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A conceptual hydrogeological model for the Lake Warden recovery catchments Esperance, Western Australia

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A Conceptual Hydrogeological Model for the Lake Warden Recovery Catchments, Esperance WA

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Dryland Salinity Theme - Project 3

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Assessment of Salinity Management Options for Lake Warden Catchments, Esperance WA: Groundwater and Crop Water Balance Modelling

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Introduction

The National Land and Water Resource Audit (NLWRA), has identified Dryland Salinity as one of seven major themes for an audit of the nation's land, water, vegetation and natural resource management. Within this theme, Project 3 has been developed to investigate a key catchment type and how management scenarios will impact on dryland salinity processes. The Lake Warden catchments have been chosen as one of four catchment water balance studies to be undertaken nationally. The catchment water balance analysis will be undertaken using numerical modelling by the CSIRO, Division of Land and Water.

Four surface water catchments, Neridup Creek, Bandy Creek, Coramup Creek and the Western Lakes catchments feed the Lake Warden System wetlands (Figure 1). These catchments cover have an area of approximately 157,000 hectares. The system of wetlands is one of nine wetland areas in Western Australia recognised as Wetlands of International Importance under the Ramsar Convention (CALM 1997). The catchments have also been given recovery catchment status under the State Governments Salinity Action Plan. Increased run-off and rising watertables resulting from the clearing of agricultural land along with encroaching urban development is having a direct impact on the wetlands. As Recovery catchments under the Salinity Action Plan, communities within the Lake Warden catchments are receiving a high level of funding and priority access to Catchment Support Teams for catchment planning aimed primarily at protecting biodiversity.

Included in this report are descriptions of the physiography of the region and detailed descriptions of five hydrogeological zones identified within the Esperance agricultural region that cover the Lake Warden catchments (Figure 3). Each zone can be further divided by rainfall isohyets that can represent broad changes in agricultural practices. Finally a conceptual model of the hydrogeology is developed for input into the catchment water balance model being undertaken by the CSIRO. The model will assist in regional planning and development, catchment and farm planning, insight into the limits of agricultural management options and for local extension to the farming and district communities for issues related to natural resource management.

Maps and cross-sections are available in digital format. Design files and documentation are listed in Appendix 1.

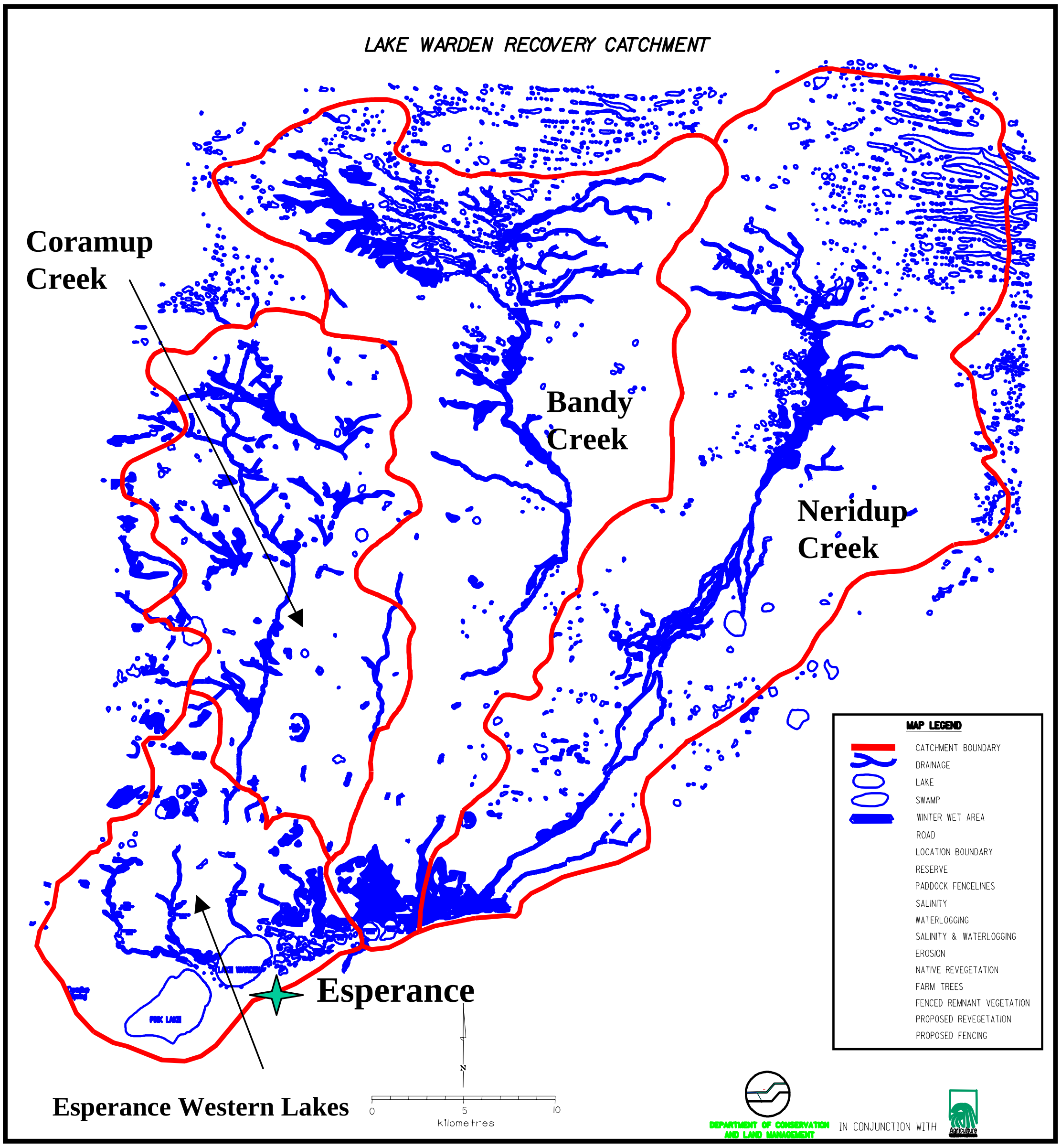

Figure 1. Lake Warden Recovery Catchment - boundaries and surface drainage.

Regional physiography

Climate

The Esperance agricultural region has a Mediterranean climate with cool, wet winters and dry, temperate summers. Average annual rainfall ranges from 670 mm at Esperance and decreases rapidly away from the coast to 350 mm in the northern Mallee. Annual Class A pan evaporation ranges from approximately 1840 mm at Esperance to around 2200 mm at Salmon Gums (Luke *et al.* 1987). The increase in evaporation parallels the decrease in rainfall, resulting in a decrease in the agricultural growing season from seven months at Esperance to approximately five months at Salmon Gums. Approximately two-thirds of the annual rain falls between

May and October (66 per cent at Jerramungup and 67 per cent at Esperance Downs Research Station). Rain bearing depressions from ex-tropical cyclones and local thunderstorms occur from October to March. Wind directions are generally from the north-east and south-east in summer. The eastward passage of low-pressure fronts in winter can result in gale force winds from the north and west.

Figure 2 shows monthly rainfall since 1977 at the Esperance Downs Research Station. The research station is located in the Dalyup River catchment to the west of the Coramup Creek catchment divide (Figure 1). The graph demonstrates wetter periods such as 1989, 1992 and an extreme rainfall event in January 1999.

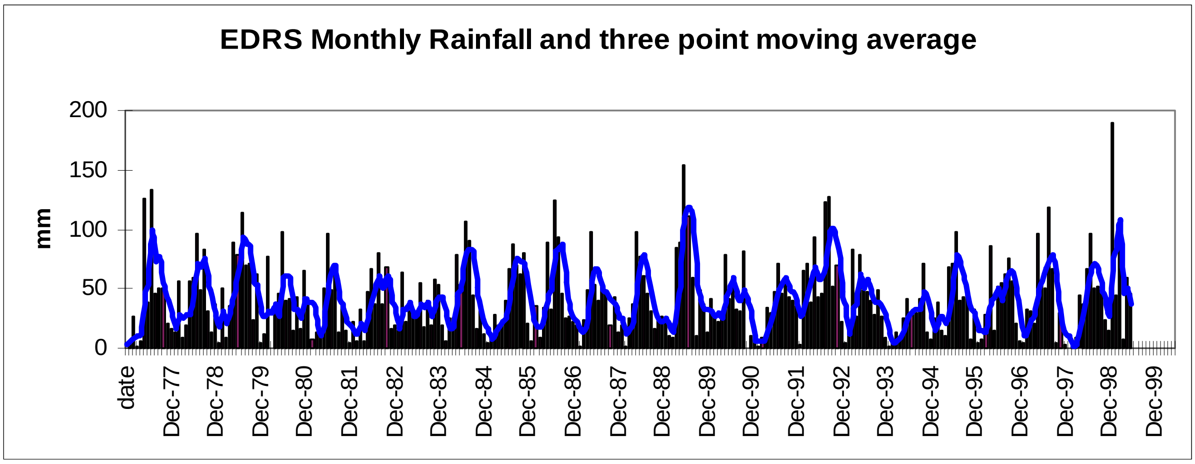

Figure 2. Monthly rainfall - EDRS.

Physiography and land systems

Elevations within the catchment decrease gradually from the top of the catchments (approximately 50 km inland and 160 m AHD) to the Southern Ocean until reaching a low escarpment at 20-60 m AHD. The escarpment falls to a narrow undulating coastal plain of around 20 m AHD with poorly drained sand dune and swale systems. Inland, and along the coast, monadnocks form palaeo-islands in the landscape to elevations up to 345 m AHD.

The region can be broadly divided around the 450 mm annual rainfall isohyet into a mallee area in the north and a coastal sandplain (Esperance sandplain) in the south. Rounded depressions and swamps are scatted across the sandplain and fill with water during winter. Further inland in the mallee, the depressions become more clustered with salt lakes. Lunettes form on the eastern margins and the clusters are elongated in a generally east-west direction.

Within the Lake Warden catchments, Nicholas has identified eight main land systems (Figure 4). These include Esperance, Scaddan, and Halbert that represent almost 90 per cent of the catchment area. Land systems combine areas of similar soils, landforms, climate and vegetation with mapping to national guidelines (ACLEP Australian National Land Evaluation Program). This information is available for all of the Lake Warden catchments at 1:250,000 scale.

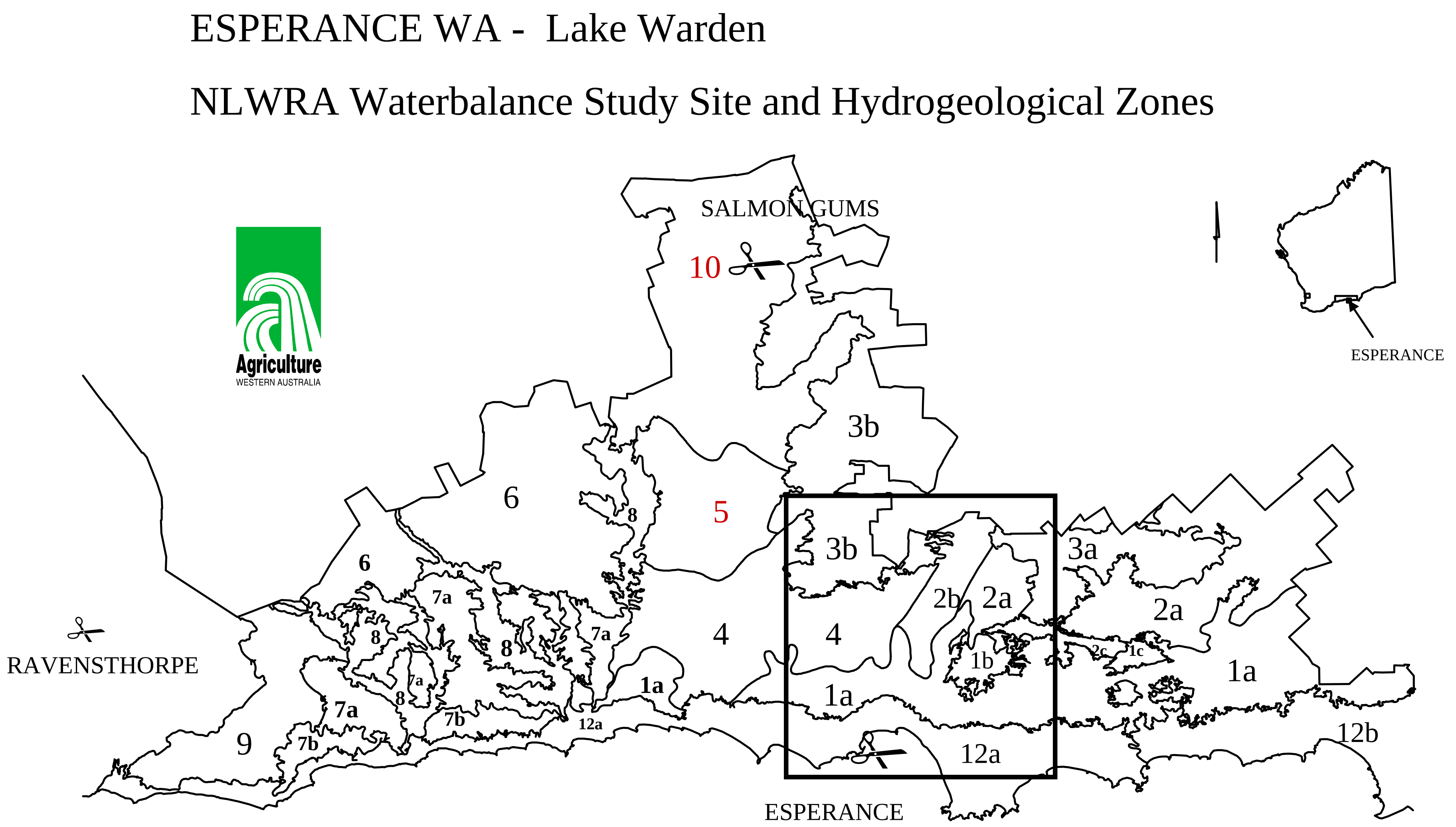

Figure 3. Location map and hydrogeological zones.

Soil landscape mapping has been completed for approximately 80 per cent of the catchments at 1:50,000 scale. A hierarchical legend is used to describe both land systems and soil-landscapes to account for different scales of information and varying complexity of landscape. Land system information is stored in a GIS environment to allow spatial interrogation. Common fields describing landform attributes are used within this database (e.g. Soil Groups in Appendix 2) and the AgBores database to facilitate integration.

Table 1 shows the hectares and percentage of each land system within the catchments. Summary descriptions are included in Appendix 2 and describe topography and the percentages of the main soil types within each land systems. Descriptions are based on McDonald *et al.* (1990).

Table 1. Total hectares and percentage of each land system within Lake Warden Recovery Catchments

System	Code	Hectares	Percentage of catchment
Esperance	245Es	96,649	56.5
Scaddan	246Sc	33,092	19.3
Halbert	246Ha	22,561	13.2
Gore	245Go	8,304	4.9
Tooregullup	245To	4,064	2.4
Ney	245Ne	2,888	1.7
Condingup	245Co	2,167	1.3
Wittenoom	246Wm	1,450	0.8

Soils and farming systems

Sandplain soils are dominantly deep duplex soil with of 30-80 cm of fine sand and ferruginous gravels topsoils overlying a dense sodic (ESP >6) clay subsoil. Approximately two-thirds of these soils are prone to annual waterlogging. Deep, loose gradational sands are the major associated soil consisting of greater than 80 cm of fine sand.

In the Mallee the dominant soil type is shallow sandy-surfaced alkaline duplex. The depth of sandy topsoil is typically less than 30 cm with some areas less than 5 cm.

Water repellent topsoils can increase water logging and salinity problems by increasing run-off and inhibiting water entry into the soil. Light rains on water repellent soils at the start of the season affect germination and crop establishment. All 800,000 hectares of the sandplain contains soils susceptible to water repellence. All Sandplain and Mallee soils are susceptible to wind erosion.

Salt storage *in the top 6 m* of the regolith ranges up to 1,285 t/ha in the Mallee and 898 t/ha on the sandplain.

The dominant soil types have been grouped and their distribution is shown in Figure 5. A more detailed description of soil groups within land systems is given in Appendix 2.

Farming systems can be broadly separated by rainfall isohyets:

>550 mm - 80 per cent pasture (50/50 cattle/sheep)
20 per cent cropping (80 per cent oats - 20 per cent barley)

450-550 mm - 60-70 per cent sheep, 30-40 per cent crop

350-450 mm - 60 per cent crop, <40 per cent sheep

<350 mm - Mainly crop

A database for the Esperance region including the Lake Warden catchments is being compiled of current and future/potential farming systems for each soil group within each of the land systems described in Appendix 2. This work is being carried out as part of the NLWRA Project 1 (Extent and Impacts of Dryland salinity). The data will be compiled and be available in September 1999 and could be used for farm scale modelling within this audit project. Farming systems will be described according to the percentage of soil type within each land system. This data will link to the water balance calculator model, AgET (Argent and George 1997) and to the south coast economic model - MIDAS (Pannell and Bathgate 1991).

Surface drainage

The present surface drainage patterns are a product of the geological history of the South Coast of Western Australia. Prior to the Eocene (54 to 38 million years ago), drainage was to the west towards the Perth Basin and to the east towards the Eucla Basin. Uplifting of the Darling Plateau and tilting of the continental margin during the Tertiary Period (65 million years ago to the present) diverted drainage to the south. To the west of Esperance, ephemeral rivers and creeks have incised the Tertiary plateau. On the plateaux, surface drainage usually terminates in paperbark (*Melaleuca* spp.) and yate (*Eucalyptus occidentalis*) swamps. To the east of Esperance, catchment boundaries are very poorly defined. Drainage lines filled with Eocene sediments are now being reactivated as a result of land clearing that has increased run-off and raised watertables**.** These drainage lines terminate in coastal wetland areas such as the Lake Warden system.

Geology

Pre-Cambrian crystalline basement rocks from either the Archaean Yilgarn Craton or the Proterozoic Albany-Fraser Orogen, underlie the Esperance district. The Archaean basement rocks (about 2300 million years old) occur mainly to the west of Esperance and are similar to those in much of the WA wheatbelt. These basement rocks are made up of granites and gneisses with some older greenstone belts occurring near Ravensthorpe. The Archaean rocks are divided from the basement rocks of the Albany - Fraser Orogen (rocks about 1800 million years old) along a line which runs approximately north east from the Dalyup River. Basement rocks were overlain by Tertiary sediments (around 40 million years ago) of the Plantagenet Group. Basement rocks form coastal headlands, offshore islands or can be seen inland as high points in the landscape such as Wittenoom Hills or Mt Howick. Quaternary sand and limestone deposited over the last two million years extends along the coastline.

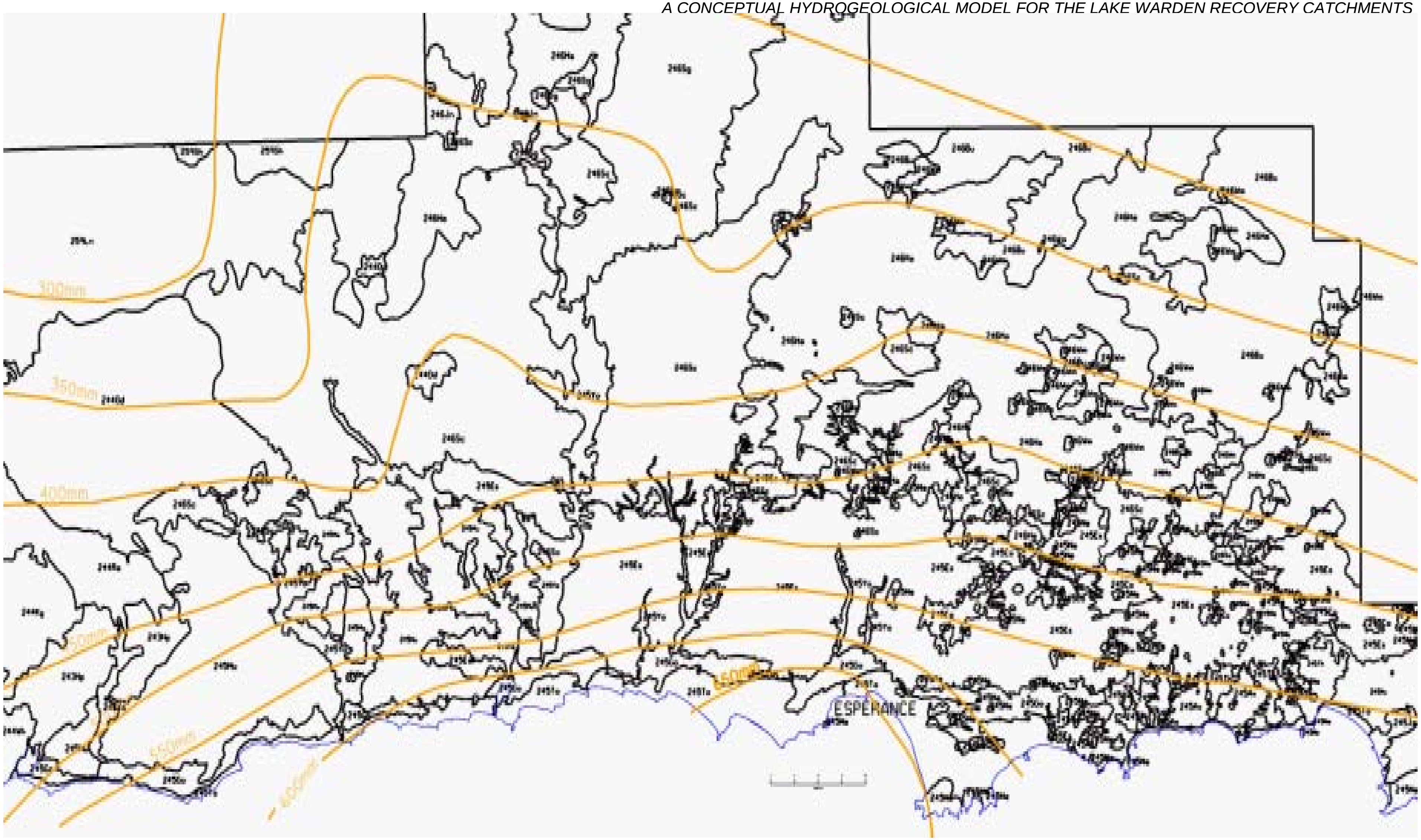

Figure 4. Land systems and rainfall isohyets.

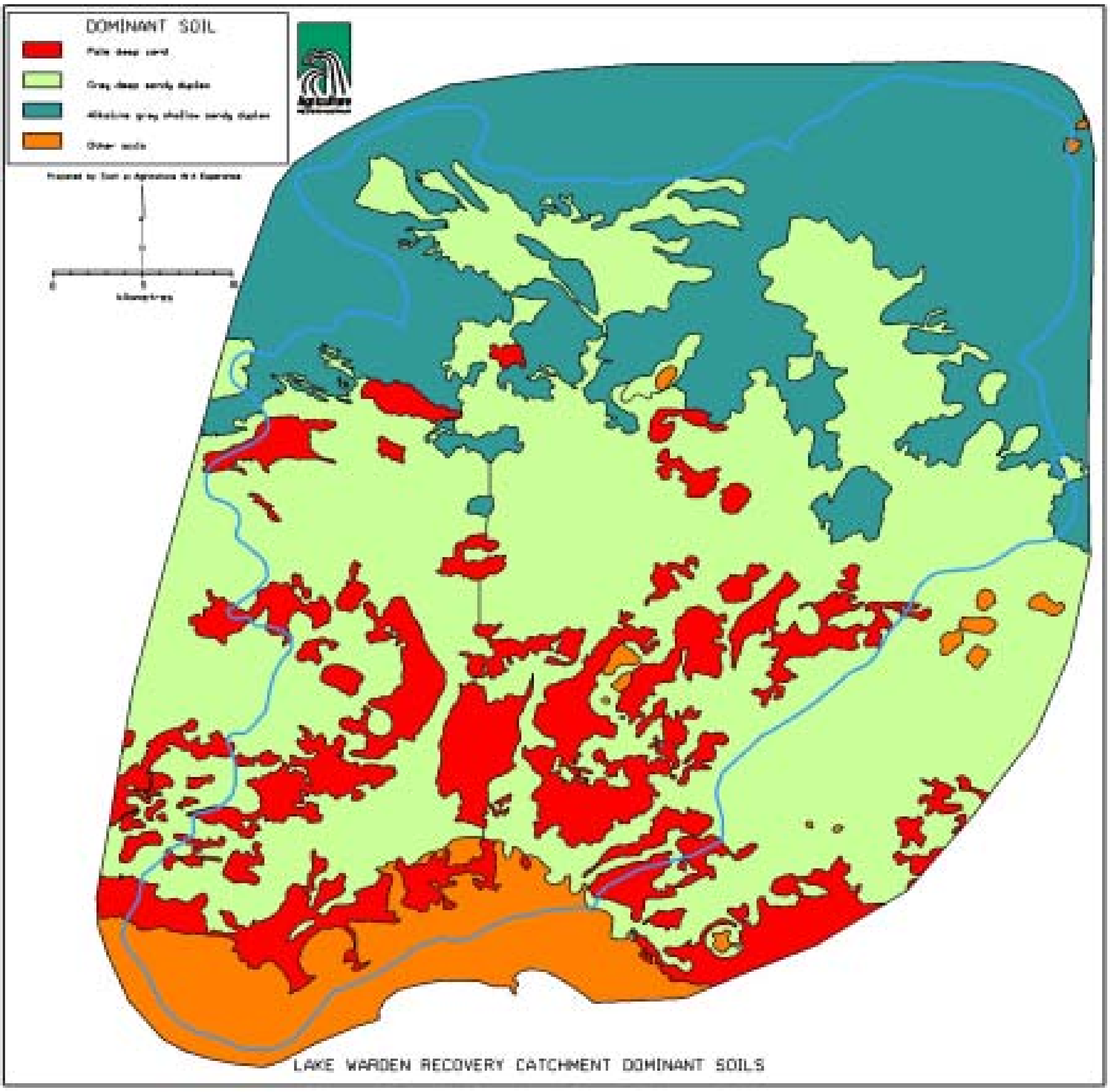

Figure 5. Dominant soils in the Lake Warden Catchments.

Antarctica began to break away from Australia in the Cretaceous (135 to 64 million years ago) which resulted in the continental margin sagging to form the Bremer Basin (Cockbain and Hocking 1990). A marine transgression in the Middle to Late Eocene (about 40 million years ago) deposited the Werillup Formation and the Pallinup Siltstone units of the Plantagenet Group in palaeodrainage lines and regional depressions in basement rocks. The Werillup Formation consists of a dark grey siltstone, sandstone, claystone and lignite (brown coal) and limestone deposited in fluvial or backswamp environments. The Pallinup Siltstone consists of siltstone and spongelite (lithified sponge spicules) deposited in a marine environment.

The Darling Plateau began to be uplifted in the Oligocene (about 30 million years ago) resulting in the southern coastline tilting towards the south, forming the Ravensthorpe Ramp; the hinge line is known as the Jarrahwood Axis (Cope 1974). Drainage lines were partly rejuvenated and sand deposits were redistributed by the wind forming present day sand sheets and dune systems. Carbonate leaching and lateritisation took place to form the present topography and soil profiles.

Hydrogeology

Tertiary sediments overlie Precambrian basement rocks over much of the region. Redistributed aeolian sands formed during the marine transgression mask the underlying geology over most of the Esperance agricultural advisory district. Around Esperance, basal sands of the Werillup Formation are restricted to lows in the basement topography and are relatively more permeable than the Pallinup Siltstone. Groundwaters in the Plantagenet Group and Werillup Formation sediments are usually saline. Drilling to the north-east of Esperance has located the Werillup Formation along palaeodrainage lines. The extent of the Werillup Formation under the sandplain is still unclear.

Studies in the Esperance district have shown that four aquifers may be present; a deep semi-confined/confined ‘regional’ or intermediate aquifers in weathered basement rocks; semi-confined/unconfined aquifers in overlying Tertiary sediments, and shallow seasonal perched aquifers in duplex soils (responsible for waterlogging) and perched aquifers in deep sand sheets and dunes. These aquifers may be connected vertically and with the exception of the perched aquifers, are often saline. Bedrock highs and ridges orientated in a north-east to south-west can separate the ‘regional’ and intermediate aquifers.

The fine-grained nature of the Pallinup Siltstone and the upper part of the Werillup Formation result in low hydraulic conductivities and groundwater yields. Spongolite sections of the Pallinup Siltstone are more permeable. To the east of Esperance fine-grained sand lenses with minor clay are present up to 3.5 m thick in Pallinup Siltstone sequences. Recharge to groundwater through Tertiary sediments could occur through preferred pathways such as solution cavities and root channels. These pathways have been observed to extend to depths up to 8 m below the surface. Recharge in areas of shallow bedrock is believed to occur through both matrix flow and macropores and rates may be higher around bedrock highs and basement outcrops than over broader flatter areas. In flatter parts of the landscape with Tertiary sediments, recharge may only be occurring through matrix flow (Hall pers. comm.).

Regionally, hydraulic gradients appear to be less than 0.1 per cent and generally reflect the surface topography. Prior to clearing, many aquifers were probably separated by Precambrian bedrock barriers that form palaeo-islands and bedrock ridges within the overlying Tertiary sediments.

Dolerite dykes do not intrude into the sediments forming barriers to groundwater flow. Bedrock highs and ridges are the major barriers that water can accumulate behind to form saline seeps. In many areas where there is shallow bedrock, such as the central part of the Esperance District, watertables are within 2 m of the surface and are the cause of secondary salinity. As watertables rise in Mallee areas, the salts in soils with high salt storage are being remobilised along drainage lines, causing seepage scalds. Fault zones in basement rock may also have high salt storages however given the lack of structure (fractures and jointing) in exposed monadnocks, their influence on groundwater movement is considered minimal.

Groundwater salinity increases away from the coast with fresh to brackish water occurring within 20 km of the coastline. Perched aquifers in Quaternary deep sands and sand sheets both on the coast and inland can contain water of stock quality (<2,000 mS/m). Lateral movement of water through these sands towards topographic lows causes seasonal waterlogging. Other drainage end points, such as paperbark and yate swamps, may be either recharge or discharge sites for deeper regional aquifers.

Groundwater on the sandplain ranges from 45 to 5,065 mS/m while groundwater salinity in mallee areas is up to 13,300 mS/m. Long-term bore monitoring has shown that groundwaters are generally rising from 0.1 to 0.3 m/year and in some cases, to 0.5 m/year (see Appendix 4).

In many areas of the sandplain and mallee, saline groundwaters are within 10 m of the surface. Approximately 560 monitoring bores with time series data are held on the Esperance AgBores database (Heinrich and Bennett 1997).

Approximately a third of annual rainfall occurs outside the traditional growing season. Since clearing for agriculture recharge to groundwater has increased. Native vegetation in the region is estimated to use 95 per cent of rainfall while farm systems in place at Esperance are estimated to be using only 90 per cent of the annual rainfall (Hall 1997). There is clearly an urgent need to reduce recharge to groundwater and address water balance issues.

Salinisation models - National classification

A catalogue of15 generic hydrogeological models of groundwater systems have been used to described the broad characteristics of salinisation across Australia (RIRDC 1998). Groundwater systems responsible for dryland salinity in the Esperance Region are described using this classification system (Appendix 3) according to their presence within hydrogeological zones shown in Figure 3.

Six models from the national classification system have been used or have been interpreted in the context of additional local data. The occurrence of each of these models within each hydrogeological zone within the Lake Warden recovery catchments are shown in Table 2.

Table 2. Groundwater systems responsible for dryland salinity in the Esperance Region

National classification system (RIRDC 98)	**Esperance groundwater system** (Diagram Appendix 5)	**Process** (description - Appendix 5)	**Hydro-geological zone** (Figure 1)	**Groundwater system**
4.1	1	Seepage over bedrock highs	1,2,4	Local
4.2	2	Seepage at break of slope	1,2,4	Local
4.5	3	Seepage from sediments	4	Local
4.6	4	Sandplain seep	1,2,4	Local
4.8	5a	Topographic Low - seepage/discharge	3	Local
4.15	5b	Topographic Low - seepage/discharge	1,2,4	Intermediate
	6	Baseflow	1,2,4	Local, Intermediate

Description of hydrogeological zones

Locations of identified hydrogeological zones are shown in Figure 3. Each zone has been based on geology and geomorphology using interpretations of airborne and ground based geophysics such as fixed frequency and transient electromagnetics, radiometrics, magnetics along with Landsat satellite imagery, geology maps and reports, field observations, drilling and bore monitoring results. In addition, observations and land system mapping by B. Nicholas and S. Gee (Natural Resource Assessment Group, AGWEST) have been used to define boundaries. The attributes for each hydrogeological zone within the Lake Warden catchments are shown in Appendix 4.

Zone 1

1a = Es land system
1b = Es and Co land systems

Average rainfall: >450 mm/year
Geology: *Eocene* Plantagenet Group Sediments, Pallinup Siltstone, Werillup Formation; *Archean* and *Proterozoic* granites, gneisses and migmatites
Soils: Shallow duplex, Deep gradational sands
Vegetation: Coastal Heath
Land systems: Es, Co
Drainage: Internal and poorly defined

This zone consists of cleared Esperance Sandplain at or near the coast. The southern boundary abuts uncleared coastal vegetation and wetland systems (Zone 12) and extends to the shoreline to the east. Other boundaries are adjacent to Zones 2 and 4 to the north. The boundary was defined by BMR radiometrics (1981) and is interpreted as a Tertiary shoreline. This interpretation was confirmed from airborne electromagnetic surveys (QUESTEM) and subsequent drilling programs. Sandplain topography consists mainly of level to undulating plain with poorly developed drainage lines and areas of internal drainage, which terminate in paperbark (*Melaleuca* spp.) and yate (*Eucalyptus occidentalis*) wetlands. Areas of deep sand are common to the north-east as longitudinal dunes or sand sheets (Zone 1B). Tertiary sediments unconformably overlie fresh bedrock. Isolated bedrock highs (palaeo-islands) occur within the landscape beneath sandplain cover or as large outcrops or monadnocks.

Four aquifers are present; a deep semi-confined/confined aquifers in weathered basement rocks; semi-confined/unconfined aquifers in overlying Tertiary sediments, shallow seasonal perched aquifers in duplex soils (responsible for waterlogging) and perched aquifers in deep sand sheets and dunes. These aquifers may be connected and, with the exception of the perched aquifers, are often saline.

North of Fisheries Road groundwater systems have low hydraulic gradients (generally <0.1 per cent) with flow directions influenced by basement topography. Water quality decreases to the north. Rates of watertable rise are generally 0.1-0.3 m/yr at approximately 10 m depth.

Hydrogeological investigations near Mt Howick (Short and Skinner 1998) have shown that Tertiary sediments thin out towards granitic basement highs and that the basement highs can separate regional groundwater systems. Work at this site and Greens Rd in the Neridup catchment (Figure 6) shows that bedrock highs can be associated with land units having topographic relief and greater than 1 per cent slope. Groundwater recharging on these high points moves towards lower parts of the landscape such as drainage lines and depressions. Recharge in areas of shallow bedrock occurs through both matrix flow and macropores and rates may be higher around bedrock highs and basement outcrops than over broader flatter areas. In flatter parts of the landscape with Tertiary sediments, recharge may only be occurring through matrix flow (Hall pers. comm.). Groundwater moves through weathered basement profile and increases groundwater pressures beneath the Tertiary sediments.

Johnson and Baddock (1998) described a shoreline facies unit when producing a hydrogeological sheet for the Esperance and Ravensthorpe Shires. The unit they describe is shown within Zone 1. This unit is not recognised in this report as evidence for its existence is minimal and other explanations and interpretations could be made of supporting evidence.

Dryland salinity risk and other land degradation hazards

Dryland salinity in this zone is estimated to be currently impacting on 6 per cent (15,500 ha) of the cleared agricultural land (263,000 ha). Remnant vegetation represents approximately 2 per cent of the agricultural land. Long term monitoring has shown that watertables are rising at 10 to 30 cm per annum with watertables at about10 m. It is estimated that 25 per cent of agricultural land has potential to become saline.

The majority of soils are susceptible to annual waterlogging. The fine-grained sandy soils are water repellent and at risk from wind erosion.

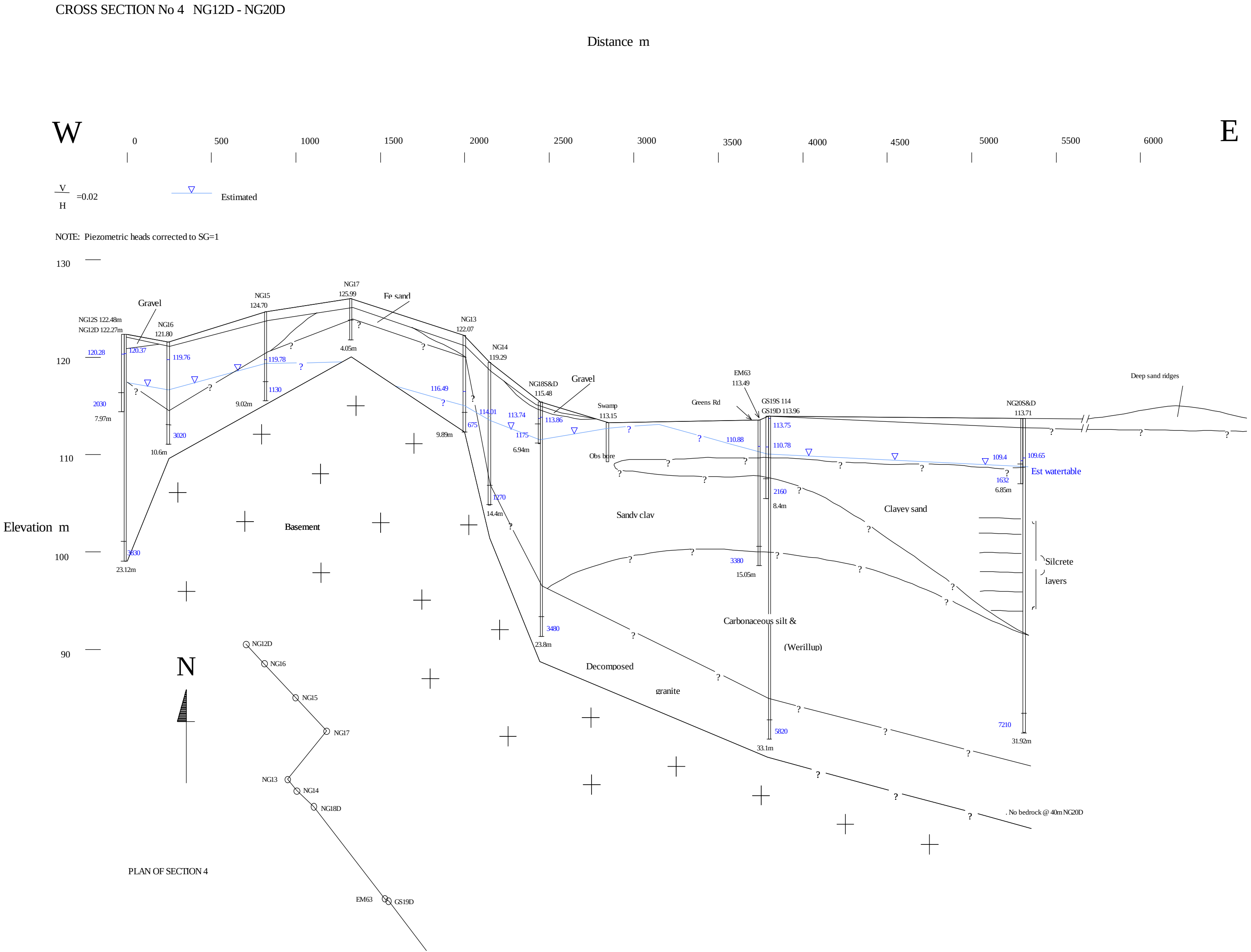

Figure 6. Greens Road cross-section - Zone 1.

Zone 2

2a = Sc land system
2b = Sc, Co land systems
2c = Sc - faulted basement

Average rainfall: 350-525 mm/year
Geology: *Eocene*, Plantagenet Group Sediments, Pallinup Siltstone, Werillup Formation; *Archean* and *Proterozoic* granites, gneisses and migmatites
Soils: Shallow duplex, Deep gradational sands
Vegetation: Mallee vegetation, halophytes in drainage lines
Land systems: Sc, Co
Drainage: Internal and poorly defined

This is topographically similar to Zone 1 with no clearly defined or significant drainage lines. Topography consists mainly of level to undulating plain with poorly developed drainage lines and areas of internal drainage which terminate in yate or paperbark swamps. The zone is mainly representative of mallee-type vegetation. Areas with primary salinity and halophyte vegetation and chains of salt lakes can reflect location of palaeochannels. These areas have been generally left uncleared. Weathering profiles can be deeper in these areas and the Werillup Formation is usually intersected at depth when drilling.

Proterozoic bedrock is often found within 10 to 20 m of the surface and forms basement ridges trending north-west to south-east, reflecting the regional trend. Groundwater is saline (>20,000 mS/m). Typical cross-sections from the Neridup Catchment are shown in Figures 7 and 8. Preferentially weathered zones in basement rocks are sites of high salt storage. Minor faults in basement rocks trending east-west can contain high salt storages and may have an influence on surface salinity. Plantagenet group sediments unconformably overlie basement rocks and no outcrops have been observed in the field. The Werillup Formation is restricted to palaeodrainage lines. Near-surface clays may act as aquitards to underlying saturated sediment/weathered bedrock profiles.

Groundwater systems are similar to Zone 1 however groundwater is usually within 5 m of the surface and saline. Isolated bedrock highs (palaeo-islands) occur beneath sandplain or as large outcrops or monadnocks. Groundwaters are rising up to 0.5 m/yr. and are below stock quality. Drainage lines crossing areas of high salt storage in areas of shallow watertables are mobilising stored salts causing secondary surface salinity. Clay layers may restrict vertical movement of watertables and localised shallow watertables appear to occur near salt lakes or where clays layers thin or lens out.

Dryland salinity risk and other land degradation hazards

Dryland salinity is estimated to be impacting on 11 per cent (19,400 ha) of cleared agricultural land (191,000 ha). Remnant vegetation represents about 5 per cent of cleared agricultural land. Long term monitoring has shown that watertables are rising 30-50 cm per annum and at about 5 m. It is estimated that 31 per cent of agricultural land has potential to become saline. The fine-grained sandy soils are water repellent and at risk from wind erosion.

Zone 3

3a = 450 mm rainfall
3b = 450 mm rainfall

Average rainfall: <450 mm/year
Geology: *Eocene*, Plantagenet Group Sediments, Pallinup Siltstone, Werillup Formation; *Archean* and *Proterozoic* granites, gneisses and migmatites
Soils: Shallow duplex, Gradational sands
Vegetation: Mallee vegetation, halophytes in drainage lines
Land systems: Sc, Ha
Drainage: Internal with numerous salt lakes

This zone is clearly defined from satellite images and characterised by chains of east-west trending elongated playa lakes. Present salt lake systems may form the upper catchment boundary for major palaeodrainage systems (visible on satellite images) which drain to the north and north-east towards the Eucla Basin. This zone is divided regionally into two according to rainfall, 3A > 450 mm and 3B < 450 mm.

Within the Lake Warden catchments, recharge within Zone 2 is moving laterally towards this zone and raising watertables. The Tertiary sediments are deep and watertables are generally shallow on the margins but may be deepen towards uncleared areas within the major palaeodrainage lines. A typical cross-section is shown in Figure 9. This cross-section is located at the boundary between Zones 2a and 3a, at the top of the Neridup Catchment.

Surface drainage occurs by overland and throughflow on duplex soils to salt lakes. The margins of these lakes are affected by waterlogging or inundation in wet years or after a series of wet years.

Dryland salinity risk and other land degradation hazards

Dryland salinity in this zone is estimated to be currently impacting on 5 per cent (2,100 ha) of the cleared agricultural land (65,600 ha). Remnant vegetation represents approximately 10 per cent of cleared agricultural land. It is estimated that 20 per cent of agricultural land in this zone has the potential to become saline.

The fine-grained sandy soils are water repellent and are at risk from wind erosion. Increased periods of inundation and shallow watertables between the salt lakes is causing areas to become bare and saline. Deflation through wind erosion often occurs and removes the A-horizon of soils.

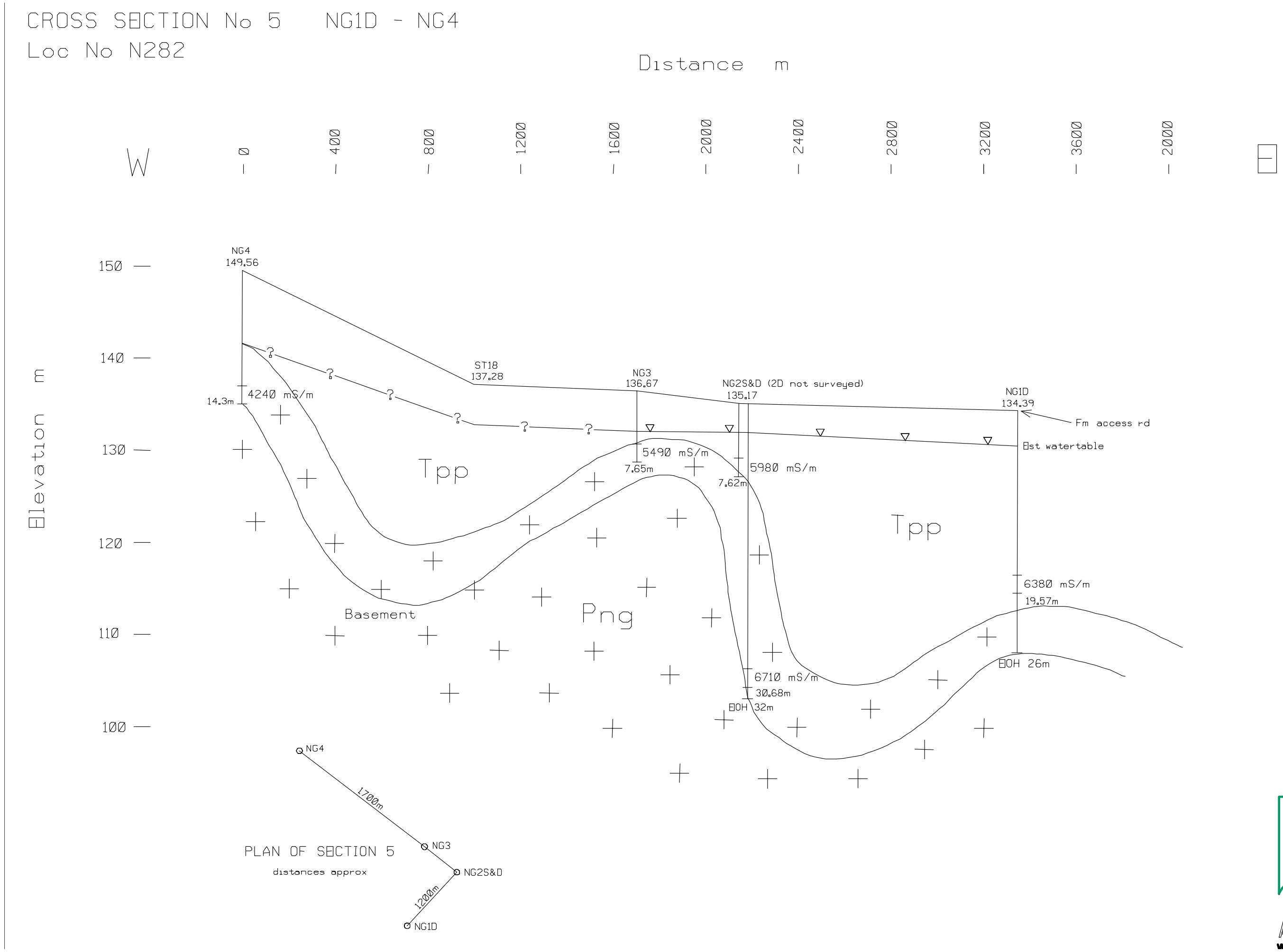

Figure 7. Zone 2 cross-section.

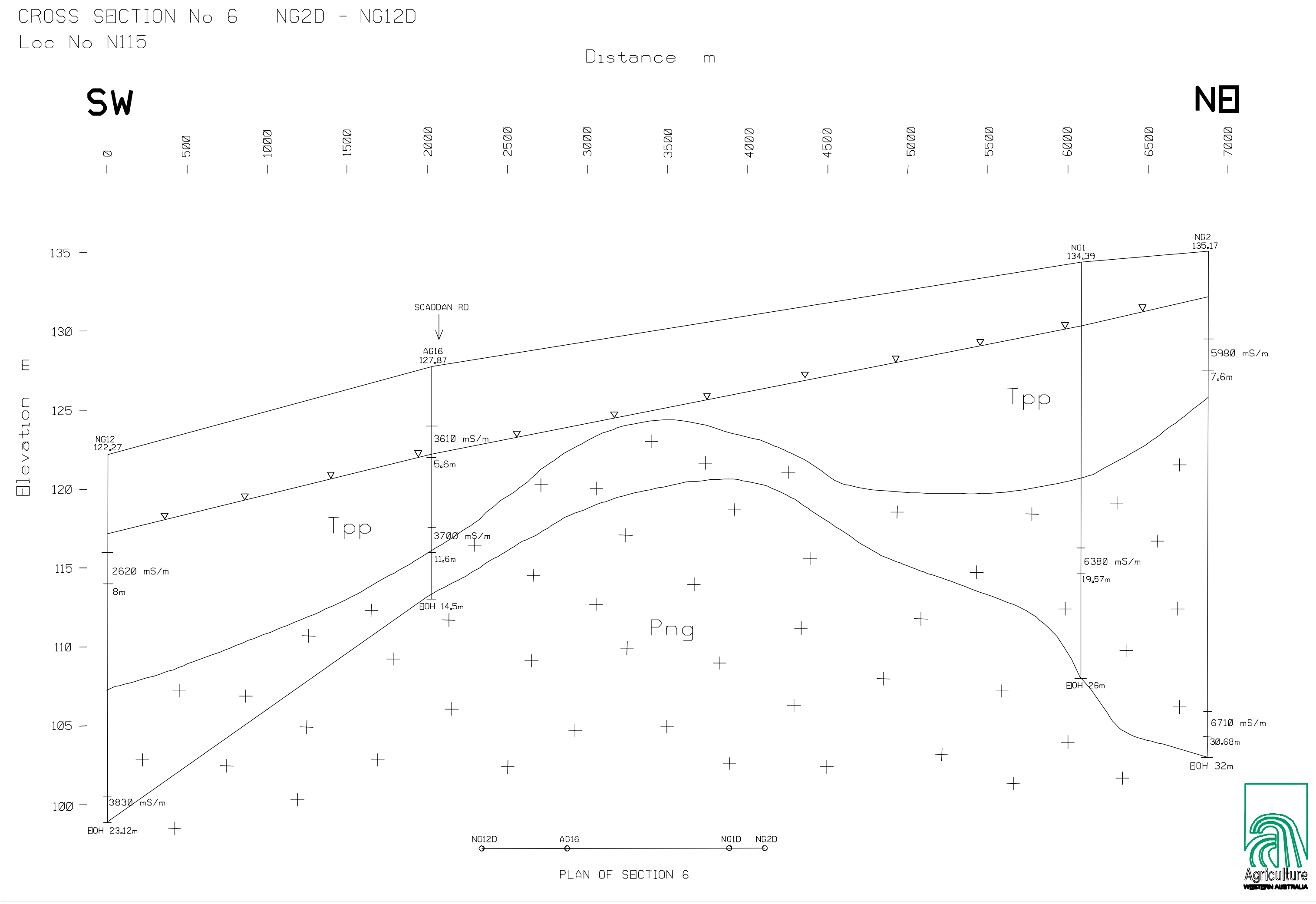

Figure 8. Zone 2 cross-section.

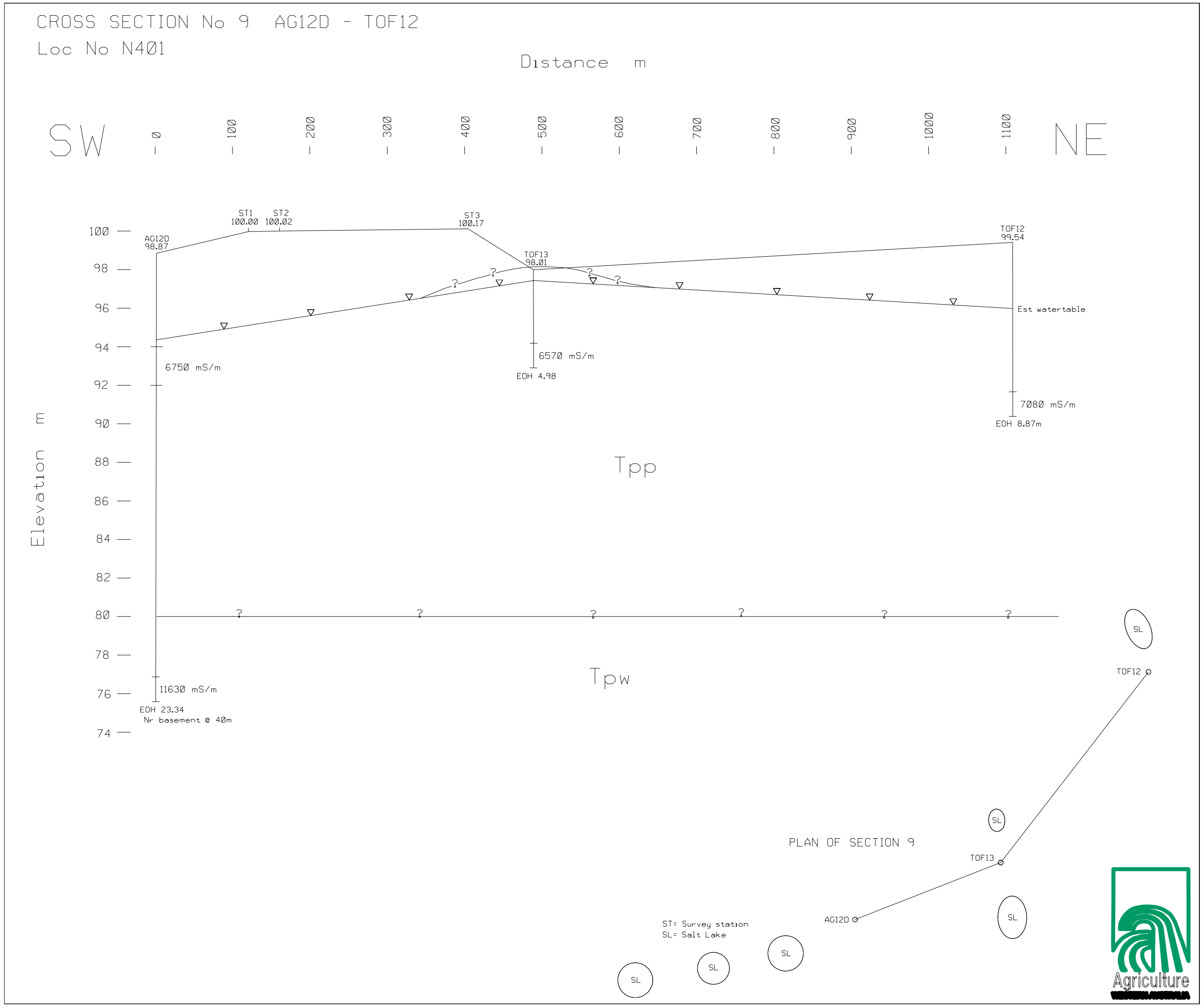

Figure 9. Zone 3 cross-section No. 9.

Zone 4

Average rainfall: >450 mm/year
Geology: *Eocene*, Plantagenet Group Sediments, Pallinup Siltstone, Werillup Formation; *Archean* and *Proterozoic* granites, gneisses and migmatites
Soils: Shallow duplex, Deep and Gradational sands
Vegetation: Sandplains vegetation, halophytes in drainage lines
Land systems: Es
Drainage: Internal and shallow incised drainage lines

Area characterised by regionally shallow bedrock with numerous bedrock highs and deep buried weathering profiles along drainage lines. Regolith profiles are characterised by shallow bedrock highs (orientated approximately north-south) with a thin veneer of Tertiary sediments and deeper Tertiary weathering profiles along drainage lines. Werillup Formation sediments may be present at depth along these drainage lines. Perched watertables are present in deeper sand units and contain fresher water. This water discharges as seeps and is often utilised as a fresh water resource via soaks. Perched systems may be coupled with more saline intermediate watertables. Drainage lines have been partly rejuvenated and exhibit primary salinity and halophyte vegetation. Watertables are generally within 2 m of the surface. Water quality is generally >2000 mS/m. The 450 mm rainfall isohyet defines the northern boundary and represents a general change in agricultural practices.

Recharge occurs across the landscape. Water moves vertically down the weathering profile to a weathered basement rock zone about 2 m thick, then laterally to drainage lines. The Esperance Downs Research Station (EDRS) is situated within Hydrogeological Zone 4 and is located in the Dalyup River catchment to the west of the Coramup Creek catchment divide (Figure 1). A typical cross-section for this zone is shown in Figure 10. Detailed work and groundwater data are available for EDRS (Short and Skinner 1996). In 1995, watertables had a mean depth of 1.1 m and a median conductivity of 2475 mS/m. Salt storages in the top 6 m of the regolith had a median value of 133 t/ha. Slopes on EDRS are generally less than 1 per cent, particularly east of the Norseman-Esperance Highway. Duplex soils are common and consist of fine-grained sands and lateritic gravels to a depth of about 1 m over fine to medium grained sandy clays. All 83 monitoring bores on the station to 1994 recorded a saturated zone above basement rocks. Groundwaters are usually within 1 to 2 m of the surface during winter and can fall to 3 m from the surface in the driest periods such as March 1995.

Historical drilling records (Berlait 1952) shows water levels at the time of clearing at EDRS. Seven drill holes recorded watertables 3.7 to 6.7 metres below the surface between March to June 1952, with three of the seven holes being dry. Records show that in 1952 annual rainfall (464 mm) was slightly below average with 1951 at 192 mm above average (687 mm).

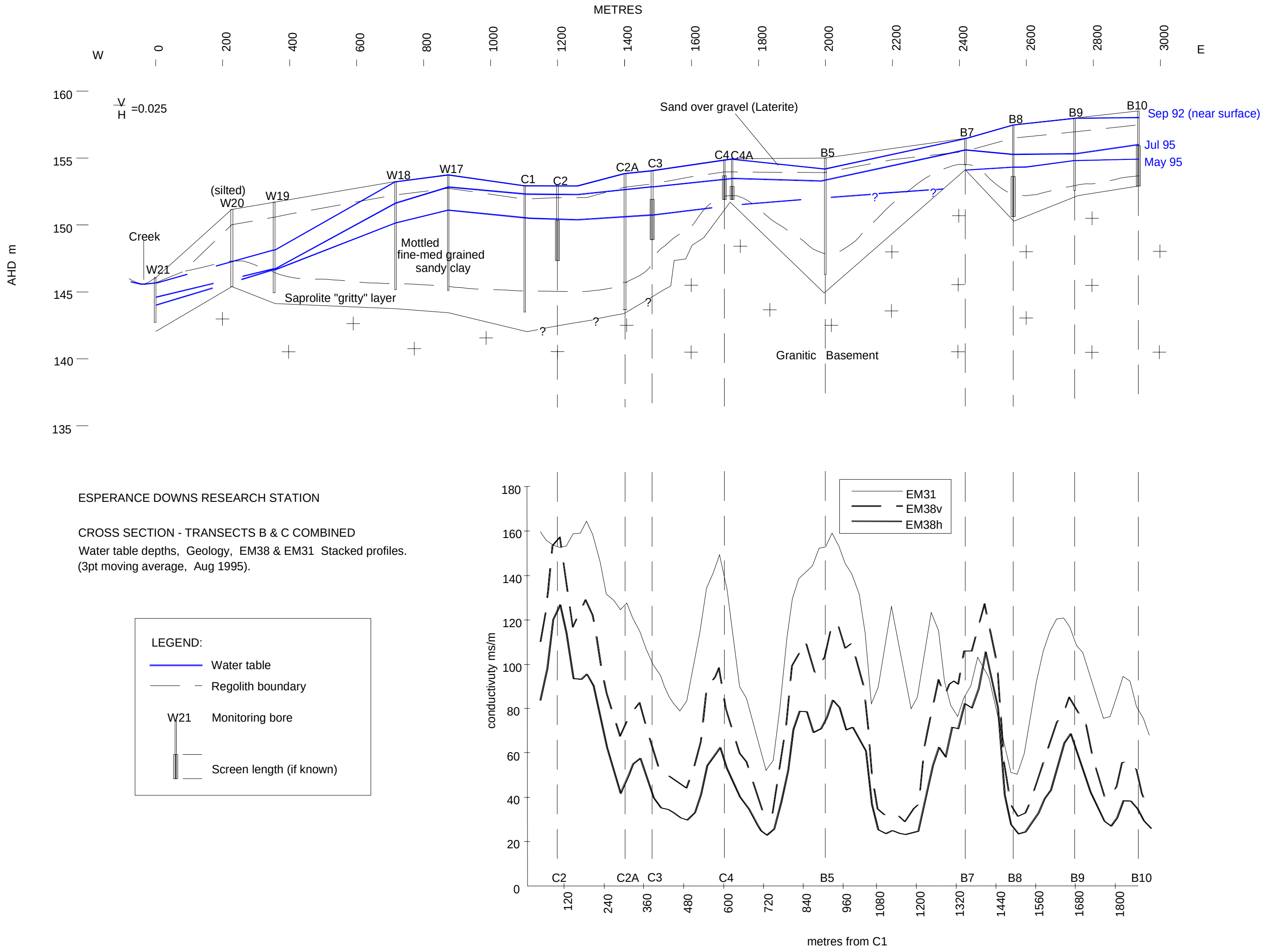

Figure 10. Cross-section from EDRS showing changes in groundwater levels in response to rainfall, the regolith profile, hydraulic gradients and the results along two transects of a geophysics survey.

The ‘gritty’ decomposed granitic profile overlying the basement is up to 2 m thick (Figure 10). Berliat (1952) recorded this decomposed granitic layer and where saturated, away from deep drainage lines, the saturated zone in 1952 was less than 0.7 m thick above basement rock.

George (1978) estimated hydraulic conductivity (Ks) values from a rough water balance calculation as approximately 5.5 m/day for the regolith above basement. This value is probably reasonable for the ‘gritty’ decomposed granite overlying fresh rock. Kaolinitic clays and sedimentary material overlying this zone, may have values possibly two orders of magnitude less (0.05 m/day). Recharge to the saprolite ‘gritty’ layer is probably through preferred pathways such as macropores around soil peds and old root channels. Recharge rates may be higher around basement highs through weathered bedrock profiles. Discharge along drainage lines from the eastern side of EDRS enters tributaries to the Daylup River whose end point for drainage waters is Lake Gore and surrounding coastal wetlands.

Dryland salinity risk and other land degradation hazards

Dryland salinity in this zone is estimated to be currently impacting on 11 per cent (14,500 ha) of the cleared agricultural land (136,100 ha). Remnant vegetation represents approximately 1 per cent of the cleared agricultural land. It is estimated that 24 per cent of agricultural land in this zone has the potential to become saline. The fine-grained sandy duplex soils are water repellent and are at risk from wind erosion. Shallow watertables, poor drainage and waterlogged soils are major constraints to agriculture.

Zone 12

12a = Coastal Plain
12b = Shallow basement

Geology:	*Eocene*, Plantagenet Group Sediments, Pallinup Siltstone, Werillup Formation; *Archean* and *Proterozoic* granites, gneisses and migmatites
Soils:	Shallow duplex, Deep and Gradational sands, Dune sands
Vegetation:	Coastal heath
Land systems:	To, Go

Zone 12 represents the coastal zone between agricultural land and the Southern Ocean. Outside of town boundaries, little clearing has taken place. The zone contains the Lake Warden wetland system and is represented by the Tooregullup and Gore land systems (Figure 3, Appendix 2). Where drainage lines have developed along the coast they extend only a few kilometres inland.

Coastal Quaternary sands and limestones overlie Tertiary sediments. Bedrock highs outcrop forming monadnocks. Shallow unconfined saline groundwater systems with fresh water lenses provide the potable water supplies at Esperance. These aquifers are replenished annually by rainfall.

Dryland salinity risk and other land degradation hazards

Dryland salinity in this zone is not considered a significant issue. Wetlands and coastal vegetation is threatened by increased run-off from agricultural areas in the catchments. Since clearing, the volume of discharge from catchments has increased along with nutrients and salt loads. Within the wetlands, uncontrolled encroaching urban development is causing degradation.

Conceptual model

A summary of the hydrogeology of each zone within the catchments is shown in Appendix 4. For each zone, a range of values is given for hydrogeological attributes such as the depth to watertable, water quality, rainfall, salt storages (in the top 6 m of the regolith) and regolith thickness. The table also includes landform attributes for each zone.

The available data have been interpreted and this is presented in a series of maps and cross-sections. Figure 11 shows the surface topographic catchment divides defining the four catchments that terminate in the Lake Warden wetland system. Five interpreted hydrogeological units are shown. Perched systems in surficial Quaternary sands are not shown. Interpreted groundwater divides and flow directions are also shown. The relationship between each of these units is demonstrated by cross-section A-A’, B-B’ and C-C’ (Appendix 5).

Figure 12 shows the hydrogeological zones and reflects both hydrogeology and overlying land systems within the catchments. Transects 1 to 3 show a profile along each flowline. Transect 1 includes Zone 1b that includes the Condingup land system (245Co) comprising gently undulating plains of sand sheets and linear dunes with fresh to brackish perched groundwater systems. Transects 2 and 3 are similar to each other. All transects include numerous monitoring bores with time series water level data. The locations and attributes of these bores are listed in Appendices 6 and 7. Transects are shown in Appendix 8.

Geology and hydrology

For groundwater modelling purposes, the Lake Warden catchments can be divided into five layers within the regolith above Proterozoic basement rocks. Drilling by Agriculture WA has intersected deeply weathered Pallinup siltstone and weathered basement in most holes. Cross-sections showing the relationship between layers are shown in Appendix 7 and in Figures 11 and 12.

Proterozoic

Two layers, subdivided by degree of weathering are recognised in the Proterozoic granitic basement rocks. The first layer is the unweathered fresh basement rocks and these can include chlorite biotite gneiss, pink granite gneiss and granitic rocks.

A weathered zone represents the second layer and consists of course angular quartz and off white kaolin clays (saprolite). This usually saturated ‘gritty’ zone above fresh rock in the catchments is similar to that observed elsewhere in the district (Short and

Skinner 1996). In very shallow bedrock profiles such as on the crest of hills, the weathered, unsaturated zone is ferruginous and oxidised.

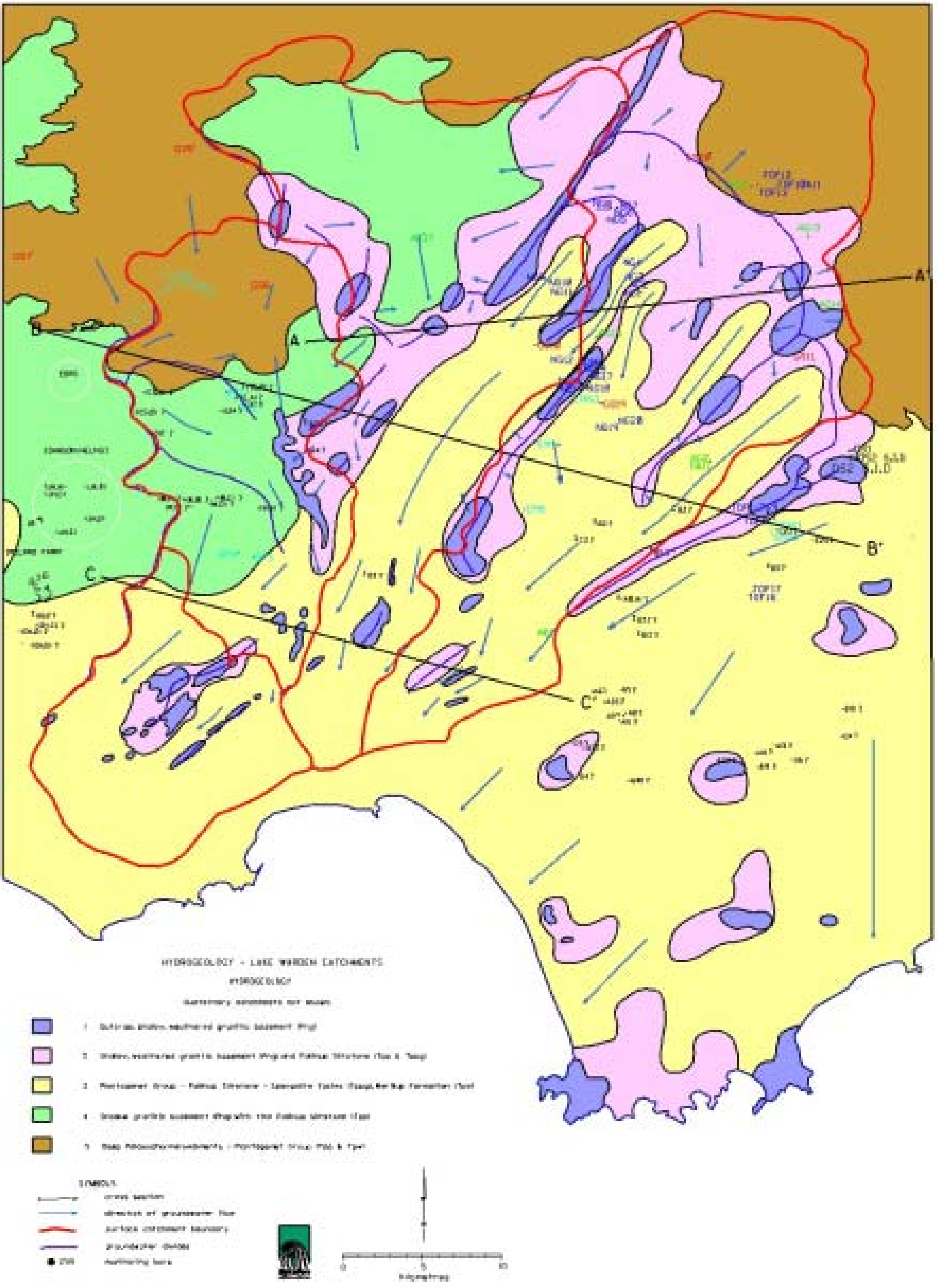

Figure 11. Hydrogeological units, catchment boundaries and location of cross-sections.

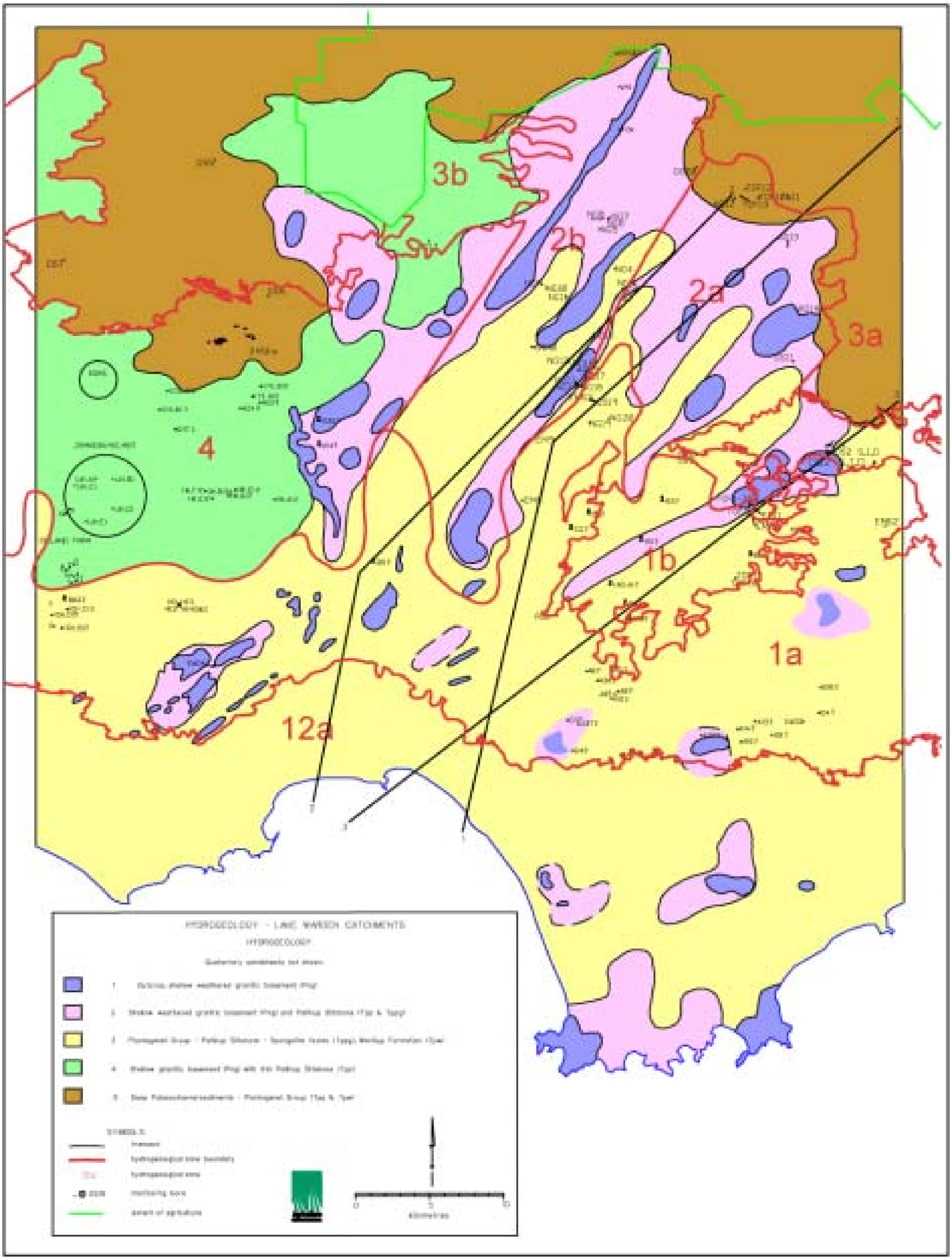

Figure 12. Hydrogeological units, zones, location of transects and monitoring groundwater bores.

The weathered zone above fresh rock is a result of the progressive weathering of primary minerals. The thickness of this layer is approximately 5 m and is unlikely to be uniform. Hydraulic properties in this zone are likely to be variable due to irregular weathering (e.g. core stones). Discharge can occur in drainage lines at the interface between the basement rocks and Tertiary sediments through this weathered basement material. Saturated hydraulic conductivities (Ks) could be expected to range from 0.1 to 10 m per day however no slug or pump testing has been carried out. During drilling, sample return can be poor after the watertable is encountered making changes in lithology and the exact position of boundaries difficult to determine.

Eocene

The weathered Tertiary Pallinup Siltstone varies between buff, yellow orange and brown mottled sandy clays, with or without limonitic and haematitic mottling. Silcrete and calcrete fragments are fairly common and pisolitic gravel is present near the surface in some holes. Dark grey-green carbonaceous silts of the Werillup Formation can be present from approximately 20 metres below the surface in some drill holes. Samples from near the watertable were often more red/brown - orange (oxidised) and sticky with clay.

Sand lenses up to several metres thick can be present within the Tertiary profile and consist of well-sorted, medium-grained, off-white, yellow and orange sand with generally < 10 per cent clay. The sand was probably deposited in a fluvial environment and suggests reworking of the Pallinup siltstone after deposition.

Two layers for modelling are recognised. The Werillup Formation unconformably overlies the weathered basement rocks and does not outcrop in the Esperance region. It presence appears to be restricted to palaeodrainage lines and depressions within the deeper basement rocks. When drilled it generally consists of sandy to fine-grained carbonaceous clays and lignite and is saturated with highly saline groundwater.

The overlying Pallinup Siltstone consists of siltstone and spongelite deposited in a marine environment. Spongelite units are more permeable and make up the majority of the layer within the modelling area.

Intermediate and local aquifers are found within these sediments and are separated by bedrock highs and ridges. Groundwater is usually saline and stratified becoming more saline with depth. Watertables are within 10 m of the surface and become shallower towards the northern areas of Zone 1.

Hydraulic conductivity (Ks) values may be in the order of 0.05 m/day however no pump testing data are available. The spongelite within the Pallinup Siltstone has a higher hydraulic conductivity.

Quaternary and Recent

Quaternary sands make up the final two surficial layers and can be divided by their relative depths. These sands represent the A-horizon of soils and vary between 0.1 and 7 m deep. They contain perched aquifers, are often waterlogged during winter, susceptible to wind erosion and are non-wetting. The presence of deeper sands forms the are the basis for the subdivision of Zone 1b (Figure 11).

Key discharge and recharge areas

Research across the Esperance region on a number of study sites has shown that discrete groundwater systems are present and separated by basement highs. Outcropping or shallow basement rock occurs as topographic high points within the landscapes. Areas of shallow bedrock can be mapped from aerial photography interpretation (topographic highs) and as small rises in elevation on topographic contour maps. Drilling programs have shown that bedrock highs are often associated with land units having greater than 1 per cent slope. Ridges of basement rocks form groundwater divides and can be linked along regional northeast to south-west trends within the basement geology. This trend is clearly seen on regional geophysical maps. Tertiary sediments thin out against these areas of basement highs. Weathered basement material in these areas is closer to the surface and may be more permeable with a higher hydraulic conductivity (Ks) in the regolith than the surrounding sediments. Lower pH and EC values at shallow bedrock sites may also indicate increased leaching through these profiles.

The surface drainage depressions rapidly become inundated after rainfall. Being broad shallow bodies of water, evaporation probably accounts for most water loss.

Annual rainfall not used by vegetation is infiltrating past the root zone in higher parts of the landscape and increasing groundwater storage. Recharge through preferred pathways, such as old root channels in the relatively thinner sediment layers occurs when the A horizon of duplex soils is saturated. Where sediments are thicker (>10 m), the depth of the clays makes recharge through preferential pathways unlikely. The subsoils are often dense (SG 1.6) and it is not clear if the roots of native vegetation extended this far. Here the clay-rich Tertiary sediments appear to act as an aquitard.

Bores located where sediments begin to thin can exhibit continuously rising water levels and lower water salinities. The response of bores near the top of shallow basement rocks to rainfall events is rapid (e.g. NG 7, Figure 6). This is attributed to rainfall rapidly infiltrating the weathered bedrock profile.

Many bores drilled into the watertable through Tertiary sediments in Zone 1 exhibit rising trends (e.g. EM 38, NG19 and NG 20). Many piezometer nests within these sediments show upward vertical gradients. Henschke (1981) noted that work done by Holmes (1979) shows that given a positive head gradient and with enough time, significant amounts of salt and water can be transported through apparently dry and slowly permeable strata. Barometric efficiency calculations at the National windbreaks study site on Belalie Farm to the east of Esperance in these sediments suggests that the aquifer at the site is in the lower range for semi-confined aquifers (Hall 1998). Investigations to date suggest that recharge rates may be higher around bedrock highs and basement outcrops than over broader flatter areas with thick clay layers (Short and Skinner 1998). Bores record an initial increase in pressure after a recharge event that is followed by upward discharge that finds an annual equilibrium levels at atmospheric pressure (i.e. the watertable).

At EDRS and Belalie Farm, the hydrological system is believed to discharge continuously through the deeper ‘gritty’ weathered basement layer overlain by Tertiary sediments towards the drainage lines. Similar conclusions have been drawn in the Neridup survey area.

Hydrograph responses

The hydrographs of monitoring bores within the Lake Warden catchments and surrounding areas are shown in Appendix 9. Bores are grouped according to hydrogeological zone and have been labelled to identify land systems. Note that the position within the landscape is not shown.

Hydrographs for bores in deeper sands (Hydrogeological Zone 2b, Transect 1) at Condingup are shown in Appendix 10. These bores are located within a research site monitoring the impacts of timber belts on groundwater levels and a summary of the site along with a cross-section has been included. Note that the groundwater system is fresher due to recharge through the deeper sands.

Most bores show responses to climatic extremes or episodic recharge events and drier and wetter seasons (Figure 2). Within the Esperance region, 1986, 1989, 1992 were wetter years with significant high rainfall events. The response from the high rainfall event in January 1999 can also be seen in some bores. The period from 1994 to mid-1995 was the driest on record with 1994 recording the second lowest annual rainfall on record (282 mm).

Groundwater in regional aquifers is moving toward lower parts of the landscape such as drainage depressions and local swamps. Discharge at these sites has not been investigated. Flow rates (Ks) through the weathered bedrock may be high with any discharge to low points in the landscape being removed by evaporation.

Questions to be asked by the model

- Under current farming systems, at what depth below the surface will watertables be in 2000, 2020 and 2050?
- If current recharge on key recharge areas is reduced by 5 per cent, 20 per cent, 50 per cent and 90 per cent, where will watertable levels be in 2020 and 2050?
- If current discharge on key discharge areas is increased by 5, 20, 50 and 90 per cent where will watertable levels be in 2020 and 2050?
- If both Recharge and Discharge are changed as above what will be the impact on watertables?
- Using the optimal Lower Recharge farming systems on all land management units in the catchment, what will be the reduction in recharge and the impacts on watertables in the years 2020 and 2050?
- Surface run-off implications?
- What public assets are at risk?

References

Argent, R.M. and George, R.J. (1997). Wattle - A water balance calculator for dryland salinity management. MODSIM 97, International Congress on Modelling and Simulation, Hobart. (Note: AgET is the new name for Wattle).

Berliat, K. (1952). Report on exploratory drilling for water, Esperance Plain: Western Australia Geological Survey, Annual Report.

BMR Radiometrics (1981). *Radiometric contours*, Esperance Sheet 1:250,000 sheet: Western Australia. BMR, Canberra.

CALM (1997). *Esperance Lakes Nature Reserves, Draft Management Plan*. Department of Conservation and Land Management for the National Parks and Nature Conservation Authority, Perth, Western Australia.

Cockbain, A.E. and Hocking, R.M. (1990). *Geological Evolution: Phanerozoic*. In: Geology and Mineral Resources of Western Australia, Geol. Surv. West. Aust. Memoir 3.

Cope, R.N. (1974). Tertiary epeirogeny in the southern part of Western Australia. Annual Report, Geol. Surv. West. Aust.

Hall, D. (1998). *In:* he Physical and Hydrogeological Characteristics of a South Coast Sandplain Site: East Howick site survey (ed. R.A. Sudmeyer). Resource Management Technical Report 167, Agriculture WA.

Hall, D. (1997). *Adopting Higher Water Use Farming Practices in the Esperance Region.* In: Increasing Plant Water Use to Reduce Salinity (ed. R.J. Short), Resource Management Technical Report 169, Agriculture WA.

Heinrich, L. and Bennett, D.L. (1997). AgBores Software, V.2. Agriculture WA.

Henschke, C.J. (1981). *Hydrological Studies in Soil Salinity*. DRM Tech. Report 19. Western Australian Department of Agriculture.

Holmes, J.W. (1979). *The Whittington Interceptor drain trial*. Report to Public Works Department, 18 October 1979.

Johnson, S.L. and Baddock, L.J. (1998). *Hydrogeology of the Esperance-Mondrain Island Sheet 1: 250,000 sheet:* Western Australia, Water and Rivers Commission, Hydrogeological Map Explanatory Notes Series, Report HM2.

Luke, G.J., Burke, K.L. and O'Brien, T.M. (1988). *Evaporation Data for Western Australia*, DRM Tech. Report. 65. Department of Agriculture.

Pannell, D. and Bathgate, A. (1991). MIDAS Model of an Integrated Dryland Agricultural, Department of Agriculture Western Australia, Perth.

Short, R.J. (1997). *Hydrogeological systems and Managing the Water balance at Esperance, WA. In* Increasing Plant Water Use to Reduce Salinity (ed. R.J. Short), Proceedings of a Seminar, Esperance 1996, Resource Management Technical Report 169, Agriculture WA.

Short, R.J. and Skinner, G. (1996). *Esperance Downs Research Station - Salinity and Water Monitoring*, Misc. Publication. 22/96, Agriculture WA.

Short, R.J. and Skinner, G. (1998). The *Hydrology, Geology and Climate of the National Windbreaks Program Site, Belalie Farm, Howick WA. In:* The Physical and Hydrogeological Characteristics of a South Coast Sandplain Site: East Howick Site Survey (ed. R.A. Sudmeyer). Resource Management Technical Report 167, Agriculture WA.