Department of Primary Industries and Regional Development
GOVERNMENT OF WESTERN AUSTRALIA

Research Library

Resource management technical reports

Natural resources research

1997

The salinity and hydrology of the Tambellup townsite and Jam Creek Catchment

R Ferdowsian

A T. Ryder

Follow this and additional works at: https://researchlibrary.agric.wa.gov.au/rmtr

Part of the Agriculture Commons, Natural Resources Management and Policy Commons, Soil Science Commons, and the Water Resource Management Commons

Recommended Citation

Ferdowsian, R, and Ryder, A T. (1997), *The salinity and hydrology of the Tambellup townsite and Jam Creek Catchment*. Department of Agriculture and Food, Western Australia, Perth. Report 172.

This report is brought to you for free and open access by the Natural resources research at Research Library. It has been accepted for inclusion in Resource management technical reports by an authorized administrator of Research Library. For more information, please contact jennifer.heathcote@agric.wa.gov.au, sandra.papenfus@agric.wa.gov.au, paul.orange@dpird.wa.gov.au.

ISSN 1039-7205
1997

The Salinity and Hydrology of Tambellup

R. Ferdowsian and A. Ryder

Resource Management Technical Report No.172

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.

Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

© Director General, Department of Agriculture Western Australia 2004

Acknowledgments

We are indebted to Dr. Don McFarlane, Dr Richard George and Dr. Jo McFarlane who reviewed this report. We also appreciate the assistance of the Tambellup Shire for providing fuel for drilling, Peter Rowe and Brian Lloyd, who surveyed the bores and Bob Love for helping us in drilling.

Table of Contents

SUMMARY

1. Introduction and background

The study area covers the Tambellup Town and the Jam Creek Catchment (top photograph on cover). The Tambellup Town is located 115 km north of Albany. The town has a population of 360 people (800 in the whole Shire).

Tambellup 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 grounds. Many hectares of land in the Jam Creek Catchment has become salt-affected and salinity is on increase.

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

The Catchment Hydrology Group has been asked to study the salinity status of the Tambellup townsite and suggest management options which reverse the increasing salinity trend.

2. Methods and materials

Twelve 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. One existing bore had been drilled near the Tambellup School by Agriculture WA in 1992 and three by Tambellup Shire, on the western bank of the Gordon River. Groundwater levels and salinities in these bores were used to assess the salinity status of the area 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 August 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 AgET (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 catchment above the Tambellup Town.

3. Results

3.1. Hydrology

Hydrological systems and their aquifers

The are nine landform patterns in the study area that have been grouped into four hydrological systems: Crests; Undulating plains with swampy floors; Swampy terrains and valleys with seasonal flow.

Crests and Undulating Plains with swampy floors are on or near catchment divides of the study area. Swampy Terrains occupy the lower parts of the study area. The valleys with seasonal flow form the depressions and creek lines. The Tambellup 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 (See Terminology for definition). Most areas of the Plains with swampy floors and valleys have local aquifers but their lower areas 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 Tambellup townsite

The regolith in most of the bores had a sandy layer and below it a heavy silty clay which acts as a semi-confining layer reducing interaction between the shallow and deep groundwater. Between June and September 1997, shallow groundwater levels in residential and industrial parts of Tambellup were between zero and 1.70 m below soil surface. During the same period, the deep (>8 m) groundwater levels were between 0.65 m and 2.40 m below ground level. These levels are very close to the soil surface.

A perched shallow aquifer had formed under the town. Groundwater had a downwards gradient and the shallow perched aquifer was recharging the deep regional one. As a result, the deep groundwater levels rose by an average 0.47 m between 15th June and 26th September.

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.

---

[1] Technical terms used in the report are defined in Appendix 2

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.

Groundwater salinities

Salinity of the perching aquifer was between 240 mg/L and 1000 mg/L with the exception of a very shallow bore (1 m deep), in salt-affected land which had a relatively higher salt content (2,250 mg/L).

Groundwater salinities in deep bores in town varied between 6,000 mg/L and 25,500 mg/L. Groundwater salinity in 82 % of deep bores were >11,000 mg/L. The higher groundwater salinities represent salinity of the regional groundwater and were found in those bores which had a semi-confining layer. The lower salinities were found in those bores without that layer.

3.2. Recharge in the study area

Recharge in the agricultural land

Annual rates of recharge in agricultural areas probably vary between 0 and 150 mm/year, depending on annual rainfall and vegetation cover. In a year with average rainfall, bare sandy soils, clover-based pastures, cereals, shrubs and lucerne will contribute about 130, 95, 50, 4 and 4 millimetres of recharge respectively.

Recharge in the Tambellup townsite

The Tambellup Town has about 50 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 0.47 m between 15th June and 26th September 1997.

3.3. Potential salinity of the study area

At present over 770 ha (9.6%) of areas in the Jam Creek Catchment is salt-affected. Under the current management options, the affected areas may eventually increase to >1,930 ha (23.9%). Salt-affected land in the upper parts of the study area is and will be in the shape of narrow strips and confined to creek lines. In the lower parts of the catchment, however, soil salinity is affecting broad flat areas.

The area of Tambellup townsite is entirely in *Swampy terrains* hydrological system. The extent of soil salinity in *Swampy terrains* is very high and it will increase in the future. About 17% of the Tambellup townsite is salt-affected at present. This figure may increase to 26% of the townsite in the future if the present management practices are continued.

The north-western parts of the Oval is salt-affected. If groundwater levels continue to rise the whole Oval may have salinity problem.

3.4. Management options to reduce the extent of salinity in the Jam Creek Catchment

At present 9.6% of the Jam Creek Catchment is salt-affected. The extent of soil salinity may increase to 24% of that catchment area if the current management practices are continued. To reverse the increasing groundwater levels and increasing salinity, the present rates of recharge in the Jam Creek Catchment need to be reduced. This reduction can be made by:

- Reducing recharge and increasing surface and sub-surface runoff (using surface drains);
- Increasing the area under perennial pastures;
- Introducing phase cropping;
- Increasing water use by revegetating selected areas;
- Managing creek lines and water courses, swamps, lakes and salt-affected areas
- Improving the productivity of existing crops and pastures;
- Regenerating existing native vegetation;

In the report the first five of these issues are discussed.

3.5. Management options in the Tambellup townsite that have direct effect on the extent of salinity in the town

To reduce the extent and the impact of salinity on residential parts of town, recharge in the cleared areas in and near Tambellup should be reduced. In this report the options have been grouped into seven categories:

- Management of surface runoff in the Tambellup Town;
- Management of agricultural land east and north of the town;
- Management of the Industrial Tip site;
- Management of the natural vegetation and revegetation around town;
- Direct groundwater management;
- Managing the sewerage system;
- Other recommendations.

1. Introduction and background

1.1. The study area

The study area covers the Tambellup Town and the Jam Creek Catchment (Figure 1). The Tambellup Town is located 115 km north of Albany. The town has a population of 360 people (800 in the whole Shire; ABS Census,1991). The townsite boundary (Figure 1) encloses 540 ha of which 95 ha has been cleared for residential, industrial and recreational land use (top photograph on the cover page). The Jam Creek Catchment that contributes to salinity of the Tambellup town is located north-east of the townsite. The area of this catchment is 8,050 ha and includes approximately 55% of the Tambellup townsite. The Tambellup townsite is dissected by the Gordon River which enters the north-west corner and exits near the south-eastern corner of the townsite. The residential and industrial parts of the town are established on the eastern bank of Gordon River and extend to the northern bank of the Jam Creek (Figure 1 and top photograph on cover page).

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. Estimates in 1996 indicated that in the Upper Gordon Catchment, 11.3% of agricultural land was salt-affected. The affected area may eventually increase to 25% in the future unless recharge in cleared areas is reduced (Ferdowsian et al, 1996).

Tambellup 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 is affecting the sporting ground. Salinity in the Tambellup Town is partly caused by recharge and groundwater level rises in the Jam Creek Catchment which is experiencing increasing salinity.

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 Tambellup 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 Tambellup 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:

1. to investigate the geology of the area; For example find out if there are any sediments and other geological features such as faults which may affect the hydrology of the area;
2. to document the present groundwater levels and salinities in the study area;
3. to find if the aquifer is regional (See Terminology for definition) or local, which may affect the treatments needed;
4. to define recharge and discharge systems and predict the high recharge areas;
5. to investigate any effects that natural vegetation around the Tambellup has on groundwater levels;
6. to identify areas that are in danger of becoming saline under current management options;
7. to estimate groundwater levels near the oval and predict its viability as a sports ground;
8. to recommend management options that may reverse the present salinity trend in the area;
9. to facilitate the 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 30°C. There are occasional heat waves (mostly in February), during which the maximum temperature exceeds 40°C, or rarely, 45°C. The mean monthly temperature in July (the coldest month) is 9.8°C. During about 12 days per year, the minimum temperature drops below 2.0°C.

The mean annual rainfall is about 448 mm (Bureau of Meteorology, 1993). Seventy three 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 360 mm and in 20% of years (decile 8) exceeds 500 mm.

The mean monthly evaporation from a Class A pan varies between 47 mm in June and 273 mm in January (Figure 2; Luke *et al*. 1989). The mean annual Class A evaporation is 1660 mm. Mean monthly rainfall exceeds the pan evaporation during June and July (Figure 2).

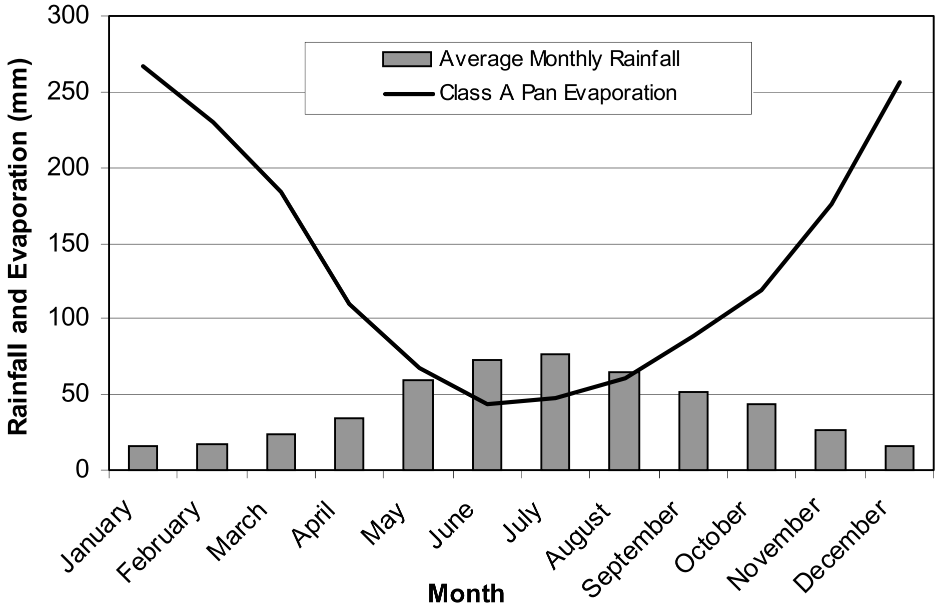

Figure 2: Monthly rainfall (Bureau of Meteorology, Station 10643) and, evaporation from Class A pan (Luke et al. 1989) for Tambellup.

3. Methods and materials

3.1. Drilling methods

Bores (Figure 3) were sited using aerial photographs (1:25,000 scale,1993). A total of 11 deep holes (between 8 and 32 m) and 6 shallow holes (<5 m deep) were drilled between 9th and 11th 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 the future monitoring. Drill logs and information on these holes (T1D to T12D) are presented in Appendix 1. These logs show groundwater levels and salinities, salt storages and lithology.

Five other bores had been drilled previously, two near the school, by Agriculture WA in 1992 and three along the eastern bank of Gordon river. The levels and salinity of groundwater in these bores were used to estimate the salinity of groundwater and find the flow direction of the aquifer.

3.2. Soil and water analyses

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

Soil samples were oven dried at 70°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 ($EC_{1:5}$). The $EC_{1:5}$ 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).

3.3. 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 and where 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.

3.4. Recharge estimation

Annual recharge has been estimated within the study area using “AgET” 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.

3.5. 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).
- Groundwater contours and trends in groundwater levels were used to confirm the areas which are in danger of becoming saline.

3.6. 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 Jam Creek Catchment which flows under the Tambellup 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 four hydrological systems: Crests; Undulating plains with swampy floors; Swampy terrains and valleys with seasonal flow (Figure 5). The following paragraphs give a brief description of these hydrological systems.

4.1. Crests

This group includes three LFPs: Broad crests,, Undulating rises and Gently undulating plains. Landform patterns in this system are on or near catchment divides and have very low relief (15 m-30 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. Basement rocks are shallow to moderately deep (<20 m). Occasional rock outcrops may be found on crests, upper or mid-slopes. 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 mostly occurs in well-defined depressions and creek lines which are in the lowest part of the area. Occasional hillside seeps may occur on the lower slopes due to groundwater level build up above granitic highs. Almost all areas of this HS are recharge areas, especially waterlogged sandy head water depressions and flat crests.

4.2. Undulating Plains with swampy floors

This group is in mid-catchment positions, and surrounds the valley floors and includes two LFPs: *Gently Undulating Plains* with saline depressions which has low relief (10-30 m); and *Very Gently Undulating Plains* which has extremely low relief (< 10m). 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. Very Gently Undulating Plains on the other hand have very little undulation and broad depressions which are not well-defined. 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 salty 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

This HS includes the broad and stagnant flats and floors in mid and lower catchment of the Jam Creek. Tambellup town site is built on this HS. Landform patterns in this HS have extremely low relief (< 10m). Stream channels which are sparse to widely spaced, are poorly defined. 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 : *Stagnant alluvial or sedimentary flats, Flood Plains* and *Flats with Swales and sand dunes.* Swales are linear, level-floored open depression left relict between sand dune ridges built up by wind. The Tambellup townsite is within *Swales and sand dunes*.

4.4. Gently inclined valleys

This HS has one LFP with the same name. It forms the valleys in the upper one third of the catchment (Figure 5). Valleys have well-defined drainage lines with > 0.4% longitudinal slope and erosional floors. These erosional floors change to *Flood Plains* further downstream (in *Swampy Terrains*), which have depositional depressions with <0.2% longitudinal slope. Bedrock in valleys is moderately shallow (<10 m).

5. Physiography

Myers, J.S. (1989) produced 1:1,000,000 geological map of Western Australia. His maps show the major north-west faults some of which extend to more than 300 km. One of these faults is Darkan Fault which passes through Wadjekanup River and Tambellup Town site (Figure 6). Ferdowsian (unpublished information) mapped other faults and shear zones in the study area (Figure 6). Tambellup is on cross section of two major faults, Darkan and Gordon Faults (Figure 6). There are also shear zones which cross the study area (Figure 6). The creeks in the study area are formed along major faults and shear zones.

The Darkan and Gordon Faults were probably existing prior to the Tertiary period. They formed valleys which were 30 m deeper than the present Gordon River bed. During Eocene period, the North Stirling area was invaded by Eocene Sea. The sea extended into and occupied the fault lines and deep valleys and change them into inlets and narrow waterways. Pallinup sediments gradually filled these inlets. The deposited material were initially derived from the nearby granitic hills. Thus these sediments which forms the lowest parts of the Pallinup sediments may be coarser than the Pallinup silts which were deposited in the Eocene Sea and away from the granitic highs. At a later stage finer material were deposited over the coarser sediments. These finer material have formed the confining layers that are discusses later (Section 7). Bore T1 shows that the depth of Tertiary sediments can be more than 30 m. All depositional sequences was observed in the profile of bore T1.

During second half of Tertiary period the landscape was pushed north-west. This push caused uplifting and folding of the region. Evidences of uplifting (folding) may be seen in Pallinup siltstone which is found in the North Stirling area (Photo 1; from Ken’s place).

6. Geology

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

6.1. Geology of the Crests (CR)

This HS has developed on *in situ* weathered profiles. The basement rocks under this HS are composed of medium and even-grained granites of Archaean origin, intruded by few 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 USH20 (Appendix 1), although it is 30 km west of the study area, resembles the drilling profile in this HS.

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

This HS is the transitional zone between *Crests* and *Swampy Terrains*. The basement rocks are also Archaean in origin. The weathering profile is moderately deep (10 to 20m) but few rock outcrops occur on the upper slopes and mid slopes. Weathering profiles in 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.

6.3. Geology of Swampy terrains (ST)

The soil profiles in this HS are usually deep (>25m). The basement rocks are medium-grained granites of Archaean origin, intruded by dolerite dykes. In most areas of this HS, the basement rocks or the *in situ* weathered profiles are covered by sediments of Tertiary age (Pallinup Siltstone) and overlying Quaternary material. In the Tambellup Town area the *in situ* weathered layer may not be found. Bore T1 (Appendix 1) which was the deepest bore (32.5 m deep) we drilled in the study area, had 2 m of aeolian sediments (wind deposited sand) over 30 m of Pallinup silty clay and fine sand over basement rock. Maximum depth of aeolian sand was 5 m (bore T1). Depth of sand decreased further south (Figure 7). Bores which are south and south-east of the town did not have any sand. There is a shallow aquifer in the aeolian sand which flows towards the Gordon River (Section 7.2).

Top of the Pallinup sediments is like a semi-confining layer

With the exception of areas around bores T1 and T6, the latest Pallinup sediments which are under aeolian sands are composed of heavy silty clay which is a semi-confining layer and limits mixing of the deep and shallow groundwaters. The material in this layer changes to clayey sand and clayey silt in the north-west and east of the study area (Bores T1, T6 and T8) where it becomes less confining. The depth of the semi-confining layer is between 2 m and 8 m (Figures 8a, 8b, 8c, 8d, and 8e). The average thickness of this layer is 3.7 m in the north and 6.5 m in the south of the study area. The semi-confining layer formed the top of Pallinup sediments before it was partly eroded and later overlain by wind deposited sand.

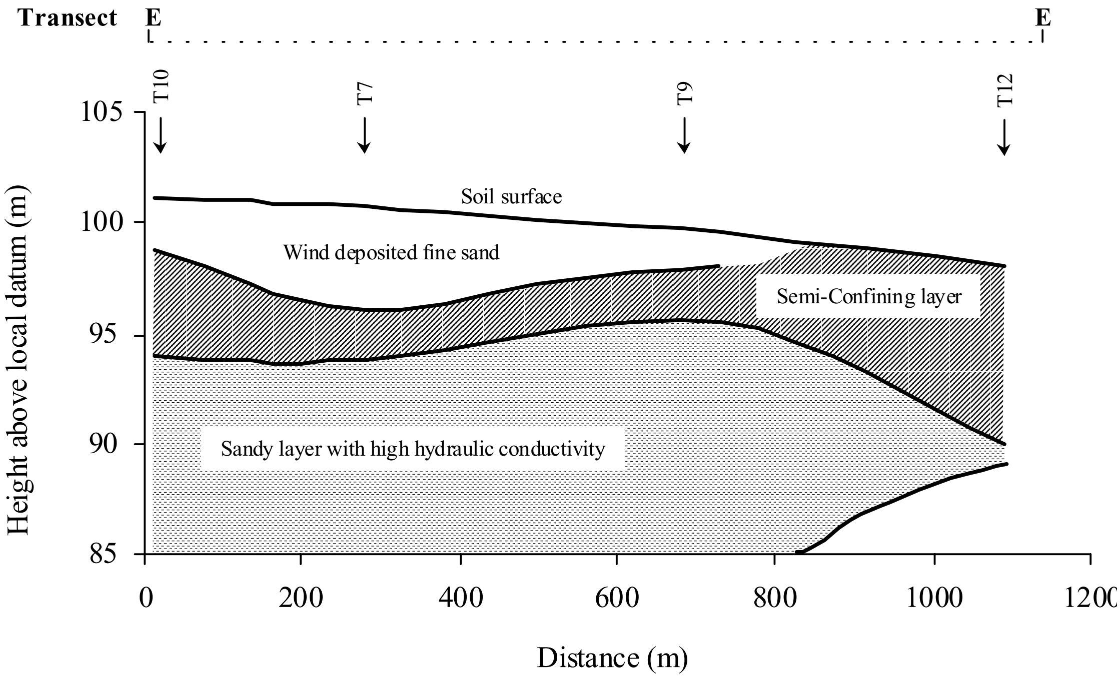

Figure 8e: This north-south cross section passes along the eastern parts of town and shows a sandy layer at depth, a semi-confining layer above it and wind deposited fine sand which is deeper in the north and shallower or non-existent in the south.

Tertiary sediments which are beneath the semi-confining layer are composed of fine sand and silt which has high hydraulic conductivity and contains the deeper and more saline aquifer. Groundwater in this sandy layer is probably fed by on site recharge as well as by recharge in the agricultural areas.

The high and low hydraulic conductivities affect groundwater hydrology and salinity in the study area (Groundwater hydrology). It also presents opportunities for managing groundwater levels (see management).

6.4. Geology of gently inclined valleys

This HS has moderately shallow (<10 m) basement rocks which are composed of medium and even-grained granites of Archaean origin. Geological structures such as shear zones and faults have affected the present position of the valleys and the depressions which feed them (Figure 6). Some of the shear zones have resulted in formation of short depressions which are found on both sides of the valleys. The shear zones have high hydraulic conductivities and because of that, the short depressions have become discharge zones for saline groundwater.

7. Hydrology

7.1. Surface hydrology

The Tambellup townsite is mainly within *Flats with Swales and sand dune* landform pattern. Swales are linear, level-floored open depression left relict between sand dune ridges built up by wind. The sand dunes do not generate any runoff while swales become inundated and could generate runoff. The sand dunes have blocked the drainage lines and reduced surface runoff. The swales are becoming more frequently inundated than pre-clearing time. The stagnant areas contribute to the rising groundwater. By improving surface runoff and reducing inundation less water will be available to recharge the aquifer.

There are many areas in the Tambellup townsite which are become inundated in winter months (June to October). These areas include (For street names see figure 3):

1. Playground near Owen and Norrish road crossing (Photo 2);
2. Areas all along the railway track (Photo 3);
3. Vacant blocks east of Norrish St and north of North Tce (Photo 4);
4. Stagnant flat that is at the end of water supply track and includes the industrial dump site;
5. Areas west of Garrity St and south of the road going to Cemetery;
6. Recreational areas west of the Gordon River and near the dam wall (Photo 5);
7. Stagnant areas east of Gordon River and both sides of Temby St;
8. The northern third of the sports grounds;
9. Areas between Gordon River and Russell Saggers St;
10. Areas north of Owen St and east of Taylor St;
11. Areas north of Henry St where the Owen St joins it;
12. Areas north of the grain bins which is recipient of surface runoff from the gently undulating farm land as well as the *in situ* rainfall.

There are seven poorly-defined drainage lines that are or may be removing some of the surface runoff (drains 1 to 7; Figure 9). The necessary drainage improvements are discussed later (Section 12.1). these seven depressions are:

1. The north-western drain (No. 1a; Figure 9) which is approximately 450 m long, 1.5 m wide and between 0.5 and 1.3 m deep, starts near junction of Garrity and the Cemetery streets. The head water areas of this drain are becoming salt-affected. This drain passes through a wetland that is south west of the two road

junction, then passes through approximately 270 m of sand dune and then is cut into a second flat. It eventually discharges into the wetlands east of Gordon River. The banks of the excavated section passing through the sand dune has collapsed at many places. It is not likely that this drain can carry any flow under the present conditions. This drain is the only natural drainage to remove the increasing surface runoff generated from agricultural land north of the townsite.

2. The two north-eastern swales (No. 2 and 3; Figure 9) collect surface runoff generated from the farming land, north-east of the townsite. These swales are poorly defined and poorly drained. Areas around depression No. 2 have been excavated and used as industrial dumping ground. The area upstream of the dump is becoming saline. The industrial dumping grounds contribute to the rising groundwater levels in the Tambellup townsite (Section 6.2). To improve drainage of these two swales, a drain must be constructed in each. The drains have to pass through the adjacent farmland before discharging into the Jam Creek.

3. The Oval is constructed in a swale. Soil samples from this Oval showed that there is > 0.5 m sandy soil above heavier subsoil. Some soil from the north-western section have probably been removed to extend the elevated areas to south of Oval. This has reversed the gradient of the Oval which is now slopping from south-east to north-west. The removal of soil has resulted in shallower groundwater levels in the north-western corner of the Oval which is becoming salt-affected (Section 11.3; Salinity status of the Oval).

4. Depression No. 4 is also a swale which is difficult to drain. A drain may have to pass through the farmland to east of the area.

5. Depression No.5 starts from north-west of the Oval and passes along the East Trace crosses the Henry St and Owen St and discharges into the Jam Creek. This depression goes through large areas with shallow perched groundwater.

6. Drain No. 6 is in the south section of the town (Figure 9). This drain crosses the railway line and the Garrity St before discharging into Gordon River. This drain despite being close to playground near Owen and Norrish road crossing fails to prevent inundation of nearby areas (Photo 2).

7. Depression No. 7 is a swale parallel to Gordon River and west of Tambellup Hotel. This depression holds water during June to November. The source of water in this depression is the *in situ* rainfall as well as discharging groundwater. The cellar of the Tambellup Hotel which gets flooded by discharging saline groundwater (1000 mS/m), is pumped out regularly. The pumped water enters into depression No. 7 as well.

None of the above depressions are well-functioning and none can effectively remove the surface runoff from their catchments. With the exception of a short drain (No. 6) there is no depression or drain to remove surface runoff from areas along the railway track or from some of the vacant blocks. As a result, large areas become regularly inundated in June, July and August Section 7.1. As we discuss later (Section 10.2), the inundated areas contribute large volume of water to the shallow aquifer which eventually adds to the deep groundwater levels.

There have been two heavy rainfall events during past 42 years, which have flooded large areas:

1. In January 1982 between 210 mm and 275 mm rain fell over the entire Gordon and Jam Creek catchments. The heavy rainfall caused both the Gordon River and the Jam Creek to overflow and inundate large areas including the Tambellup Town. In the town centre water level rose to 1.24 m above ground level. We have estimated the maximum depth of water in the Gordon River which was probably > 6.5 m. The width of the flooded area exceeded 2.7 km. It is estimated that the flow rate exceeded 3,300 m^3 per second.

2. A similar rainfall event occurred in February 1955, when between 170 mm and 215 mm rain fell over the entire region. We do not know of the extent of flooding caused by this event.

The 1982 rainfall event was an exceptional and may not occur more than once in a century. There is hardly any measures to prevent damages caused by such event. Damages from smaller floods may be minimised. This issue is discussed under treatments.

Photograph 1: Evidence of uplifting and folding may be seen in folded Pallinup siltstone, which is found in the North Stirling area (40km east of Tambellup)

Photograph 6: Another consequence of high groundwater levels is the rising damp, which may be seen on many walls. On the left is a rendered wall, on the right a brick wall

7.2. Type and attributes of aquifers in the Jam Creek Catchment and the Tambellup townsite

The *Crests* of the Jam Creek Catchment 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. The boundary of these aquifers are the same as the physical catchment and subcatchment boundaries. The local aquifers continues under the slopes of the *Plains with swampy floors* and under slopes of *valleys.*

Aquifers in the *Swampy terrains* are larger and regional which flows towards the Gordon River and eventually discharges through the seepage zones which are along the banks and in bed of Gordon River. The boundary of the regional aquifer differs from the surface runoff boundary and extends under the whole Tambellup townsite (Section?).

The depressions in the *Plains with swampy floors* and *valleys* 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* and *valleys* 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 Tambellup Town is affected by farming practices in agricultural areas of the Jam Creek Catchment as well as by the management of local water within the townsite.

There is a seasonal perched aquifer under Tambellup Town

The upper layer of Pallinup sediments which are under aeolian sands are composed of heavy silty clay which is a semi-confining layer (Section 7.3). The semi-confining layer may extend under most of the *Swampy terrains.* The regional aquifer is flowing under the semi-confining layer. A seasonal perched aquifer is formed over the semi-confining layer during the winter months (June to September). This aquifer has fresher water than the deeper regional one. Under natural vegetation, the perched aquifer is depleted annually by the native plants. In cleared parts specially in Tambellup Town, the perched aquifer has become a permanent one the boundaries of which extends to the surrounding natural vegetation. As an example bores T7 and T10 which are in natural vegetation were dray until we drilled through the semi-confining layer at 7 m depth (on 11th June 1997). Then the deep groundwater came up and rested at approximately 2.5 m below soil surface. There was no perched groundwater in these two sites. However, all the bores drilled in cleared parts of the town with the exception of bore T11 had perched groundwater. Bore T11 which was between two planted rows of trees had no shallow ground water (at 2.2 m depth). It however developed a temporary shallow groundwater later in July which rested at 1.7 m below soil surface.

7.3. Groundwater hydrology under the Tambellup townsite

Groundwater levels

In September 1997, groundwater levels in deep bores (> 8 m), under Tambellup Town were between 0.65 m and 2.40 m below ground level (Figure 10) . Deep groundwater levels in 55% of the sites were within 1.5 m of the soil surface. These high groundwater levels are within the capillarity ranges in medium or heavy-textured soils (loamy sand over clay) found in southern parts of the town.

In September 1997, the maximum depth of shallow groundwater level (in 2 m deep bores) under Tambellup was 1.7 m. The levels of shallow groundwater in many areas, were at or above the soil surface (Figure11) and were discharging. At discharge sites, which included the fringes of town, near the banks of Gordon River and Jam Creek a mixture of deep and shallow groundwaters were seeping out. The seepage water was saline and its salinity increased as elevation of the site decreased. Salinity of a seep 30 m west of bore T5 (Figure 3) was 908 mS/m while salinity of water that seeped into the cellar of the Tambellup Hotel was 1000 mS/m.

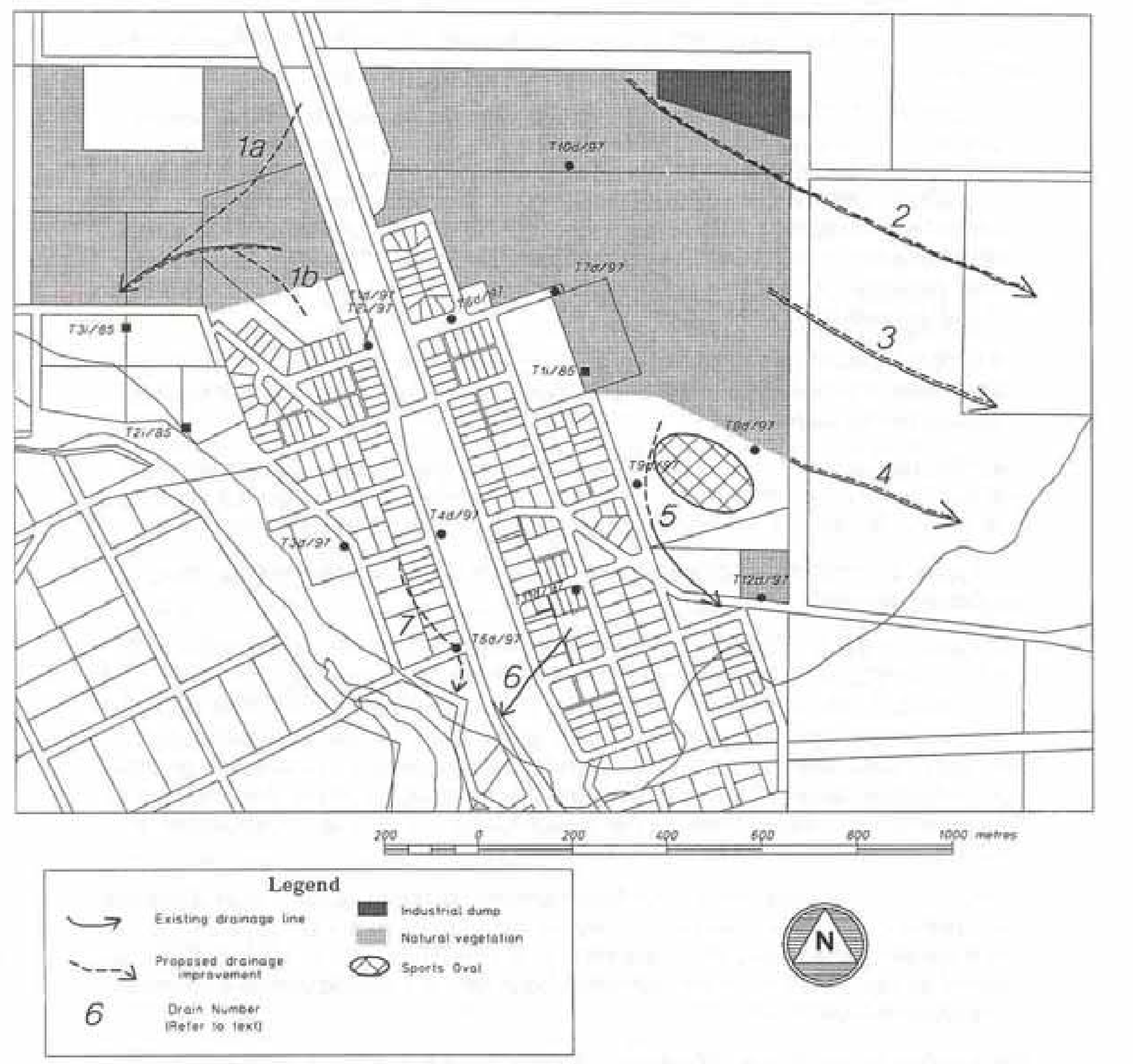

Figure 9: There are seven depressions around town that if improved can remove more of the surface runoff.

The water is frequently pumped out of the cellar to avoid flooding the building. Another consequences of high groundwater levels is the rising damp which may be seen on many walls (photograph 6) and is deteriorating the buildings.

Seasonal groundwater level rises in Tambellup

The mean annual rainfall in Tambellup is about 448 mm (Bureau of Meteorology, 1993). Seventy one percent of the annual precipitation falls between April and September. In 1997, the seasonal rainfall during April to September, was only 10 mm (3%) less than the mean long-term precipitation during the same period (Table 1). Thus, the seasonal groundwater level rises in 1997 should be close to groundwater level rises in a year with mean rainfall pattern.

Table 1: The seasonal rainfall during April to September 1997, was 10 mm less than the mean long-term precipitation during the same period. The monthly precipitation during this season was very similar to a season with mean rainfall pattern.

	April	May	June	July	August	September	Seasonal total
1997	9	83	87	48	51	31	309
Mean	31	56	65	68	54	45	319

Groundwater levels under natural vegetation which is above the town, rose by 0.25 m between June and September (Figures 12 and 13). This rise could be attributed to recharge under agricultural areas as well as under the industrial dump. During the same period, groundwater levels in deep bores under the Tambellup townsite, rose by average 0.47 m. The maximum rise in deep groundwater levels (0.70 m) was under the town centre (Figures 12 and 13). The areas with highest rise stretched along the railway track (Figure 13).This rapid rise in groundwater levels is attributed to the recharge in the residential and industrial parts of the town.

Between June and September 1997, groundwater levels in shallow bores were higher than the deep ones (Figure 14). The deference of the two groundwater levels created a downwards gradient which recharged the aquifer. The maximum downwards gradient was 2.0 m (Figure 15). Comparison of depth of sand in the town (Figure 7) and downwards gradient (Figure 15) shows a higher downwards gradient was formed in deep sandy areas. This is probably due to higher recharge in deep sandy profiles. Areas around bore T11 had an upwards gradient in June and very little or no gradient in August and September. That bore is between two rows of trees in the Bowling Club car park. The trees have probably used the shallow groundwater and created an upwards gradient. This situation is referred to later (Section 12.4).

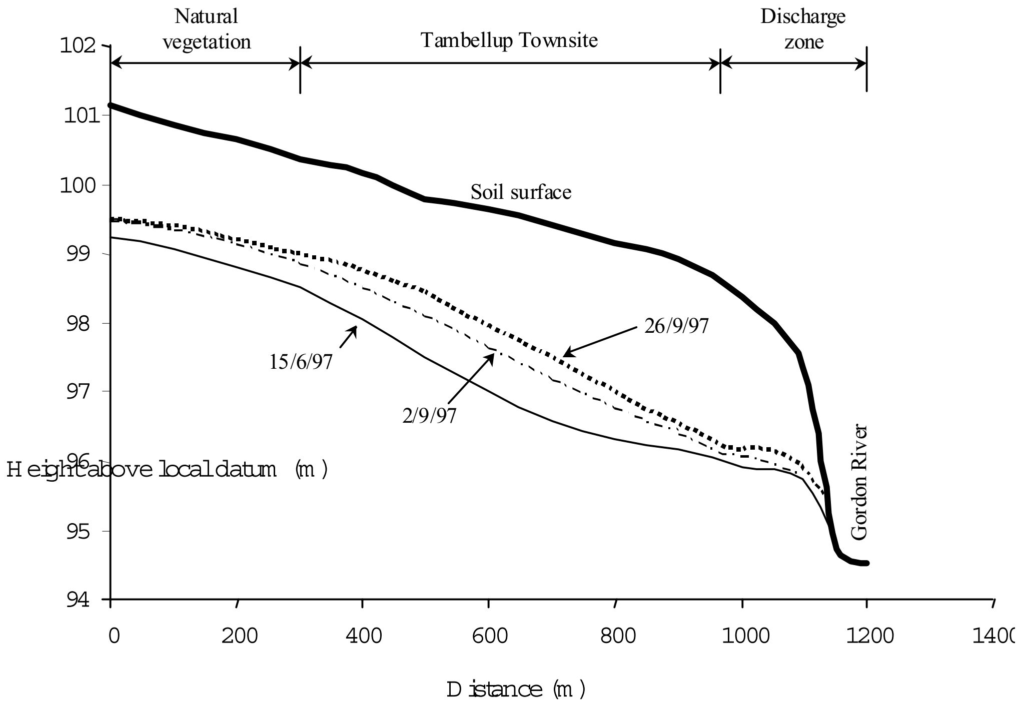

Figure 12: Groundwater levels in the cleared parts of the Tambellup Town had rapid rise between 15 June and 24 July 1997 while groundwater levels in natural vegetation very little rise during the same period.

Groundwater flow and changes in flow lines

There were 9 rainy days in the Tambellup Town between May and September 1997 when daily rainfall exceeded 9 mm (Table 2). Recharge as a result of these events as well as the monthly rainfall (Table 1) have affected the isopotential and flow lines during that period. Figures 16 and 17 show the isopotential of deep groundwater levels as well as the flow lines in mid-June and late September 1997. These two figures may be interpreted considering the geology of the area (Section 6.3), the rainfall events between May and September 1997 (Table 1) and groundwater levels (Figure 10):

- The Tambellup Town is built on Tertiary sediments which have a semi-confining clayey layer within 8 m from the soil surface and a porous sandy layer below that.
- A deep regional aquifer exists in the sandy layer and its groundwater flows from the north-east to the south-west, towards the Gordon River.
- A perched aquifer is formed over the semi-confining layer, under the cleared parts of the Tambellup Town which flows the same direction as the regional one.

- The two aquifers interact in two ways. Away from discharge sites, the perched aquifer recharges the regional one. Near discharge sites, the more saline groundwater comes up, it then is diluted by the shallow and fresher groundwater and the mixture of the two discharge in seepage zones.
- Groundwater discharges in low laying areas of the Tambellup Town and along the banks and bed of the Gordon River.
- The initial source of this regional aquifer is the Jam Creek Catchment which is north-east of the Tambellup Town. The source of the perched aquifer is recharge under the town.

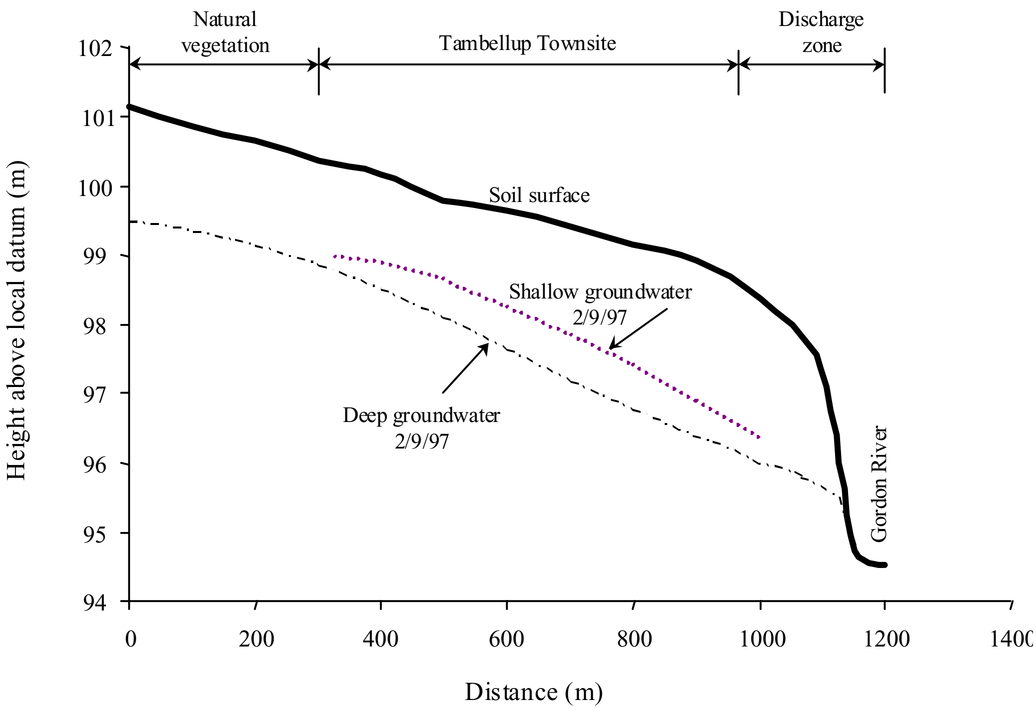

Figure 14: During winter months (June to October 1997), the shallow groundwater levels in Tambellup townsite were higher than the deep ones causing a downwards gradient and recharging the deep aquifer.

- The main contributing agricultural areas to the regional aquifer and salinity in Tambellup are the chain of sand dunes which are between 1.5 and 2 km north-east of town as well as the stagnant floor of the Jam Creek which is east of the sand dunes.
- The regional aquifer is topped up by recharge within the Tambellup Town.
- The mid-June flow lines (Figure 16) shows that only those lines passing through the Oval are diverging. The zone of divergence starts from the Oval and continues south-west and through the town.
- All of the late September flow lines which pass through the Tambellup Town, are diverging (Figure 17). Divergence of flow lines under the Tambellup Town is an indication of high recharge rate within the town (See next Section).

Table 2: Days between May and September 1997, when rainfall exceeded 9 mm per day

Months	May		June		July		August		September
Days	19	26	3	9	7	14	4	11	15
Rainfall (mm)	51	24	21	10	9	17	17	16	9

Cleared agricultural and residential areas contribute to groundwater

There are many indications showing the agricultural areas north-east of Tambellup and residential areas within the town contribute to groundwater and salinity in the town:

Flow lines and isopotentials (Figures 16 and 17) show that:

- Flow lines and isopotentials (Figures 16 and 17) show that the cleared agricultural areas and the Industrial Tip which are north-east of the Tambellup Town are the initial source of groundwater that flows under the townsite. The swales and creek beds in these areas are severely waterlogged, occasionally inundated 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.
- Flow lines (Figures 16 and 17) are along a set of shear zones which have a north-easterly direction (Figure 6) and have affected the present position of the creeks in the study area (Section 5). These shear zones which are in the basement rocks, are conduits for groundwater to flow in. One of the main shear zones passes through the salt-affected depression which is south of the water supply catchment. This shear zone which also passes through the town, will probably bring groundwater from as far as the eastern boundaries of the Jam Creek Catchment.
- A perched groundwater has formed under industrial and residential areas of the town (figure 14) which has created a down-wards hydraulic gradient (Figure 15). Due to driving force of this gradient, shallow groundwater recharges the deep regional aquifer forcing its levels to rise (Figure 13).
- Flow lines diverge as they pass through the town (Figures 16 and 17). 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 there is no single or main discharge site and the seepage areas are scattered along the bank and bed of Gordon River.

2. Shallowing of the aquifer may also cause divergence of the flow lines. However, there is no evidence showing a reduction in depth of aquifer in the study area. 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. The sandy layer in which the regional aquifer flows is very homogenous and there was no indication of any barrier to groundwater flow. Actually half of the mid-June flow lines were parallel (Figure 16).
4 Excessive recharge under the Tambellup townsite may form a groundwater mound and cause divergence of the flow lines. We believe there is excessive recharge in the Tambellup townsite and that this recharge is probably the main cause of the diverging flow lines.

8. Groundwater salinities

Salinity of the perching aquifer was between 240 mg/L and 1000 mg/L with the exception of a very shallow bore (1 m deep), near bore T1 which had a relatively high salt content (2,250 mg/L).

Groundwater salinities in deep bores in town varied between 6,000 mg/L and 18,600 mg/L (Table 3; Figure 11). A 3 m deep bore that had been drilled by the Tambellup Shire along the eastern bank of Gordon river (near Russell and West Streets) had even higher salinity (25,500 mg/L; Salinity of sea water is 35,000 mg/L). Groundwater salinity in 82 % of deep bores were >11,000 mg/L. The higher groundwater salinities represent salinity of the regional groundwater and were found in those bores which had a semi-confining layer. The lower salinities were found in those bores without that layer. The lower groundwater salinities in these bores was probably due to dilution of the saline regional aquifer by the fresher perching one. As an example, bore T1 had little or no semi-confining layer. Five water samples that we took from between 1 m and 32 m depth showed groundwater salinity increased gradually from 2250 mg/L to over 13,200 mg/L (Figure 18).

Table 3 : Drilling depth, ground level, salt storage and groundwater salinities (1997) in the study area.

Bore No*	Location (nearest road crossing)	Drilling depth (m)	Ground level (m)	Salt storage (t/ha)	Groundwater salinity (mg/L)**
T1D	Crawford and Garrity	32.50	99.98	1829	13,255
T2I	Crawford and Garrity	5.00	100.16	207	4,370
T3D	Gordon and Donald	8.00	97.03	554	18,645
T4D	Gordon and Garrity	8.00	99.17	129	12,210
T4S	Gordon and Garrity	2.15	99.04	NA***	310
T5D	Temby and Garrity	8.00	96.82	228	13,700
T5S	Temby and Garrity	2.15	96.92	NA	1,005
T6D	Crawford and Cousins	8.00	101.17	27	8,790
T6S	Crawford and Cousins	2.15	101.17	NA	240
T7D	north-east of School	8.00	100.76	203	16,940
T8D	East of Oval	8.00	99.73	63	5,885
T9D	West of Oval	9.00	99.65	134	11,330
T9S	West of Oval	2.15	99.68	NA	910
T10D	Water supply track	8.15	101.17	327	12,490
T11D	Crowden and Taylor	8.00	98.63	490	13,970
T11S	Crowden and Taylor	2.00	98.59	NA	NA
T12D	Owen and Henry	10.5	98.09	974	16,940
T1I	East of School	4.87	100.51	NA	1,270
T2I	East of weir on Gordon	3.10	96.42	NA	9,660
T3I	Russell and Saggers	3.30	97.01	NA	8,790
T4I	Russell and West St	2.90	NA	NA	25,520

* D = deep; I = intermediate; S = shallow;

**Conversion: Divide mg/L by 5.5 to obtain mS/m.

*** NA = Not available

9. Salt storage and salt concentration

Drilling of all but one bores stopped at between 8 m and 10 m depth (Table 3). Salt storage (total soluble salt; TSS), in the top 8 m of the bores varied between 27 t/ha and 550 t/ha (Table 3 and Appendix 1). The lowest salt storage (27 t/ha; 0.3 kg/m^3) was in bore T6D which is in an area with >4.0 m sand. Comparison of salt storages in the first 8 m depth with depth of sand in the Tambellup Town (Figure 7) shows that the areas which have deeper sand have lower salt storages. This shows that even before clearing the deep sandy areas had occasional recharge that leached salt out of their profiles. The leaching was related to the depth of sand in that area.

Only one of the bores (T1) was drilled to basement rocks (32.5 m). Salt storage in the first 8 m depth of T1 was 346 t/ha and in the whole profile (32,5 m) 1,830 t/ha. This amount of salt (1,830 t/ha) will probably represent the salt storage in the Tertiary profiles in the study area. The average salt concentration in sediments was 4.3 kg/m^3. However, the highest salt concentration was 20 kg/m^3. The highest salt concentrations was in a second clayey layer which was found at depth in some profiles (Figures 8c and 8d).

All of the profiles which were out of the deep sandy areas had one or more salt bulges. There was no significant (> 4 kg/m^3) salt bulges in 5 out of 6 bores which were in deep sandy areas (Appendix 1; bores T4, T6, T8 and T9).

10. 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:

$$P = R_o + ET_a + dS + dI + U$$

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;

dI 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 dI can be ignored and the equation becomes:

$$U = P - R_o - ET_a$$

10.1. Recharge in agricultural parts of the study area

Annual recharge has been estimated within the study area using "AgET" 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. Estimation of ET_a is based on Pan Evaporation Method (FAO, 1977).

Estimates made with AgET indicate that there has been regular annual recharge in cleared agricultural parts of 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 sand dunes or have only volunteer pasture. In these areas, up to 30% of the annual rainfall may recharge the aquifer.

Occasional recharge may occur under tagasaste and natural vegetation, where deep sandy profiles exist (Table 4). This fact is confirmed by the salt storage profiles in deep sandy areas (Section 9). Even before clearing the deep sandy areas had occasional recharge that leached salt out of their profiles.

Table 4: In the Tambellup area, some cleared agricultural land may have as much as 150 mm of recharge per annum.

Annual rainfall		Annual recharge (mm/year) under two soil types and under various land use options*							
Exceedence probability	Rainfall (mm)	Bare soil	Volunteer pasture	Clover pasture	Cereals	Lucerne	Perennials	tagasaste	Trees
Deep sand									
75%	401	115	80	80	40	2	15	2	0
50%	448	130	95	95	50	4	20	4	2
25%	484	155	115	115	60	8	30	6	4
Shallow loamy duplex soil									
75%	401	90	55	55	30	0	5	0	0
50%	448	110	75	70	50	0	20	0	0
25%	484	130	90	90	65	0	25	0	0

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

We do not have any data for bores in the Jam Creek Catchment to show how these high recharge rates have risen the groundwater levels in that area. There are however, many bores in the neighbouring Peter Valley Catchment which is 20 km south-west of the study area. Landholders have monitored these bores during past two years. Groundwater levels in 9 bores in that catchment were below 2.5 m from soil surface in June 1995. These levels have risen by an average 0.44 m per year since drilling. Figure 19 shows the rising trend in one of these bores which has had about average rate of groundwater level rise. These rates of groundwater level rises are probably occurring in the Jam Creek Catchment.

10.2. Recharge in the Tambellup 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 Tambellup 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 16 ha. We have assumed that 50% of the annual rain falling on this area will recharge the aquifer. This volume will be 36,000 m^3 in an average rainfall year or additional 52 mm over the 69 ha of residential, industrial and recreational parts of the town (46 mm in dry years; 58 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 Tambellup Town, which are built on deep sand, can be as much as 44% of the annual rainfall.

Annual rainfall		**Annual recharge (mm/year) in sandy areas**			
Exceedence probability	Rainfall (mm/year)	Bare soil (mm)	(%)	Volunteer pasture (mm)	(%)
75%	401	165	41	125	31
50%	448	185	42	150	33
25%	484	215	44	170	36

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 town centre rose by 0.47 m between 15th June 1997 and 26th September 1997 (Figure 13). In contrast, groundwater levels in bore T10 which is in middle of natural vegetation, but affected by agricultural areas, rose by 0.25 m during the same period.

11. Potential salinity of the study area

Clearing of natural vegetation for agriculture has increased recharge, causing groundwater levels to rise. The rising groundwater has mobilised the salt stored in the soil profile. In low lying areas, groundwater levels, are at or close to soil surface and saline water seeps out through capillary pores, old root channels and hillside seeps and causes soil salinity. Salinity is probably the biggest land degradational hazard in the study area.

11.1. Salinity status of the Jam Creek Catchment

The area of the Jam Creek Catchment (Figure 1) is 8050 ha and extends to west of Gordon River. This Catchment covers 55% of the Tambellup townsite. At present over 770 ha (9.6%) of areas in the Jam Creek Catchment is salt-affected (Figure 20). Under the current management options, the affected areas may eventually increase to >1,930 ha (23.9%). Salt-affected land in the upper parts of the study area is and will be in shape of narrow strips and confined to creek lines

(Figure 20). In the lower parts of the catchment, however, soil salinity is affecting broad flat areas. The present extent and the potential salinity in the Jam Creek Catchment may be related to its landform patterns (Table 6).

Table 6: Present and potential soil salinity in the Jam creek Catchment

Landform patterns	**Total area**	**Present extent of salinity**		**Potential salinity**	
	(ha)	**(ha)**	**(%)**	**(ha)**	**(%)**
Broad crests	235	00	00	1	0.4
Undulating rises	2180	9	0.4	126	5.8
Gently undulating plains	1509	5	0.3	142	9.4
Gently undulating plains with saline depressions	2289	148	6.5	555	24.2
Very gently undulating plains	230	5	2.2	39	17.0
Stagnant flats	70	21	30.0	49	70.0
Flood plains	595	353	42.5	513	86.0
Flats with swales and sand dunes	728	139	19.0	375	51.5
Valleys	216	94	43.0	127	58.8
Total	8052	774	9.6	1927	23.9

11.2. Salinity status of the Tambellup townsite

The area of Tambellup townsite is 540 ha and is entirely in *Swampy terrains* hydrological system. The extent of soil salinity in *Swampy terrains* is very high and it will increases in the future. About 17% of the Tambellup townsite is salt-affected at present (Table 7 and Figure 21). This figure may increase to 26% of the townsite in the future (Table 7; Figure 21) if the present management practices are continued.

Table 7: Approximately 17% of the Tambellup townsite and the Oval Catchment may become salt-affected in the future.

Total area (ha)	Present salt-affected area (ha)	(%)	Potential salinity (ha)	(%)
540	91	16.9	143	26.5

The residential and industrial part of the town has less salinity than the whole townsite. The deep sandy soils in the northern parts of Tambellup Town have stopped capillary rises, preventing soil salinity. However, areas around bore T1 (Figure 3) despite having 5 m of sand are going saline. Shallow (< 1 m) perched groundwater at this site was brackish (2,255 mg/L). We measured salinity of soil samples from that site. Electrical conductivity of 1:5 soil:water solution from top 1 m sandy profile, was 76 mS/m (strongly salt-affected). Despite that there was no surface indication of salinity in that area.

The areas north of the Grain Bins and north-east of its dam are strongly salt-affected. It is likely that these affected areas will grow in the future.

In the southern parts of the town where deep sandy profiles are non-existence saline groundwater is rising through capillary pores, evaporating at the soil surface and causing soil salinity. In June and July 1997, active seeps were found bout 15 m west of bore T5 (Figure 3) which is close to the Highway. These seeps were discharging saline groundwater (4,990 mg/L; TSS). Later, in August the seeps stopped flowing but the whole area west of the Highway continued discharging through capillary voids.

11.3. Salinity status of the Oval

The only obvious surface indication of salinity in the Oval is patchy grass in the northern parts of the sports ground. We collected soil samples and one water sample from north-west and south-east of the Oval and analysed for evidences of salinity (Table 8). The result shows that the north-western parts of the Oval is the first area to become salt-affected. If groundwater levels continue to rise the whole Oval may have salinity problem.

Table 8: Soil and water samples from the Oval show that the subsoils are salty, brackish groundwater is close to soil surface and parts of the sporting grounds is becoming salt-affected.

Depth interval (cm)	Soil type	Electrical conductivity of 1:5 soil:water solution (mS/m)	Electrical conductivity of water sample (mS/m; June 97)	Salinity status of the soil samples
North- western site				
0 - 5	Fine sand	18.5	No water	slightly affected
10 - 15	Fine sand	11.2	No water	Not affected
60 - 80	Fine sand	24.0	415 (brackish)	slightly affected
South-eastern site				
0 - 5	Fine sand	10.2	No water	Not affected
10 - 15	Fine sand	9.8	No water	Not affected
60 - 80	Fine sand	22.0	No water	Slightly affected

12. Management options in the Jam Creek Catchment

The management options discussed in this section are applicable to the nearby agricultural areas other than the Jam Creek Catchment. For example, areas west of the townsite and the Gordon River have considerable salinity problems which need management to reduce the extent of salinity.

Before discussing the management options to reduce the extent of salinity in the Jam Creek Catchment and Tambellup townsite, we need to restate some of our observations (Sections 6 and 7):

- The Tambellup Town is within *Swampy terrains* hydrological system (Section 6.3). The soil profiles in this HS consists of Pallinup siltstone and overlying aeolian sand.
- A regional aquifer flows from the north-east of the town to the south-west and towards the Gordon River. This aquifer is semi-confined
- A shallow perched aquifer has formed under the cleared parts of the Tambellup Town which recharges the regional one.
- The initial source of the regional aquifer is the Jam Creek Catchment while the source of the perched aquifer is recharge under the town.

Two hypothesis can be made from the above statements:

- If the whole or at least the lower parts of the Jam Creek Catchment is treated the levels of the regional aquifer will drop.
- Drop in groundwater levels will reduce the potential salinity in that catchment as well as in the Tambellup Town.

At present 9.6% of the Jam Creek Catchment is salt-affected. The extent of soil salinity may increase if the current management practices are continued.

To reverse the increasing groundwater levels and increasing salinity, the present rates of recharge in the Jam Creek Catchment need to be reduced. This reduction can be made by:

- Reducing recharge and increasing surface and sub-surface runoff (using surface drains);
- Increasing the area under perennial pastures;
- Introducing phase cropping;
- Increasing water use by revegetating selected areas;
- Managing creek lines and water courses, swamps, lakes and salt-affected areas
- Improving the productivity of existing crops and pastures;
- Regenerating existing native vegetation;

These issues are discussed in the following sections.

12.1. Reducing recharge and increasing surface and sub-surface runoff using drainage

Waterlogging reduces crop and pasture yields but this is often unnoticed. Waterlogging may be noticed when it has affected crops or pastures badly. Many farmers think that their land is waterlogged only when they can see free water on the soil surface. However, waterlogging occurs when free water is found within the top 0.30 m of the soil profile. When water fills the soil profile and appears on the soil surface, it is called inundation or surface ponding. Waterlogging may be slight, moderate or severe to very severe.

In 20% of years (two wettest years out of ten), between mid-May and mid-September, rainfall exceeds the sum of plant water use, evaporation and runoff. Most of the excess water stays in the root zone of crops and pastures causing waterlogging. Water logging happens even in a year with mean annual rainfall (448 mm) but it is only limited to June and July. In wet years up to 60% of the study area becomes moderately to very severely waterlogged. Some areas may even become inundated for more than one or two weeks. Surface drains help to reduce the incidence of waterlogging and inundation and so improve cropping capability.

Cox (1988) studied the effect of graded interceptor drains on waterlogging and crop yield between 1984 and 1985 in a catchment 3 km north-east of Narrogin. The annual and growing season (May to October) rainfalls, in this area, during those three years (Tables 9) are comparable with annual rainfalls in the study area (Table 10).

Table 9: Annual and growing season rainfall (May to October) and drain flow in Narrogin between 1984 and 1986

	1984	1985	1986
Annual rainfall (mm)	462	435	377
Growing season rainfall (mm)	330	356	267
Drain flow (mm)	7.6	8.1	4.0

Table 10: Variation in annual and growing season rainfall (May to October) in the study area

Period of rainfall	Wet years (decile 8 rainfall)	Mean rainfall	Dry years (decile 2 rainfall)
Annual rainfall (mm)	500	448	360
Growing season rainfall (mm)	396	337	285

Cox's findings on waterlogging and the effect of drains will be applicable to the Jam Creek Catchment. Cox concluded that:

- Low seasonal rainfall was sufficient to cause *in situ* waterlogging in areas with a shallow topsoil.
- Drains in pasture generated more runoff than those in crops. This indicated that crops may be using more water than the pasture.
- The drains became increasingly effective as rainfall increased.
- Recut drains produced more runoff than drains that had not been maintained.
- The drains removed between 4 and 8 mm of the growing season's rainfall (drain spacing was 102 m).
- There was less waterlogging up to 50 m downslope and 7 m upslope of the drains in wet years, provided drain channels were cut into the clay subsoil.
- There was a positive return on investment in drains, even when the future benefits were discounted and inflation was taken into account. The greatest benefits occurred when the area was frequently cropped and the probability of waterlogging was high.
- The income generated by the improved yields over 20 years at the Narrogin site far outweighed the costs of drain installation, maintenance and loss of productive land.
- The optimum drain spacing, based on maximum net present value over 20 years, was 40, 60, 80, and 100 m for areas with 90, 70, 50, and 30% waterlogging probability (for a crop-crop-pasture rotation).

In the Jam Creek Catchment, drains may remove between 4 mm (in a very dry year) and 20 mm (in a year with decile 8 rainfall) of the annual rainfall. Removing this water will reduce waterlogging and improve plant growth and water use. The net effect is a reduction in recharge. The total reduction is greater than the excess runoff the drains remove. The harvested fresh water may be stored in dams for use on farm or dumped in creeks if not needed.

Type of drains for the study area

Ferdowsian *et al.* (1997) studied a deep drain that was constructed in the North Stirling area in 1985 to remove saline groundwater.

They concluded that:

1. Existence of sandy lenses had made that area one of the most suitable areas for constructing deep drains in the district. The gains were unlikely to happen elsewhere where the profiles are less permeable.
2. Despite being one of the best areas for deep drainage, the income from the reclaimed area (8 ha) was not enough to recover the construction expenses (more than $30,000);

Thus we only recommend well-designed, open surface drains built by graders or occasionally by a scraper which collect fresh perched water.

Selection of drains and drain spacing should be based on the attributes of the LFPs and HSs . In deep gravely sands or sandy soils with a clayey sub-soil more than 0.60 m deep, it is not feasible to construct surface drains. Waterlogging of these soils is not common enough to warrant the expense. All drains should be designed by accredited professional person.

12.2. Reducing recharge by growing perennial pastures

Various workers (Nulsen and Baxter 1982; Carbon *et al*. 1982; Nulsen 1984; and Joffre *et al*. 1988), found that perennial pastures used more water than annual pastures. Their ability to use more water could be attributed to their deeper root zone (Ferdowsian and Greenham, 1992), denser root system and their ability to intercept and use the summer rainfall provided they were not dormant. However, some perennial pastures such as perennial ryegrass (*Lolium perenne*) and cocksfoot (*Dactylis glomerata*) may not use more water than the annual pastures because they have a shallow root system (Ferdowsian and Greenham, 1992). The extra water that a mixture of annual and perennial pastures uses is equal to the available water in the additional depth that their roots occupy plus out of season rainfall (summer active perennials). The available water in the additional depth of root zone may be as much as 50 mm for deep rooted perennials (eg. kikuyu).

Smith *et al* (in preparation) studied various perennial pastures in four High Water Use Agricultural Systems, in the South West of Western Australia during 1994 and 1995. The mean annual rainfall of their selected sites is between 465 (Kojonup site) and 620 mm (Dinninup site) per annum. Their findings could be applicable to the Jam Creek Catchment:

Productivity of perennial pastures:

During their study period (1994-95) the pastures which were able to provide significant quantities of out of season feed were tall wheat grass planted in valley floors over shallow watertable and lucerne planted over watertable at 2-5 m depth. The out of season productivity of other perennials was dependant on summer and autumn rainfall.

Profitably of perennial pastures

Their studies showed that lucerne in Kojonup and mixed stand of tall wheat grass with phalaris and puccinellia at Williams, Kojonup and Frankland produced sufficient quantity and quality pastures to be profitable. The positive environmental effects of these treatments was added benefit.

We recommend that a mixture of annual and perennial pastures is grown to reduce recharge in the study area. Table 11 shows the recommended perennial pastures for different Land Management Units (LMUs) of the study area.

Table 11: The recommended perennial pastures for different Land Management Units (soils) in the study area. Numbers (between 1 and 5) are in order of decreasing preference (This table is copied from Ferdowsian and Ryder, 1997).

Land Management Units	Recommended Perennials
Deep well-drained white sand (>0.50 m)	Tagasaste (1) Perennial veldt grass (2)
Deep well-drained yellow or brown sand (>0.50 m)	Tagasaste (1) Lucerne (1) Perennial veldt grass (2)
0.50 to 0.60 m gravelly sand over clay	Tagasaste (2) Lucerne (2) Cocksfoot (2) Perennial veldt grass (3)
0.30 to 0.50 m gravelly sand over clay	Lucerne (1) Cocksfoot (2) Tagasaste (2) Perennial veldt grass (3)
Well-drained loamy sand or clay close to the soil surface	Lucerne (1) Tall wheatgrass (2) Cocksfoot (2) Tall fescue (3) Phalaris (3)
Deep waterlogged sand (>0.50 m)	Tall wheatgrass (1) Tall fescue (1) Kikuyu (2) Phalaris (3)
Waterlogged loamy soil	Strawberry clover (1) Tall wheatgrass (1) Tall fescue (2) Phalaris (2)
Waterlogged clayey soil	Strawberry clover (1) Tall wheatgrass (1) Tall fescue (2) Phalaris (2)
Slightly to moderately salt-affected soil	Strawberry clover (1) Tall wheatgrass (1) Tall fescue (2) Phalaris (2)
Moderately to strongly salt-affected soil	Puccinellia (1) Salt bush (1) Tall wheatgrass (3)
Active discharge sites	Saltwater couch (1) Puccinellia (2) Tall wheatgrass (3)

For more information on perennial pastures refer to Bulletin 4253; "Perennial pastures for areas receiving less than 800 mm annual rainfall" (1994), by R.A. Sudmeyer, C. Saunders, I. Maling and T. Clark. WA Department of Agriculture.

12.3. Reducing recharge by phase cropping

In areas that have a low annual rainfall (<500 mm) and low rates of recharge (<50 mm), farmers have managed to reduce the extent of soil salinity by phase cropping Ferdowsian and Ryder,1997). Phase cropping is a rotation in which a few years of cropping (cereals or pulses) are followed by a few years of pasture (lucerne or any other perennial mixed with annual pasture) that in turn are followed by cropping. The cropping phase may be between two and three years in areas that receive >500 mm of rain per annum, and four years in areas that have very low rainfall (<400 mm). The economic life of lucerne is considered to be between four and six years. This period may be reduced if the land is required for cropping. During the cropping phase, recharge will build up moisture in the soil profile. This storage can then be used by lucerne.

Most of the success stories are related to growing a mixture of lucerne with other perennial pastures such as phalaris, tall wheatgrass and annuals. There are many success stories where lucerne has lowered groundwater levels. The following case shows the effect of lucerne on groundwater levels in the *Catchment Divide* and *Plains with Swampy Floors.* The results are applicable to most areas of the Jam Creek Catchment (with the exception of sand dunes and inundated areas).

Lucerne was sown in July 1992 into a 70 ha paddock on a property near Jacup (30 km east of Jerramungup, 350 mm annual rainfall). The site had been cleared in 1964. Lucerne continues to persist with volunteer annual clover and grasses. Grazing has been continuous over winter and rotational over summer; 1 week on and 5 weeks off.

Salinity first appeared in 1981 and had expanded to 3 ha by 1992. The salt-affected area has stabilised since 1992 or has reduced slightly (Geoff Bee; the land holder, personal communication). Agriculture. WA drilled two bores in this area in 1989.

The first bore is in *Crests* and the second one is in upper areas of *Plains with Swampy Floors*. Groundwater levels in both bores have dropped since lucerne was planted. Figure 22 shows groundwater trends in one of those bores as well as the annual rainfall (Jerramungup rainfall). It also shows groundwater level trends in bores which were in similar HSs, but under annual pastures and crops. Figure 22 indicates that:

- Groundwater levels under three sites were within 1 m of the soil surface and experienced similar fluctuations between 1990 and 1993.
- Annual rainfall was lower than normal in 1994,1995 and 1996.
- Groundwater levels under annual pastures have stayed almost the same and show a seasonal fluctuation.
- Crops, have probably use more water than the annual pastures and have lowered the groundwater levels by 1.5 m during the dry years (1994 – 1996).
- Groundwater levels under lucerne have dropped to 3.0 m below the original levels; this is 1.5 m more than the water level reduction under crops.

12.4. Revegetating selected areas and limitations caused by the salinity of groundwater.

Tree and shrub planting is one of the necessary treatments for the Jam Creek Catchment. There are three reasons for revegetating of selected areas:

- reduces recharge;
- stabilises sand dunes and increases the productivity of deep sands;
- creates shelter belts and prevents wind erosion on cropping areas.

Trees use water and reduce the overall recharge in an area and consequently the volume of water that the aquifer has to handle. Any reduction in recharge will also reduce the extent of soil salinity. Trees will only use the fresh water that is stored within the soil profile and to a lesser extent, any relatively fresh water that may be at the top of the aquifer. When planting trees to reduce salinity, the following points should be considered:

- salinity in a catchment cannot be eliminated if large blocks of natural or planted vegetation are in one part of the catchment and nothing is on the rest;
- if trees are required for using excess water they must be scattered as widely as possible throughout the area;
- strip plantations are the best option because isolated trees are difficult to protect;
- if the strip plantations are to be self-supporting and self-pruning (for timber production), they have to be at least six rows wide;
- the tree spacing in strip plantations should be as close as possible to encourage deep root penetration and good forms (shape).
- at least 20% of the landscape should be under shelter belts.

Sand dunes became mobile units as soon as their natural vegetation was removed. Two factors affect the mobility of the units:

- They are composed of fine silty sand that is subject to wind erosion.
- The undulation of the land units that surround them gives a wave-shaped motion to the wind making it more erosive than elsewhere.

Erosion of sand dunes is usually accompanied by the deposition of a blanket of white sand that may cover large areas and degrade agricultural land. Bare sandy ground with low water holding capacity results in high rates of recharge and is a hydrological disaster.

It is recommended that the sand dunes in the Jam creek Catchment be revegetated. Perennial veldt grass and tagasaste should be planted to protect these areas.

12.5. Managing creek lines and water courses, swamps, lakes and salt-affected areas

Creek lines and water courses, swamps, lakes and salt-affected areas and their fringes should be fenced off and revegetated. Before fencing, a Geonics EM38 should be used to mark the areas that are in immediate danger of salinity ie readings of (EC_a >60 mS/m). Trees for salt-affected areas may have a small commercial or grazing value. Their main benefit is in reclaiming land and helping reduce the extent of salinity in the other parts of a catchment. Planting trees and shrubs on or near, salt-affected areas may only have a temporary effect if other measures to control salinity are not in place. Without other treatments, depending on the local site hydrology, salt may accumulate in the root zone of trees and eventually kill them.

13. Management options in the Tambellup townsite that have direct effect on the extent of salinity in the town

There are management options that have a direct effect on the extent of salinity in the Tambellup townsite. These options are to reduce the rate of recharge within and near the Tambellup Town.

To reduce the extent and the impact of salinity on residential parts of town, recharge in the cleared areas in and near Tambellup should be reduced. The options have been grouped into seven 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. The seven categories are:

1. Management of surface runoff in the Tambellup Town;
2. Management of agricultural land east and north of the town;
3. Management of the Industrial Tip site;
4. Management of the natural vegetation and revegetation around town;
5. Direct groundwater management;
6. Managing the sewerage system;
7. Other recommendations;

13.1. Management of surface runoff in the Tambellup Town

- The Tambellup Townsite is poorly drained. There are at least 12 sites which are regularly inundated in winter (Section 7.1; Surface hydrology) and are probably health hazard areas. These sites should be drained. ***
- It is recommended that the excess runoff from roofs and other structures (eg silos) is drained as quickly as possible and discharged into the main creeks.**
- At present the surface runoff from the silos which are north of the Tambellup Town is stored in a dam constructed in deep sandy area. The ground around this dam is salt-affected. The salinity of water in the dam was 7,400 mg/L on 12th September 1997 and had increased to 9,530 mg/L by 6 November 1997. The dam is intercepting the regional aquifer and the surface runoff entering the dam is interacting with the saline groundwater. The annual evaporation from this dam is probably < 600 m^3. The volume of surface runoff which enters the dam in a mean rainfall year is approximately 3,800 m^3 per year (70% of annual rainfall). Thus the dam recharges the aquifer and its contribution to the regional aquifer is >3,000 m^3 in a mean rainfall year. The surface runoff from the silos should be diverted away from the dam and discharged into the Gordon River as quickly as possible or stored in a dam constructed in heavy clay soils.*** The dam may be pumped out and discharged into the Gordon River.** As the dam is pumped out, groundwater will refill the empty dam. It is not necessary to fill the present dam. The dam could be left to work as an evaporation pond.***
- Almost all the streets, residential and commercial areas are on deep (>1 m) sand. There is little or no well-defined surface drainage to remove surface runoff from

the town. All of the surface runoff recharge the aquifer. It is recommended that surface drainage in town be improved.*** These drains need to be lined to prevent recharging the aquifers.*** 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 minimum longitudinal slope of the drains is 0.004 and their carrying capacity will be approximately 80 L/sec within their concrete profile.

- There are seven poorly-defined drainage lines that are or may be removing some of the surface runoff (drains 1 to 7; Figure 9) from the fringes of town. These drains should be extended to remove stagnant water from other areas (Figure 9).*** Their beds also need improvement to remove surface runoff as quickly as possible. **
- The swales which are north-east of town and are the recipients of runoff from the agricultural areas, need realigning to prevent inundation of their floors which include the present Industrial Dump.***
- The northern drain starts near junction of Garrity and the Cemetery streets is not functioning at present. The increasing salinity at head water of this drain will result in generation of larger runoff in future than the volumes generated at present. This drain needs improvement.*** Two possible improvements are suggested:
    1. It may be realigned to pass further south through swales which are between the sand dunes;
    2. Pipes may be installed in the section passing through sand dune (approximately 270 m). This drain has high maintenance costs in the future. Realignment may be the cheapest option. A survey is needed to find the best and most practical alignment for that drain.
- The agricultural areas north of the silos generate some runoff. This runoff should be collected and discharged into the Gordon River.** The best drainage to remove this runoff is the northern drain which was discussed above.

13.2. Management of agricultural land east and north of the town

- The section of the Jam Creek which passes through the Tambellup town is well-defined. The natural vegetations on its banks however, have been cleared. The banks should be replanted to reduce recharging the regional aquifer.*** The replanting should extend into the small depressions entering the creek such as the depression No.5 (Figure 9) which is a broad swampy depression without any trees. This drain should be improved and be planted.*** Only salt tolerant trees should be planted in the depressions***.
- The Jam Creek further upstream from and north-east of town is a sluggish 500 m wide river bed. The channel bed is composed of series of swales and sand dunes and a more defines water course that may change its position during a large flood. Its swampy swales become regularly inundated. Their sand dunes are mobile and occasionally block the flow passes forcing water to form a new water course. We recommend to improve drainage in the swales of this river bed, and not in its main water course. *** The sandy swales and sand dunes in this river bed have low productivity but high rate of recharge and contribute to the regional

groundwater passing under the town (Section 7.2). It is recommended to revegetate this section of the Jam Creek bed.***

- The Oval and cleared agricultural areas east of the town contribute to the salinity of town Section 7.2). The Oval will be discussed later. The cleared agricultural areas east of the Oval have very low productivity and low water use. These areas specially their sand dunes are high recharge areas. It is recommended to revegetate these areas.**
- The paddock which is north and north-east of townsite contributes to salinity of town. These areas could be bought and planted.**
- There are large areas (approximately 180 ha) of sand dunes further north which could be revegetated. These areas do not support any perennial vegetation at this time. Planting tagasaste on these areas will change them to productive land and reduce their present recharge from 130 mm/year (Table 4) to 4 mm/year.***

13.3. Management of the Industrial Tip site

- The present Industrial Tip contributes to the regional aquifer passing under the town (Section 7.2). Any contaminated groundwater may also pass under the town. It is recommended to find a new site for Industrial Tip and revegetate the present one.***
- The hollows and depressions at the present site should be filled before revegetation occurs.**
- Any areas within the domestic dump which have been filled or are not in use can be planted with trees and understorey species.***

13.4. Management of the natural vegetation and revegetation around town

- Before discussing these issues, we would like to highlight the effect of trees on reducing recharge within the townsite:
  - ∗ Bores T11D and T11S (deep and shallow) are on the edge of the Bowling Club car park. The car park has two rows of trees. This site is the only site within cleared area of the town that did not have a downward gradient (Figure 15) and its shallow aquifer was not recharging the deep one.
  - ∗ There were no shallow aquifer under bores T7 and T10 which are both in the natural vegetation while a perched shallow aquifer existed under cleared parts of the town (Section 7.2)
- The natural vegetation around town are an asset without which the salinity problems in Tambellup could have been more than now. The most important vegetation are to the east and north of the town. The natural vegetation to the east of town is in poor condition. Excessive waterlogging and high groundwater levels has probably affected their health and may threaten their survival. Their areas have become dumping grounds for old cars and other refuse. These vegetation need to be improved.**
- Any area under natural vegetation in other parts of town which is not needed for immediate construction should be protected.***

- Any cleared land which is not being used in near future should be planted with perennials.***
- Many more trees need to be planted along the streets.*** 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 could be planted to reduce recharge in these areas.*** Westrail's input and permission may be necessary. Lucerne should be planted in areas which cannot be planted with trees (minimum clearance width).***

13.5. Direct groundwater management

- Where open drains are hazardous, subsurface drains (eg drain coil) could be installed.**
- There is no need for deep drains at present. The recommended management changes may reduce groundwater levels and remove salinity problems in the town. Construction of deep subsurface drains is subject to permission from the Commissioner of Soil and Lands Conservation. The Catchment Hydrology Group or a consultant may be asked to design the deep drainage system. Three sites may be suitable for installing deep drains:
    1. Section 1b of the north-western drain (No. 1b; Figure 9) which starts near bore T1 (Figure 3).
    2. Depression No.5 (figure 9) which starts from north-west of the Oval and passes along the East Trace crosses the Henry St and Owen St and discharges into the Jam Creek. A deep drain in this depression may be extended to drain the Oval.
    3. A deep drain along the western side of Russell St and north of the North Tce. will draw down the groundwater levels in that area and neutralise the effects of the dam on Gordon River.
- Figure 8c shows that the floor of the Gordon River is very likely in the heavy clay which is the semi-confining layer. The thickness of this layer at the river bed west of bore T5 is approximately 2.5 m. Digging a deep 3 m deep pit into the floor of the Gordon River may get into fine sandy layer and facilitate seepage from the deep aquifer. The best site to try is in depression No. 7 (Section 7.1) which is west of the Tambellup Hotel. Commissioner of Soil and Lands Conservation should be notified before construction of a discharging pit.
- It is possible to pump water and lower groundwater levels under the town.** Possible sites include areas near T1, T5 and T6 C17D which all have fine sand at depth. A feasibility study is needed to evaluate pumping groundwater and lowering groundwater levels.** To do that a few pumping tests should be carried out. It is necessary to drill observation and production holes for any pumping test. The Catchment Hydrology Group or a consultant may be asked to undertake these feasibility studies.
- It is recommended that one bore is drilled along Parker St and one near the corner of Parnell and Norrish. These two bores will give additional data on the hydrology of the area.**

13.6. Managing the sewerage system

- Septic tanks are designed to leach and therefore may recharge the aquifer. It is recommended that a sewage system be considered in the Tambellup townsite.*** The system should be designed to minimise recharge to groundwater.
- No septic tanks should be allowed in the future.***
- If a sewer system is constructed, the treated water could be used for irrigating timber plantations.*** A suitable site should be found to grow trees.

13.7. Recommendations for the Oval

Divergence of the mid-June flow lines (Figure 16) implies that the Oval and agricultural land further east contribute to the rising groundwater levels. We showed that the northern parts of the Oval is becoming salt-affected (Section 11.3). There are management options that can prevent salinity of this sports ground:

- Trees should be planted on any possible area that is not used for sport, traffic or other essential uses.*** Tree or shrub selection could be based on their water use, beautifying the surrounding areas and avoiding the possible adverse effects.***
- The northern parts of the sports ground which are becoming saline look lower than the other areas. This may be due to removal of sand from these areas to build the embankment. If other salinity control measures and recommendations are not done, these areas may have to be filled by sand to reduce the risk of salinity.**
- If salinity affects significant parts of the Oval, a deep drainage system may have to be installed. A deep drainage system will be technically possible because of deep sandy soils in the Oval. The Catchment Hydrology Group from Agriculture WA or a consultant may be asked to design a deep drainage system to suit the area.*
- A possible passage for the deep main drain will be along depression N. 5 (Figure 9)

13.8. Other recommendations

- The building blocks which are on the lower parts of the Tambellup Town may be flooded after a heavy summer rainfall (Section 7.1). It is recommended to avoid building on vacant blocks in these areas.***
- A water balance and groundwater model need to be designed for assessing the different options for the town.**
- The focus of this report is parts of the townsite east of the Gordon River. Most of the recommendations however, may be applicable to the western side. To find more specific hydrological information about the western side, further drilling and studies are needed.*

14. The future monitoring

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

- Groundwater levels should be measured once a month during the first year 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 in Gordon river and the Jam Creek during October each year (after the major rains have ceased) and sent to Agriculture WA in Albany.** Salinity of these water samples may be means of measuring the health of the catchments.

15. References

ABS (1991). “1991 Census”. Australian Bureau of Statistics.

Anon. (1996). Western Australian Salinity Action Plan.

Argent and George (1997). “AgET; a Water Balance Calculator for dryland salinity management (in Press).

Bureau of Meteorology (1993). Daily maximum and minimum temperature and rainfall (Microfiche).

FAO (1977). (Revised) Crop water requirements. Irrigation and Drainage Paper **29**. FAO, Rome.

Ferdowsian, R. (1997). “Landform Pattern map of the Western Forest Area” Agriculture WA. Albany.

Ferdowsian, R., and Greenham, K.J. (1992). "Integrated Catchment Management Upper Denmark Catchment" Tech. Report No. **130**. Div. Resourc. Manag. West. Aust. Dept. Agric.

Ferdowsian, R., and Ryder, A.T., (1997). "Salinity and Hydrology of the Mills Lake Catchment" Resource Management Technical Report No. **166**. Agriculture, West. Aust.

Ferdowsian, R., George, R., Lewis, F., McFarlane, D., Short, R. and Speed, R. 1996 The extent of dryland salinity in Western Australia. Proc. 4th National Conf. and Workshop on the Productive Use of Saline Lands, Albany, West. Aust. Promoco Conventions Pty Ltd, Canning Bridge, West. Aust. pp89-97

Luke, G.J., Burke, K.L. and O'Brien, T.M. (1987). Evaporation data for Western Australia. Div. Resourc. Mgt, W. Aust. Dept. Agric. Tech. Rep. **65**.

McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. (1984). "Australian Soil and Land Survey Field Handbook". (Inkata Press, Melbourne).

Arjen: Could you look at the text of this Appendix and make corrections; eg salt concentration etc.

Appendix 1: Drilling Logs

The following pages show the drill logs of 11 bores that were drilled in the study area and one in the nearby catchment, in April 1996. The location of the eleven bores is marked on Figure 3. 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).

Appendix 2: Terminology and abbreviations used in this report

Terminology	Description
Aeolian	Material that is deposited by wind.
Alluvial or alluvium	Material that is deposited by water in low-lying areas and floodplains.
AMG	Australian Map Grid.
Aquifer	A water-bearing underground layer (stratum), that water can be extracted from.
Archaean	Early Precambrian era (Precambrian period was between 600 and 4,500 million years ago).
Plant available water (PAWC)	Difference between field capacity and wilting point of a soil. Water which plants can obtain from unsaturated soil.
Baseflow	The extended, low flow in a creek after surface runoff has finished and when groundwater is the main contributor to the flow.
Bedrock or Basement rock	Hard rocks that are at the base of the weathered soil profile or regolith.
Capillarity	Rise of a liquid, which is in contact with a solid, due to surface tension.
Capillary	Fine spaces between soil particles which are interconnected.
Conductivity (electrical)	Ability of a rock or a solution to conduct an electrical current.
Degradation and degrade	Decline in the condition of natural resources commonly caused by human activities.
Discharge rate	Volume of water flowing through a cross section in a unit time.
Discharging	Groundwater coming to the soil surface.
Drill log	A record of material drilled and findings while drilling a bore.
Erosive velocity (m/second)	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).
Flat	An area that is almost level (<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.
Flow lines	In a laminar flow (flow that is not turbulent) molecules of liquid flow along predictable lines which are called flow lines.
Geology	Science of the earth (its origin, structures, composition, historical changes and processes).
Granite rock	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.

Terminology	Description
Gravel	Rock particles 2-4 mm in diameter.
Hydraulic conductivity	The ability of a material to conduct water.
Hydraulic gradient	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.
Hydrological system (HS)	Areas that have similar hydrological properties and may be grouped together as one unit.
Hydrology	Science of water movement in relation to land and the soil profile.
In situ; In situ weathered material	In place; Weathered material that has stayed in its place of weathering.
Landform pattern (LFP)	A toposequence (valley floor, hillside and ridge) described by its relief, slope, landform elements and degradational problems associated with its use.
Leaching	The removal of some chemical components of a rock or soil by water.
Local aquifer	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.
mg/L	Milligrams per litre.
Mottles	Mottles are spots, blotches or streaks in a soil profile which have different colours from the matrix colour of the soil.
mS/m	MilliSiemens per metre (a measure of electrical conductivity).
Off-site	Material or something that has originated elsewhere but has been transported or transferred to a site.
Palaeochannels	Ancient drainage valleys that have been filled with sediments. Palaeochannels may be call “buried alluvial channels”.
Pallinup Siltstone	Silts that were deposited in a marine environment on the south coast of Western Australia during the Eocene (~ 40 to 60 million years ago).
Pebble	A rock particle between 4 and 60 mm in diameter.
Piezometric surface or level	Height to which water level rises in a piezometer: reflects the pressure of the aquifer next to the screen depth.
Proterozoic	Late Precambrian period, which is between 600 and 1,500 million years ago.
Recharge	A component of rainfall that drains below the root zone of vegetation and joins the groundwater.

Terminology	Description
Regional aquifer	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). We have used this term for aquifers which are smaller than the nationally known regional aquifers such as in Murray-Darling Basin or artesian aquifers.
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/m^3) 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).
Swale	Linear, level-floored open depression excavated by wind or left relict between ridges built up by wind.
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.

Terminology	Description
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.