LANDFORM MAPPING AND RECHARGE ESTIMATIONS FROM HORSHAM TO DIMBOOLA

April 2002

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LANDFORM MAPPING AND RECHARGE ESTIMATIONS FROM HORSHAM TO DIMBOOLA

February 2002

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ABSTRACT

Twenty-one landform units were identified within the Horsham to Dimboola study area and an estimate of groundwater recharge from hydrograph fluctuations was determined for each unit. Low-lying landform units were shown to have higher recharge rates due to greater contributions during rainfall events by surface and shallow sub-surface flow, causing accumulation of water at these points in the landscape, thus increasing the potential for groundwater recharge. Landform units of greater extent but with lower recharge values are of as much, if not greater, concern to salinity problems in the area. A partial water balance revealed that an average 16% of rainfall in the region contributes to groundwater recharge.

INTRODUCTION

Scope and aim of study

The objective of this investigation was to identify differing landform units and subsequently quantify recharge rates between Horsham and Dimboola. The report documents the understanding and process used in defining landforms to identify areas of groundwater recharge. Assisting the improvement of water quality and environmental conditions, both locally and regionally, due to the improved knowledge of groundwater processes, are direct benefits of this investigation. The Centre for Land Protection and Research (CLPR), Agriculture Victoria, has undertaken this work as part of a continuum of landform mapping throughout the Wimmera Catchment. This project is funded through Project R219: Hydrogeological research and investigations for the Wimmera Salinity Management Plan on behalf of Catchment and Water (Department of Natural Resources and Environment) through the Wimmera Catchment Management Authority.

Study area

Location

The study area chosen for this project extends from Dimboola southwards within the Wimmera Catchment of west-central Victoria. Spanning approximately 158 000 hectares the east, west and southern boundaries represent an approximate 10 km buffer on either side of the Wimmera River. Figure 1 depicts the location of the study area. Townships located within the study area include Horsham, Natimuk and Pimpinio.

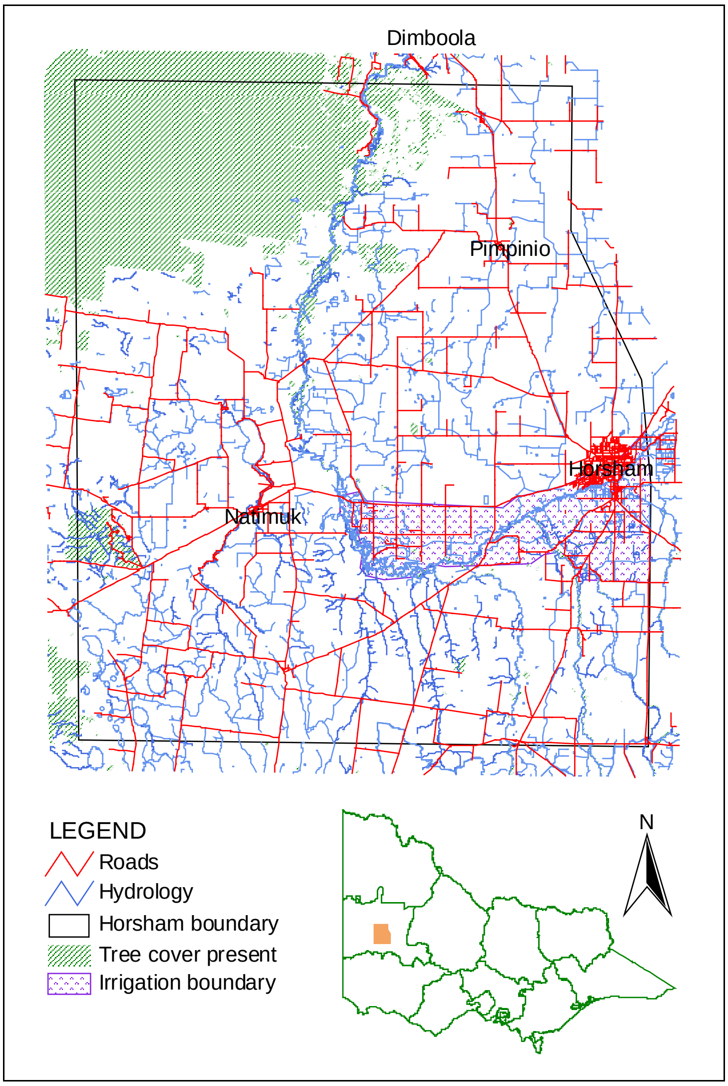

Figure 1 Location map for the Horsham-Dimboola mapping area

Physiography

The topography of the area ranges from 360 m AHD at Mt Arapiles to 110 m AHD along the Wimmera River, however the majority of the area lies within an elevation range of less than 150 m AHD. The Little Desert National Park is located in the north of the study area and consists of undulating dunes, which decrease in elevation to the east and south as the sand dunefields taper out. The Wimmera River enters the area in the east flowing westerly through Horsham and abruptly turns before Natimuk and flows north towards Dimboola.

Climate

The Horsham-Dimboola area receives an average rainfall of 424.15 mm/yr (average taken from Horsham Composite, Dimboola Post Office, Natimuk and Pimpinio monitoring stations). Most rainfall is received during the winter/spring period where cooler temperatures reduce evaporation allowing the majority of recharge to groundwater systems to occur. Potential evaporation rates (average of 1500 mm/yr - Longerenong monitoring station) increase significantly in the summer months and can be up to ten times greater than rainfall on a monthly basis (see Figure 2).

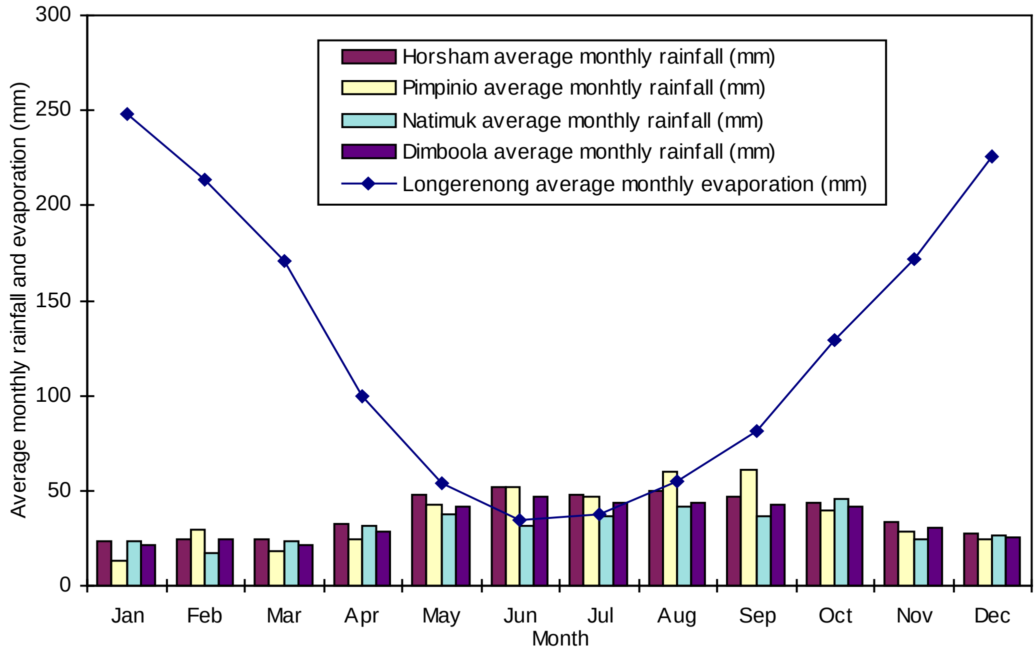

Figure 2 Average monthly rainfall and evaporation in the Horsham-Dimboola area

Land use

Agricultural land is predominant throughout the area. Areas of significant public land also exist, including Mt Arapiles in the south-west, the Little Desert National Park in the north-east, a series of saline and freshwater lakes and swamps, and river frontage. Major farming enterprises undertaken within the area are cropping and grazing of sheep and some cattle. Grazing becomes more predominant in the southern parts of the study area.

Previous studies

Landform classification north of this study has previously been conducted (Hocking 1999; Hocking 2000; Muller & Hocking 2002). A summary of other studies that have used radiometrics for mapping and the hydrograph method for calculating recharge are detailed in Muller and Hocking (2002).

GEOLOGY/GEOMORPHOLOGY

The geology that defines the landscape consists of marine, fluvial and aeolian sediments of Carboniferous, Tertiary and Quaternary deposits. Outcrops of Carboniferous (Grampians Group) sandstone constitute the oldest landforms of the area. In particular, Mt Arapiles forms a prominent landmark rising high above the surrounding plains. Mt Arapiles was believed to be an island during the Tertiary marine incursion. It displays wave eroded features at the base of its formation (Cayley & Taylor 1997).

Parilla Sand strandlines have been formed by a retreating shoreline and are preserved across the landscape as NNW trending ridges approximately 2-4 million years ago (WCSMP 1992).

Dissection of the landscape following the marine incursion occurred during a major wet phase approximately 50 000-30 000 years ago (WCSMP 1992). This led to the development of rivers and lake systems and the deposition of sands and clays known as the Shepparton Formation. Following this, a more arid phase occurred due to glaciation causing sea levels to drop. This initiated wind blown processes and the deposition of the Woorinen Formation (aeolian sediments from locally sourced deposits of varying textures). Intermittent lakes developed approximately 25 000 years ago exposing lake bed sediments during periods of low rainfall which were subsequently blown into source bordering crescent shaped dunes (lunettes) formed on the downwind side (King 1984).

Fine grained Lowan Sand blankets a majority of the older sediments in the form of irregular shaped east-west trending dunes which typify the Little Desert region. More recent alluvial sediments (Coonambidgal Formation) flank existing waterways dissecting the older floodplain of the Shepparton Formation, which is seen to occur as elevated terraces 2-5 m above recent drainage lines (Morand *et al*. in prep.).

HYDROLOGY/HYDROGEOLOGY

The surface drainage of the Horsham-Dimboola study area is highly influenced by NNW trending Parilla Sand ridges where drainage has developed between these strandlines with a predominantly NNW flowing trend (King 1984).

The change in flow direction of the Wimmera River from westerly to northerly, west of Horsham, is inferred to have occurred due to structural uplift (King 1984) possibly associated with the Dundas Tableland in the south-west (Morand *et al*. in prep.). The uplift ended the northerly flow from the Glenelg region via the Douglas Depression (located west of Mt Arapiles) into the Wimmera system (Morand *et al*. in prep.).

The surface geology has a significant impact on salinity forming processes for the area. Hydraulic separation of the deep regional aquifers (the Murray Group Limestone and Renmark Group sediments) by layers of low permeability strata (aquitards) inhibits interaction with near surface aquifers. The geological units that constitute the near surface aquifers are the Parilla Sand, the Shepparton Formation, the Woorinen Formation, the Lowan Sand and deposits of recent rivers and swamps.

The Parilla Sand Aquifer is characterised as a regional groundwater system, its widespread and continuous distribution makes it the most dominant watertable aquifer in the area. Regionally, the groundwater movement in the aquifer trends towards the Wimmera River with a shallow gradient that can be as low as 2 cm/km. On a local scale these gradients can be more significant (i.e. up to 2 m/km) due to variations in topography, permeabilities and groundwater mounding. Salinities of the regional aquifer range from 10 000-30 000 EC (Hocking 1997) in the Wimmera region.

Salinities of the numerous lakes and depressions in the area are governed by their intersection with the Parilla Sand Aquifer. Those that do intersect the watertable are typically saline, where discharging groundwater concentrates further by evaporation (King 1984). Lakes and depressions (waterbodies) that do not intersect the watertable are generally fresh as they are filled by surface runoff and act as recharge points to the Parilla Sand Aquifer.

The Shepparton and Coonambidgal formations have local to intermediate groundwater systems, depending on their continuity along and adjacent to drainage lines. The main source of recharge to these aquifers occurs during high rainfall events where surface water ponds and infiltrates slowly into the profile and possibly to the regional aquifer.

The varying landforms and textural properties of the Woorinen Formation make its aquifer characteristics difficult to define. The discontinuity and variance of this unit infers that local groundwater processes mainly act within the unit, where recharge and discharge may occur within short distances of each other.

The Lowan Sand aquifer is characterised by fine grained wind blown deposits of unconsolidated sand, permitting rapid infiltration by rainfall. Salinity can occur adjacent to these aquifers as they are typically underlain by aquifers of lower permeabilities. This can lead to groundwater mounding within the aquifer (Luke & Hocking 2000) resulting in local discharge, generally at the break-of-slope.

Groundwater discharge into the Wimmera River is significant north of Horsham, contributing to approximately 35% of the salt load entering Lake Hindmarsh (Hocking 1997). Considerable elevation variance between the river and its surrounding landscape creates a significant hydraulic gradient towards the Wimmera River.

METHODOLOGY

Mapping procedure

A landform unit has a unique morphological, textural and topographical signature that distinguishes it from other features of the landscape. By identification and delineation of landforms and subsequent grouping by association and patterns, a landscape can be broken up into distinct units.

Landform units for the Horsham-Dimboola area were mapped at 1:50 000 using potassium radiometric data (produced and supplied by Minerals and Petroleum Victoria). Definition of these landform units required some degree of theoretical knowledge of geology and soil types as well as their topographic relationships. Previously mapped salinity was used to assist in identification of saline landform units.

Recharge calculations

An estimation of recharge for individual landforms has been obtained using the hydrograph method, where seasonal groundwater level fluctuations (monitored by bores) in unconfined aquifers are applied in the following relationship:

$$Pi = h \times Sy \qquad \text{(derived from Todd 1980)}$$

where

Pi = recharge (the portion of rainfall that reaches the watertable)
h = net annual recharge based on annual watertable fluctuations in selected monitoring bore time-series hydrographs (see Figure 3)
Sy = specific yield (the ratio defined by the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil, or in other words, the drainable porosity)

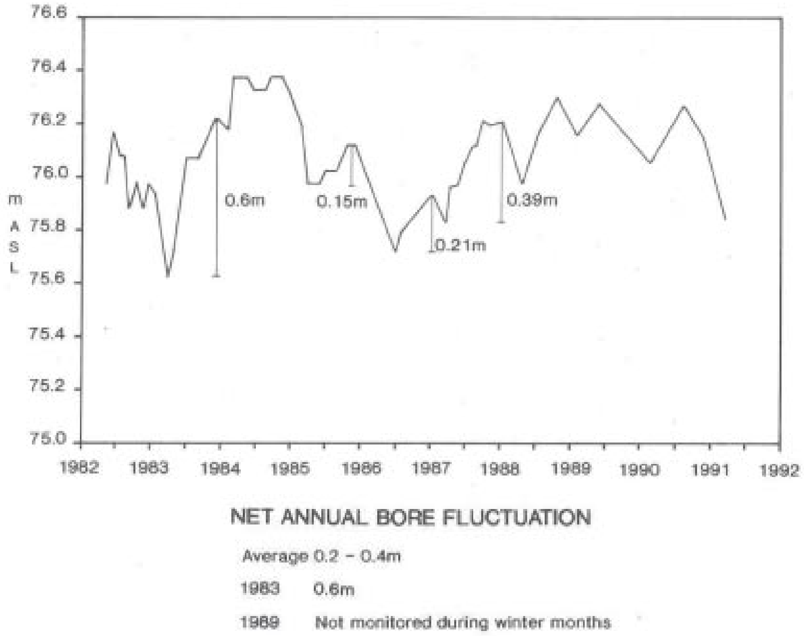

Figure 3 Example of recharge estimation from bore hydrographs (source: Strudwick 1992)

Values for specific yield were as follows (taken from Strudwick 1992):

- Parilla Sand: 0.21
- Other aquifers (i.e. Shepparton Formation): 0.18

All monitored bores in unconfined aquifers were used in recharge estimations and were categorised by the landform unit they occurred within. Mean recharge was then calculated for each landform unit.

RESULTS

Landform mapping

Twenty-one landforms were defined to describe textural and topographic variation throughout the landscape:

- Fine Sand Rise
- Lower Sand Rise
- Coarse Sand Rise
- Undulating Sand Rise
- Low Undulating Sand Rise
- Undulating Clayey Sand
- Heavy Rise
- Broad Plain
- Sandy Broad Plain
- Undulating Clay Plain
- Floodplain
- Remnant Drainage (Floodplain)
- Swale
- Broad Swale
- Saline Soil
- Lake Depression (Saline)
- Lake Depression (Non-saline)
- Depression (Non-saline)
- Arapiles
- Arapiles Colluvium
- Grampians Bedrock

Figure 4 depicts the landform units defined in the Horsham-Dimboola area and Table 1 shows the various characteristics of the landforms in the study area. Map 1 (see attached CD) is a more detailed version of Figure 4.

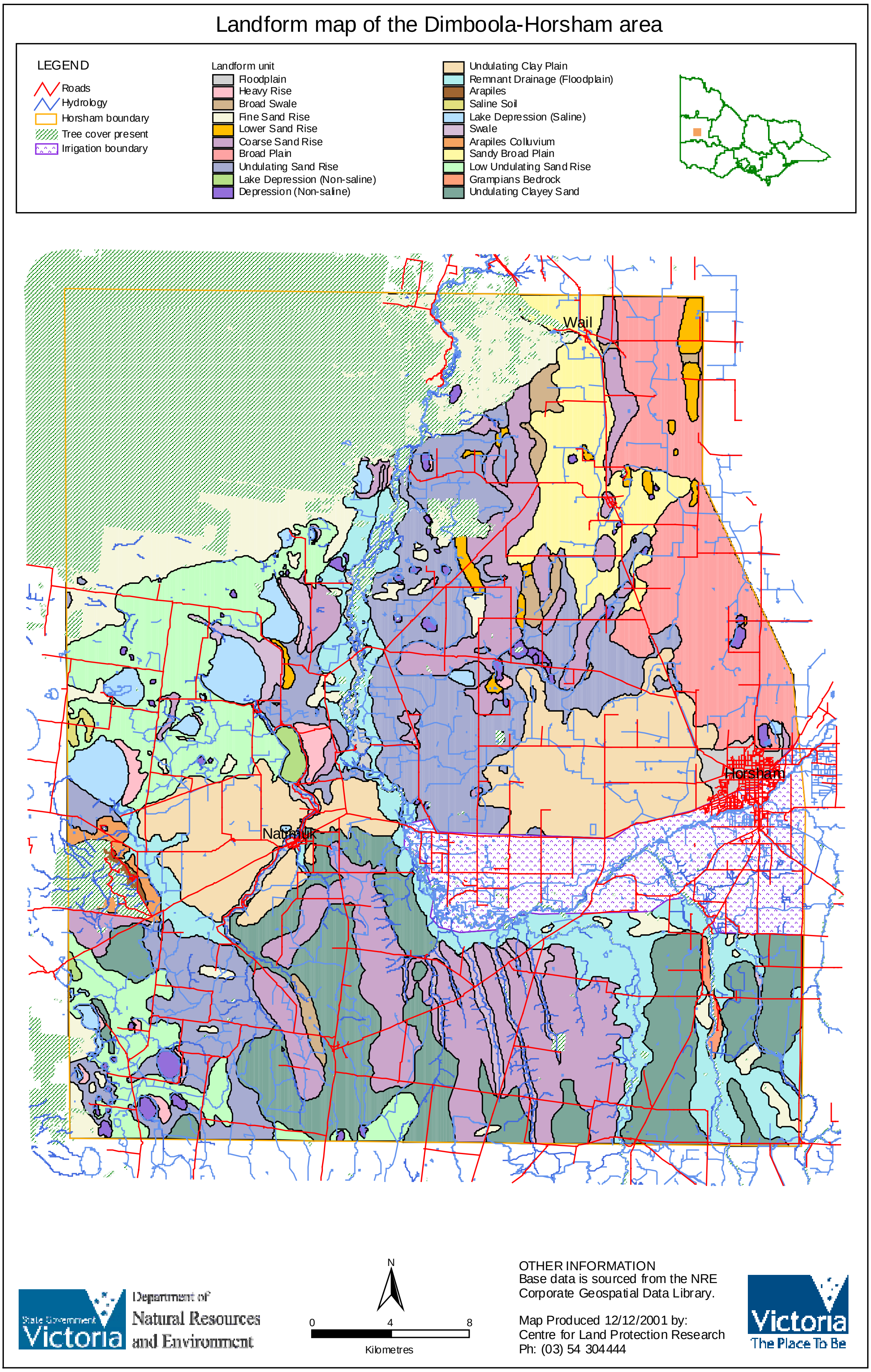

Figure 4 Landform unit map of the Horsham-Dimboola mapping area. Refer to Map 1 (see attatched CD) for detailed map

Table 1 Table 1 shows the various characteristics of the landforms in the study area.

Landform	Geology	Morphology	Radiometric response	Description	Landscape position
Flood plain (see plate 1)	Coonambidgal and Shepparton Formations	Flat, narrow, discontinuous units. Dissected below adjacent landscape	Varied but typically has a medium response	Unconsolidated fine to coarse sand, gravel, silt and clay. Deposits of present/past drainage lines	Low- lying landscape position. Adjacent to modern streams
Lunette	Yamba Formation	Crescent shaped, sometimes undulous or multiple.	High when clay dominant and low when sand dominant	Sand-size clay pellets and sand	Occur on the eastern side of past and present lake systems
Broad swale	Varied	Broad flat elongated drainage lines in between dunes	Varied, usually higher than adjacent dunes		Low-lying flat landscape between dunes
Fine sand rise	Lowan Sand	E-W dunefields (Little Desert) or discreet deposits. Varying thicknesses and extents	Very low	Unconsolidated, well rounded, fine grained sand	Wind blown sediments that overly other landforms
Sand rise	Woorinen Formation and Parilla Sand	Low discrete rises, generally small extent. Some with NNW trends	Lower than surrounding landform responses	Sandier soils that surrounding units	Lower topographic expression than coarse sand rises but elevated above plains
Coarse sand rise (see plate 2)	Parilla Sand	Elongated NNW trending dunes	Low to very low	Fine to coarse sand containing ferruginous layers	Elevated shoreline remnants

Landform	Geology	Morphology	Radiometric response	Description	Landscape position
Broad plain	Woorinen Formation	Low or no topographic relief	Varied, medium to high	Heavy soils: clays and sands	Flat low and extensive
Broad plain basin	Quaternary	Small swamp-like deposits	Medium to high (varied)		Low lying internal catchments in more regional landform units
Undulating sand rise	Predominantly Woorinen Formation	Undulous, difficult to define individual, more discreet landforms	Medium response	Predominantly sands	Intermediate topography. Lower than coarse sand rise but more undulous than broad plain
Lake depression (non-saline)	Quaternary	Irregular flat morphology, sometimes kidney shaped	Low to very low		Low-lying freshwater bodies elevated above watertable
Depression (non-saline)	Quaternary	Mostly circular	Varied		Low-lying discrete points in landscape that occur above the watertable
Undulating clay plain	Parilla Sand? Woorinen Formation?	Flat extensive plains, some dissected by recent drainage	High to very high	Very heavy soils	Flat and low but more elevated than broad plain

Landform	Geology	Morphology	Radiometric response	Description	Landscape position
Remnant drainage (floodplain)	Shepparton Formation	Flat, terraced floodplain of past drainage, dissected by more recent drainage	Medium	Clays, sands, silts, gravels	Low landscape position, adjacent to modern and past drainage systems
Arapiles	Grampians Group	Large resistant outcrop with numerous isolated rock outcrops	Low to very low	Quartzose sandstone, siltstone and minor mudstone (undergone contact metamorphism)	Highest topographic expression in study area rising well above the plains
Saline soil	Quaternary	Generally basin shaped low-lying depressions	Medium to high		Low discrete points in landscape that intersect the watertable
Lake depression (saline) (see plate 3)	Quaternary	Irregular shaped water bodies, some kidney shaped with flat extents	Varied		Low-lying salt water lakes that intersect the watertable
Swale	Varied	Elongated, steep, narrow drainage lines between dunes, NNW trends	Varied, usually higher than adjacent dunes		Narrow internal drainage between dunes
Arapiles colluvium	Recent colluvium	Colluvial slopes surrounding source	Low to very low	Scree and outwash deposits, conglomerate, sand and clay	Elevated above landscape occurring on and adjacent to Arapiles slope

Landform	Geology	Morphology	Radiometric response	Description	Landscape position
Sandy broad plain	Woorinen Formation	Flat broad plain with undefinable sandier units	High but lower than broad plain due to higher sand content	Heavy soils, sands and clays	Flat, low and extensive
Low undulating sand rise	Woorinen Formation and Parilla Sand	Low undulating undefinable sandy units	Medium	Predominantly sands	Lower and less undulous than undulating sand rise
Undulating clayey sand	Parilla Sand	Undulating, slightly elevated plateau	Medium	Weathered Parilla Sand, contains greater clay content and iron nodules	More elevated than other broad flatter units
Grampians bedrock (see plate 4)	Grampians Group	Fractured bedrock	High	Quartzose sandstone, siltstone and minor mudstone	Flat bedrock exposed by stream incision. Underlies all other landforms

Plate 1 Road-cutting intersecting a Coarse Sand Rise landform unit displaying irregular ferruginised layers developed in the coarser sand beds which can inhibit deeper recharge (for scale, note lens cap near centre)

Plate 2 Weathered profile of the Undulating Clayey Sand landform unit (for scale, note lens cap near centre)

Plate 3 Floodplain landform unit of the Wimmera River viewed from the secondary floodplain (Remnant Drainage landform unit)

Plate 4 Mitre Lake is a large saline lake depression typical of those that occur within the Douglas Depression of the Horsham-Dimboola mapping area

Plate 5 Mt Arapiles (in distance) occurs as a distinctly elevated landform above the surrounding area

Recharge estimations

Figure 5 (below) depicts average recharge rates within each landform unit. Limited bore distribution did not make it possible for each landform unit to be assigned a recharge value. In order to improve the definition of recharge, recharge values estimated for landform units that occurred in mapped areas further north (Muller & Hocking 2002) were used to apply values for the same landform units in the Horsham-Dimboola study area. It was determined that an average of 20% more recharge occurs in this southern area due to higher rainfall rates (see Table 2). Landforms that had no recharge values in either the current study area or previously mapped areas were estimated based on textural composition and landscape position. A summary is given in Table 3 of the validity of the recharge values based on the number of bores located within landform units, and the method used to determine recharge rates in landform units that lacked groundwater information.

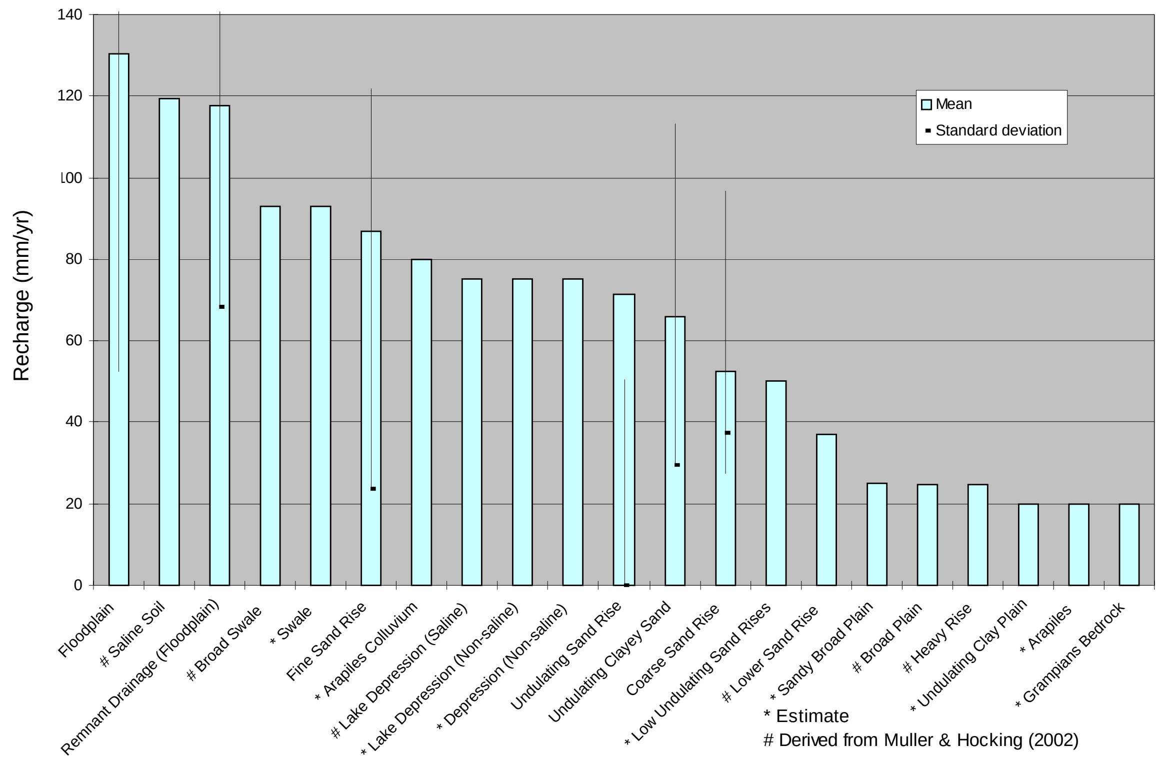

Figure 5 Average annual recharge estimations for the landforms in the Horsham-Dimboola area

Table 2 Relative recharge rates for the Horsham-Dimboola and Old Dimboola Shire areas expressed as a percentage of the comparison of recharge rates for landform units with recharge estimates found in both areas (Horsham-Dimboola and Old Dimboola Shire)

Landform unit	Recharge* (mm/yr)	Recharge** (mm/yr)	% of recharge* to recharge**
Floodplain	95	143	66
Remnant Drainage (Floodplain)	85	130	65
Undulating Sand Rise	75	54	138
Fine sand rise	55	105	53
Coarse sand rise	41	54	76
Average % of recharge* to recharge**			80
Estimated % of increased recharge in the Horsham-Dimboola area			20

* Average annual recharge for landforms in the Old Dimboola Shire
** Average annual for landforms in the Horsham-Dimboola mapping area

Table 3 Summary of how recharge estimates were determined and the number of bores available for each landform unit

Landform unit	No. of bores in recharge estimation	Other methods of recharge estimation	Annual recharge value (mm)
Floodplain	27		130
Saline Soil	8		119
Remnant Drainage (Floodplain)	2		118
Broad Swale	0	Determined from Mintern and Hocking (2001)	93
Swale	0	Determined from Mintern and Hocking (2001)	93
Fine Sand Rise	13		87
Arapiles Colluvium	0	Estimation based on lithology	80
Lake Depression (Saline)	1		75
Lake Depression (Non-saline)	0	Comparable to Lake Depression (Saline) unit	75
Depression (Non-saline)	0	Comparable to Lake Depression (Saline) unit	75
Undulating Sand Rise	18		72
Undulating Clayey Sand	5		66
Coarse Sand Rise	8		53
Low Undulating Sand Rises	0	Thought to have a lower recharge rate than Undulating Sand Rise unit due to smaller elevation variance	50
Lower Sand Rise	1		37
Sandy Broad Plain	0	Comparable to Broad Plain unit	25
Broad Plain	0	Estimated from a bore from the Wimmera Plains	25
Heavy Rise	0	High clay content inhibits recharge	25
Undulating Clay Plain	0	Lower than Broad Plain unit	20
Arapiles	0	Estimation based on lithology	20
Grampians Bedrock	0	Estimation based on lithology	20

DISCUSSION

Landform mapping

The reliability of the mapping technique in identifying landforms varied considerably throughout the study area. Strong contrasts in radiometric signatures were valuable in the delineation of soil/geology. Where less significant variation in radiometric response occurred, change in topographic relief became the more dominant mapping method. The reliability increased significantly where both these contrasts were evident. The accuracy of the mapping was much reduced in areas where delineation was difficult with both mapping techniques. Previously mapped salinity (stored on the NRE corporate geospatial database) did not always match with current on-ground conditions. This was noted and re-mapped accordingly, and incorporated into the final map layer. Variation between the current and previously mapped salinity may result from a number of scenarios including: (i) incorrect identification of initial saline sites; (ii) recovery of these sites due to present drier climatic conditions; (iii) the occurrence of salinity being a result of local processes which respond more rapidly to climatic change than salinity driven by the regional aquifer system.

Recharge estimation

Recharge estimations suggest that recharge in low-lying landscapes is more significant than recharge in elevated areas. This is most likely a result of the accumulation of water during wet periods allowing greater potential for recharge. To reduce the impact of evaporation on hydrograph fluctuations, bores that had a depth to watertable of less than 3 m were removed from these estimations. Bores located within 1 km of the Wimmera River were also discarded as they are influenced by the variation in river waterlevels.

The estimation of recharge from bore hydrograph data should be considered as a qualitative rather than a quantitative measure as (i) calibration of these values to field measurements has not been undertaken and (ii) the data is site specific and generally not sufficient to account for spatial variability.

Total recharge can be determined as the product of annual recharge rates and total landform areas (see Table 4). Table 4 also includes the percentage of average annual rainfall (420 mm/yr) that contributes to groundwater recharge. It can be seen that the Fine Sand Rise landform unit contributes the greatest amount of recharge within the Horsham-Dimboola area. This estimate may be excessive as most bores that monitor the watertable levels in this unit occur in unvegetated areas, whereas the majority of this unit has vegetation cover. Based on the recharge calculation in this study, an estimated average 16% of rainfall across the Horsham-Dimboola area can be attributed to groundwater recharge.

Annual hydrograph fluctuations represent a number of environmental conditions including direct recharge (rainfall), lateral recharge, flood recharge, evapo-transpiration, surface runoff and sub-surface flow. The primary objective of applying the hydrograph method was to quantify the amount of vertical recharge and prioritise landforms of high recharge. Landforms in low-lying landscapes are likely to be more influenced by lateral groundwater impacts rather than direct recharge, this should be acknowledged when assessing the results.

Table 4 Percentage of rainfall that actually recharges (based on an average rainfall of 420 mm/yr)

Landform unit	Area (hectares)	Recharge rate (mm/yr)	Volume (ML)	% Rainfall that recharges
Floodplain	2061	130	2679	31
Heavy Rise	866	25	216	6
Broad Swale	1153	93	1072	22
Fine Sand Rise	30028	87	26124	21
Lower Sand Rise	1079	37	399	9
Coarse Sand Rise	16919	53	8967	13
Broad Plain	9530	25	2383	6
Undulating Sand Rise	17963	72	12933	17
Lake Depression (Non-saline)	54	75	41	18
Depression (Non-saline)	1135	75	852	18
Undulating Clay Plain	12307	20	2461	5
Remnant Drainage (Floodplain)	10488	118	12376	28
Arapiles	968	20	194	5
Saline Soil	141	119	167	28
Lake Depression (Saline)	2842	75	2132	18
Swale	2089	93	1943	22
Arapiles Colluvium	712	80	570	19
Sandy Broad Plain	6063	25	1516	6
Low Undulating Sand Rise	7483	50	3742	12
Grampians Bedrock	281	20	56	5
Undulating Clayey Sand	23661	66	15616	16
TOTAL	158064		96439	
AVERAGE RECHARGE				16

CONCLUSIONS

Identification and characterisation of 21 landform units and subsequent assignment of groundwater recharge rates has been conducted in the Horsham to Dimboola study area. It was found that recharge is more significant in low-lying landscape positions. The Floodplain landform unit recorded the highest calculated recharge rate (130 mm/yr). Although this is the highest recharge rate the aerial extent of this landform is narrow, therefore the actual contribution to the shallow watertable aquifer is minor. Landforms that have lower recharge rates but occur to greater aerial extent (i.e. Fine Sand Rise landform unit) can actually contribute more to the watertable.

RECOMMENDATIONS

The following recommendations have been drawn from this study:

- Areas identified with relatively high recharge rates to be treated to reduce groundwater recharge.
- In order to improve the monitoring of groundwater trends across a broader range of landform units within the study area, the distribution of monitoring bores needs to be increased. This needs to be done in a strategic manner targeting landform units that lack sufficient data for recharge estimations.
- Rehabilitation of river frontage vegetation to reduce groundwater recharge during flooding events.

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