The salinity and hydrology of Cranbrook

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Information for contributors

Scientists who wish to publish the results of their investigations have access to a large number of journals. However, for a variety of reasons the editors of most of these journals are unwilling to accept articles that are lengthy or contain information that is preliminary in nature. Nevertheless, much material of this type is often of interest and value to other scientists and to administrators, and should be published. The Resource Management Technical Report Series provides an avenue for dissemination of such material. It is a series of occasional papers in the general subject area of resource management and is published by Agriculture Western Australia.

Intending contributors should contact the Natural Resource Management Service Unit. All papers will be reviewed by at least two referees and a relevant Group Leader.
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Summary

1. Introduction and background

The study area covers the Cranbrook townsite (top photograph on cover) and two catchments that affect it (Figure 1). The Cranbrook Town is located 85 km north-north-west of Albany and it has a population of 320 people (1190 in the Shire; ABS Census 1991).

Cranbrook is experiencing increasing salinity problems. Saline groundwater levels are close to the soil surface and cause deterioration of buildings, roads, infrastructure, death of trees and scalding of land including the sporting ground.

The objective of this study was to define the present salinity status of the Cranbrook Town and develop management strategies to overcome or reduce the severity of salinity.

2. Methods and materials

Eighteen bores were drilled in the winter of 1997. The drilling profiles were described while drilling and soil samples were collected from every metre depth interval for analysis. The electrical conductivity (EC) of a 1:5 soil-water solution and the total soluble salt (TSS) were measured in soil samples from bores. Two existing bores had been drilled near the oval and near the school by Agriculture WA in 1992. Groundwater levels and salinities in these bores were used to assess the salinity status of the oval and complement the drilling in the town.

Since the initial readings, groundwater levels have been measured on a monthly basis.

The level of all bores were surveyed in June 1997. The relative groundwater levels in the bores were used to draw groundwater isopotentials and estimate groundwater flow directions.

Annual recharge was estimated for the study area using WAttle (Argent and George 1997).

Three methods were used to find the extent of present salinity and the potential extent of soil salinity in the study area: i) 1993 aerial photographs; ii) a Geonic EM38 instrument confirmed the severity of salt-affected areas; and iii) groundwater level trends and groundwater level contours identified areas in danger of salinity.

Landform pattern maps of the area were used to differentiate between and describe the attributes of various landforms of the catchments above the Cranbrook Town.
3. Results

3.1. Hydrology

Hydrological systems and their aquifers

There are three hydrological systems in the study area: Crests and Undulating Plains with swampy floors which are on or near catchment divides of the study area and Swampy Terrains which occupy the lower parts of the study area. The Cranbrook townsite is located in Swampy terrains that have extremely low relief.

The Crests have local aquifers\(^1\) that are separated by basement granite highs or structural fractures within the basement. In contrast, aquifers in the Swampy terrains, are regional. The Plains with swampy floors are a transitional zone between the two types of aquifers.

Surface hydrology

The surface drainage system in the town is not sufficient to remove the excess rainfall. This lack of drainage causes water to pond in many parts of the town (>12 sites). The inundated areas contribute to groundwater level rises in the study area.

Groundwater hydrology under the Cranbrook townsite

Groundwater levels under the Cranbrook townsite in September 1997 were between 0.05 m above and 2.20 m below, the soil surface. Groundwater levels in 75% of the sites were within 1.6 m of the soil surface. These levels are very close to the soil surface.

The regolith in a few bores consisted of heavy silty clay which acts as a barrier to groundwater flow, forcing it to change its flow direction. Drilling showed that a palaeochannel (buried alluvial channel) with a south-east and north-west direction passes through the centre of town. This palaeochannel is in-filled by coarse sediments. The palaeochannel provides an easier path for groundwater flow compared to the areas with a heavy textured profile.

Flow lines and isopotentials show that groundwaters which develop in cleared agricultural areas contribute to the groundwater that flows under the townsite. These areas are severely waterlogged and occasionally inundated. As a result they have the potential to provide very high rates of recharge that cause groundwater levels to rise.

Flow lines diverge as they pass through the town. The increasing distance between the flow lines probably indicates a high rate of recharge in town which creates a groundwater mound and increases the flow rate.

\(^1\) Technical terms used in the report are defined in Appendix 2
Groundwater salinities

Groundwater salinities varied between 3,000 mg/L (Brackish) and 19,700 mg/L (very saline). The lowest groundwater salinities were in the town centre. At this site, groundwater in the shallow bore was fresh (1030 mg/L) but in the deeper one it was brackish (3020 mg/L).

3.2. Recharge in the study area

Recharge in the agricultural land

Annual rates of recharge in agricultural areas probably vary between 0 and 170 mm/year, depending on annual rainfall and vegetation cover. In a year with average rainfall, bare sandy soils, volunteer pastures, clover based pastures, shrubs and lucerne will contribute about 140, 105, 100, 15 and 0 millimetres of recharge respectively.

Recharge in the Cranbrook townsite

The Cranbrook Town has about 85 mm/year additional recharge compared to the agricultural areas. This additional recharge is from septic tanks, runoff from roof tops and watering gardens. An indication of the high recharge under the townsite is the rapid groundwater level rises during winter: Groundwater levels in deep bores in cleared parts of town rose by an average 0.94 m between 20th June and 19th September 1997.

3.3. Potential salinity of the study area

The extent of the present and potential soil salinity in an area depends on its position in the landscape. Crests have less salinity and waterlogging than the other areas. All the creek beds in Plains with swampy floors are, or will eventually become salt-affected. The extent of potential soil salinity in Swampy terrains is very high and it increases in the lowest parts of this hydrologic system. The townsite which is entirely in Swampy terrains has very little obvious soil salinity at present (<1%). However saline groundwater levels are very close to the soil surface. It is estimated that about 17.5% of the townsite may eventually become salt-affected.

About 6% of the Oval catchment is salt-affected. These areas may increase to 16.5% in future. The sporting grounds are already partly salt-affected and their salinity will increase in future. To reverse the salinity trend in this area, the entire Oval Catchment will need to be treated.

4. Management options to reduce the extent of salinity in the Cranbrook townsite

Thirty eight recommendations have been made to reverse the salinity trend in the Cranbrook townsite (Section 11) and classed into 7 categories:

- Managing surface runoff in the Town;
- Managing the Cranbrook Creek;
- Direct groundwater management
Managing the sewerage system;
Reducing recharge in town by revegetating vacant areas;
Managing natural vegetation;
Managing agricultural areas;
A possible new site for the Sporting Ground;
Other recommendations.
1. Introduction and background

1.1. The study area

The study area covers the Cranbrook Town and two up-slope catchments that affect it (Figure 1). The Cranbrook Town is located 85 km north-north-west of Albany. The town has a population of 320 people (1190 in the Shire; ABS Census, 1991). The townsite boundary (Figure 1) encloses 485 ha of which 130 ha has been demarcated as residential, industrial and recreational areas. The two catchments that contribute to the townsite and its sporting facilities are named the Cranbrook and the Oval Catchments respectively (Figure 1). The area of the Cranbrook Catchment is 2520 ha and the area of the Oval Catchment 570 ha. The town is established on the stagnant, lower slopes of the Cranbrook Catchment with the main tributary of Pinjalup Creek (Figure 1) passing through it and discharging into the Gordon River 11 km downstream. In this report we refer to this creek as the “Cranbrook Creek”.

1.2. The salinity problem

Rain and dust bring a small amount of airborne salt (cyclic salt; 20-50kg/ha/year) to catchments. In the low rainfall agricultural areas (which receive less than 1000 mm per annum), much of the cyclic salt is stored in the soil profile. Clearing the native vegetation for agriculture has reduced evaporation, increased recharge and resulted in rising groundwater levels, mobilising the stored salt. This salt-laden groundwater then surfaces as valley floor and hillside springs and seeps, causing soil salinity and contaminating previously potable water resources.

Cranbrook is experiencing increasing salinity problems. Levels of saline groundwater are close to the soil surface and cause deterioration of buildings, roads, death of trees and scalding of land including the sporting ground.

The government of Western Australia recognises the threat of salinity to the rural towns. There is a provision to rescue the salt-affected rural towns in the Western Australian Salinity Action Plan (1996). Funding of $2 million has been proposed (from State and Commonwealth) for salinity studies and the implementation of recommended plans. Agriculture WA has been given the task of consulting with local government authorities in rural catchments to assess salinity risks and plan action to deal with rising groundwater. The Catchment Hydrology Group has been asked to study the salinity status of the Cranbrook townsite and suggest management options which reverse the increasing salinity trend.

1.3. Objectives of this study

The objective of this study was to define the present salinity status of the Cranbrook Town and then develop management strategies to overcome the salinity. To achieve this it was necessary to understand the hydrology of the catchment and then suggest appropriate management options. To understand the hydrology of the catchment, it was necessary:
• to investigate the geology of the area; For example find out if there are any sediments and palaeochannels (buried alluvial channel) which may affect the hydrology of the area.

• to document the present groundwater levels and salinities in the study area;

• to define recharge and discharge systems and aquifer conditions; For example to find if the aquifer is regional or local, which may affect the treatments needed.

• to investigate any effects that natural vegetation around the Cranbrook has on groundwater levels;

• to identify areas that are in danger of becoming saline under current management options;

• to estimate groundwater levels near the oval and predict its viability as a sports ground;

• to recommend sites for future sporting facilities;

• to recommend management options that may reverse the present salinity trend in the area;

• to facilitate future monitoring of groundwater levels and salinities and any effect that the treatments may have.
2. Climate

The study area has a Mediterranean climate with hot, mostly dry summers and cool, wet winters. The mean maximum temperature in January, which is the hottest month, is $28.5^\circ$C. There are occasional heat waves (mostly in February), during which the maximum temperature exceeds $40^\circ$C, or rarely, $45^\circ$C. The mean monthly temperature in July (the coldest month) is $10.4^\circ$C. During about 7 days per year, the minimum temperature drops below $2.0^\circ$C.

The mean annual rainfall is about 480 mm (Bureau of Meteorology, 1993). Seventy percent of the annual precipitation falls in the growing season between May and October (Figure 2). The annual rainfall in 20% of years (decile 2) is below 417 mm and in 20% of years (decile 8) exceeds 560 mm.

The mean monthly evaporation from a Class A pan varies between 44 mm in June and 267 mm in January (Figure 2; Luke et al. 1989). The mean annual Class A evaporation is 1650 mm. Mean monthly rainfall exceeds the pan evaporation during June to August (Figure 2).

![Figure 2: Monthly rainfall (Bureau of Meteorology, Station 10537) and, evaporation from Class A pan (Luke et al. 1989) for Cranbrook.](image-url)
3. Methods and materials

Drilling methods

Bores (Figure 3) were sited using aerial photographs (1:25,000 scale, 1993). A total of 11 deep holes (between 11 and 26 m) and 7 shallow holes (<8 m deep) were drilled between 13th and 20th June 1997, using the Catchment Hydrology Group’s Gemco HM12 Rotary Air Blast drill rig. Soil samples were collected from every metre depth interval.

All the holes were cased with 40 mm PVC pipe for future monitoring. Drill logs and information on these holes (C1D to C18D) are presented in Appendix 1. These logs show groundwater levels and salinities, salt storages, depth to basement rock and lithology.

Two other deep bores had been drilled previously, near the oval and near the school, by Agriculture WA in 1992. The levels and salinity of groundwater in these bores were used to assess the salinity status of the oval and to complement the drilling in the town.

Soil and water analyses

Standard techniques used by Agriculture WA laboratories were used to analyse soil and water samples:

Soil samples were air dried at 60°C for more than 5 days, crushed and sieved (<2 mm). Distilled water was added to samples to make a 1:5 soil water suspension (by weight) for measuring their electrical conductivities (EC1:5). The EC1:5 figures were multiplied by 0.0032 to estimate the percentage (by weight) of the total soluble salt concentration (TSS) in soil samples.

- Electrical conductivity (EC) of the water samples was measured as an indication of salinity and expressed as milliSiemens per metre (mS/m). The electrical conductivity figures were multiplied by 5.5 to estimate their total soluble salt (TSS in mg/L).

Bore data collection and analyses

Bores were sampled and their water levels measured between 2 and 5 days after drilling. Since the initial readings, the groundwater levels have been measured monthly. These water levels are used to estimate the fluctuation in groundwater level and to describe the interaction between the shallow and deep groundwaters (ie find out when most recharge is taking place).

All bores were surveyed and their relative groundwater levels were used to draw groundwater isopotentials and estimate the direction of groundwater flow.
Recharge estimation

Annual recharge has been estimated within the study area using “WAzzle” which is a simple Water Balance Calculating program developed by the Natural Resource Management Unit, Agriculture WA and the University of Melbourne. This model uses average climate data and representative soil and plant information obtained within the agricultural areas of Western Australia.

Extent of soil salinity

Three tools were used to estimate the extent of present and potential soil salinity in the study area:

- 1993 aerial photographs were interpreted to mark salt-affected areas and areas that were considered to be in danger of soil salinity;
- A Geonic EM38 instrument was used to confirm the present extent and severity of salt-affected areas, based on Ferdowsian and Greenham’s recommended limits (1992);
- Contours and trends in groundwater levels were used to confirm the areas which are in danger of becoming saline.

Landform patterns and hydrological systems

Landform pattern maps of the area produced by the Catchment Hydrology Group (Ferdowsian, 1997; Figure 4) were used to differentiate between and describe the attributes of various landforms of the catchment above the Cranbrook Town.
4. Landform patterns and hydrological systems of the study area

A landform pattern (LFP) is a topo-sequence (valley floor, hillside and ridge) described by its relief, slope, landform elements and degradational problems associated with its use. Landform patterns are differentiated by their attributes that are assessed within a circle of about 300 m radius (McDonald et al. 1984). There are nine LFPs in the study area (Figure 4).

Hydrological systems (HS) are combinations of LFPs that have similar hydrological properties and may be grouped together as one unit. The nine LFPs of the study area have been grouped into three hydrological systems: Crests; Undulating plains with swampy floors; and Swampy terrains (Figure 5). The following paragraphs give a brief description of these hydrological systems.

4.1. Crests

This group includes four LFPs: Broad crests, Low hills, Undulating rises and Gently undulating plains. Landform patterns in this system are on or near catchment divides and have very low to low relief (15 m-90 m; within a radius of about 300m). Their crests and slopes are erosional surfaces while their open depressions are erosional and aggradational and gradually become swampy downstream. Waterlogging is limited to their lower slopes, to floors of open depressions and to flat crests. The extent of soil salinity is very low (<5%) and only occurs in defined creek lines which are in the lowest part of the area. Almost all areas of this HS are recharge areas, especially waterlogged sandy depressions and flat crests.

4.2. Undulating Plains with swampy floors

This group is in mid-catchment positions and includes two LFPs: Gently undulating plains with saline depressions; and Rises. Gently undulating plains with saline depressions are undulating areas with broad depressions. Their broad depressions have no defined creek lines and saline water spreads over them. Rises on the other hand have well defined creek lines which contain their saline flow. These LFPs have continuous and active erosion and aggradation. Waterlogging and salinity are confined to the floors of their open depressions their lower slopes. Their broad crests may also become waterlogged. Their groundwater is more saline than that in the Crests but is less than that in the Swampy Terrains with extremely low relief. Saline groundwater reaches the surface in the depressions through root channels and hillside seeps and spreads over the land causing soil salinity.
4.3. Swampy terrains that have extremely low relief

The Cranbrook townsite is located in Swampy terrains that have extremely low relief. Landform patterns in this HS have extremely low relief (< 10m). Stream channels are sparse to widely spaced and are insufficient to drain their soils. Erosion and aggradation is continuously active to frequently active. Salt storages and groundwater salinities of these LFPs are greater than those in the other LFPs. Potentiometric levels of the groundwater are often near the soil surface (<2 m). Groundwater comes to the surface through root channels and capillary pores causing soil and stream salinity. The underlying granitic rocks are deeply weathered and rock outcrops are very rare. Their in situ weathered granites may be covered by sedimentary material. This group contains three LFPs: Very Gently Undulating Plains; Lowland Flats with well defined drainage and Stagnant alluvial or sedimentary flats.
5. Geology

Geology of the area can be related to the hydrological systems:

5.1. Geology of the Crests (CR)

This HS has developed on in situ weathered profiles. The basement rocks under the north-eastern corner of this HS (low Hills; Figure 5) are mainly quartzite (metamorphosed sandstones) which are part of the metasediments of the Stirling Range Formation. Basement rocks in other areas of this HS are composed of medium and even-grained granites of Archaean origin, intruded by many dolerite dykes which run mainly east to west. The weathering profiles are shallow to moderately deep (< 20m) and change from sand or loamy sand near the soil surface to sandy clay (or heavy sandy clay), and then to moderately weathered basement rock with coarse grit (saprolite) and then to basement rock. Bore C11 (Appendix 1), although it is not in Crests, resembles the drilling profile in this HS.

5.2. Geology of Undulating Plains with swampy floors (UPSF)

This HS is the transitional zone between Crests and Swampy Terrains. The basement rocks are Archaean in origin with fewer exposed dolerite dykes than in the Crests. The weathering profile is moderately deep (10 to 30m) although a few rock outcrops occur on the upper slopes. Weathering profiles in the higher parts of this HS resemble the profiles in the Crests (ie they have layers of sandy clay over a thin layer of gritty material (saprolite) over basement rock). The lower areas of this HS have a few metres of alluvium near the soil surface. The alluvium is derived from granitic hills and covers the in situ weathered profiles. Bore C15 (Appendix 1), although it is not in this HS, resembles the drilling profile in lower areas of this HS.

5.3. Geology of Swampy terrains (ST)

The soil profiles in this HS are deep (>25m). The basement rocks are medium-grained granites of Archaean origin, intruded by dolerite dykes. In most areas of this HS, the in situ weathered profiles are covered by sediments of Tertiary age (Pallinup Siltstone) and overlying Quaternary alluvium. Rounded pebbles (5 to 20 mm in diameter) of both Stirling Ranges metasediments and Archaean granites are found on the soil surface of this HS. There were four types of soil profiles in this HS:

- Bores C4D, C6D, C8D and C17D (Figure 3) all had sedimentary profiles. The maximum observed depth of sediments was >23 m, in bore C8D. These sediments had high hydraulic conductivities as indicated by the in-flow of ground water while drilling.
- Bores C13D and C18D had 8 m and 11 m respectively of coarse sediments over weathered granite. Hydraulic conductivities of the sedimentary layers were high but the conductivities in the in situ weathered materials were low.
- Bores C3D, C11D, C15D and C16D had very little or no sediment over heavy sandy clay profiles which were medium-grained granites weathered in situ. The sandy clay had a low hydraulic conductivity.
Bores C1D and C10D had 7m and 2.5 m respectively of heavy textured sedimentary sandy clay over *in situ* weathered dolerite. These two profiles had extremely low hydraulic conductivities and made little water while drilling.

The high and low hydraulic conductivities affect groundwater flow lines in the study area as explained in section 6.3 “Groundwater hydrology”.
6. Hydrology

6.1. Surface hydrology

There are four natural and constructed drainage systems (Figure 3) that remove excess surface water from the study area: the Cranbrook Creek, the Northern Creek, the Oval Creek, and the surface drainage system within the town.

A. The Cranbrook Creek is the most important surface drainage in the study area because of its size and because it recharges the aquifer under the town. This creek starts in the undulating farming areas south-east of the Salt River and Ronaldshaw Road crossing (Figure 1). The creek crosses the Salt River Road 500 m north-west of that crossing (Sample Site 1; Figure 3) and flows into Location CG10. The creek inundates large areas in Location CG10 before entering the natural vegetation south-east of Cranbrook. The creek has been diverted near the town water supply dam (Figure 3) to avoid flooding the town and to prevent saline water entering the Town and Bowling Club Dams (Figure 3). Its new water course is a constructed drain (2.5 m wide and 0.5 m deep) which crosses the Salt River Road near Pynup Road (Site 2; Figure 3). It eventually crosses Industrial Tip Road, the Railway, the Great Southern Highway (south-west of the town) and Grantham Road (Site 4, Figure 3).

This drain has a well defined and eroded channel throughout its length, with the exception of a 800 m section across the Industrial Tip Road and downstream of the Great Southern Highway crossing. The longitudinal slope of this drain is between 0.33% and 0.50%. Flow velocities above 0.5 m/sec will be erosive and are achieved by flows more than 1 m³/sec. The sand and silt deposits in natural vegetation near Climie and Woulfe Streets are from eroded parts of the same drain. There are large areas near Industrial Tip Road which have severe waterlogging (Photograph 1). The drain discharge inundates some of these areas (Photograph 2).

At low flow rates (ie 1 L/sec) the baseflow at Site 1 is saline (Table 1) and infiltrates an area of natural vegetation before it reaches Site 2. At higher flow rates (>10 L/sec), the creek becomes brackish (Table 1) and flows continuously to the Gordon River. At high flow rates the creek will recharge the aquifer in the area of natural vegetation and gain water (surface runoff as well as groundwater seeps) downstream of Site 3. On 5 August 1997, the salinity of the creek increased along its channel (Table 1). This indicates that there are seepage zones discharging saline groundwater into the creek channel.

B. The Northern Creek catchment is entirely within the area of natural vegetation. Provided the natural vegetation in this catchment is not disturbed, it will not contribute to the salinity problem of the town. This creek crosses the Great Southern Railway line. There are depressions on both sides of the railway line which pond water after rainfall (Photograph 3). Some of this water will eventually recharge the aquifer and the rest will evaporate.
Table 1: The baseflow of the Cranbrook Creek (13 June) is saline. When the flow rate increases (30 July) it becomes brackish. It looses some of its flow in an area of natural vegetation between Sites 1 and 2.

<table>
<thead>
<tr>
<th>Sampling dates</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
<th>Site 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Salinity (mg/L)</td>
<td>Flow (L/sec)</td>
<td>Salinity (mg/L)</td>
<td>Flow (L/sec)</td>
</tr>
<tr>
<td>13/6/97</td>
<td>6480</td>
<td>1</td>
<td>no flow</td>
<td>00</td>
</tr>
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<td>30/7/97</td>
<td>3718</td>
<td>50</td>
<td>3454</td>
<td>20</td>
</tr>
<tr>
<td>5/8/97</td>
<td>2002</td>
<td>90</td>
<td>2024</td>
<td>90</td>
</tr>
</tbody>
</table>

* NM: Not Measured

C. The Oval Creek has a 570 ha catchment of which 80% is cleared. The lowest part of this catchment changes to stagnant flats and floodplains. The Sports Ground is within these landform patterns. The lowest parts of the oval and the surrounding areas will frequently become inundated by in situ rainfall as well as runoff from the catchment. Groundwater levels are close to the soil surface and interact with the runoff. This catchment has a severe and increasing salinity problem which will be difficult to reverse (Sections 10 and 11).

D. The surface drainage system in the town consists of shallow (<0.3 m deep) roadside drains. These drains were removing about 3 L/sec of water on 13th June 1997, after 20 mm rainfall during the previous night and about 1.5 L/sec, on 5th August 1997 after 11 mm of rainfall. The drains are not sufficient to remove heavy rainfall so there is ponding in many parts of the town. The ponds contribute to rising groundwater levels in the study area. The main ponding areas within the town are:

- Areas between Industrial Tip and Salt River Road (Photograph 2);
- Excavated areas beside the railway track (Photograph 3);
- Railway Reserves south-east of town (Photograph 4);
- Horse paddocks south-west of town (Photograph 5);
- Along the streets within town;
- Northern parts of Frederick Square;
- Areas around the Oval (Photograph 6);
- Natural vegetation near Climie and Woulfe Street;
- Gravel pits near Water Supply dams;
- Areas between Mason and Campbell Streets;
- Areas both sides of Mason Street and near Currie Street;
- Areas west of Gardiner Street.
6.2. Type and attributes of aquifers in the Cranbrook Catchment

The Crests have small local aquifers that flow in basement fractures (near catchment and subcatchment divides) and in saprolite zone (along slopes). These aquifers are separated by basement granite highs. Aquifers in the Swampy terrains are larger and regional. The Plains with swampy floors are a transitional zone between the two types of aquifers. As groundwater levels rise into the upper sediments, a larger proportion of the aquifers in the depressions of Plains with swampy floors will become connected.

In areas where the aquifer is local, the salinity and rising groundwater is an on-site issue. Therefore managing land outside the boundary of a local aquifer will have little or no effect on that aquifer. However, the management of land within a local aquifer will affect others downstream. In contrast, salinity in areas with regional aquifers is affected by on-site as well as off-site management. Thus the Cranbrook Town is affected by farming practices on higher parts of the catchment as well as by the management of local water within the townsite.

6.3. Groundwater hydrology under the Cranbrook townsite

Groundwater levels

Groundwater levels in deep bores under the Cranbrook townsite, kept rising between 20th June and 19th September (Table 2). The average rise during that period was 0.94 m. In September 1997, deep groundwater levels under the townsite were between 0.05 m above, and 2.20 m below, the soil surface (Table 2). Groundwater levels in 75% of the sites were within 1.6 m of the surface. These high groundwater levels are within the capillarity ranges. Saline groundwater may rise through capillary pores, evaporate at the soil surface and concentrate salts near the soil surface.

Groundwater levels were lower under natural vegetation in comparison with those under the town and had no or little rise (Table 2). In fact, the groundwater level in C18D, which is in the middle of natural vegetation, fell by 0.25 m between June and September 1997. During the same period, levels in C13D which is on the edge of natural vegetation rose by 0.4m. This level was higher than expected and we believe that it was due to localised groundwater recharge around Pynup Road (See next section; groundwater flow).

Groundwater flow

The heavy silty clay (Appendix 1) found in bores C1D and C10D and to a lesser extent in bores C3D, C11D, C15D and C16D had very low hydraulic conductivities. The regolith around these bores, especially C1D and C10D, creates a barrier to groundwater movement forcing it to rise and change its flow path. Figures 6 and 7 show how the groundwater flow lines change direction and go around a barrier between C11D and C1D bores. The In situ weathered dolerite found in bore C1D confirms the existence of this barrier. Another indication of this barrier is the increase in hydraulic gradient (closer isopotential lines; Figures 6 and 7) as groundwater passes through the barrier. The increased gradient is because groundwater is held behind the barrier. Most of groundwater is forced to flow around these obstacles and along a longer path which has higher hydraulic conductivity.
Table 2: In the Cranbrook townsite, groundwater levels in deep bores were rising between 20th June and 19th September 1997. This rise was in response to rainfall but did not happen in the natural vegetation (Bore 18D).

<table>
<thead>
<tr>
<th>Bore No*</th>
<th>Location</th>
<th>Depth (m) of groundwater on 4 sampling dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20th June</td>
</tr>
<tr>
<td></td>
<td>Rainfall (mm) between this date and the last groundwater level measurements</td>
<td>not applicable</td>
</tr>
<tr>
<td>1D</td>
<td>Climie/Woulfe St</td>
<td>3.51</td>
</tr>
<tr>
<td>2S</td>
<td>Climie/Woulfe St</td>
<td>1.01</td>
</tr>
<tr>
<td>3D</td>
<td>Edward/South end</td>
<td>1.88</td>
</tr>
<tr>
<td>4D</td>
<td>Climie/Dunn St</td>
<td>2.68</td>
</tr>
<tr>
<td>5S</td>
<td>Climie/Dunn St</td>
<td>2.23</td>
</tr>
<tr>
<td>6D</td>
<td>Edward/Grantham</td>
<td>2.61</td>
</tr>
<tr>
<td>7S</td>
<td>Edward/Grantham</td>
<td>2.49</td>
</tr>
<tr>
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<td>Frederick Square</td>
<td>2.07</td>
</tr>
<tr>
<td>9S</td>
<td>Frederick Square</td>
<td>2.16</td>
</tr>
<tr>
<td>10D</td>
<td>Sports Ground</td>
<td>1.94</td>
</tr>
<tr>
<td>10I</td>
<td>Sports Ground</td>
<td>+0.04**</td>
</tr>
<tr>
<td>11D</td>
<td>Industrial Tip Rd</td>
<td>1.12</td>
</tr>
<tr>
<td>12S</td>
<td>Industrial Tip Rd</td>
<td>0.97</td>
</tr>
<tr>
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<td>Holmesdale St; on the edge of natural vegetation</td>
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</tr>
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<td>Holmesdale St; On the edge of natural vegetation</td>
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<td>Rubbish Tip Rd</td>
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<td>16D</td>
<td>Edward St north end</td>
<td>2.06</td>
</tr>
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<td>17D</td>
<td>Grenfell St western end</td>
<td>2.78</td>
</tr>
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<td>18D</td>
<td>Water Supply Track; in natural vegetation</td>
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<td>School</td>
<td>not available</td>
</tr>
<tr>
<td>19D</td>
<td>School</td>
<td>not available</td>
</tr>
</tbody>
</table>

* D = deep;  S = shallow;  I = intermediate;  ** = above ground level
Figure 6: In June 1997, flow lines were bending around bore C1D and C11D indicating that the area between is on a barrier to groundwater flows. The main flow lines were originating from the cleared areas south of the Industrial Tip.
Figure 7: Groundwater isopotentials and the flow lines in September 1997 were similar to those in June 1997. The flow lines showed that the aquifer was partly fed by the cleared areas south of the Industrial Tip.
Bores C18D, C13D, C4D, C8,97 and C17D are on a south-east/north-west transect (Transect A-A1; Figures 3 and 8) which passes through the centre of the Cranbrook Town. The regolith in these bores shows a palaeochannel that passes through the centre of town. This palaeochannel is in-filled by coarse sediments (Figures 8, 9 and 10). Two cross-sections through this palaeochannel show that the width of it changes from one cross-section to another (Figures 9 and 10). Figure 11 shows the approximate location of the palaeochannel.

Flow lines tend to join the palaeochannel (Figures 6, 7 and 11) and follow because the palaeochannel provides an easier flow path for the groundwater relative to areas with a heavy-textured regolith. It is likely that the dolerite dyke which was found in the C1D bore continues under the palaeochannel. Continuation of the dolerite dyke will not affect the flow of groundwater in buried sediments which are in the palaeochannel.

Figure 8: A south-east north-west longitudinal section of the palaeochannel in the study area which passes through bores C18D, C13D, C4D, C8D and C17D. This Figure shows a zone with high hydraulic conductivity that facilitates groundwater movement and is probably the deepest sediments in the in-field palaeochannel.
Figure 9: A south-west north-east cross-section of the palaeochannel in the study area which passes through bores C11D, C13D and C15D. This cross-section shows the width of the in-field palaeochannel and a zone with high hydraulic conductivity that facilitates groundwater movement.

Figure 10: A south-west north-east cross-section of the study area which passes through bores C3D, C6D and C16D. This cross-section shows the width of a zone of high hydraulic conductivity across the palaeochannel.
Bores C18D, C13D, C4D, C8,97 and C17D are on a south-east/north-west transect (Transect A-A1; Figures 3 and 8) which passes through the centre of the Cranbrook Town. The regolith in these bores shows a palaeochannel that passes through the centre of town. This palaeochannel is in-filled by coarse sediments (Figures 8, 9 and 10). Two cross-sections through this palaeochannel show that the width of it changes from one cross-section to another (Figures 9 and 10). Figure 11 shows the approximate location of the palaeochannel.

Flow lines tend to join the palaeochannel (Figures 6, 7 and 11) and follow because the palaeochannel provides an easier flow path for the groundwater relative to areas with a heavy-textured regolith. It is likely that the dolerite dyke which was found in the C1D bore continues under the palaeochannel. Continuation of the dolerite dyke will not affect the flow of groundwater in buried sediments which are in the palaeochannel.

*Cleared agricultural and residential areas contribute to groundwater*

Flow lines and isopotentials (Figures 6 and 7) show that:

- Cleared agricultural areas which are south-west of the Salt River Road and both sides of Pynup Road (Figures 6 and 7) contribute to groundwater that flows under the townsite. These areas, which are south of the Industrial Tip, are severely waterlogged, occasionally inundated (Photographs 1, 2 and the lower photograph on cover) and have very high rates of recharge that cause groundwater levels to rise. They provide the hydraulic head to drive the aquifer under the town.

- A groundwater mound has formed along a line which starts from Mitchell St and continues to bore 6D (Figures 3, 6 and 7). This mound is in the center of town and is due to a rise in groundwater levels under the town which in turn is due to high rates of recharge within that area. The profile of the bores drilled in this area (3D, 4D, 6D, 8D and 17D; Appendix 1) show that the top 1 m of their profile has a sandy texture. These sandy profiles will have higher rates of recharge than the clayey ones (C1D, C10D, C11D and C15D).

- Flow lines diverge as they pass through the town (Figures 6 and 7). Divergence may be due to 4 factors:
  1. Discharge sites will draw the flow lines towards them and create convergence near salt-affected areas and divergence away from them. However, this factor may not be the main cause of diverging flow lines in the study area because the main discharge area is north-west of town (Figure 13). These discharge areas should, if anything, create a convergence in the centre of town.
  2. Shallowing of the aquifer may also cause divergence of the flow lines. However, the aquifer in the palaeochannel of the study area is deepest between bores 4D and 17D which is the divergence zone. Thus shallowing of the aquifer is not the cause of divergence in this study area.
  3. Reduction in the hydraulic conductivity of an aquifer may also cause divergence of flow lines. Bore C17, which is at the lowest part of townsite had the highest groundwater yield (0.5 L/sec; other bores yielded < 0.3 L/sec) and the fastest recovery time in the study area. These results indicate
that the hydraulic conductivity is not falling and therefore does not cause the flow lines to diverge.

4. Excessive recharge under the Cranbrook townsite may form a groundwater mound and cause divergence of the flow lines. We believe there is excessive recharge in the Cranbrook townsite and that this recharge is probably the main cause of the diverging flow lines.

- The paddock which is north-west of town (north of bore 6D; Figures 6 and 7) has a high recharge rate and causes a rise in groundwater levels upstream of that area. This is indicated by the large distance between the isopotential lines near that area (Figures 6 and 7).

- The flow lines that pass through the eastern part of town gradually get closer to each other. This may be due to two factors:
  1. the groundwater mostly passes under natural vegetation and some of it is probably used.
  2. there may be very coarse material in the palaeochannel which could extend as far as bore C16D. In this case the very high hydraulic conductivity would increase the flow velocity and reduce the distances between the flow lines.
7. Groundwater salinities

Groundwater salinities varied between 1000 mg/L and 19,700 mg/L (Table 3; Figure 11). The freshest groundwater was near the Climie and Dunn Street intersection where the salinity in the shallow bore (3.6 m; C5S) was fresh (1030 mg/L) and in the deep bore (11 m; C4D) was brackish (3020 mg/L).

Groundwater in all the bores in north-eastern parts of town (bores C10D, C10I, C15D, C16D and bore C19D which is at the school) was very saline (>15,000 mg/L). These bores had heavy clayey profiles, are in or near natural vegetation and are in flat landforms. These three factors have allowed salt to accumulate. Six bores which had the freshest groundwater had >1 m of sand below the soil surface (Figure 11).

With the exception of the Holmesdale site (bores C13D and C14S; in natural vegetation), each pair of shallow and deep bores showed that groundwater salinity increased at depth (Table 3). This trend was also detected in sites with only one bore. As an example, groundwater at site 17D was sampled as drilling depth increased. Groundwater salinities in this bore were <3,000 mg/L at 2.5 m, 10,900 mg/L at 8 m and 12,160 mg/L at 11 m. The fresher groundwater in shallow profiles is because recharge in those areas dilutes the saline groundwater. The groundwater salinity did not increase with depth under natural vegetation (Holmesdale Site, Table 3). This may indicate that in the townsite, recharge mainly occurs in cleared areas.
Figure 11: Groundwaters were less saline where there was >1 m of sand below the soil surface.
Table 3: Drilling depth, ground level, salt storage and groundwater salinities (1997) in the study area.

<table>
<thead>
<tr>
<th>Bore No*</th>
<th>Location</th>
<th>Drilling depth (m)</th>
<th>Ground level (m)</th>
<th>Salt storage (t/ha)</th>
<th>Groundwater salinity (mg/L)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1D</td>
<td>Climie/Woulfe St</td>
<td>15.5</td>
<td>252.44</td>
<td>1109</td>
<td>12,220</td>
</tr>
<tr>
<td>2S</td>
<td>Climie/Woulfe St</td>
<td>5.0</td>
<td>252.97</td>
<td>Shallow bore</td>
<td>280</td>
</tr>
<tr>
<td>3D</td>
<td>Edward/South end</td>
<td>26.0</td>
<td>250.52</td>
<td>2729</td>
<td>9,560</td>
</tr>
<tr>
<td>4D</td>
<td>Climie/Dunn St</td>
<td>11.0</td>
<td>252.97</td>
<td>177</td>
<td>3,020</td>
</tr>
<tr>
<td>5S</td>
<td>Climie/Dunn St</td>
<td>3.6</td>
<td>252.96</td>
<td>Shallow bore</td>
<td>1,030</td>
</tr>
<tr>
<td>6D</td>
<td>Edward/Grantham</td>
<td>8.0</td>
<td>251.58</td>
<td>241</td>
<td>5,450</td>
</tr>
<tr>
<td>7S</td>
<td>Edward/Grantham</td>
<td>4.0</td>
<td>251.52</td>
<td>Shallow bore</td>
<td>4,380</td>
</tr>
<tr>
<td>8D</td>
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<td>23.0</td>
<td>251.86</td>
<td>2516</td>
<td>14,300</td>
</tr>
<tr>
<td>9S</td>
<td>Frederick Square</td>
<td>4.0</td>
<td>251.83</td>
<td>Shallow bore</td>
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</tr>
<tr>
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<td>Sports Ground</td>
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<td>249.91</td>
<td>1581</td>
<td>14,410</td>
</tr>
<tr>
<td>10I</td>
<td>Sports Ground</td>
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<td>251.08</td>
<td>Not available</td>
<td>16,060</td>
</tr>
<tr>
<td>11D</td>
<td>Industrial Tip Rd</td>
<td>15.7</td>
<td>254.48</td>
<td>1869</td>
<td>15,130</td>
</tr>
<tr>
<td>12S</td>
<td>Industrial Tip Rd</td>
<td>4.0</td>
<td>254.45</td>
<td>Shallow bore</td>
<td>11,770</td>
</tr>
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<td>13D</td>
<td>Holmesdale St</td>
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<td>Shallow bore</td>
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<td>15D</td>
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<td>253.11</td>
<td>1072</td>
<td>16,560</td>
</tr>
<tr>
<td>16D</td>
<td>Edward St north end</td>
<td>19.5</td>
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<td>2829</td>
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<tr>
<td>17D</td>
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<td>Shallow bore</td>
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</tr>
<tr>
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<td>School</td>
<td>unknown</td>
<td>252.08</td>
<td>Not available</td>
<td>17,710</td>
</tr>
</tbody>
</table>

* D = deep; I = intermediate; S = shallow;
**Conversion: Divide mg/L by 5.5 to obtain mS/m.
8. Salt storage and salt concentration

Salt storage (total soluble salt; TSS), in the drilled depth of the deep bores varied between 180 t/ha and 2830 t/ha (Table 3 and Appendix 1). The lowest salt storage (177 t/ha; 1.6 kg/m³) was in bore C4/97 which is in the palaeochannel. This bore also had the freshest groundwater (3020 mg/L). The average salt concentration in sediments in the palaeochannel was 3.6 kg/m³. Those profiles below the palaeochannel and in bores outside it averaged 11 kg/m³.

All of the profiles had one or more salt bulges. Salt bulges in eight out of the 12 deep bores showed >20 kg of salt per cubic metre. These bulges were all in the in situ weathered material.
9. Recharge in the study area

Recharge is that component of annual rainfall that by-passes the root zone of vegetation and joins the groundwater.

Recharge is difficult to measure directly, but soil water balance methods can be used to estimate it indirectly. The soil water balance can be written as:

\[ P = R_o + ET_a + dS + dl + U \]

where:

- \( P \) is precipitation;
- \( R_o \) is runoff and includes surface runoff as well as shallow subsurface seepage;
- \( ET_a \) is actual evaporation (including transpiration);
- \( dS \) is change in water stored in the soil profile;
- \( dl \) is change in water stored above the soil surface (inundation);
- \( U \) is recharge to the groundwater.

When annual estimates of recharge are made, the \( dS \) and \( dl \) can be ignored and the equation becomes:

\[ U = P - R_o - ET_a \]

9.1. Recharge in agricultural parts of the study area

Annual recharge has been estimated within the study area using “WAttle” which is a simple Water Balance Calculating program developed by the Natural Resource Management Unit, Agriculture WA and the University of Melbourne (Argent and George (1997). This model uses average climate data and representative soil and plant information obtained within the agricultural areas of Western Australia.

Estimates made with WAttle indicate that there has been regular annual recharge in the study area. There is some variation in the rate of recharge depending on annual rainfall and vegetation cover (Table 4). Some parts of the study area are bare ground or have only volunteer pasture. In these areas, up to 30% of the annual rainfall may recharge the aquifer.
Table 4: In the Cranbrook area, cleared agricultural areas may have as much as 170 mm of recharge per annum.

* Method used by Ferdowsian and Greenham (1992) for calculating annual recharge gives slightly lower recharge figures than WAttle. However our intention is to show the magnitude of the problem, which could be highlighted by either method.

9.2. Recharge in the Cranbrook townsite

Table 4 is based on the assumption that there are no irrigated areas or septic tanks, and that all areas have significant evapotranspiration. This assumption is not accurate for the Cranbrook townsite. A high proportion of rain which falls on the Water Supply Catchment area and runoff from roof tops as well as most of the roads will recharge the aquifer under the townsite. The total catchment area which will not have significant evaporation, and its runoff is harvested for domestic use, is about 45 ha. We have assumed that 50% of the annual rain falling on this area will recharge the aquifer. This volume will be 110,000 m³ in an average rainfall year or an additional 85 mm over the 130 ha of residential, industrial and recreational parts of the town (75 mm in dry years; 90 mm in wet years). When these figures are added to Table 4, higher recharge figures are obtained for the town in comparison with the agricultural areas (Table 5).

Table 5: Recharge in residential, industrial and recreational areas of the Cranbrook Town is very high and can be as much as 50% of the annual rainfall.

An indication of high recharge under the townsite is the rapid rise in groundwater level during winter months. Groundwater levels in deep bores in the cleared parts of town rose by an average 0.94 m between 20th June 1997 and 19th September 1997 (Figure 12). In contrast, groundwater levels in C18D, which is in middle of the natural
vegetation, dropped by 0.25 m during the same period. Groundwater levels in bores which were on the edge of natural vegetation and near inundated areas had moderate rises between 20th June and 19th September:

- Groundwater in bore C15D, which is on the edge of natural vegetation and 40 m away from a stagnant broad depression rose by 1.26 m.
- Groundwater in bore C13D, which is also on the edge of natural vegetation but away from any inundated areas, rose by only 0.4 m.
10. Potential salinity of the study area

The extent of present soil salinity, and the potential for salinity to develop in the future depends upon position in the landscape. Salinity in the upper parts of the study area is mainly confined to creek lines (Figure 13). There is very little or no risk of soil salinity in the undulating areas of Crests, but in the lower areas of this hydrological system, groundwater is discharging into the creek beds. As groundwater levels rise, more of the depressions will become saline (Figure 13). The groundwater levels may also rise upstream of dykes and granitic highs and cause hillside seeps. Crests have less salinity and waterlogging than the other areas. They have high rates of recharge which will contribute to the salinity of lower areas.

Many of the creek beds in Plains with swampy floors are, or will eventually become, salt-affected. The extent of soil salinity in this HS is more than in the Crests but much less than in the Swampy terrains.

The extent of soil salinity in Swampy terrains is very high and it increases in the lowest parts of the HS. The townsite is entirely in Swampy terrains. Only limited areas of the Cranbrook townsite is salt-affected at present (Table 6), but it is estimated that 17.5% of the townsite’s area (485 ha; Figure 1) may eventually become salt-affected (Table 6; Figure 13).

The Oval Catchment has a similar salt hazard (16.5%; Table 6). The sporting grounds are partly salt-affected and their salinity will increase in future. To reverse the salinity trend in this area, the whole Oval Catchment would need to be treated.

The potential salinity of parts of the catchment that lie above the townsite is very low. This is because of the large areas of natural vegetation upstream of the townsite. If these areas become degraded much more land would become salt-affected.

Table 6: Approximately 17% of the Cranbrook townsite and the Oval Catchment may become salt-affected in future.

<table>
<thead>
<tr>
<th>Catchments</th>
<th>Area (ha)</th>
<th>Salt-affected area (ha)</th>
<th>Salt-affected area (%)</th>
<th>potential salinity (ha)</th>
<th>potential salinity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment above townsite</td>
<td>2030</td>
<td>33</td>
<td>1.6</td>
<td>80</td>
<td>4.0</td>
</tr>
<tr>
<td>townsite</td>
<td>485</td>
<td>3</td>
<td>0.6</td>
<td>85</td>
<td>17.5</td>
</tr>
<tr>
<td>Oval Catchment</td>
<td>570</td>
<td>33</td>
<td>5.7</td>
<td>94</td>
<td>16.5</td>
</tr>
</tbody>
</table>
Figure 12: Groundwater levels in the cleared parts of the Cranbrook Town had rapid rise between 20 June and 24 July 1997 while groundwater levels in natural vegetation did not change during the same period.
Figure 13: Salinity in the upper parts of the study area is mainly confined to creek lines. Large areas in the Cranbrook townsite are in danger of becoming salt-affected. The extent of salinity increases further downstream.
11. Management options to reduce the extent of salinity in the Cranbrook townsite

There are many management options which can help reverse the salinity trend in the Cranbrook townsite. The options have been grouped into eight categories, and marked with between one and three stars, to show the most essential and urgent treatments. The more the stars, the more urgent the treatment.

11.1. Management of surface runoff in the Town

- The Cranbrook Townsite is poorly drained. There are at least 12 sites which are regularly inundated in winter (See section 6.1; Surface hydrology). These sites should be drained. ***

- It is recommended that the excess runoff from roofs and other structures (e.g. silos) is drained as quickly as possible and discharged into the main creeks or dams for use on the Oval and gardens in summer.***

- Almost all the street drains are in areas which have deep (>1 m) sand. A portion of the runoff in these drains will recharge the aquifer. It is recommended that these drains are lined.** Lining could be in the form of small (0.6 m wide by 0.15 m deep) U-shaped concrete channels with adequate expansion joints. To reduce the construction costs the freeboard could be made of earth. The main drains will have a longitudinal slope of 0.004 and will carry approximately 80 L/sec within their concrete profile.

11.2. Management of the Cranbrook Creek

- A trapezoidal-shaped, shallow channel should be constructed along stagnant segments of the Cranbrook Creek to minimise water spreading out and flooding large areas. ***

- These segments are: in Location CG10;** both sides of Industrial Tip Road;*** and in natural vegetation near the Climie and Woulfe Street intersection.**

- The newly constructed section of the Cranbrook Creek and some sections in the natural vegetation are being eroded. It is estimated that > 300 m³ of soil has been washed away along this drain. It is recommended that concrete or rock drop structures or gabions are constructed along the steep sections of the drain to reduce the longitudinal slope to less than 0.003. ***

11.3. Direct groundwater management

- Where open drains are hazardous, subsurface drains (e.g. drain coil) should be installed.**

- Deep (>3.0 m) subsurface drainage may be necessary if the other measures are not sufficient by themselves to prevent groundwater from rising.* A design for subsurface drainage is needed to remove some groundwater as well as part of the surface runoff. The Catchment Hydrology Group or a consultant may be asked to design the deep drainage system.
• It is possible to pump water and lower groundwater levels under the town.**
  Possible sites include areas near C4D, C8D and C17D which are along the palaeochannel. A feasibility study is needed to evaluate pumping groundwater and lowering groundwater levels.** To do that a few pump tests should be carried out. It is necessary to drill observation and production holes for any pump test. The Catchment Hydrology Group or a consultant may be asked to do these feasibility studies. C4D may provide water of stock-quality which can be used on farms.*

• It is recommended that one bore is drilled along Gillam St. and one on the south-eastern corner of the town (the corner of the disposal site). These two bores will give additional data on the hydrology of the area.**

11.4. Managing the sewerage system

• Septic tanks are designed to leach and therefore may recharge the aquifer. It is recommended that a sewerage system is installed in the Cranbrook townsite.***

• No septic tanks should be allowed in future.***

• If a sewer system is constructed, the treated water could be used for irrigating timber plantations.*** A possible site to grow trees is both sides of Rockwell Road; 700 m north of the current Sports Ground.

11.5. Reducing recharge in town by revegetating vacant blocks of land

Some of the following suggestions may require purchasing, leasing or swapping land from nearby farms. This may be done based on a short-term or a long-term plan depending upon urgency (see number of stars) of the treatment.

• Vacant blocks may be high recharge sites. Any vacant block which is not going to be built on should be planted with trees, shrubs (or lucerne) and understorey species which grow well in the area.***

• Many more trees need to be planted along the streets.*** The faster the trees grow, the more water is transpired. Trees should be selected in relation to their water use, form and the effect of their roots and branches on infrastructure.

• Cleared areas along the railway need to be planted urgently to reduce recharge in these areas.*** Lucerne should be planted in areas which cannot be planted with trees (minimum clearance width).***

• The present horse paddocks are also high recharge areas. It is recommended that new horse paddocks are found outside the Cranbrook Catchment.***

• If new areas are found, the existing horse paddocks could be planted with productive timber trees to reduce groundwater levels in the Cranbrook Catchment.***

• Any areas within the Industrial Tip area or the domestic dump which have been filled or are not in use should be planted with trees and understorey species.***
11.6. Management of natural vegetation

- The natural vegetation around and within the Cranbrook townsite is a valuable asset, without which, the Cranbrook townsite would have been badly salt-affected. It is recommended to:
  - avoid clearing any uncleared areas;***
  - protect the natural vegetation;***
  - encourage the understorey to grow;**
  - avoid any more clearing for dumps, water supply purposes etc and locate these facilities on farming land.***

11.7. Management of agricultural areas

- Areas near and south-east of the Industrial Tip are stagnant areas which are becoming salt-affected. These areas should be mounded and then put under salt tolerant trees (*E. Camaldulensis*). Mounding should be along the maximum slope, so that the drains which are formed can remove any ponded water.***
- Areas north of Grantham and Edward intersection should be planted to trees.**
- Location CG10 needs surface drains,** a reformed creek bed** and more tree planting** if the landholder agrees.
- The Upper Cranbrook Catchment needs catchment planning and measures to reverse its salinity trend.**
- The Oval Catchment needs urgent changes to its management to prevent further salinity.*** This will involve surface water management, phase cropping and extensive revegetation.

11.8. A possible new site for the Sports Ground

- The long-term use of the present sporting grounds is in doubt. The groundwater is very saline and is at ground level. Managing the present site will be difficult and costly. We therefore believe the long-term plan should be to construct a new sports ground.***
- Sports grounds have high rates of recharge. The potential site should be preferably outside the Cranbrook Catchment. We have visited a few sites and recommend a very low ridge to the south-west which is on the Cranbrook Catchment divide** (Figure 13).
- The existing Sports Ground needs closely spaced surface drains to remove inundation and waterlogging.***
- After treatment, the grounds could be used for a nature reserve or a park with salt-tolerant trees and shrubs.
- If it is decided to keep and manage the present sporting grounds the Catchment Hydrology Group or a consultant may be asked to list the engineering solutions which may make the grounds useable.
11.9. Other recommendations

- It is recommended that all future buildings are constructed on top of a pad consisting of at least 0.5 m of sand.

- A water balance needs to be calculated for assessing the different options for the town.
12. Future monitoring

It is essential to monitor the salinity situation in the Cranbrook Catchment. The collected data may be sent to Agriculture WA in Albany for interpretation. The following monitoring is necessary:

- Groundwater levels should be measured once a week during the next two winters, once a month during the first summer and three monthly thereafter.

- Groundwater salinities should be measured once every second year, preferably in April. Samples should be collected only after flushing the holes.

- Weekly water samples should be collected from surface runoff during October each year (after the major rains have ceased) and sent to Agriculture WA in Albany. Seven sites are recommended for sampling: Sites 1 to 4 along Cranbrook Creek (Figure 3); the Northern Creek where it flows under the Great Southern Highway, and in the Oval Catchment at both Rockwell Road crossings.
13. References


Appendix 1:

The following pages show the drill logs of 12 bores that were drilled in the study area in April 1996. The location of these bores is marked on Figure 1. These logs do not include the shallow bores which were drilled next to deep ones. The drill logs contain the following information:

- Eastings and northings (Australian Map Grid) of sites;
- Salt concentrations in the profile (kg/m$^3$), which range from 1 to 30;
- Total salt stored (t/ha) in the drilled profile, which ranges from 240 to 2830;
- Groundwater salinity (mS/m), which ranges from 550 to 3590. To convert mS/m to mg/L, multiply these figure by 5.5.
- Water level below the ground (m), which ranges from -0.08 to -3.4;
- Which landform pattern it is drilled in;
- Interpreted geology;
- A full description of the soil profile (lithology).
Drilling Log Cranbrook 1997

C1d

**Easting:** 550301  **Northing:** 6204299  **Salt Storage (TSS t/ha):** 1109

**Groundwater salinity (mS/m):** 2440  **Water level below ground (m):** -1.52

**Date:** 13/6/97  **Slotted depth (m):** -14 to -16.5

**Landform Pattern:** Flats (less than 5 m relief) with well defined drainage.

**Hydrological System:** Swampy terrains.

**Interpreted Geology:** 0-0.5 m alluvium, 0.5-7 m sediments, 7-17 m *in situ* weathered dolerite, 17 m bedrock.

---

**Drilling log**

- 0-6 m silty clay 10YR 7/1 (white)
- 6-13 m heavy sandy clay 7.5YR 7/6 (reddish yellow)
- 13-16.5 m greenish grey silty clay 5Y 7/1 (light grey)
- 16.5 m basement rock

---

**Salt Storage Profile**

![Salt Storage Profile Graph]

---

**Legend**

- heavy sandy clay, sandy clay
- coarse sandy clay
- fine sand, loamy sand, loamy clay sand
- silt, silty clay
- saprolite
- heavy silty clay
- water table
- bedrock
- coarse sand
Drilling Log Cranbrook 1997

C3d

**Easting:** 549975  **Northing:** 6204640  **Salt Storage (TSS t/ha):** 2729

**Groundwater salinity (mS/m):** 1738  **Water level below ground (m):** -1.13

**Date:** 13/6/97  **Slotted depth (m):** -23.6 to -26.1

**Landform Pattern:** Flats with well defined drainage (less than 5 m relief).

**Hydrological System:** Swampy terrains.

**Interpreted Geology:** 0-6 m sediments, 6-26 m fine to medium-grained *in situ* weathered granite, 26 m basement rock.

**Drilling log**

- 0-1 m loamy sand 10YR 7/1 (white)
- 1-5 m sandy clay 10YR 7/4 (very pale brown)
- 5-6 m sandy clay loam 2.5Y 8/4 (pale yellow)
- 6-24 m heavy silty clay 10YR 8/2 (white)
- 24-26 m weathered medium-grained granite 10YR 8/2 (white)
- 26 m basement rock

**Salt Storage Profile**

**Legend**

- heavy sandy clay, sandy clay
- coarse sandy clay
- fine sand, loamy sand, loamy clay sand
- silt, silty clay
- saprolite
- heavy silty clay
- water table
- bedrock
- coarse sand
Drilling Log Cranbrook 1997

Easting: 550737  Northing: 6204767  Salt Storage (TSS t/ha): 177

Groundwater salinity (mS/m): 549  Water level below ground (m): -2.36

Date: 13/6/97  Slotted depth (m): -9 to -11

Landform Pattern: Very gently undulating plains (less than 10 m relief).  Hydrological System: Swampy terrains.

Interpreted Geology: 0-1 m alluvial sand, 1-5 m heavy textured sediments, 5-7 m coarse alluvial sand, 7-11 m coarse alluvial sand and clay.

Drilling log

- 0-1 m sand 10YR 7/1 (white)
- 1-5 m sandy clay 10YR 7/6 (yellow)
- 5-7 m sandy clay loam 2.5Y 8/4 (pale yellow)
- 7-11 m coarse sandy clay 10YR 8/3 (very pale brown)

Salt Storage Profile

Legend

- heavy sandy clay, sandy clay
- coarse sandy clay
- fine sand, loamy sand, loamy clay sand
- silt, silty clay
- saprolite
- heavy silty clay
- water table
- bedrock
- coarse sand
Drilling Log Cranbrook 1997

C6d

Easting: 550245  Northing: 6204896  Salt Storage (TSS t/ha): 241
Groundwater salinity (mS/m): 990  Water level below ground (m): -1.94
Date: 17/6/97  Slotted depth (m): -6 to -8

Landform Pattern: Very gently undulating plains (less than 10 m relief). Hydrological System: Swampy terrains.
Interpreted Geology: 0-1 m alluvial sand, 1-3 m Pallinup silty clay, 3-6 m Pallinup silty clay, 6-8 m Pallinup sandy clay. (Profile is comprised completely of sedimentary deposits).

**Drilling log**

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Material</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.5 m</td>
<td>sand</td>
<td>10YR 7/1 (white)</td>
</tr>
<tr>
<td>0.5-1 m</td>
<td>clay sand</td>
<td>10YR 7/6 (yellow)</td>
</tr>
<tr>
<td>1-3 m</td>
<td>sandy clay</td>
<td></td>
</tr>
<tr>
<td>3-6 m</td>
<td>coarse sandy clay</td>
<td>10YR 8/6 (yellow)</td>
</tr>
<tr>
<td>6-8 m</td>
<td>sandy clay</td>
<td>10YR 8/3 (very pale brown)</td>
</tr>
</tbody>
</table>

**Salt Storage Profile**

![Salt Storage Profile Graph]

Legend

- heavy sandy clay, sandy clay
- coarse sandy clay
- fine sand, loamy sand, loamy clay sand
- silt, silty clay
- saprolite
- heavy silty clay
- water table
- bedrock
- coarse sand
Drilling Log Cranbrook 1997

东经: 550556  北纬: 6204927  盐存储 (TSS t/ha): 2516
地下水盐度 (mS/m): 2600  水位地面以下 (m): -1.7
日期: 17/6/97  钻孔深度 (m): -21.5 to -23

地形图案: 非常轻微起伏的平原 (低于 10 m 海拔)。

水文系统: 沼泽地形。

解释地质: 0-2 m 洪积沙, 2-11 m 洪积粗砂粘土, 11-13.5 m 洪积粗砂, 13.5-23 m Pallinup 粘土。 (剖面由完全由沉积物组成的沉积物组成)。

---

### Drilling log

0-2 m 粘土质粗砂 10YR 7/4 (非常浅棕色)
2-3 m 粘土质泥 10YR 7/2 (浅灰色)
3-11 m 粗粒轻质粘土泥 10YR 8/1 (白色)

11-13.5 m 粗粒土粘土 10YR 6/1 (灰色)
13.5-23 m 粘土 10YR 6/1 (灰色)

---

### Salt Storage Profile

---

<table>
<thead>
<tr>
<th>Legend</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>red</td>
<td>heavy sandy clay, sandy clay</td>
</tr>
<tr>
<td>brown</td>
<td>coarse sandy clay</td>
</tr>
<tr>
<td>brown</td>
<td>fine sand, loamy sand, loamy clay sand</td>
</tr>
<tr>
<td>green</td>
<td>silt, silty clay</td>
</tr>
<tr>
<td>orange</td>
<td>saprolite</td>
</tr>
<tr>
<td>yellow</td>
<td>heavy silty clay</td>
</tr>
<tr>
<td>blue</td>
<td>water table</td>
</tr>
<tr>
<td>gray</td>
<td>bedrock</td>
</tr>
<tr>
<td>gray</td>
<td>coarse sand</td>
</tr>
</tbody>
</table>

---

深度 (m)  | TSS (EC1:5) kg/m3
--- | ---
0  | 0
5  | 10
10 | 20
15 | 30
20 | 40
25 |
Drilling Log Cranbrook 1997

C10d

Easting: 550429  Northing: 6205907  Salt Storage (TSS t/ha): 1581
Groundwater salinity (mS/m): 2620  Water level below ground (m): -0.2
Date: 17/6/97  Slotted depth (m): -12 to -14
Landform Pattern: Very gently undulating plains (less than 10 m relief). Hydrological System: Swampy terrains.
Interpreted Geology: 0-1 m alluvial sandy clay, 1-14 m in situ weathered dolerite.

Drilling log

0-0.5 m sandy clay loam 10YR 6/4 (light yellowish brown)
0.5-1 m sandy clay 7.5YR 6/6 (reddish yellow)
1-8 m heavy clay 10YR 8/0 (white)
8-10 m heavy clay 10YR 8/3 (very pale brown)
10-14 m heavy clay 10YR 7/1 (light grey)

Legend

- heavy sandy clay, sandy clay
- coarse sandy clay
- fine sand, loamy sand, loamy clay sand
- silt, silty clay
- saprolite
- heavy silty clay
- water table
- bedrock
- coarse sand

Salt Storage Profile

Depth (m)
Drilling Log Cranbrook 1997

C11d

Easting: 550805 Northing: 6204166 Salt Storage (TSS t/ha): 1869
Groundwater salinity (mS/m): 2750 Water level below ground (m): -0.52
Date: 19/6/97 Slotted depth (m): -13.7 to -15.7
Landform Pattern: Flats with well defined drainage (less than 5 m relief).
Hydrological System: Swampy terrains.
Interpreted Geology: 0-0.5 m alluvial sandy clay, 0.5-13 m in situ weathered granite, 13-
15.7 m saprolite, 15.7 m basement rock.

Drilling log

Salt Storage Profile

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS (EC1.5) kg/m³</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

Legend

- heavy sandy clay, sandy clay
- coarse sandy clay
- fine sand, loamy sand, loamy clay sand
- silt, silty clay
- saprolite
- heavy silty clay
- water table
- bedrock
- coarse sand
Drilling Log Cranbrook 1997

**Easting:** 551107  
**Northing:** 6204627  
**Salt Storage (TSS t/ha):** 2678  
**Groundwater salinity (mS/m):** 2250  
**Water level below ground (m):** -2.35  
**Date:** 19/6/97  
**Slotted depth (m):** -18 to -20

**Landform Pattern:** Very gently undulating plains (less than 10 m relief). **Hydrological System:** Swampy terrains.

**Interpreted Geology:** 0-8 m sediments, 8-20 m *in-situ* weathered fine-grained granite.

---

**Drilling log**

0-0.5 m clay sand 10YR 7/1 (light grey)
0.5-5 m sandy clay 10YR 7/6 (yellow)
5-8 m clayey coarse sand 7.5YR 8/2 (pinkish white)
8-12 m heavy sandy clay 7.5YR 8/2 (pinkish white)
12-15 m heavy clay 2.5Y 7/6 (yellow)
15-20 m heavy clay 2.5Y 5/2 (greyish brown)

---

**Salt Storage Profile**

---

**Legend**

- Heavy sandy clay, sandy clay
- Coarse sandy clay
- Fine sand, loamy sand, loamy clay sand
- Silt, silty clay
- Saprolite
- Heavy silty clay
- Water table
- Bedrock
- Coarse sand
Drilling Log Cranbrook 1997

C15d

Easting: 551321   Northing: 6205062   Salt Storage (TSS t/ha): 1072
Groundwater salinity (mS/m): 2690   Water level below ground (m): -1.5
Date: 19/6/97   Slotted depth (m): -9 to -11

Landform Pattern: Flats with well defined drainage (less than 5 m relief). Hydrological System: Swampy terrains.
Interpreted Geology: 0-3 m sediments, 3-11 m in situ weathered granite.

Drilling log

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.5</td>
<td>10YR 6/1 (light grey)</td>
</tr>
<tr>
<td>0.5-2</td>
<td>10YR 7/4 (very pale brown)</td>
</tr>
<tr>
<td>2-3</td>
<td>10YR 7/1 (white)</td>
</tr>
<tr>
<td>3-11</td>
<td>5YR 8/1 (white)</td>
</tr>
</tbody>
</table>

Salt Storage Profile

Legend

- heavy sandy clay, sandy clay
- coarse sandy clay
- fine sand, loamy sand, loamy clay sand
- silt, silty clay
- saprolite
- heavy silty clay
- water table
- bedrock
- coarse sand
Drilling Log Cranbrook 1997

Easting: 550676  Northing: 6205338  Salt Storage (TSS t/ha): 2829
Groundwater salinity (mS/m): 3590  Water level below ground (m): -1.33
Date: 19/6/97  Slotted depth (m): -17.5 to -17.5

Landform Pattern: Flats with well defined drainage (less than 5 m relief).
Hydrological System: Swampy terrains.
Interpreted Geology: 0-2.5 m alluvium, 2.5-19.5 m in situ weathered granite.

Drilling log

0-0.5 m gravelly sand 10YR 7/2 (white)
0.5-2.5 m sandy clay 10YR 7/4 (very pale brown)
2.5-6 m heavy sandy clay 7.5YR 8/1 (white)
6-19.5 m coarse sandy clay 7.5YR 8/1 (white)
19.5 m basement rock

Salt Storage Profile

Legend

- heavy sandy clay, sandy clay
- coarse sandy clay
- fine sand, loamy sand, loamy clay sand
- silt, silty clay
- saprolite
- heavy silty clay
- water table
- bedrock
- coarse sand
Easting: 550342    Northing: 6205164    Salt Storage (TSS t/ha): 784
Groundwater salinity (mS/m): 2210    Water level below ground (m): -2.1
Date: 20/6/97    Slotted depth (m): -12 to -14

**Landform Pattern:** Very gently undulating plains (less than 10 m relief). **Hydrological System:** Swampy terrains.

**Interpreted Geology:** 0-8 m Quaternary sediments, 8-10.5 m Quaternary sand, 10.5-14 m Pallinup silt.

### Drilling log

- 0-0.5 m sand 10YR 7/1 (light grey)
- 0.5-2 m sandy clay loam 10YR 8/4 (very pale brown)
- 2-8 m coarse sandy clay 10YR 8/2 (white)
- 8-10.5 m sand 10YR 6/1 (grey)
- 10.5-14 m silty clay 10YR 6/1 (grey)

### Salt Storage Profile

![Salt Storage Profile Graph]

**Legend**

- heavy sandy clay, sandy clay
- coarse sandy clay
- fine sand, loamy sand, loamy clay sand
- silt, silty clay
- saprolite
- heavy silty clay
- water table
- bedrock
- coarse sand
Drilling Log Cranbrook 1997

C18d

**Easting:** 551694  **Northing:** 6204202  **Salt Storage (TSS t/ha):** 672
**Groundwater salinity (mS/m):** 1492  **Water level below ground (m):** -3.1
**Date:** 20/6/97  **Slotted depth (m):** -13 to -17

**Landform Pattern:** Flats with well defined drainage (less than 5 m relief).  **Hydrological System:** Swampy terrains.

**Interpreted Geology:** 0-11 m Quaternary sediments, 11-17 m *in situ* weathered granite.

### Drilling log

- 0-0.5 m loamy sand 10YR 7/1 (light grey)
- 0.5-6 m sandy clay loam 10YR 8/4 (very pale brown)
- 6-8 m sandy clay loam 10YR 8/1 (white)
- 8-10.5 m loamy coarse sand 10YR 7/1 (light grey)
- 10.5-17 m coarse sandy clay 10YR 7/1 (light grey)

### Salt Storage Profile

**Legend**
- heavy sandy clay, sandy clay
- coarse sandy clay
- fine sand, loamy sand, loamy clay sand
- silt, silty clay
- saprolite
- heavy silty clay
- water table
- bedrock
- coarse sand

---

Depth (m)
# Appendix 2: Terminology and abbreviations used in this report

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvial or alluvium</td>
<td>Material that is deposited by water in low-lying areas and floodplains.</td>
</tr>
<tr>
<td>AMG</td>
<td>Australian Map Grid.</td>
</tr>
<tr>
<td>Aquifer</td>
<td>A water-bearing underground layer (stratum), that water can be extracted from.</td>
</tr>
<tr>
<td>Archaean</td>
<td>Early Precambrian era (Precambrian period was between 600 and 4,500 million years ago).</td>
</tr>
<tr>
<td>Plant available water (PAWC)</td>
<td>Difference between field capacity and wilting point of a soil. Water which plants can obtain from unsaturated soil.</td>
</tr>
<tr>
<td>Baseflow</td>
<td>The extended, low flow in a creek after surface runoff has finished and when groundwater is the main contributor to the flow.</td>
</tr>
<tr>
<td>Bedrock or Basement rock</td>
<td>Hard rocks that are at the base of the weathered soil profile or regolith.</td>
</tr>
<tr>
<td>Capillarity</td>
<td>Rise of a liquid, which is in contact with a solid, due to surface tension.</td>
</tr>
<tr>
<td>Capillary</td>
<td>Fine spaces between soil particles which are interconnected.</td>
</tr>
<tr>
<td>Conductivity (electrical)</td>
<td>Ability of a rock or a solution to conduct an electrical current.</td>
</tr>
<tr>
<td>Degradation and degrade</td>
<td>Decline in the condition of natural resources commonly caused by human activities.</td>
</tr>
<tr>
<td>Discharge rate</td>
<td>Volume of water flowing through a cross section in a unit time.</td>
</tr>
<tr>
<td>Discharging</td>
<td>Groundwater coming to the soil surface.</td>
</tr>
<tr>
<td>Drill log</td>
<td>A record of material drilled and findings while drilling a bore.</td>
</tr>
<tr>
<td>Erosive velocity (m/second)</td>
<td>A velocity of water above which water may erode its channel. This velocity is 0.45 m/s for sand, 0.60 m/s for silty loam and about 1.0 m/s for heavy, tight clay (all bare surfaces).</td>
</tr>
<tr>
<td>Flat</td>
<td>An area that is almost level (&lt;1% slope) and is not a crest or a depression. When a large area of level land is higher than most of the surrounding areas it is called a plain.</td>
</tr>
<tr>
<td>Flow lines</td>
<td>In a laminar flow (flow that is not turbulent) molecules of liquid flow along predictable lines which are called flow lines.</td>
</tr>
<tr>
<td>Geology</td>
<td>Science of the earth (its origin, structures, composition, historical changes and processes).</td>
</tr>
<tr>
<td>Granite rock</td>
<td>An igneous rock that has an irregular, granular texture and its grains can be seen. Composed of quartz (10-20%), feldspars (70%), mica (5-10%) and other minor minerals.</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Gravel</td>
<td>Rock particles 2-4 mm in diameter.</td>
</tr>
<tr>
<td>Hydraulic conductivity</td>
<td>The ability of a material to conduct water.</td>
</tr>
<tr>
<td>Hydraulic gradient</td>
<td>Slope between water levels in two bores that have been drilled at different sites but into the same aquifer. If the bores are along the same flow line, the gradient will be the maximum gradient of that aquifer in that area.</td>
</tr>
<tr>
<td>Hydrological system (HS)</td>
<td>Areas that have similar hydrological properties and may be grouped together as one unit.</td>
</tr>
<tr>
<td>Hydrology</td>
<td>Science of water movement in relation to land and the soil profile.</td>
</tr>
<tr>
<td>In situ; In situ weathered material</td>
<td>In place; Weathered material that has stayed in its place of weathering.</td>
</tr>
<tr>
<td>Landform pattern (LFP)</td>
<td>A toposequence (valley floor, hillside and ridge) described by its relief, slope, landform elements and degradational problems associated with its use.</td>
</tr>
<tr>
<td>Leaching</td>
<td>The removal of some chemical components of a rock or soil by water.</td>
</tr>
<tr>
<td>Local aquifer</td>
<td>Aquifer with its recharge area located close to its discharge area – short flow lines only. Groundwater levels in a local aquifer usually form an open depression and flow lines are convergent.</td>
</tr>
<tr>
<td>mg/L</td>
<td>Milligrams per litre.</td>
</tr>
<tr>
<td>Mottles</td>
<td>Mottles are spots, blotches or streaks in a soil profile which have different colours from the matrix colour of the soil.</td>
</tr>
<tr>
<td>mS/m</td>
<td>MilliSiemens per metre (a measure of electrical conductivity).</td>
</tr>
<tr>
<td>Off-site</td>
<td>Material or something that has originated elsewhere but has been transported or transferred to a site.</td>
</tr>
<tr>
<td>Palaeochannels</td>
<td>Ancient drainage valleys that have been filled with sediments. Palaeochannels may be call “buried alluvial channels”.</td>
</tr>
<tr>
<td>Pallinup Siltstone</td>
<td>Silts that were deposited in a marine environment on the south coast of Western Australia during the Eocene (~ 40 to 60 million years ago).</td>
</tr>
<tr>
<td>Pebble</td>
<td>A rock particle between 4 and 60 mm in diameter.</td>
</tr>
<tr>
<td>Piezometric surface or level</td>
<td>Height to which water level rises in a piezometer: reflects the pressure of the aquifer next to the screen depth.</td>
</tr>
<tr>
<td>Proterozoic</td>
<td>Late Precambrian period, which is between 600 and 1,500 million years ago.</td>
</tr>
<tr>
<td>Recharge</td>
<td>A component of rainfall that drains below the root zone of vegetation and joins the groundwater.</td>
</tr>
<tr>
<td>Regional aquifer</td>
<td>An aquifer that is large, its flow lines are almost straight and parallel, and it is fed by on-site as well as off-site recharge. (ie recharge can be located a long way from its discharge).</td>
</tr>
</tbody>
</table>
Regolith
Weathered or sedimentary material that overlies basement rock.

Relief
Changes in elevation within a specified distance.

Root zone
Near surface part of a soil profile where roots are active.

Salt-affected
An area where the growth of crops, pastures or natural vegetation is reduced by excessive salt in the root zone.

Salt bulge
A zone in the salt profile of a regolith that has the highest concentration of salt.

Salt storage
Salt storage is the amount of salt held in a soil profile. Salt storage is measured in terms of kg per cubic metre (kg/m³) or tonnes per hectare (t/ha). Salt storage is dependent on landform patterns and rainfall.

Silt
Soil particles that are between 0.002 and 0.02 mm in diameter. They are larger than clay and smaller than fine sand.

Subsoil
The B horizon (below the topsoil) of a soil profile. A soil horizon is a layer of soil, approximately parallel to the soil surface, with morphological properties that are different from layers below or above. The B horizon is usually a zone of accumulation (of clay, iron etc).

Tertiary
A geological period that extended between 2 and 65 million years ago. This period was characterised by active erosion and sedimentation in the south-west of WA.

Texture
Size, shape and relationship between grains of a soil or rock. The proportion of sand, silt and clay in soil.

TSS/TDS
Total soluble salts or total dissolved salts, usually measured in milligrams per litre (mg/L).

Unsaturated soil profile
A zone in the soil profile where all the pores are not filled with water and the soil contains some air in its larger pores.

Water balance
A state of equilibrium when rainfall or irrigation water in a landscape is accounted for by the sum of runoff, plant water use, evaporation, recharge and changes in soil moisture content.

Water holding capacity
Water that is held in the soil after gravitational water has drained away following soil saturation.

Waterlogging
Excess water in the root zone of plants such that it adversely affects plant growth by prohibiting the exchange of gases with the atmosphere. The soil profile need not be saturated for gas exchange to be impaired.

Water table
The upper surface of an unconfined aquifer where water will flow into a well or bore.

Weathering
Chemical, physical and biological decomposition of rocks. This can result in the formation of a soil profile.