOTE

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Western Australia

Geological Survey

Perth, 1995

1. Introduction

Perth is unique amongst Australia's capital cities in having large groundwater resources which have resulted from a favourable coincidence of suitable climatic and geological conditions. Groundwater currently supplies about 70% of Perth's total water usage, and is used for public water supply; for irrigation of parks, sporting grounds and gardens; for horticulture, and; for industrial use. Groundwater is also essential for maintaining a number of ecosystems, and careful management is needed to balance the needs of the environment, and the needs of groundwater users.

The Water Authority manages the utilization and protection of groundwater resources within a number of groundwater management areas which cover the Perth region. The Cockburn Groundwater Management Area (CGMA) is amongst the most important of these areas. Although groundwater in the area is not used for public water supply, the competing needs of the largest industrial area in Western Australia, urban development, market gardens, wetlands with a high conservation value and a vulnerable marine environment create complex groundwater management problems, particularly with the management of groundwater quality.

This report examines the current status of groundwater quality in the area, and the effect that landuse has had on water quality. The environmental impacts of the discharge of contaminated groundwater to wetlands and Cockburn Sound are also discussed.

2. Physical setting

2.1 Location and landform

The CGMA is located about 15 km to the south of Perth, and covers an area of about 900 square kilometres (Fig. 2.1). Cockburn Sound forms the western boundary to the management area, and a number of roads form other boundaries. It is located to the west of the Jandakot Underground Water Pollution Control and Public Water Supply areas (Fig 2.1), which provide groundwater for potable use.

2.2 Climate

The region has a Mediterranean-type climate, with a cool wet period from April to October, and a warm dry period from November to March. The annual average rainfall is about 800 mm, but actual rainfall may vary considerably from the average, and sequences of above or below average rainfall are common.

About 90% of the falls between April and October. However, rainfall only exceeds evaporation between May and August, and for the rest of the year there is a rainfall deficit.

2.3 Landuse

Landuse in the groundwater management area is mixed, and includes heavy industry, residential development, and land used for agricultural purposes (Fig. 2.2). The CGMA also contains a number of wetlands which have a high conservation value that is of national significance. Thomsons Lake is listed under the Ramsar Convention, and its conservation value is internationally significant. It is proposed that this and adjoining wetlands will be protected through the formation of the Beeliar Regional Park.

2.4 Geomorphology

The Cockburn Groundwater Management Area is located on the Swan Coastal Plain which consists of a series of north-south trending dunal landforms (Fig. 2.3) which increase in age in an easterly direction.

The most westerly of the dune systems are the Quindalup dunes, which are up to 5 m high, and are covered with a low coastal scrub or open tuart woodland, and abut a former shoreline that is the western boundary of the Spearwood dune system.

The Spearwood dunes form a series of north-south trending ridges up to 30 m high, which in uncleared areas are covered with a tuart woodland. A chain of wetlands containing brackish to saline water occurs in a prominent inter-dunal depression near the western margin of the spearwood dunes. Another chain of wetlands containing fresh groundwater (the Beeliar wetlands) is located where this dune system abuts the Bassendean dunes in the eastern part of the CGMA.

2.5 Geology

The CGMA is located in the Perth Basin (Playford *et al.*, 1976) and is underlain by up to 12 000 m of sedimentary rocks of Permian to Quaternary age. However, only groundwater in sediments of Late Tertiary to Quaternary age has been affected by human landuse, and therefore only these sediments are considered in this report. These sediments are informally referred to as the 'superficial formations' (Allen, 1981; Davidson, 1994) and consist of sand, silt, clay and limestone. The stratigraphy of these sediments is summarised below, and their spatial distribution is shown in Figure 2.4.

Coastal areas of the groundwater management area are underlain at shallow depth by recent, unconsolidated sand referred to as the Safety Bay Sand. These sediments are typically 3 to 10 m thick in the area, and are underlain by grey, silty sediments with seaweed fragments which were deposited when the sea-level was higher than at present. A marine scarp forms the eastern boundary of these sediments, and a thin shelly clay unit (typically less than 1 m thick) separates the Becher Sand from the underlying Tamala Limestone.

Most of the Cockburn Groundwater Management Area is underlain by the Tamala Limestone. This geological formation consists of interbedded sand and sandy limestone of marine origin up to 50 m thick, and forms prominent limestone ridges in the west, and is sandy near the surface in the eastern part of the subcrop area. A small area to the east of the Beeliar wetlands is underlain by leached, white sand up to 50 m thick of marine origin which comprises the Bassendean Sand.

The Gnangara Sand does not outcrop, and consists of very fine to very coarse sand and gravel up to 15 m thick, which is probably alluvial in origin. The Ascot Formation also shows no surface exposure, and consists of limestone and sand with shell beds and minor clay. This formation is typically 10 to 20 m thick in the CGMA, and is probably of marine origin.

3. Groundwater occurrence

Groundwater is found throughout Western Australia, and its distribution is strongly influenced by the properties of the soil and rock through which water passes, and by the prevailing climate.

The best quality groundwater is generally found where rainfall is high, evaporation is low, and soils are sandy. Under these conditions, rainfall can readily percolate into the ground to provide recharge for groundwater. At some distance below the ground, pore spaces are filled with water rather than air, and the surface at which the transition from air-saturation to water-saturation takes place is called the watertable (Fig. 3.1).

Water is stored underground in the voids between sand grains in unconsolidated sediments or sedimentary rocks. Rocks with the ability to store and allow the movement of water are called aquifers. Where the intergrain voids are well-connected, groundwater can flow easily, and these rocks are said to have a high permeability.

Groundwater may occur at shallow depth in unconfined aquifers which are recharged directly by rainfall (Fig. 3.1). Water may leak from unconfined aquifers and percolate to great depths in sedimentary rocks, creating groundwater resources in deep aquifers. These aquifers are usually sealed or enclosed by beds of rocks with a low permeability, and are known as confined aquifers (Fig 3.1).

3.2 Groundwater flow in the Cockburn Groundwater Management Area

The superficial formations form an extensive unconfined aquifer that is found throughout much of the Perth metropolitan area. Groundwater flow within this aquifer takes place within a number of flow-systems, and the dominant flow-system to the south of the Swan Estuary is the Jandakot Mound (Fig. 3.2). Groundwater flows radially away from the crest of the Jandakot Mound, and discharges to a number of surface drainages, the Swan Estuary, and the ocean. The CGMA is located at the western margin of the Jandakot Mound, and groundwater flow is predominantly to the west towards Cockburn Sound. Groundwater flow in confined aquifers beneath the groundwater management area is also to the west towards the ocean.

4. Groundwater quality and contamination

4.1 Groundwater salinity

The quality of groundwater in an unconfined aquifer can vary considerably depending on its position within a regional flow system, the rock type, and surface landuse. Most of the soluble constituents found in groundwater are derived from rainfall, from the weathering of minerals, and from the leaching of organic matter from surface soils. The amount of soluble substances dissolved in groundwater controls the groundwater salinity, and increases in salinity can affect the groundwater use, and can have environmental impacts where groundwater discharges to the surface environment. The salinity of groundwater is generally lowest in areas of groundwater recharge and in those areas where the aquifer is sandy. Salinity is typically highest in areas with clayey sediments or where groundwater discharge occurs.

The salinity of groundwater in the unconfined aquifer in the CGMA is lowest in the east (Fig. 4.1) near the crest of the Jandakot Mound, where salinity is typically less than 500 mg/L of Total Dissolved Solids (TDS), and in undeveloped areas to the east of the CGMA, groundwater with this salinity is used for public water supply. Most of the management area is underlain by groundwater with a salinity of less than 1000 mg/L TDS, and water of this quality is suitable for horticulture, and by industry.

Areas with a groundwater salinity in excess of 1000 mg/L TDS are found downstream of major wetlands (Fig. 4.1), and are caused by water being lost by evaporation and transpiration from lake surfaces and fringing vegetation as groundwater flows through the wetlands (Fig. 4.2). The highest groundwater salinities occur in the southern part of the CGMA, and are due to the outflow from Lake Coolongup, located to the south of the management area. An area of high groundwater salinity is located to the east of Lake Coogee is due to contamination of groundwater by seawater salts derived from cement manufacture.

Local changes in groundwater salinity have also occurred as a result of pumping, particularly in bores used for intensive horticulture near Lake Coogee (Hirschberg, 1989a). Fresh groundwater in coastal areas generally overlies denser, salty water (Fig 4.3), and there is often a sharp boundary between the two groundwater bodies known as a saltwater interface (Fig. 4.3). In the CGMA, the saltwater interface extends up to 2 km inland. Intense pumping of groundwater in areas underlain by this interface can cause the local upconing of saltwater (Fig. 4.3), and this is probably the cause of salinity changes in bores near Lake Coogee.

4.2 Groundwater contamination

Contamination of groundwater generally takes place when land use is changed from natural conditions. Groundwater can become contaminated when chemical substances or microorganisms are introduced into aquifers as a result of human activities at the surface, particularly as a result of agricultural, industrial or urban development.

The most severe occurrences of groundwater contamination usually result from chemical leaks or spills, and the accidental or deliberate disposal of solid and liquid wastes. These situations are referred to as 'point sources' of contamination (Fig. 4.4). Leachate from the contamination source moves downwards through the soil profile until it reaches the watertable, where it mixes with, and contaminates groundwater.

Contaminated groundwater with increased levels of dissolved constituents usually has a higher density than surrounding uncontaminated groundwater, and sinks towards the base of the aquifer. As the water mass sinks, it is displaced in the direction of groundwater flow. A contamination plume may be formed which has a shape rather like an inverted smoke plume (Fig. 4.4). The plume becomes less well defined and more diffuse in the direction of groundwater flow, and concentrations of contaminants downgradient of the source are progressively reduced by physical and chemical processes taking place within the aquifer.

Organic contaminants which are only slightly soluble in water may either float on the watertable (Fig. 4.4) if they are less dense than water (*e.g.* petroleum hydrocarbons), or sink if they are more dense than water (*e.g.* some solvents). These chemicals usually have an associated contamination plume of dissolved compounds.

Groundwater contamination may also result from the leaching of chemicals from the land surface over a large area. This 'diffuse' or 'non-point source' contamination is usually less severe than that derived from point sources, but may affect wider areas. For example, the widespread use of fertilizers in agricultural and urban areas (Fig. 4.4) can produce regional increases in the concentration of nitrate, and may render the underlying groundwater unsuitable for use as a public water supply.

Once contamination of an aquifer has occurred, it is extremely difficult to rectify, as it may take decades or centuries for the contamination to be dispersed or degraded naturally. A

number of techniques have been developed to artificially clean up contaminated groundwater, but these remedial programs are extremely expensive to carry out, and in many cases are of limited effectiveness. The most effective way of protecting the quality of groundwater is to prevent contamination taking place by controlling land use in areas overlying the groundwater sources.

4.3 Point sources of contamination

Potential point sources of groundwater contamination are widespread throughout the Cockburn Groundwater Management Area, and include waste disposal and industrial sites (Fig. 4.5). The most severe known occurrences of groundwater contamination are found in the Kwinana and Coogee industrial areas, and have resulted from a wide range of industrial activities summarised in Table 4.1. These occurrences of groundwater contamination are unlikely to have any impact on human health, as they are not located in areas used to provide drinking water or used for irrigated horticulture, but there may be environmental problems caused by the discharge of contaminated groundwater into Cockburn Sound.

Most of the industries are actively monitoring groundwater contamination and are undertaking remediation programs, which are often required as part of their operational licence conditions. However, where groundwater contamination has taken place before the current Environmental Protection Act came into force and the polluting industries are no longer operational, the investigation and management of the contamination has become the responsibility of the Western Australian Government.

Such is the case with an occurrence of groundwater contamination caused by the manufacture of agricultural chemicals by a company operational from the early 1960s until 1985. Investigations undertaken by the Geological Survey of Western Australia (Appleyard, 1993) have indicated that a groundwater contamination plume containing the herbicides 2,4-D and 2,4,5-T now extends about 800 m to the west of the former agricultural chemical plant. The contaminated groundwater could have a severe impact on marine life if it discharges into Cockburn Sound, but further research is needed to determine whether the contamination plume will reach Cockburn Sound, or whether bacterial activity will break down the contaminants into non-toxic chemical compounds.

4.4 Diffuse groundwater contamination

The major diffuse source of groundwater contamination in the Cockburn Groundwater Management Area is the widespread use of fertiliser, particularly in horticultural areas. Groundwater studies near Lake Coogee (Hirschberg, 1989a; Pionke *et al.*, 1990) have indicated that nitrate concentrations near the watertable in this horticultural area range from 9 to 80 mg/L as N, and commonly exceed the recommended drinking water limit of 10 mg/L as N. Crops are typically fertilised with a mixture of inorganic fertilisers and poultry manure, and application rates typically exceed the ability of plants to take up nitrogen by a factor of 4 to 7 (Pionke *et al.*, 1990).

Fertilisers are also widely used on domestic gardens, with up to 80 kg per hectare being applied in sewerred residential areas (Gerritse *et al.*, 1990). More than half the nitrogen applied as fertiliser may percolate past the lawn root-zone and can potentially contaminate groundwater (Sharma *et al.*, 1994). This has caused elevated nitrate concentrations in groundwater in many areas of Perth (Appleyard and Bawden, 1987; Barber *et al.*, 1994), and it is likely that there will be increases in nitrate concentration in groundwater beneath new urban areas near Thomsons Lake. There is increasing pressure to extend urban development over large areas of the Jandakot Mound, but a recent Parliamentary Select Committee on Metropolitan Development and Groundwater Supplies has recommended that urban development does not take place in areas used for public water supply.

5. Environmental impacts of groundwater discharge

5.1 Impacts on wetlands

Wetlands on the Swan Coastal Plain are surface expressions of the watertable, and there is often a good hydraulic connection between these features and the superficial aquifer. Evaporation from wetlands affects groundwater flow in their vicinity (Fig. 4.2), and groundwater from the entire saturated thickness of the superficial aquifer may discharge into wetlands that have a large surface area (Townley *et al.*, 1993).

Each wetland has a well defined catchment area or "capture zone", the vertical and lateral extent of which depends on the geometry of the wetland, and the physical properties of the underlying aquifer. Modelling undertaken by Townley *et al.* (1993) has indicated that capture zones for the East Beeliar wetlands extend to the crest of the Jandakot Mound, although the travel time of groundwater within the capture zones will vary greatly with distance from the wetlands.

Landuse within capture zones could indirectly affect water quality in the wetlands, and the discharge of contaminated groundwater into wetlands could have an adverse effect on flora and fauna. The effects of only trace levels of some contaminants could be greatly magnified through accumulation in wetland food-chains. Investigations undertaken by Townley *et al.* (1993) suggests that irrigated horticulture may be having an impact on water quality in Lake Wattleup, which is located in the CGMA.

5.2 Impact on Cockburn Sound

Groundwater may discharge a wide variety of contaminants to Cockburn Sound derived from coastal industrial and urban development, and there a number of contamination plumes in close proximity to the coast which could discharge in the future if current control measures are not maintained. Although inputs of many contaminants from groundwater are poorly quantified, a survey carried out for the Environmental Protection Authority in 1993 (EPA, 1993) suggested that they are generally small with the exception of nitrogen.

Nitrogen is an important nutrient in marine environments, and the availability of this element has a strong control on the overall health of marine ecosystems. Seagrass communities in Cockburn Sound have developed in an environment where there is a limited supply of nitrogen. Increasing inputs of nitrogen from coastal landuse has encouraged the growth of algae which can smother and deprive seagrass of light, ultimately leading to the death of these plants.

The total mass of nitrogen currently discharged to Cockburn Sound is estimated to be about 910 tonnes per year, of which 350 tonnes is estimated to be discharged from groundwater (EPA, 1993). The high groundwater inputs were confirmed by a joint government-industry sampling program (Appleyard, 1994) which indicated that most of the nitrogen is derived from industrial sources (Fig. 5.1), and that most of the nitrogen is in the form of ammonium ions. This chemical form of nitrogen is easily taken up by marine plants and encourages the growth

of algae. The ammonium ions are also associated with high concentrations of sulphate, which can react with marine sediments and cause the release of additional nitrogen held within these sediments.

Much of the nitrogen input to Cockburn Sound is discharged by drains and stormwater outfalls. These surface inputs are being progressively reduced, and within a few years groundwater discharge will be the major source of nitrogen. The Department of Environmental Protection is currently undertaking a study to determine how much nitrogen Cockburn Sound can accommodate without causing environmental stress.

6. Groundwater management in the Cockburn Management Area

The preservation of groundwater quality in the Cockburn Groundwater Management Area is achieved through the appropriate management of groundwater usage and landuse in the area. Groundwater usage in the area is controlled by the Water Authority through the licensing of groundwater abstraction, and groundwater users have an input to the licensing procedure through the Cockburn Groundwater Advisory Committee (CGAC). This committee is chaired by the Water Authority, but has representatives from other State Government agencies, Local Government, and members from industry and horticulture.

Until recently, a second government committee, the Cockburn Area Groundwater Pollution Control Technical Committee (CAGPCTC), helped manage the impact of landuse on groundwater quality, and coordinated the investigation of contamination problems in the area. However, this committee has now been disbanded, and some of its activities have been taken up by CGAC.

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TABLE 4.1 MAJOR SOURCES OF INDUSTRIAL CONTAMINATION IN THE CGMA

Activity	Contaminants	Remediation Program
Agricultural chemical manufacture	herbicides, phenolic compounds	No
Alumina processing (Refinery)	caustic soda	Yes
Alumina processing (Residue disposal)	caustic soda	Yes
Cement manufacture	seawater salts	Yes
Fertiliser manufacture	ammonium salts	No
Fertiliser manufacture (gypsum disposal)	sulphate salts	No
Hide processing	effluent with a high BOD*	No
Nickel processing (Refinery)	ammonium sulphate	No
Nickel processing (Tailings storage)	ammonium sulphate	Yes
Oil refining	petroleum hydrocarbons	Yes
Power generation (Fly ash disposal)	saline water	Yes
Starch manufacture	effluent with a high BOD*, ammonium salts	No
Wool scouring	effluent with a high BOD*	No

NOTES: * - BOD = Biological oxygen demand

