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Avon Catchment Council

Salinity Trend Analysis – Avon River Basin

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Executive Summary

GHD were contracted by the Avon Catchment Council to deliver elements of the 2005 - 2006 Investment Plan, including undertaking a salinity trend analysis of the Avon River basin. A salinity trend analysis was required to provide a better understanding of the patterns of salinity development within the region and to inform decision making associated with investment priorities.

Whilst this report focuses on technical aspects associated with salinity trend analysis within the Avon River basin, information and recommendations presented provided an important context to broader discussions associated with resource condition monitoring and salinity risk assessment within the region.

Documented in this report are:

» *The identification of six sub regions and 23 landscape units reflecting the underlying geomorphology of the region, forming the structural framework for the salinity trend analysis;*

» *Slope analysis defining primary salinity hazard areas with relevance to salinity trend analysis and risk assessment;*

» *Review of existing salinity monitoring data including Land Monitor, stream flow and groundwater monitoring; and*

» *Recommendations to the Avon Catchment Council regarding monitoring relevant to future salinity trend analysis.*

Sub Regions

Six geomorphologic sub regions within the Avon River basin were identified:

» *Western Rivers;*

» *Northwest;*

» *Central West;*

» *Central East;*

» *North East Plateau; and*

» *Southern Lakes.*

Sub regions are composed of a total of 23 landscape units. Geomorphology was the key determinant in identifying sub regional and landscape unit boundaries. Sub regional boundaries are typically associated with a series of escarpments resulting from progressive landscape erosion processes, reflective of the underlying geology of the region.

Slope Analysis

Salinity development within the Avon River basin appears to be driven by localised hydrologic influences. Slope is shown to be an important driver for predicting the distribution of salinity throughout the Avon River basin.

Slope hazard mapping appears to provide a reasonable indication of the primary hazard area for salinity development. It is most effective in providing a description of the patterns of salinity development nearing hydrologic equilibrium at a landscape scale. Slope hazard mapping is most effective in deeper regolith catchments and less effective in areas with shallow regolith. In subcatchments with a shallow regolith, local geology appears to exert much stronger control over salinity development.

The slope hazard mapping undertaken is considered preliminary, providing a reasonable indication of the landscape scale distribution of salinity potentially occurring at hydrologic equilibrium. Slope hazard mapping does not provide a means for determining the likely geographic sequence of salinity development and is not considered a salinity risk assessment tool in its own right; however slope analysis in an important component of salinity risk assessment at a subcatchment scale.

Slope hazard mapping indicates that between 12.5% and 22% of sub regions are at highest risk of becoming saline, predominately influenced by the geomorphologic traits of individual sub regions.

Groundwater Water Monitoring

The rate of rise of 453 groundwater bores was analysed to determine differences between:

- *Bores with varying depth to groundwater;*
- *Landscape position in relation to slope hazard area;*
- *Location within defined sub regions;*
- *Bores located under native vegetation compared with agricultural land; and*
- *Time series analysis (for time periods 1980 – 1990, 1990 -2000, 2000 – 2005).*

Rate of rise analysis was undertaken by the Department of Agriculture and Food, and provide to GHD for the purposes of undertaking this review.

No rate of rise data was reported by the Department of Agriculture and Food for bores managed and monitored by community groups due to unresolved data integrity and consistency issues, limiting the geographic extent of the analysis undertaken.

Significant differences were found in the rate of rise of groundwater between bores with a standing water level of less than 6 m below natural surface when compared to bores with a standing water level of more than 6 m below natural surface.

No significant differences were found in the rate of rise of groundwater bores located within and outside the slope hazard area, except for within the Central East sub region.

Differences in the rate of rise of groundwater between bores located within some sub regions were established, particularly for bores with a standing water level of less than 6 m below natural surface.

No significant difference was found between bores located under native vegetation compared with those under agricultural land. However, it is considered there is inadequate groundwater monitoring within native vegetation to provide a reasonable indication of groundwater rise under “controlled” / natural vegetated environments.

Differences in rates of rise for bores with a standing water level of less than 6 m below the surface were found for the period 2000 - 2005 when compared to groundwater rise for the period 1980 - 2000. However, the rate of rise of shallow groundwater bores appears to be influenced by large episodic events occurring in 1990 and 2000, potentially biasing the analysis.

No direct correlation was found between the rate of rise of groundwater and spread of land salinity detected by Land Monitor, even though overall spatial trends indicated by both datasets appear similar. Analysis was likely biased by different timeframes used for Land Monitor and groundwater rate of rise analysis.

Recommendation 1. Better integrate groundwater monitoring network with complimentary salinity monitoring programs including the Land Monitor project and surface water monitoring undertaken by the Department of Water.

Recommendation 2. A coordinated approach should be adopted for the monitoring of suitable quality community bores within areas with poor geographic coverage within the Ag bores network.

Recommendation 3. Undertake temporal analysis of rate of rise of groundwater consistent with timeframes used in complimentary monitoring programs, including Land Monitor.

Recommendation 4. Better understand and remove data anomalies associated with surface water flows and rainfall anomaly from rate of rise analysis undertaken for groundwater data within the region.

Recommendation 5. Undertake additional groundwater monitoring within areas of native vegetation as a priority, to provide a better understanding of groundwater response under naturally vegetated conditions.

As a general observation, it is considered that caution should be applied to interpretation of groundwater data beyond the immediate area in which the data is collected, due to the predominance of localised hydrology influencing rate of groundwater rise and salinity development within the region.

Land Monitor

Analysis of Land Monitor interpreted salinity coverages for 1987 and 1996 was undertaken to assist in establishing trends in salinity development across the Avon River basin. Land Monitor has the advantage of providing a uniform temporal and spatial approach to salinity monitoring, consistent with the underlying geomorphologic variations within the region.

Statistical analysis indicated significant differences in the pattern of salinity development between sub regions and landscape units when considering the two periods covered by Land Monitor (1987 and 1996).

Inherent errors exist within Land Monitor salinity coverages including:

- *Inconsistencies associated with ground truthing;*
- *Land Monitor tends to measure increase in severity of salinity, rather than salinity development per se; and*
- *Land Monitor does not cover the entire Avon River basin, with areas within the North East Plateau poorly represented.*

In addition, the current time sequences of salinity mapping for 1987 and 1996 constrain its capacity to predict more recent development of salinity.

Not withstanding a range of limitations, Land Monitor provides some distinct advantages over other salinity monitoring methodologies currently employed within the Avon River basin. Land Monitor provides an opportunity to assess salinity trends at a regional scale using archived data that can be repeated as knowledge of salinity development within the region improves.

Recommendation 6. Encourage further investment into the development of the Land Monitor program, including undertaking a salinity coverage for 2006 and better integrate with groundwater and surface water monitoring programs.

Recommendation 7. Support additional ground truthing in areas where Land Monitor is least accurate, in particular within the North Eastern Plateau sub region.

Recommendation 8. Revise salinity hazard mapping within the Avon River basin to determine a more accurate assessment of potential land at risk of salinity and in particular further investigate slope hazard analysis and geomorphic relationships as a potential salinity risk assessment tool.

Surface Water Monitoring

Annual base flow weighted salinity analysis was undertaken for gauging stations located at Kwolyn Hill and Gairdners Crossing (Central - West sub region) and Northam Weir, Frenches and O'Driscoll's (Western Rivers sub region). Base flows were estimated using a digital recursive filter based on the Lyne - Hollick algorithm (Lyne and Hollick 1979).

Kwolyn Hill and Gairdners Crossing gauging stations are located in the lower reaches of the Lockhart and Yilgarn Rivers respectively, where salinity and flow are greatly influenced by extremely low hydraulic grades and watercourses characterised by sluggish drainage lines and extensive lake systems. Incomplete records for salinity may have biased analysis undertaken for these gauging stations.

Analysis indicated the volume of base flow increased steadily from 1976 to the mid-1990s, followed by a reduction in the volume of base flow. This is generally consistent with rate of groundwater rise for the sub region, characterised by a rise in shallow groundwater bores followed by a reduction coinciding with declining rainfall after the mid – late 1990s. Base flow weighted salinity continued to increased throughout the monitoring period, indicating buffering of salinity of flows by the extensive lake system upstream of gauging stations.

Analysis of base flow weighted salinity within the Avon (Northam Weir Gauging Station) and Mortlock Rivers (Frenches and O'Driscoll's Gauging Stations) indicate that variations in base flow volumes are directly related to annual rainfall anomalies. The analysis also demonstrates that variations in base flow weighted salinity are inversely proportional to the volume of base flow. A stable trend in base flow weighted salinity for both rivers was evident throughout the monitoring period, consistent with results of Land Monitor analysis and limited groundwater data available within the Western Rivers sub region, indicating a limited spread of salinity.

Analysis of base flows appears to provide an effective and robust mechanism for assessment of salinity trends within the Western Rivers sub region. However the limited geographic distribution of gauging stations outside of this sub region currently restricts the capacity for surface water monitoring to be used as an effective salinity trend analysis tool throughout the region.

Monitoring stream salinity trends within the Western Rivers sub region has the advantage of directly assessing changes in catchment salinity for key environmental assets, including environmentally sensitive river pools and riparian vegetation associated with the Avon River and its major tributaries.

No base flow weighted salinity assessment was undertaken for Salt River (at Qualandary Crossing) or the south Avon River (upstream of the confluence with Salt River) due to unreliable data associated these gauging stations. Land Monitor Analysis indicated salinity development within the South Avon landscape and upstream of the Yenyening Lakes represents the most significant potential for increased salinity within the Avon River.

Recommendation 9. Encourage investment into additional surface water monitoring within the region, with a particular emphasis on understanding the influence of key lakes on salt and water balance within internally drained sub regions.

Recommendation 10. Support the recalibration of the Qualandary Crossing gauging station, and relocation of the Avon River (Yenyening confluence) gauging station to a more appropriate site.

Recommendation 11. Adopt seasonal base flow analysis as a surrogate salinity trend analysis tool for key Avon River environmental assets.

Recommendation 12. Land Monitor provides an effective mechanism for undertaking trend analysis to support strategic investment decisions, however a precautionary approach needs to be applied due the historic nature of and errors and inconsistencies contained within this data set.

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1. Introduction

GHD were contracted by the Avon Catchment Council to deliver part of the 2005 - 2008 Investment Plan, including undertaking salinity trend analysis to support investment decisions. The project was funded through the *Groundwater Source Identification and Monitoring - IWM002* and the *Salinity Management Project IWM005*.

The Groundwater Source Identification and Monitoring project (IWM002) also included related project components associated with benchmarking saline aquifers and an expansion of the bore monitoring network within the Avon River basin. These project components were undertaken by the Department of Agriculture and Food (*DAFWA 2007*).

1.1 Objective

The Avon Catchment Council required a mechanism for undertaking salinity trend assessment to guide prioritisation of investment into salinity management and underpin monitoring and evaluation of salinity within the Avon River basin. The trend analysis was also intended to form part of a salinity risk assessment tool for assessing the potential for further spread of salinity at a regional scale.

The project had regional scale multiple objectives, including:

- *Assessment of historic geographical distribution and rate of change of salinity;*
- *Determination of trends in salinity development within the Avon Region;*
- *Recommendations for key monitoring opportunities for the Avon Catchment Council; and*
- *Preliminary forecasts for the further development of salinity with the Avon River basin.*

This project was a desktop study only, with insufficient resources available to undertake specific ground truthing or additional data collection. The scope of the project involved consideration of available existing data only.

1.2 Funding

The project was funded by the National Action Plan for Salinity and Water Quality, jointly funded by the Australian and West Australian Governments and administered by the Avon Catchment Council.

2. Background

Dryland salinity is caused by a complex interaction of climate, groundwater, surface water, and landscape scale physical processes operating at a range of spatial and temporal scales (Walker et al, 2006). An understanding of these interactions is critical when considering trends in salinity development and determining an effective monitoring framework.

The Avon River basin is a heterogeneous environment, composed of distinctive landscapes and biophysical environments reflecting complex underlying geological formations, expressed within the geomorphology of the region. Climatic conditions vary across the region and have previously changed and continue to change over various time scales. These interactions present a mosaic of environments influencing the nature and rate of spread of salinity within the region.

2.1 Context

Salinity trend analysis methodologies typically reflect the patterns of salinity development within the investigated landscape. The purpose for undertaking salinity trend analysis is to assist in determining policies, and/or to prioritise investment for management or remediation of salt effected land. The trend analysis should consider both spatial and temporal changes to salinity.

A range of methods for salinity trend and risk assessment have been developed and assessed through the following programs:

- *Australian dryland salinity assessment (NLWRA 2001);*
- *MDBC Salinity Audit (MDBMC, 1999);*
- *National Action Plan for Salinity and Water Quality program;*
- *Land Monitor Project - salinity hazard mapping (Cassetta, 2000); and*
- *Queensland salinity hazard mapping (DNRW, 2006).*

Individual methodologies previously developed typically reflect available datasets, which vary considerably across the geographic regions of Australia. As a result, no specific or consistent methodology for salinity trend analysis and monitoring has been implemented across Australia. In addition, no consistent methodology for determining the reliability of salinity monitoring has been employed (Walker et al, 2006).

Salinity investigations previously undertaken within the Avon River basin are generally geographically restricted, focussing on individual subcatchments. These investigations attempt to collate sufficient information to understand climate, landscape and biophysical interactions influencing salinity at a subcatchment scale. Outcomes of the investigation are extrapolated to infer potential impacts on surrounding or neighbouring catchments, where the same biophysical interactions are thought to occur. However, extrapolation of inferences across functionally different hydrogeological units can be erroneous, particularly at a regional scale.

In undertaking the salinity trend analysis within the Avon River basin it was important to first consider the key drivers and factors influencing the development of salinity. Variations in regolith thickness, hydraulic conductivities, catchment geomorphology and structure of the underlying geology are factors likely to influence the patterns of salinity development of a subcatchment and sub regional scale.

2.2 Key Factors Influencing Salinity Hazard

Salinity hazard mapping generally consider three principal drivers for salinity:

1. *Quantity of salt stored in the landscape;*
2. *Recharge potential - capacity for water movement into groundwater; and*
3. *Discharge sensitivity - areas in the landscape most likely to be influenced by salinity.*

2.2.1 Quantity of salt store

Salt makes its way into the landscape via atmospheric discharge through rainfall, and although very dilute, salts accumulate within the soil profile over long periods of time.

Within the Avon River basin, salts are stored primarily within the lateritic regolith, having been deposited over literally millions of years through rainfall.

The freshest groundwater is generally associated with catchment divides, with the salinity of groundwater increasing towards the valley floor. The Avon River basin is characterised by very high salt stores, with valley floor salinities often approaching and in some cases exceeding seawater in salt concentrations.

2.2.2 Recharge Potential

Rainfall infiltrating beyond the root zone joins the groundwater system. Whilst this is a natural process, the extent of recharge changes in response to changes in land use and climatic conditions. For example, the proportion of rainfall that recharges groundwater is typically greater under annual crops and pastures that would be the case under more deeply rooted vegetation.

A recharge estimation tool was previously developed by DAFWA called AgET. The tool uses daily pan evaporation, a crop factor (water use potential of a range of annual and perennial crops and pasture) and soil types to determine the available and stored water of the soil profile of multiple horizons to determine water excess. The tool has previously been linked with a GIS engine and applied at a catchment scale for determining recharge potential for the purpose of determining drivers for salinity development and in assessing revegetation strategies involving applications of perennial pastures within the Lake Warden catchment of Western Australia (Roberston et al, 2005). Other examples of integration of GIS engines with surface water modelling and crop production for assessing changes to catchment hydrology were undertaken by CSIRO in New South Wales (Eevi et. al 2006). However implementing tools of this nature at a regional scale presents significant challenges due to the scale and complexity of the areas in question, coupled with relatively limited available data for model calibration.

2.2.3 Discharge Sensitivity

Discharge sensitivity refers to areas of the catchment where saturation of the upper soil profile is more likely to occur, resulting in evapo-concentration of salts at the soil surface, causing soil salinity.

Landscape positions more likely to suffer from discharge sensitivity include:

» *Change in hydraulic grade or slope (including break of slope);*

» *Change in permeability of the substrate, due to changes in permeability (either vertically or horizontally) resulting in a reduction in potential groundwater movement;*

» *Geological features such as structural boundaries, faults, dykes or bedrock highs; and*

» *Physical barriers such as roads or dams.*

2.3 Methodology

Methodologies adopted in undertaking salinity hazard analysis vary across the states and regions of Australia. Methodologies used are generally grouped into the following three classes:

Composite Index Methods - combine several layers of spatial data, using weighted indexes reflecting a combination of risk factors based on current knowledge of salinity drivers. Risk factors may include soil type, land cover, topography etc. Typically a linear approach is used to score salinity risk for individual land units identified through overlaying (combining) multiple risk layers.

Examples of this methodology include Tickell (1994) and Searle & Baillie (1998), documenting application of this methodology in the Northern Territory and South East Queensland respectively.

The effectiveness of this methodology is governed by the level of understanding of the relative importance of individual salinity risk factors and the availability of data sets that specifically reflect these risk factors.

This methodology was not adopted due to insufficient base data at an appropriate scale for undertaking salinity hazard analysis and the relatively limited understanding of specific interactions of salinity risk factors and their influence over the development of salinity within the region.

Strongly Inverse Methods - are similar to the *composite index method*, except that the area currently impacted by salinity is used to determine interactions of salinity risk factors. The methodology defines individual weighted risk factors, based on the current distribution of salinity.

The methodology is based on the principle that salinity will continue to develop along the same pattern that has previously occurred. This methodology requires accurate salinity mapping, access to reliable datasets for key risk factors, and a well developed understanding of the physical characteristics and variations with the plan area. This method is likely to be most effective in areas where salinity is relatively well developed.

The Strongly Inverse method was not adopted due to the relatively inaccurate nature of salinity mapping within the Avon River basin in addition to generally insufficient base data at an appropriate scale for undertaking the risk assessment.

Trend Based Methods: historic changes in the development of salinity can be used as a means for predicting future trends in salinity. Trend based approaches may include:

- *Analysis of remotely sensed maps to determine changes in land salinity over time;*
- *Assessment of stream base flow salinity trends to determine geographic and temporal changes in salinity within the catchment; and*
- *Monitoring of groundwater levels where linkages to spatial salinity development is well established.*

It was considered that a trend based approach represented the most effective mechanism for undertaking strategic salinity analysis within the Avon River basin, primarily due to the nature and extent of available data.

Data sets used in the analysis included:

» *Groundwater trend data provided by DAFWA (Agbores database);*

» *Surface water monitoring data provided by the Department of Water (DoW – WIN database); and*

» *Land salinity mapping (Land Monitor project).*

3. Sub regional Geomorphologic Zones

In undertaking the salinity trend analysis within the Avon River basin it was important to adopt appropriate sub regional units reflecting the patterns of temporal and spatial development within the region. Presented in this section is an overview of the geomorphology of the Avon River basin and an introduction to sub regional geomorphologic units adopted in the subsequent trend analysis undertaken.

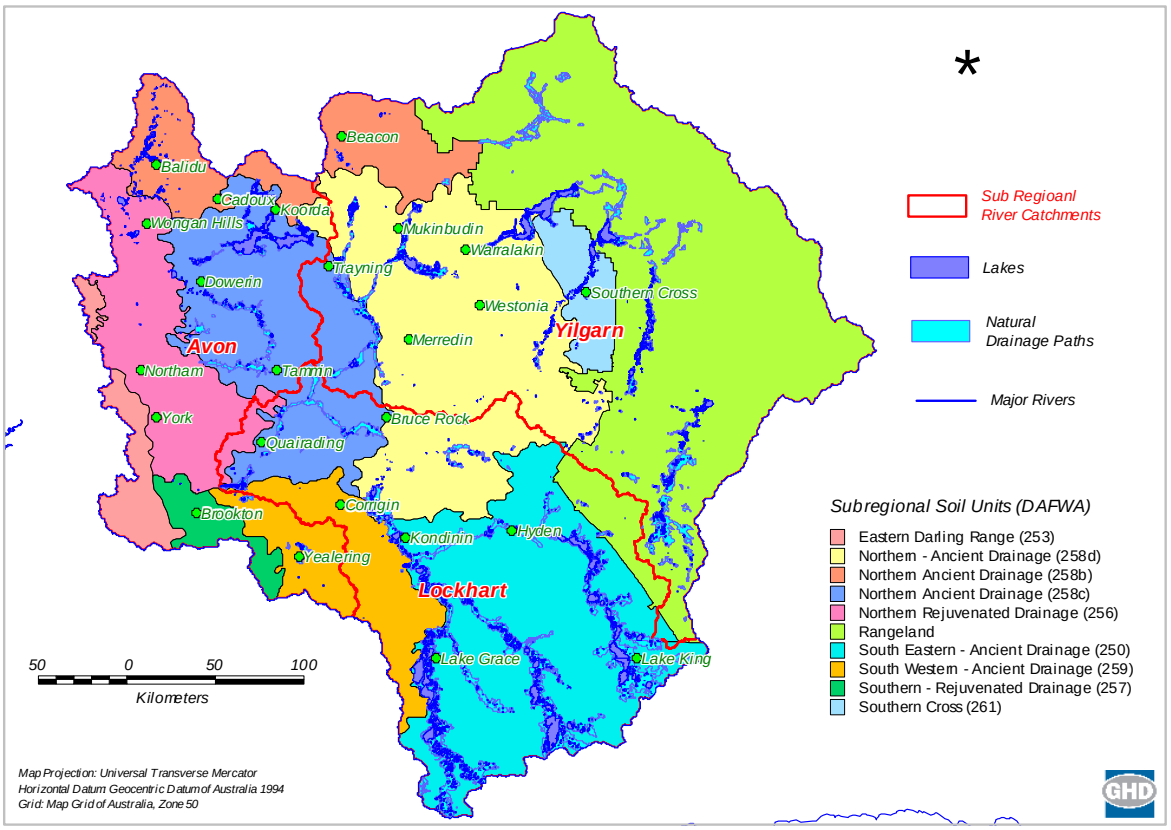
3.1 Background

Sub regional zones within the Avon River basin have previously been described using two separate methodologies (refer Figure 1).

1. *River Catchments. The Avon River basin has been described as consisting of 3 sub regions, based on the major river / lake chains of the Avon, Yilgarn and Lockhart Rivers.*

2. *Regional Soil Mapping. Regional soils mapping was undertaken by DAFWA at 1:100,000 scale based on aerial photograph interpretation. Soils have been clustered into landscape and sub regional soil groups, leading to the description of soil sub regions within the southwest of Western Australia.*

Figure 1 Soils Sub Regions and River Catchments – ARB (DAFWA)



Data source: DAFWA GIS coverages (2007)

Investigations undertaken found no correlation between salinity trends and sub regional units formed from major river catchments or regional soil groupings (also described as "hydrozones" by Ghauri (2004), featured in Figure 1. Previous studies also failed to identify a correlation between hydrozone classification and distribution of groundwater responses within the Avon River basin (Ghauri 2004).

An alternative methodology for describing sub regional boundaries was considered necessary in describing sub regional responses to salinity development within the Avon River basin.

3.2 Geological Context

In defining appropriate sub regional units for assessing salinity trends within the Avon River basin, it is necessary to understand the basic underlying geology of the region.

The Avon River basin is a heterogeneous environment, resulting from the interaction of its complex underlying geology with at least three major periods of landscape transformation through extensive erosion of the regolith.

The geology of the Avon region consists predominantly of NNW trending belts of strongly metamorphosed and derformed Achaean sedimentary and felsic, mafic and ultra mafic intrusive rocks (greenstone) set within the larger areas of weakly metamorphosed and deformed Achaean granites and geisses (de Broekert et al, 2005).

Granites and gneisses typically range in age from 2.5 - 3.2 billion years. The western part of the Avon River basin is dominated by a remnant gniess terrane. The central part of the region is dominated by large granitic plutons and associated recrystallised granites and gneisses. The eastern part of the region is dominated by an extensive greenstone belt associated with felsic, mafic and ultra mafic volcanic intrusions (Figure 3) (GSWA).

Three major landscape transformation processes have occurred within the history of the region:

1. *Extensive glaciation occurred during the Carboniferous period. A huge continental ice sheet covered Gondwana Land (including Antarctica, Southern Africa and Southern Australia) during the period 360 to 280 million years ago (mya). The ice sheet is reported to have been in the order of three to five km thick. Its massive weight planed off the landscape in a NNW - SSE direction, reflecting the predominate underlying crystalline structure of the Yilgarn Craton. As this massive ice sheet melted during the Permian period (280- 250 mya) it carved out a series of valleys predominantly with a north - south orientation (Beard 1998);*
2. *Insitu weathering of the basement and associated regolith development occurred during the early Carboniferous (300 mya), late Jurassic (160 mya) and Late Cretaceous (100 mya) periods. This was intersected by periods of erosion and sedimentation, reported to have occurred mainly during the early Cretaceous (150 mya) and the early Jurassic (200 mya). The Perth and Eucla basins which received sediments from the Yilgarn block are reported to contain 12 and 15 km of sediments respectively, predominantly of early Jurassic and early Cretaceous origin (Hocking et al. 2001; de Broekert et al. 2005);*
3. *The breakup of Gondwana Land during the Cretaceous period resulted in uplift of the Yilgarn Craton followed by extensive erosion during the early tertiary period (Eocene and Miocene ~ 50 – 20 mya). This period of renewed erosion resulted in the establishment of east to west inset valleys superimposed over the previous north-south orientated drainage within the central and eastern parts of the region. More extensive erosion within the western part of the region resulted in the removal of most of the pre-existing regolith and inset valleys, resulting in a younger more rejuvenated landscape; and*

4. *A brief period of renewed landscape erosion and paeleochannel formation, occurred during the Pleistocene (2 mya) followed by a period of aridity.*

3.3 Sub Regions

The geomorphology of the Avon River basin formed as a result of a series of landscape erosion processes. Prior to the tertiary period, the basin was predominantly a south draining plateau, with the remnants of pre-tertiary drainage lines still evident within the older plateau landscapes within the northeast and southeast of the region. The accompanying extensive lake systems are typically associated with inset valleys and paeleochannels predominately created during the carboniferous period (Beard 1998).

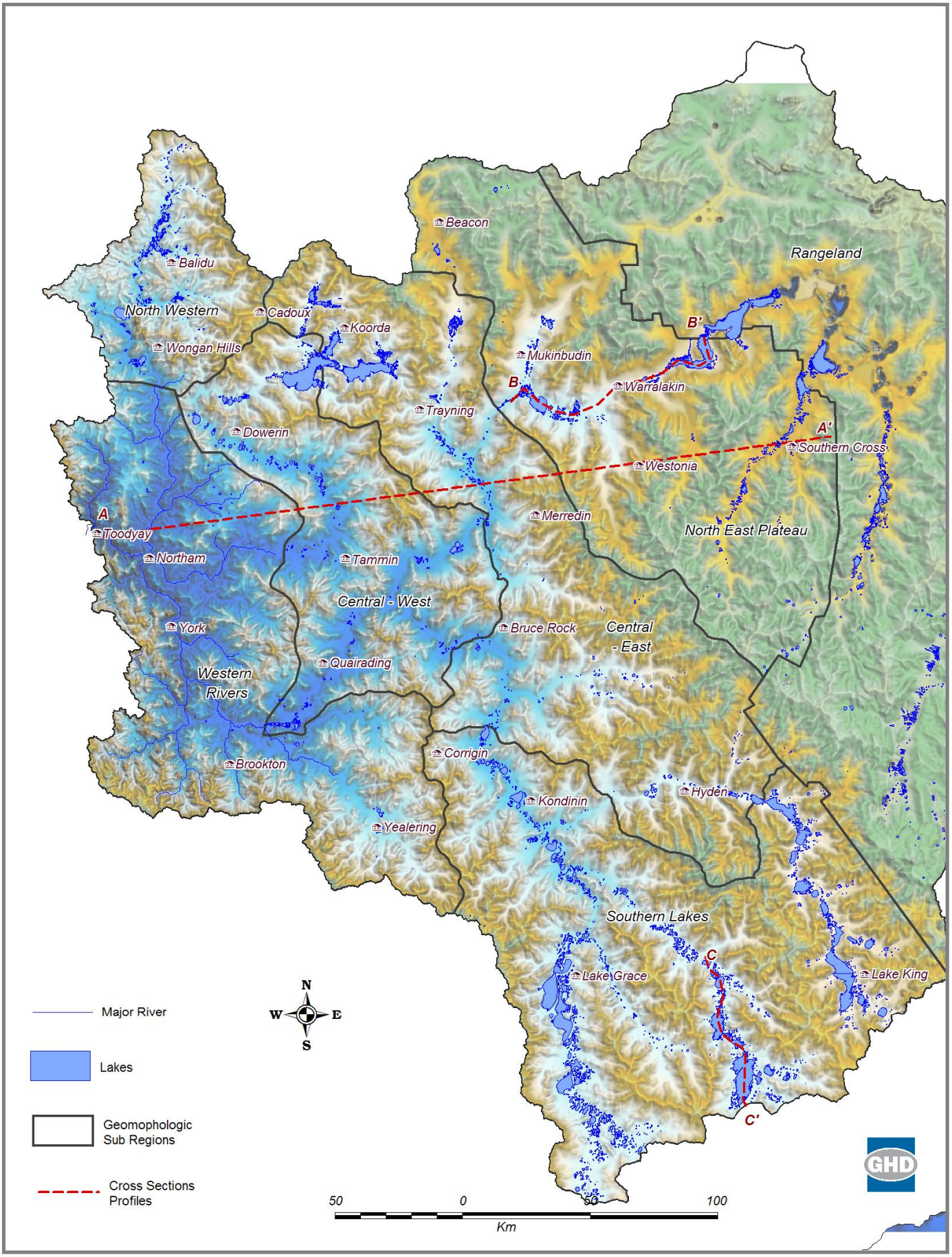
By the early Tertiary period, much of the of Avon River basin drained towards the west due to uplifting of the Yilgarn Craton in response to continental drift. The central part of the region is characterised by east - west orientated drainage superimposed on the previously predominant north - south orientated drainage, a result of extensive erosion of the deeply weathered regolith.

The western part of the region, located west of the Meckering line, has undergone extensive recent erosion (during the quaternary period). This is the only part of the Avon River basin which is freely draining, with most runoff discharged from the region via the Avon River. The remainder of the Avon River basin is dominated by lake chains and is predominantly internally drained, resulting in a large salt store within lower landscapes throughout the region.

Geomorphologic sub regions presented herein were developed with consideration to geology, geomorphology and patterns of salinity development expressed within the Land Monitor salinity coverages. A more detailed description of the methodology used in analysis of Land Monitor data is provided in Section 5.2.

Six geomorphologic sub regions were identified during the study, presented in Figure 2. Sub regions are in turn composed of a total of 23 landscape units, presented in Figure 3.

The geomorphology of the region was the key determinant for alignment of sub regional boundaries. Figure 2 illustrates the relationship between geomorphology and identified sub regional boundaries. Sub regional boundaries are typically associated with a series of escarpments appearing to have developed due to landscape erosion processes associated with predominantly east - west orientated drainage of the early tertiary period.



Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 50

Figure 2. Geomorphologic Sub Regions - Avon River Basin

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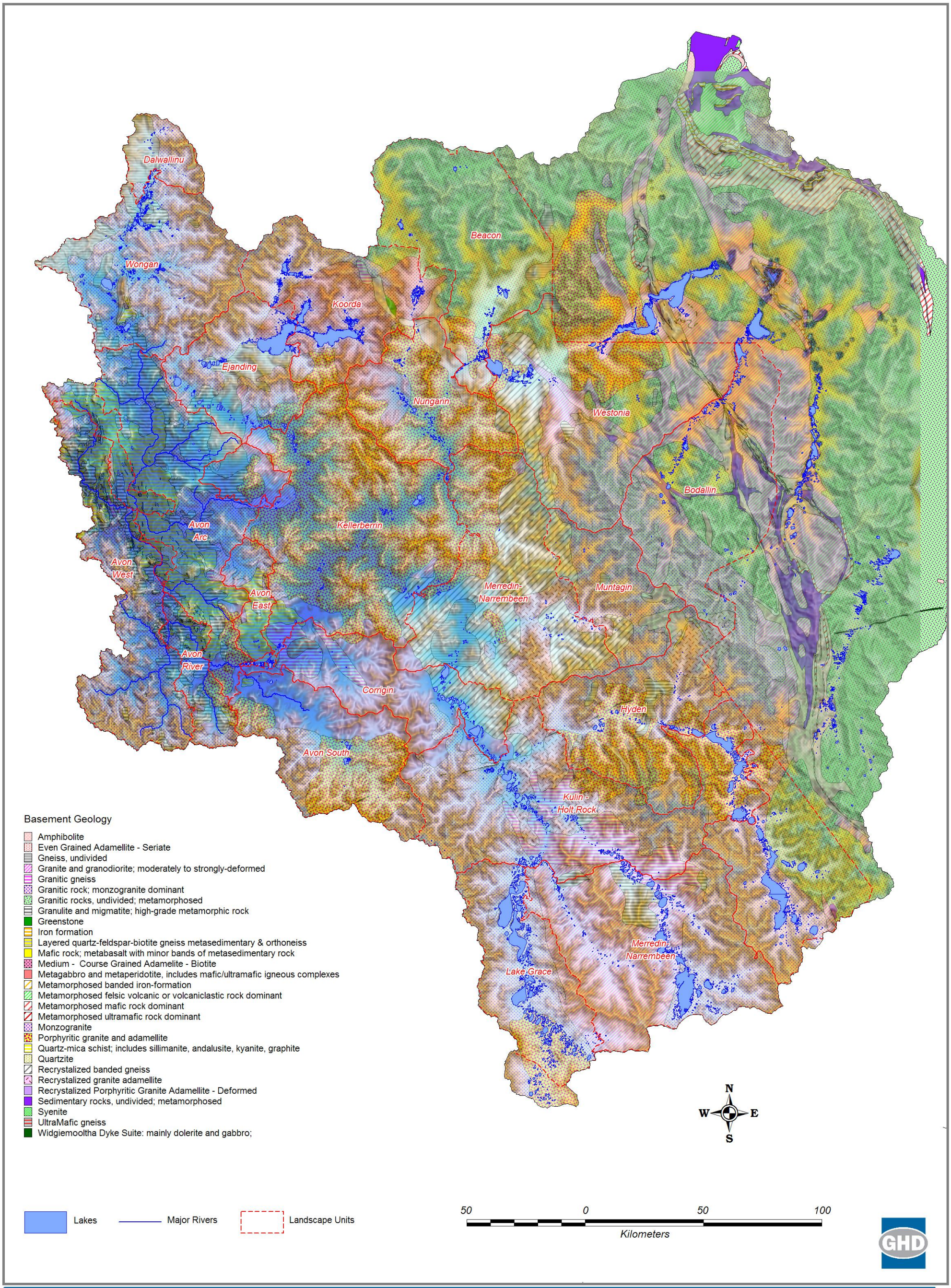

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid Of Australia, Zone 50

Figure 3. Geology and Landscape Units - Avon River Basin

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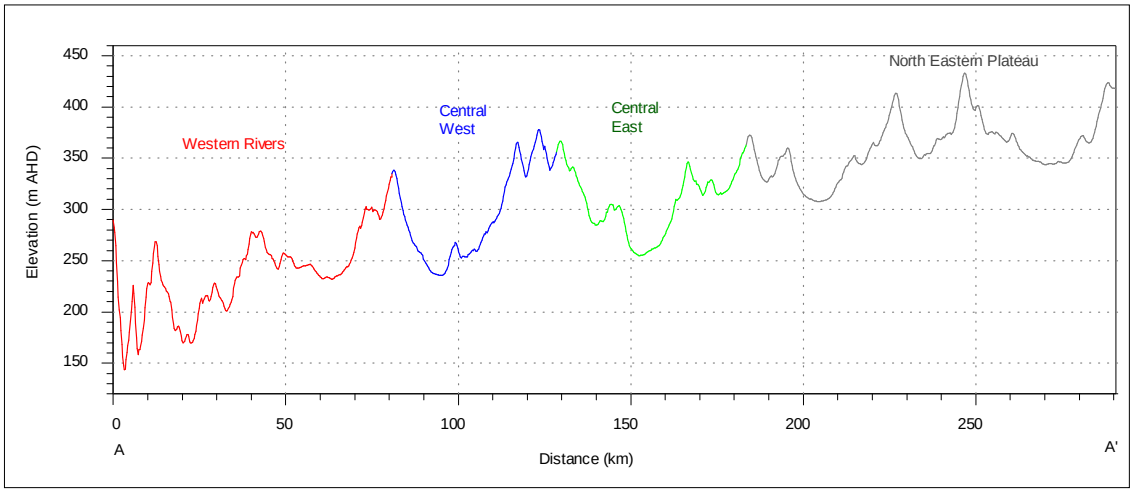
Presented in Figure 4 is a cross section highlighting the increase in the extent of erosion from east to west across the Avon River basin (refer Figure 2 for location of cross section). The Western Rivers sub region is characterised by the deeply incised Avon River with valley base levels of between 150 - 200 m AHD. The Central West and Central East sub regions are less deeply incised with base levels of approximately 250 m AHD. The North Eastern Plateau is characterised by broad flat valleys composed from poorly incised and remnant lateritic profiles.

Figure 4 West – East Cross Section – Avon River Basin



The orientation of geomorphologic sub regions and landscape units also appears to, in part, reflect underlying geology. The geological map of the Avon River basin presented in Figure 3 was derived from a composite of the 1:500,000 basement Geological and 1:250,000 Geological Series sourced from the Geological Survey Western Australia.

Figure 3 illustrates the complex underlying geology of the region and the extent to which geology influences surface water hydrology. Most significant lakes and changes in the grade of major natural drainage lines (denoted by a change frequency and size of lakes) are associated with contacts between major geological units. The orientation of major rivers within the west of the region appears to be principally governed by the underlying geology. Free-flowing rivers appear to be associated almost exclusively with the "metamorphic belt" (predominately composed of gneiss and migmatite) associated with the Western Rivers sub region.

Presented in sections 3.4 to 3.9 is an overview of geomorphologic sub regions of the Avon River basin.

3.4 Western River Catchments

The Western Rivers sub region is the only river based sub region of the Avon River basin. This is the youngest and most incised sub region, containing free draining rivers and few isolated lakes restricted to its most upstream margins. The Avon River typically has a grade of between 0.7% and 1% and generally follows underlying structural geological components.

The sub region is heterogeneous in nature, made up of 6 distinct landscape units:

1. ***Avon West -*** incorporating the area of land west of the Avon River. This is the most deeply incised landscape of the region, underlain by Achaean granite (predominately monzogranite). It is characterised by deeply incised small catchments, generally exhibiting shallow regolith and steep gradients. This landscape contains the freshest rivers of the region contributing an important flushing mechanism to the Avon River.
2. ***Avon River –*** made up of a series of small catchments typically adjacent to the Avon River, separating the Avon West and Avon Arc landscape units. This is a relatively young landscape, appearing to have been formed as a result of recent renewed erosion resulted in small well drained catchments with relatively low salinity risk.
3. ***Avon Arc*** - the landscape located east of the Avon River, underlain by a metamorphic belt representing some of the oldest rocks within the region. Subcatchments are moderately incised and generally well drained, with watercourses predominately west flowing tributaries to the Avon River. These subcatchments are among the most saline in the Avon River basin.
4. ***Avon East –*** is made up of a series of four subcatchments located to the east of the Avon Arc landscape unit. Catchments are generally less well incised, containing small lakes and poorly defined drainage lines.
5. ***Avon South -*** represents the most upstream landscape of the Avon River, incorporating the less well drained subcatchments south of the Yealering Lakes confluence. This landscape is typically of granitic origin and relatively poorly incised with well developed salinity.
6. ***Corrigin -*** overlaps the Western Rivers and Southern Lakes sub regions. The orientation and geomorphology of natural drainage appears to indicate that it drained into the Southern Avon River in recent geological history, however is now relatively poorly defined, discharging to the Yenyening Lakes. Salinity is relatively well developed within this landscape.

3.5 North West

The North West sub region is dominated by sluggish drainage lines typically discharging to lake clusters. The sub region's saline character reflects its geomorphology and landscape position, in that it is internally drained, has a relatively high rainfall and has experienced a long period since clearing when compared to most other sub regions.

This sub region consists of two distinct landscape units:

1. ***Dalwallinu*** - located in the northern part of the sub region (north of Pathara). This landscape is poorly incised with broad flat valleys, characterised by clusters of small lakes.

   The geology of Dalwallinu is dominated by coarse grained granite (monzogranite) intersecting undivided gneiss in the western half of the landscape unit.

   Salinity appears to be largely restricted to primary valley floor areas with outcrops of salinity within secondary catchments, likely to be controlled by local geological features such as bedrock highs.

2. ***Wongan*** - salinity in the Wongan Landscape Unit appears well developed with salinity appearing to extend over most valley floor areas within the landscape unit.

   The geology of the Wongan landscape is dominated by coarse grained granite (monzogranite), with areas of undivided gneiss and high grade metamorphic geology (granulite and migmatite). Major geological units appear to exert significant influence over the orientation of lakes and salinity.

   Located immediately west of the Wongan Hills town is a small north-south orientated range (Wongan Hills). Metamorphosed mafic igneous rocks, including meta basalt, are accompanied by metamorphosed felsic volcanic rocks, metasediments including recrystallised banded iron formation (BIF), chert and schists. The small range of hills appears to exert significant influence over the geomorphology of the landscape unit.

   The Wongan Landscape appears to have north - south orientated drainage superimposed over older east - west orientated drainage.

3.6 Central - West

The Central - West sub region is characterised by large subcatchments discharging to a broad sluggish primary drainage line containing extensive lake systems.

The sub region consists of two distinct landscape units:

1. ***Ejanding*** - the Ejanding landscape unit is underlain by a complex mosaic of coarse grained granite (monzogranite), medium - coarse-grained adamelite, undivided gneiss and high grade metamorphic rocks (granulite and migmatite). The lower landscape is dominated by a series of lakes, orientated adjacent to major geological contacts.

   The major lake chain draining in a south easterly direction within Ejanding appears to have undergone flow reversal, resulting in a very flat, poorly drained primary drainage line.

   Subcatchments are typically moderately saline with salinity associated with primary valley catchments, extending into most secondary subcatchments.

2. ***Kellerberrin*** - is dominated by a massive porphyritic granitic intrusion known as the Kellerberrin batholith. This imposing geological feature dominates the central Avon River basin. The Kellerberrin batholith appears to be more resistant to weathering than the surrounding landscape, exhibiting higher peaks and a higher proportion exposed bedrock and associated shallower regolith, relative to other landscapes in this part of the region.

   Salinity appears relatively well developed and associated with extensive primary valley floor flats and mid – upper drainage lines of secondary catchments, associated with changes in hydraulic grade and influenced by shallow regolith and local bedrock highs.

3.7 Central - East (Merredin, Koorda, Narembeen, Hyden)

The Central – East sub region is located between the Central – West and North Eastern Plateau. This is a relatively complex sub region consisting of five distinct landscape units. Salinity is less well developed than in the neighbouring Central West sub region, predominantly associated with extensive valley floor environments, intersected by small clusters of wetlands.

1. ***Koorda -*** is dominated by large terminal wetlands receiving discharge from relatively poorly defined subcatchments. Koorda appears to have predominantly northeast - southwest orientated drainage superimposed on ancient north - south orientated drainage.

   The geology of the Koorda landscape unit is dominated by coarse grained granite (monzogranite) and medium - coarse-grained adamelite,

2. ***Nungarin*** - is located on the northeast corner of the Kellerberrin Batholith.

Nungarin displays a similar geomorphology to the Kellerberrin landscape unit of the Central – West sub region, principally due to the resistant weathering quality of the Kellerberrin batholith on which this landscape unit is located.

Nungarin and Kellerberrin landscapes display usual salinity characteristics when compared to other landscape units throughout the region. In particular, mid - upper landscape valley floor areas appear to be at higher risk of salinity resulting from shallow regolith and predominance of bedrock highs.

3. ***Merredin – Narembeen*** - is dominated by east – west oriented drainage discharging to predominately north – south oriented primary drainage lines.

   Merredin – Narembeen is located on some of the oldest basement geology of the region, made up primarily of a block of recrystallised banded gneiss, intruded by recrystallised granite and adamellite and more recently by porphoritic granite and ademallite.

   Primary drainage lines are typically very saline, influenced by complex interactions between underlying geological structures.

4. ***Muntadgin*** - is located to the east of the Merredin - Narembeen Landscape unit. It is underlain by coarse grained granite (monzogranite) and exhibits different geomorphology and pattern of salinity development to its sister landscape to the west. Catchments are more regular with primary drainage lines less saline and influenced by a less complex underlying geology than is evident within the Merredin – Narembeen landscape unit.

5. ***Hyden*** - is dominated by an east - west orientated primary drainage line interspersed by clusters of lakes.

   The geology of the Hyden landscape unit is dominated by a large porphyritic granite pluton, intruded into coarse grained granite (monzogranite) and gneiss interspersed with a series of high grade metamorphic rocks. The orientation of the primary drainage line and location of lakes is principally influenced by unlying geological contacts and by a large dolerite intrusion orientated southwest - northeast across this landscape unit.

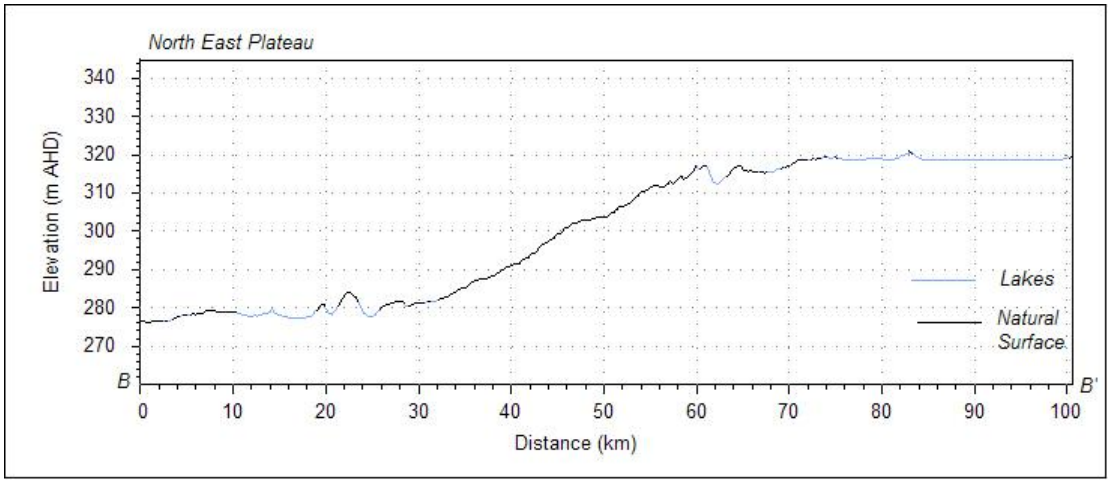
   Salinity appears to be relatively well-developed with this landscape unit.

3.8 North Eastern Plateau (Beacon – Southern Cross)

The North Eastern Plateau is the oldest sub region within the agricultural zone of the Avon River basin, having been subjected to the least amount of erosion since the carboniferous period.

This sub region is internally drained and characterised by a very sluggish watercourse dominated by massive lake systems. The major east – west oriented watercourse within the sub region is stepped, as illustrated in Figure 5. This step appears to be controlled by a porphyritic granite intrusion located in the central east of the sub region.

Figure 5 Profile of a Major Watercourse – North Eastern Plateau



Salinity within the North Eastern Plateau appears less well developed than in other sub regions, with secondary subcatchments typically exhibiting less than 1% salinity, according to Land Monitor salinity mapping. The sub region contains three landscapes units.

The geomorphology of this sub region is distinct from other sub regions within the Avon River basin, making direct comparison regarding potential salinity development within this sub region potentially problematic. However, the pattern of salinity development within this sub region appears most similar to that of the neighbouring East Central sub region.

The sub region is made up of three landscape units:

1. ***Beacon*** - the geology of the Beacon landscape unit consists almost entirely of granite described as subdivided and metamorphosed. Major drainage lines are predominantly orientated north - south, with geomorphology characterised by small discrete subcatchments draining perpendicular to major watercourses.

   Limited salinity data is available for Beacon as satellite scenes utilised by Land Monitor captured only a small part of this landscape unit.

2. ***Westonia*** - Westonia is underlain by complex geology including coarse-grained granite (monzogranite), recrystallised banded gneiss and moderately to strongly-deformed granite and granodiorite. The eastern part of the landscape is dominated by a greenstone belt, including amphibolite, metamorphosed ultramafic and metamorphosed sedimentary rocks.

   The current east - west orientated primary drainage line appears superimposed over a series of older north - south orientated drainage lines that appear to have undergone reversal through probable uplift. Salinity appears predominantly associated with extensive north - south and east - west orientated drainage lines.

3. ***Bodallin*** – Bodallin's geology consists of largely metamorphosed granite rocks intersected by metamorphosed undivided sedimentary rocks and the greenstone belt to the east.

   The geomorphology is characterised by poorly defined subcatchments, discharging to south - north orientated primary watercourses that appears to been have been reversed from their pre-existing flow direction.

   Salinity appears scattered throughout this landscape unit and significantly influenced, together with the orientation of lakes, by the orientation of numerous geological contacts.

3.9 Southern Lakes (Kulin, Lake Grace, Newdegate, Lake King)

The southeast sub region is distinct from others within the Avon River basin, due principally to the predominantly north – south orientated lake chains that appear to be associated with the previous drainage of the carboniferous period. Landscapes are typically internally drained, with watercourses exhibiting grades of less than 0.03%.

The sub region is made up of five relatively similar landscape units:

1. ***Corrigin –*** overlaps the Southern Lakes and Western Rivers sub regions. Corrigin is underlined almost entirely by recrystallised porphyritic granite and recrystallised banded gneiss.

   Landscape geomorphology is characterised by meandering primary drainage lines and irregular shaped catchments. Salinity appears relatively evenly dispersed throughout subcatchments, the orientation of which appears greatly influenced by the underlying geology.

2. ***Kulin - Holt Rock*** - is characterised by southeast - northwest orientated lake chains containing moderate to large wetland basins.

   The geology of this landscape is comprised predominantly of coarse-grained granitic rocks (monzogranite) containing remnant granitic gneiss intruded by minor areas of porphyritic granite and adamellite. The orientation of major lakes is strongly influenced by major geological contacts. Salinity is associated with large primary drainage lines and is interspersed throughout subcatchments.

3. ***Lake Grace -*** is the western most of three extensive lake chains making up the southern portion of the Avon River basin. The geology of this landscape unit is predominantly coarse-grained granitic rock (monzogranite dominant); intruded by porphyritic granite and adamellite.

   The geomorphology is dominated by a single primary lake system extending the entire length of the landscape unit. Subcatchments are relatively short in length discharging directly to the centrally orientated lake chain.

   Salinity appears predominantly associated with the primary lake chain, with outbreaks of salinity dispersed throughout secondary catchments.

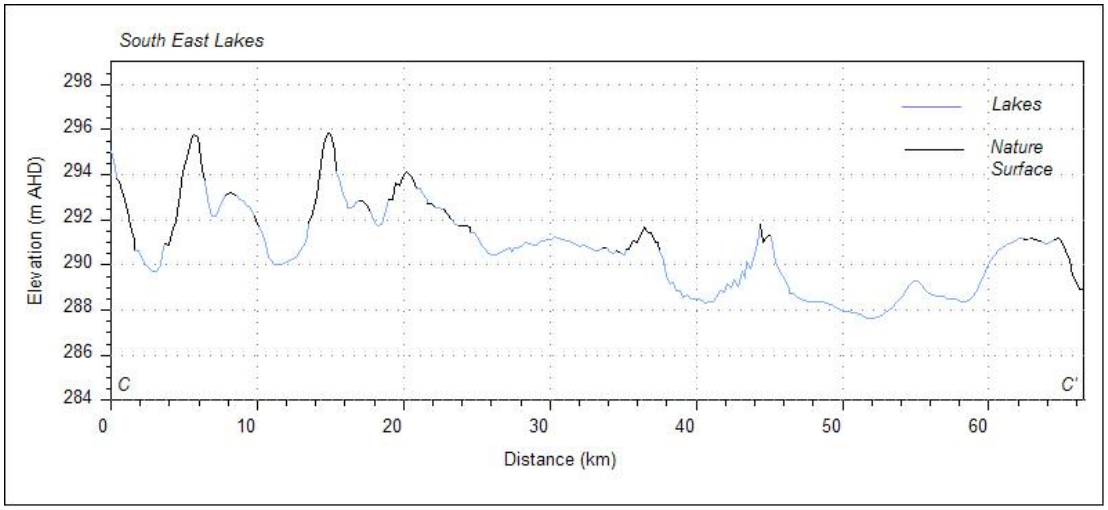
4. ***Newdegate -*** is the central lake chain of three orientated in the south of the Avon River basin. It consists of two major drainage lines, including Lake Bryde and Newdegate.

The Newdegate lake chain appears to fall gradually towards the south (Figure 6), thought to be a previously south draining river, captured through geological uplift along the southern margin of the Avon River basin.

The geology of the Newdegate landscape unit is dominated by a large block of moderate to strongly deformed granite and granodiorite in the west, coarse-grained granite to the south and an area of high-grade metamorphic rock (granulite and migmatite) in the north.

Salinity appears to be predominantly associated with major valley floor environments, with areas of salinity dispersed throughout secondary catchments.

Figure 6 Longitudinal Profile of the Newdegate Lake Chain



5. ***Lake King*** - The Lake King landscape unit is the eastern most lake chain of the southeast lake region. This landscape unit is almost entirely underlain by coarse-grained granite rocks (predominantly monzogranite) and is dominated by large extensive lake systems.

Salinity is well dispersed throughout the catchment and appears to be influenced by local geological structures. The orientation and geomorphology of lakes also indicates a response to underlying geological structural components.

4. Slope Analysis

In undertaking the salinity trend analysis, it was considered necessary to define the hazard area in which salinity is most likely to occur. The specific methodology used and outcomes of the analysis undertaken are present below.

4.1 Background

Understanding the role of / and interactions between regional and local groundwater systems and the extent to which surface water interactions influence salinity development, are important elements when considering alternative monitoring and risk assessment strategies.

At a subcatchment scale, consideration of a range of key hydrogeological parameters provides insight into the underlying hydrogeological processes influencing the salinity development. These include:

- *Aquifer thickness;*
- *Catchment hydraulic conductivities;*
- *Width and slope of the catchment and influence of underlying geology;*
- *Extent of rainfall excess, and time since clearing; and*
- *Distribution of landscape salt stores.*

There are very few subcatchments within the Avon River basin where there is sufficient information of key hydrogeological parameters to develop a detailed understanding of underlying hydrogeology. In the absence of detailed hydrogeological information, alternate methods for salinity risk assessment are required. Analysis of a range of datasets, including rainfall trends, time since clearing, soils, catchment geomorphology and patterns of salinity development can provide insight into hydrogeological processes influencing salinity development at a subcatchment scale.

Time since clearing is considered to be one of the most significant drivers for salinity development within the region. However no reliable coverage of time since clearing was available for the Avon River basin and development of such a dataset was well beyond the scope of this project. Analysis of rainfall trends within the region were undertaken as background to this project, however detailed trends are not reported here, although discussion of rainfall trends are included in this report.

A preliminary assessment of existing soil coverages for the Avon River basin was undertaken, however difficulties arise from the scale of mapping, lack of consistency between data sheets and nature of soil descriptions hampered the application of soil data to salinity trend analysis within the study area.

Previously, valley hazard mapping was undertaken within the Land Monitor project, providing a coverage of salinity hazard including the area of the Avon River basin. Valley hazard mapping was developed by combining Landsat scenes, digital elevation

models and surface water accumulation models to determine areas at risk of salinity, or more correctly with a salinity hazard. Models were developed using a range of variables including landscape position, height above stream height, proximity of areas of known salinity and land slope. Whilst not a risk assessment tool *per se*, valley hazard mapping has been used extensively as a means of determining the area most likely to become saline. However, height above stream level, which was the primary variable used in the analysis has a limited theoretical basis for application to salinity risk or hazard assessment.

It is considered that Land Monitor valley hazard mapping provides a reasonable boundary delineating an area outside of which salinity is less likely to occur. It is less reliable in predicting where salinity is most likely to occur.

Assessment of discharge sensitivity suggests that salinity is most likely to occur in low sloping areas of the landscape or as a result of a change in grade. In theory a change in hydraulic grade, or where a hydraulic grade falls below a particular threshold, predisposes areas to profile saturation due to groundwater and surface water responses and/or an interaction between the two. A change in hydraulic conductivity may also result in profile saturation (upslope of the "barrier"). Changes in hydraulic conductivity are likely to result from variations in the underlying geological substrate, and are often reflected in the surface geomorphology.

Slope mapping has previously been used for undertaking salinity hazard and risk assessment. Salinity risk assessment mapping was undertaken for the Buntine – Marchagee catchment and combined Land Monitor with a range of spatial data sets including DEM derivatives and soils-landform units (Short et al, 2006).

It was found that landscape slope analysis has potential for identifying landscape areas and features most likely to influence the *pattern of salinity development* at a subcatchment or landscape scale within the Avon River basin. Slope analysis is considered to have potential as a hazard mapping tool because it provides a mechanism for incorporating key elements of risk, including landscape position, identifying areas of likely high salt concentration and slope, which generally reflects important underlying geological structural components.

4.2 Methodology

The analysis undertaken included derivation of slope threshold maps from a high-definition DEM with a grid size of 100 m (sourced from the Land Monitor project). A grid size of 100 m was selected principally for data management reasons, but also to reflect the relative accuracy of the assessment undertaken.

The digital elevation model was developed from 100 m spot heights using the minimum curvature method. The minimum curvature method was used to minimise the complexity of resulting slope derivation maps.

Preliminary slope analysis included derivation of the following low slope thresholds:

- *Less than 1.8% slope;*
- *Less than 1.5% slope;*

- *Less than 1% slope;*
- *Less than 0.7% slope;*
- *Less than 0.5% slope; and*
- *Less than 0.35% slope.*

Derived low slope areas were clipped to the Land Monitor valley hazard areas to remove middle and upper landscape areas of low slope. The resulting low slope areas, contained within the Land Monitor valley hazard areas, were compared with Land Monitor salinity coverages to establish low slope thresholds with the highest correlation to areas of previously mapped salinity. This is an iterative process based on interpretation of slope contours with known geomorphological zones and surface salinity.

High slope areas extracted derived slope maps included areas:

- *Greater than 2.5% slope;*
- *Greater than 3% slope; and*
- *Greater than 4% slope.*

High slope areas (ie. greater than reported slope threshold), were overlayed with available soil and geological series coverages (GSWA). Areas of more than 3% slope appeared to display a similar pattern to rock outcrop areas identified within the 1:100,000 soil mapping (sourced from DAFWA). Areas of greater than 2.5% slope appeared to display a similar distribution to exposed rock / shallow bedrock identified within the 1:250,000 Geological series (sourced from GSWA).

A combination of low and high slope areas was found to provide a similar distribution to mapped salinity (Land Monitor). Salinity was found to be associated with areas of low slope areas (primary low slope threshold), or areas of low to moderate slope (secondary low slope threshold), where those areas were within close proximity (described by a buffer distance) to an area of high slope (high slope threshold).

For example, in the Lakes District, salinity appeared to be largely restricted to areas of slope less than 0.35%, or in areas up to 1.0% slope, but only where that area was located within 500 m of an area of more than 2.0% slope.

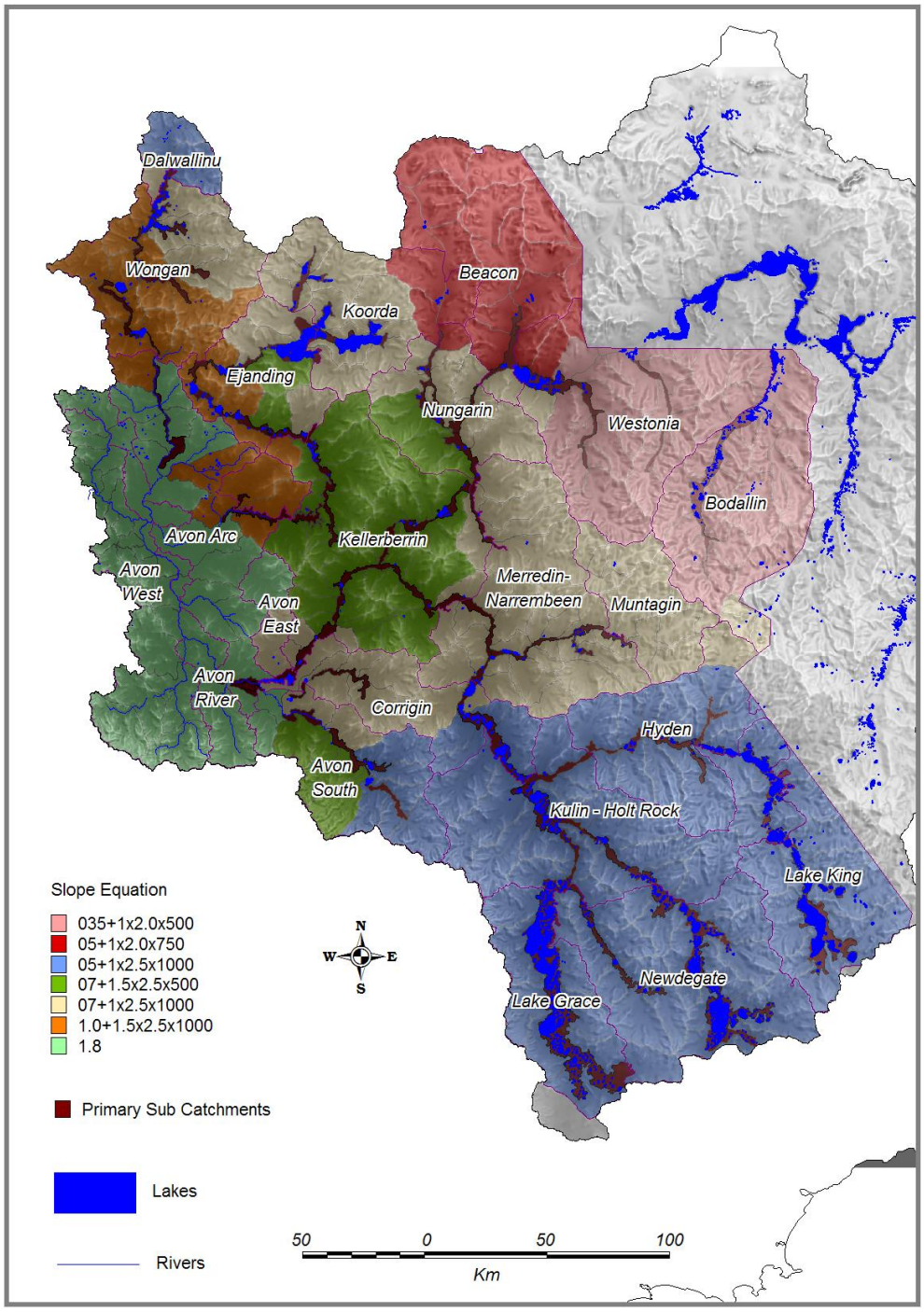
Primary and secondary low slope thresholds, high slope threshold and buffer distances were determined for individual subcatchments through trial and error to obtain best fit with the current pattern of salinity development. The resulting thresholds are presented in Table 1 and Figure 7.

Table 1 Slope Area Formulas – Used in Slope Hazard Mapping

Map Reference	Primary Low Slope Threshold	Secondary low Slope Threshold	High Slope Threshold	Buffer distance
0.35+1x2.0x500	0.35%	1.0%	2.0%	500m
0.5+1x2.0x750	0.5%	1.0%	2.0%	750 m
0.5+1x2.5x1000	0.5%	1.0%	2.5%	1000 m
0.7+1.5x2.5x500	0.7%	1.5%	2.5%	500 m
0.7+1x2.5x1000	0.7%	1.0%	2.5%	1000 m
1.0+1.5x2.5x1000	1.0%	1.5%	2.5%	1000 m
1.8	1.8%	-	-	-

The analysis undertaken utilised a trend based approach, focussing on the patterns of spatial distribution of salinity throughout the region. The analysis was undertaken at a subcatchment scale and has been used as a basis for assessing the potential extent of catchment salinity at a landscape unit and sub regional scale.

Figure 7 Slope Area Boundaries Avon River Basin



Slope hazard mapping boundaries were developed independently of Sub Regional and Landscape zones (Figure 7).

4.3 Results

Summary statistics of slope hazard mapping are presented in Table 2. Between 75% (north east plateau) and 91% (north-west) of salinity mapped by Land Monitor appears to fall within the slope hazard area. It is considered distortion within the digital elevation model resulting from processing techniques used in the analysis accounts for some proportion of salinity falling outside of the mapped slope hazard area.

Table 2 Sub Regional and Landscape Slope Hazard Mapping Summaries

Sub region	*Landscape*	*Landscape Area (sq km)*	*Area of Salinity (Land Monitor - sq km) - 1996*	*Proportion of Landscape Saline – (1996)*	*Proportion of Salinity inside Slope Hazard Zone*	*Slope Hazard Area*	*Slope Hazard - percentage of Landscape*
Western Rivers	Avon Arc	4,226	275.6	6.5%	85%	864	20.5%
	Avon East	1,305	49.0	3.8%	86%	246	18.8%
	Avon River	1,796	44.5	2.5%	80%	251	14.0%
	Avon South	3,240	164.2	5.1%	87%	594	18.3%
	Avon West	3,583	35.0	1.0%	65%	252	7.0%
	Sub total	***14,149***	***568***	***4.0%***	***84%***	***2,207***	***15.6%***
North Western	Dalwallinu	802	24.5	3.1%	81%	118	14.8%
	Wongan	4,026	456.0	11.3%	92%	836	20.8%
	Sub total	***4,827***	***481***	***10.0%***	***91%***	***954***	***19.8%***
Central - West	Corrigin	2,722	91.6	3.4%	82%	460	16.9%
	Ejanding	2,506	197.2	7.9%	92%	607	24.2%
	Kellerberrin	6,547	360.2	5.5%	91%	1,540	23.5%
	Sub total	***11,775***	***649***	***5.5%***	***90%***	***2,607***	***22.1%***
Central - East	Hyden	2,884	91.2	3.2%	81%	378	13.1%
	Koorda	2,833	105.0	3.7%	83%	433	15.3%
	Merredin-Narrembeen	5,416	117.5	2.2%	89%	1,075	19.9%
	Muntagin	1,948	12.2	0.6%	68%	252	12.9%
	Nungarin	2,729	170.9	6.3%	94%	622	22.8%
	Sub total	***15,809***	***497***	***3.1%***	***87%***	***2,761***	***17.5%***
Southern Lakes	Kulin - Holt Rock	6,510	273.8	4.2%	88%	898	13.8%
	Lake Grace	3,020	217.2	7.2%	76%	603	20.0%
	Lake King	3,225	45.0	1.4%	71%	423	13.1%
	Newdegate	5,619	161.4	2.9%	80%	794	14.1%
	Sub total	***18,374***	***697***	***3.8%***	***81%***	***2,718***	***14.8%***
North Eastern Plateau	Beacon	986	50.2	5.1%	92%	228	23.1%
	Bodallin	1,707	40.5	2.4%	56%	185	10.9%
	Westonia	4,623	95.0	2.1%	75%	499	10.8%
	Sub total	***7,315***	***186***	***2.5%***	***75%***	***913***	***12.5%***

Slope hazard mapping and Land Monitor salinity coverage are presented in Figure 8.

The analysis indicates a correlation between the extent of salinity within individual subcatchments and the proportion of salinity occurring within the slope hazard mapping

area. In other words, the more saline a catchment, the higher proportion of salinity that falls with the slope hazard area. This reflects the extent to which local hydrologic processes influence the development of salinity within the region. In subcatchments where salinity is in the early phases of development, a more diffuse pattern of salinity distribution is evident. As salinity progresses within a subcatchment, a more definable pattern of salinity distribution appears, with typically 80 – 90% of salinity located within the slope hazard area for subcatchments with more than 10% of land area impacted by salinity. In primary valley subcatchments, (were the slope hazard area accounts for 40 - 70% of the subcatchment area), 82 – 96% of salinity occurs within the slope hazard area.

4.4 Conclusion

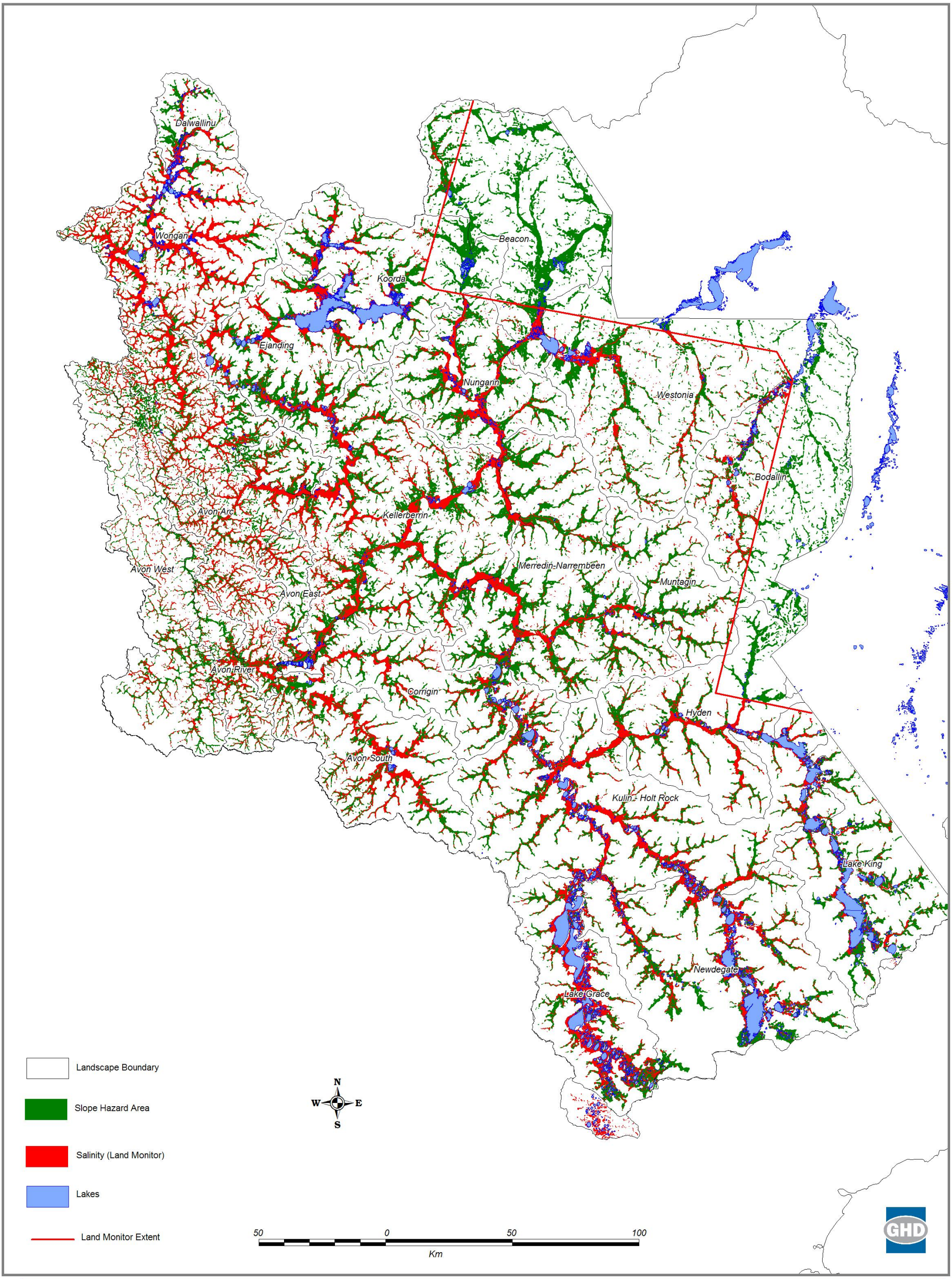
Whilst slope is not the only factor influencing salinity development, slope analysis appears to represent a simple mechanism for predicting the patterns of salinity distribution throughout much of the Avon River basin at a landscape scale. The analysis indicates salinity development is typically driven by local landscape influences, suggesting a predominance of local hydrologic processes driving salinity development.

It is considered slope hazard mapping undertaken provides a reasonable indication of the primary hazard area for salinity development. It is most effective in providing a description of the patterns of salinity development at equilibrium at a catchment or landscape scale.

Slope hazard mapping appears to be most effective in deeper regolith catchments and less effective in areas with shallow regolith, including the Western Rivers and landscapes associated with porphyritic granitic intrusions, including the Kellerberrin batholith. In subcatchments with shallow regoliths, local geology appears to exert much stronger control over salinity development than in subcatchments with a deeper regolith, where salinity distribution appears to be more consistent with slope hazard mapping. It is likely that in shallow regolith subcatchments, local geological influences are not as well reflected in landscape geomorphology, and/or the scale used for slope analysis is not sufficiently detailed to detect the resulting minor variations in geomorphology.

Whilst slope hazard mapping appears to provide a reasonable indication of the landscape scale distribution of salinity likely to occur nearing hydrologic equilibrium, it does not provide a means for determining the likely geographic sequence or associated time frames of salinity development a subcatchment scale. As a result, slope hazard mapping is not degraded as a salinity risk assessment tool in its own right. More detailed subcatchment scale investigations are required to effectively determine the risk of salinity development at intra-subcatchment and paddock scales.

Slope hazard mapping indicates that between 12.5% and 22% (for the North East Plateau and Central West sub regions respectively) of the landscape are at highest risk of becoming saline (Table 2). This is in contrast to the 27.5% (region wide) predicted by Land Monitor Valley hazard mapping.



Map Projection: Universal Transverse Mercator
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Figure 8 Slope Hazard and Land Monitor Salinity - Avon River Basin

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5. Land Salinity Assessment (Land Monitor)

The Land Monitor project provides a range of products associated with vegetation and salinity monitoring, useful in establishing trends in salinity development. An assessment of salinity trends report by Land Monitor was undertaken and is presented in this section.

5.1 Background

The Land Monitor project developed maps showing changes in salt affected land over the southwest agricultural district of Western Australia. The methodology involves processing historic calibrated Landsat satellite imagery in conjunction with elevation data and ground truthing.

Land Monitor is a salinity mapping tool that applies a multidisciplinary approach incorporating multiple satellite imagery scenes, geographic data and ground truthing to produce salinity mapping. Outputs for Land Monitor include products useful in mapping, monitoring and predicting salinity development at a landscape – sub regional scale.

The area covered by Land Monitor analysis is 24 million hectares using a base pixel size of 25 m, indicating application for a large catchment / sub regional scale analysis (Spies and Woodgate 2005).

The technique employed a combination of LANDSAT bands 4, 5 and 7 for sequences of spring and summer scenes for the period 1988 – 2000. Processes associated with developing land monitor salinity images include (Caccetta and Beeston 2000):

- *Co-registering images to a common base map;*
- *Locating sites for all vegetation cover types;*
- *Stratifying the study area into zones - with similar rainfall, land use, geology and soil types;*
- *Training data to examine separation of ground cover types through applied discriminate analysis including conical variant analysis;*
- *Combining cover class probabilities for each scene date with landscape position and calculating the probability of pixels being affected;*
- *Undertaking post-processing to remove obvious errors including dams, roads, rocks etc;*
- *Undertaking a ground truthing and reapplication of analytical analysis techniques described above; and*
- *Undertaking validation and accuracy assessment.*

Outputs from the Land Monitor project include (Caccetta et al. 1999):

» *Areas not saline;*

» *Areas mapped as saline in 1987;*

» *Areas mapped as not saline in 1987, saline in 1996;*

» *Dark vegetation (including remnant vegetation, wet scrub and reeds); and*

» *Wet areas – subject to inundation.*

Areas mapped as salt affected by Land Monitor are in reality areas of land displaying persistent low productivity over the period of analysis, which is typically three years. As a result there are inherent errors contained within the Land Monitor salinity data sets, including errors of commission (areas mapped as saline that are actually not saline) and errors of omission (areas of salinity not detected by Land Monitor).

Commission errors are generally associated with bare soil including dams, roaded catchments, roads, farmyards, reflective white sands and areas of sparse vegetation cover.

Omission errors are either associated with thresholds and sensitivities of the Land Monitor analysis, or saline land not displaying typical reflective properties. Omission errors generally fall into the following categories (Caccetta et al, 1999; Furby 2000):

» *Areas of salt affected land of less than one hectare are not reliably mapped by Land Monitor. When combined with filtering of upper landscape areas through assessment of the landscape position, small areas of salinity such as hillsides seeps are not reliably detect by Land Monitor;*

» *Sites where saline land is detected but the area is underestimated, generally associated with salt flats where margins are still cropped;*

» *Mildly saline land, or more correctly, land where the impact of changed hydrology is not advanced enough to result in sufficient bare ground to be detected by Land Monitor. Typically land salinity must be severe enough to result in less than 80% cover of a salt tolerant species such as barley grass to be detected by Land Monitor as saline; and*

» *Saline areas with a good cover of salt tolerant pastures, including salt bush are generally not detected as saline by Land Monitor.*

Interpreting outputs from Land Monitor requires an understanding of the sensitivity of Land Monitor in detecting saline land. For instance, areas of salinity mapped as non-saline in 1987, and as saline in 1996 were in likelihood impacted by salinity in 1987 but the impacts of salinity were not severe enough to be detected by Land Monitor. In this way, Land Monitor measures the increase in the severity of salinity, father than salinity development *per see*. At the very least, there is a delay in Land Monitor detecting salinity development within the region, in addition to some distortion in the rate of change of salinity, resulting from different areas of salinity developing at different rates. However, because Land Monitor consistently applies the same methodology over time and space, inference can be drawn from trends displayed within the underlying data. However, care should be taken

when considering absolute values reported by Land Monitor regarding the incidence of salinity throughout the study area.

Errors of commission and omission are reported by Land Monitor for the Swan – Avon area.

Table 3 Reported Errors of Commission and Omission - Land Monitor Salinity Mapping

	Commission Errors	***Omission Errors***
Tammin	*4% - 8%*	*19% - 25%*
Kellerberrin	*8% - 15%*	*2% - 8%*
Bencubbin	*5% - 15%*	*5% - 22%*
Jackson	*40%*	*6%*
Southern Cross	*4%*	*11%*
Newdegate	*3% - 5%*	*9%*

Caccetta et al, 1999; Furby 2000; Wallace 2003; Dunne & Beetson 2001

Land Monitor more accurately identifies salinity in some areas of the Avon River basin than in others. Ground truthing of Land Monitor was undertaken by a number of individuals throughout the Avon River basin, resulting in variability in the accuracy of Land Monitor's prediction of salinity as outlined in Table 3. Omission errors generally outweigh commission errors resulting in an under-prediction of the area of land impacted by salinity. Notable exceptions include the Jackson and Kellerberrin Landsat scenes where significant errors in commission result in Land Monitor overestimating the area of land impacted by salinity, predominately associated with reflective sands being incorrectly identified as saline land.

An electromagnetic survey of regionally significant roads within the Avon River basin, undertaken within the ACC Protection of Transport Assets project, indicated 70% of EM31 and EM38 readings collected within areas described as saline by Land Monitor were "*moderately to extremely saline* (GHD[3], 2008)."

Analysis of salinity reported by Land Monitor compared to aerial mapped salinity was previously undertaken within the Hotham Murray Williams catchment. This investigation indicated Land Monitor underestimated the instance of salinity by as much as 25% over salinity mapped in 2007. However an 80% correlation existed between the area of salinity at a subcatchment scale reported by Land Monitor when compared to aerial mapped salinity (GHD[2] 2008).

In general, Land Monitor appears relatively effective in identifying reasonably large areas of saline land where the impacts of salinity are relatively well advanced. As a result Land Monitor appears to detect a change in severity of salinity, rather than the change in salinity development. Land Monitor also typically underestimates the area of land impacted by salinity, however in some areas, where ground truthing was less effective, Land Monitor appears to slightly overestimate the area impacted by salinity resulting from errors of commission.

5.2 Methodology

5.2.1 Data Management

Land Monitor salinity coverages for 1987 (mapped as saline in 1987) and 1996 (ie. not mapped as saline in 1987 but mapped as saline in 1996) were supplied by the Department of Land Information (Landgate) in a vector format as an ARC GIS shape file. Land Monitor vector shape files were cleaned using ARC GIS, removing errors and anomalies resulting from conversion of original raster to vector file formats.

Vector shape files for Land Monitor Valley Hazard were also sourced from the Department of Land Information (Landgate) and cleaned to remove anomalies and errors.

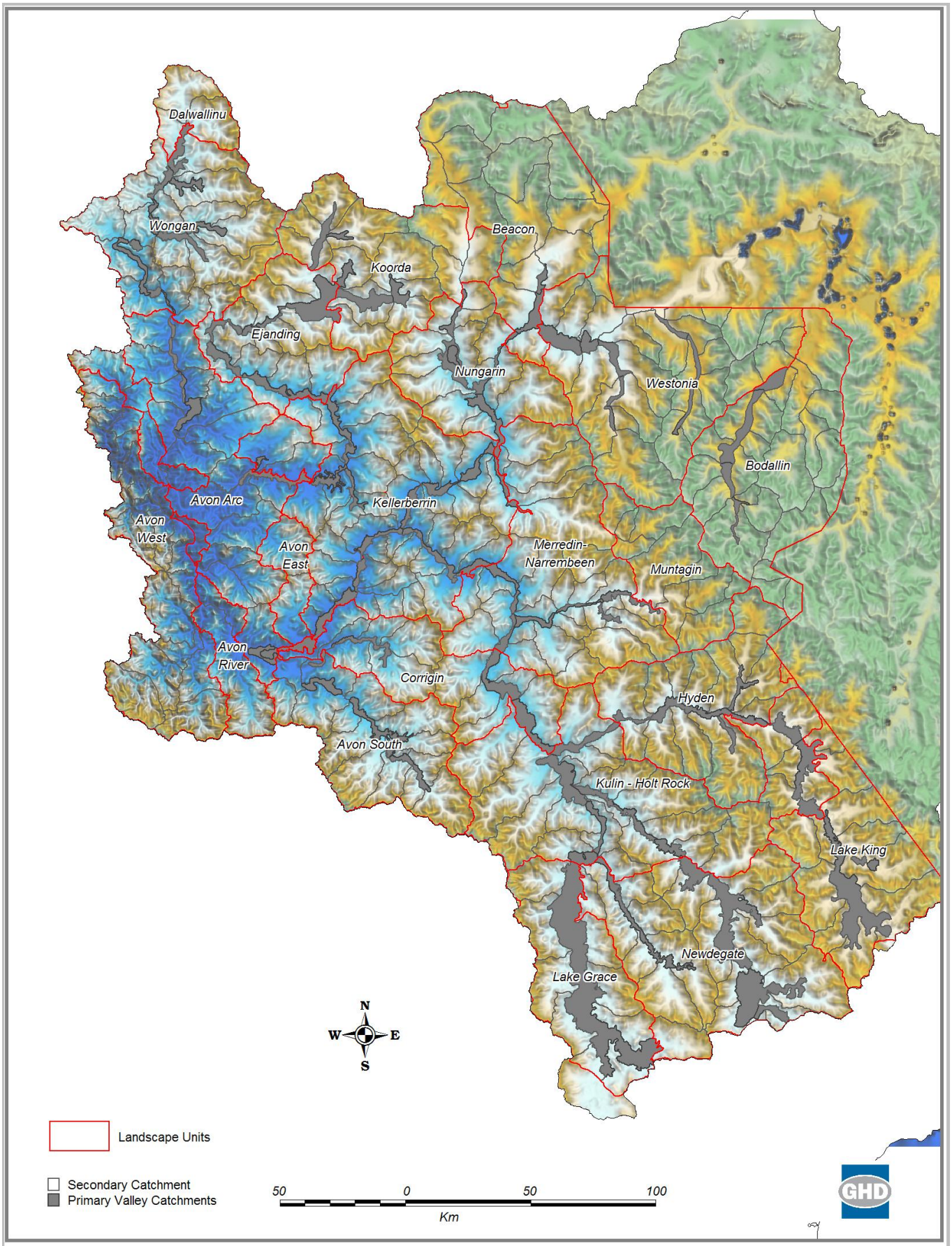
Land Monitor salinity coverages were clipped to the Land Monitor Valley hazard area to remove remaining upper landscape commission errors including dams, roaded catchments, farmyards and other areas of consistently low producing land that are not related to salinity and in particular, poorly producing deep white sands responsible for significant commission errors in the Jackson scene (refer Table 3).

5.2.2 Review of Subcatchment Boundaries

A review of subcatchment boundaries was undertaken to ensure consistency as subcatchments formed a "*common denominator"* for undertaking the subsequent Land Monitor analysis.

Surface water catchment boundaries were supplied by the Department of Agriculture and Food originally sourced from the Department of Water. Subcatchment boundaries were edited using the Land Monitor high-definition DEM to provide consistency in catchment size and distribution. The high-definition digital elevation model (DEM) was produced using filtered 10m spot heights generated from the Land Monitor project to create a 100 m grid DEM for the Avon River basin.

The resulting subcatchment boundaries were defined as "*Primary Valley*" catchments associated with large broad inset valleys containing lake chains of the Eastern Avon River basin, or "*secondary catchments*" including individual subcatchments typically discharging to major rivers or to "*Primary Valley*" catchments (Figure 9).



Map Projection: Universal Transverse Mercator
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Figure 9. Sub Catchments - Avon River Basin

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5.2.3 Analysis

Analysis of Land Monitor salinity coverages was undertaken to determine spatial and temporal trends in salinity development at a subcatchment scale across the Avon River basin.

The area of Land Monitor detected salinity for both 1987 and 1996 was calculated for each subcatchment within the Avon River basin using a GIS based spatial interpretation approach.

The Land Monitor coverage 1987 is an estimation of salinity in 1987. The Land Monitor 1996 salinity coverage is the area detected as becoming saline after 1987 and before 1996.

Three thematic maps are presented providing a first order salinity trend analysis for the Avon River basin, described by the following equations:

» *Total salinity reported by Land Monitor:* $(A_{87} + A_{96})/ A_{cat}$ (Figure 10)

» *Proportion of land impacted by salinity between 1987 and 1996:* A_{96} / A_{cat} (Figure 11)

» *Proportion of total salinity occurring after 1987 and prior to 1996:* $A_{96}/(A_{87} + A_{96})$ (Figure 12)

Where

A_{87} *: Area of salinity detected by Land Monitor in 1987.*

A_{96} *: Area of salinity detected by Land Monitor that occurred after 1987 and before 1996).*

A_{cat} *: Catchment area within Land Monitor study area.*

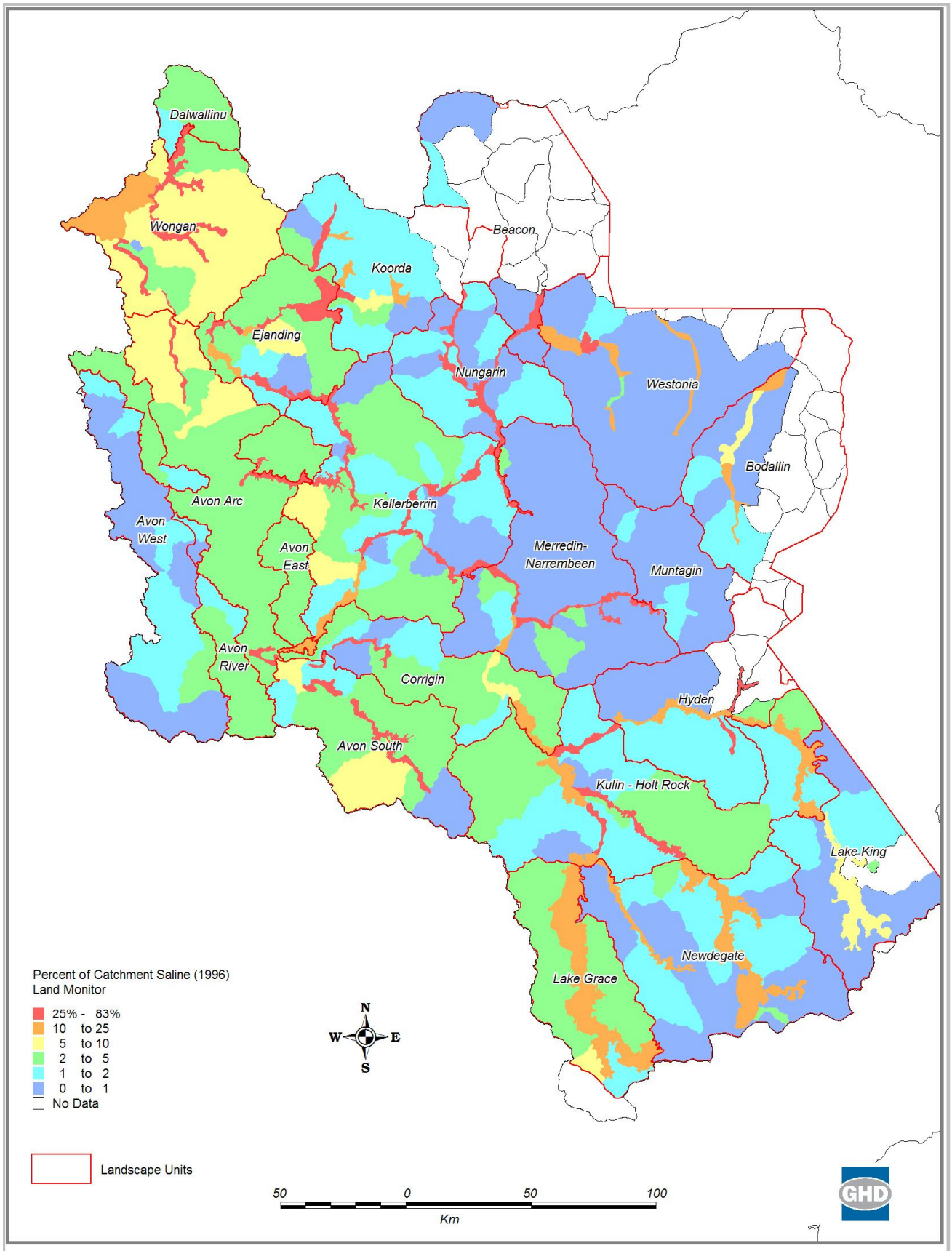

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Figure 10. Sub Catchment Salinity 1996 (Salinity)

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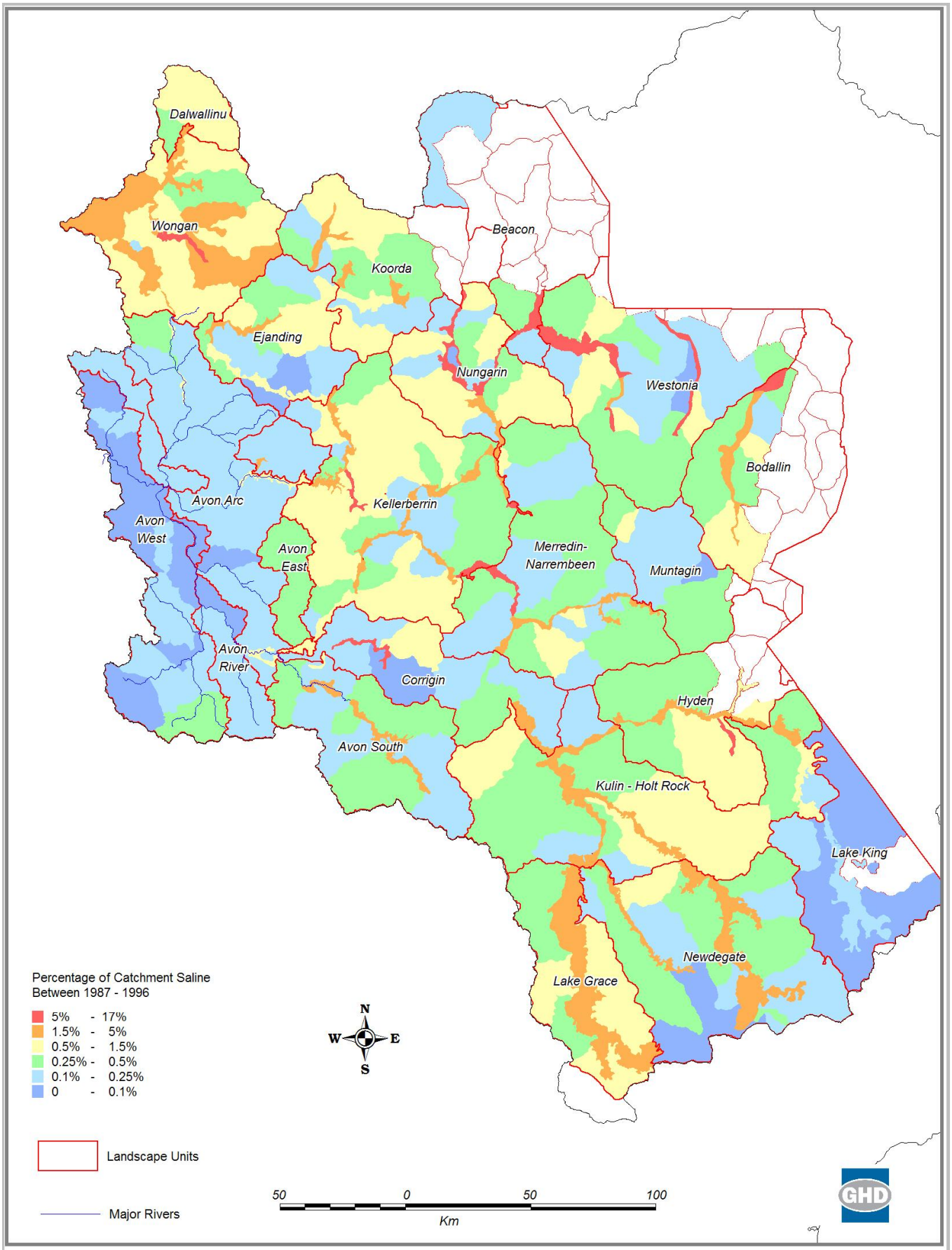

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
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Figure 11. Sub Catchment Salinity (1987 - 1996)

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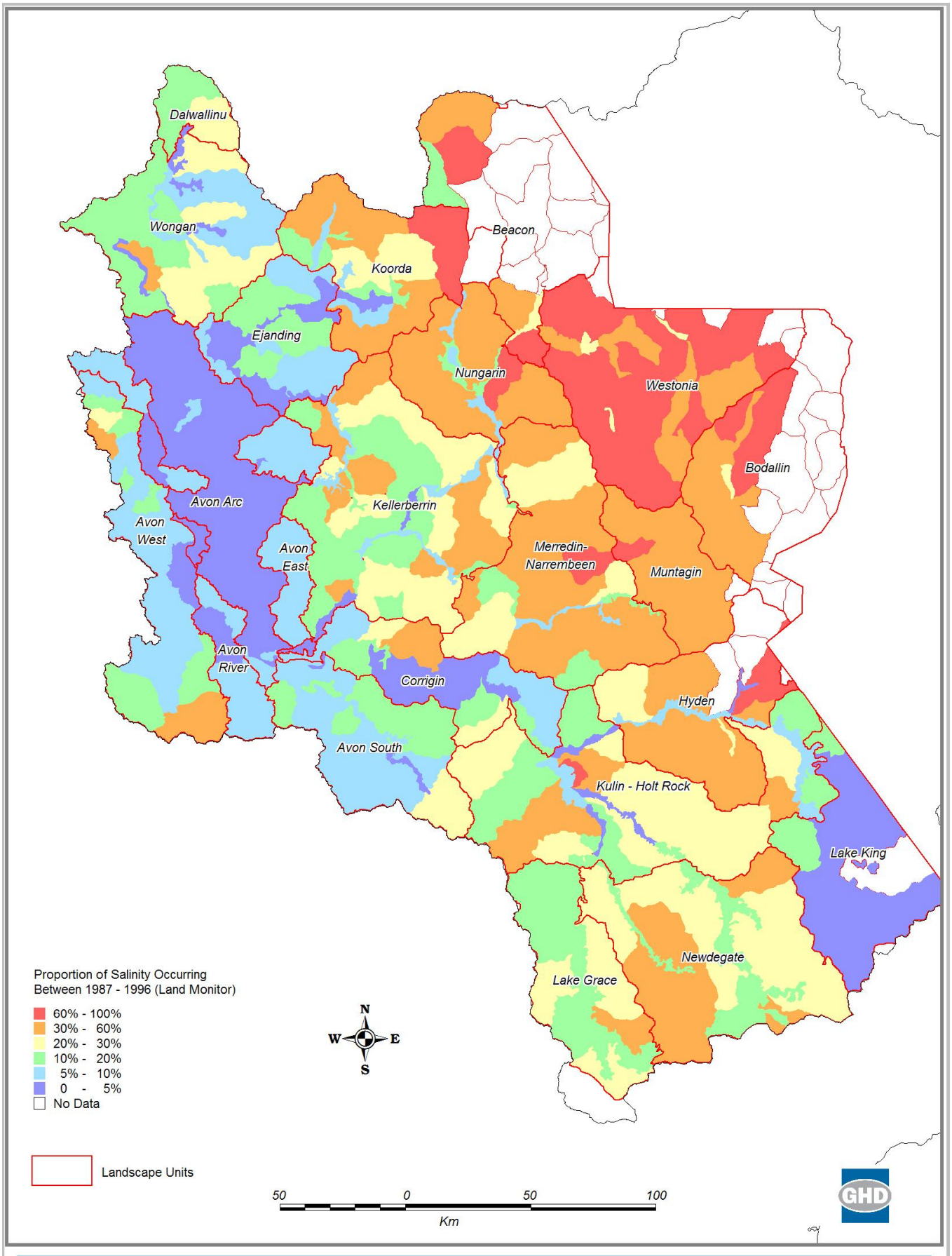

Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
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Figure 12. Proportion of Sub Catchment Salinity Occurring after 1987

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Table 4 Sub Regional Salinity Extent and Trends – Land Monitor

Sub Region	Proportion of sub region saline in 1996 – Land Monitor	Est. Base Rate of Increase – Land Monitor
North West	10.1%	1.05%
Western Rivers	4.0%	0.18%
Central West	5.6%	0.51%
Central East	3.2%	0.48%
North East Plateau	2.5%	0.71%
Southern Lakes	4.0%	0.44%

Note: Calculations of salinity do not include Land Monitor water mask.

Presented in Table 4 is a summary of the extent of sub regional salinity in 1996 and the estimated proportion of salinity as a percentage of total salinity that occurred between 1987 and 1996 as recorded by Land Monitor. It should be noted that proportion of salinity that occurred between 1987 and 1996 is a gross estimate only, because Land Monitor detects the change in severity of existing salinity, rather than the development of new salinity. The analysis assumes a consistent trend in the development of salinity over time at a sub catchment scale, which may not be correct in all cases. Therefore, figures presented for the rate of increase of salinity should be considered on the basis of a comparative analysis only.

5.2.4 Statistical Analysis

Statistical analysis of interpreted Land Monitor salinity data for individual subcatchments was undertaken at both sub regional and landscape unit scales using a series of statistical tests to identify trends and / or relationships that may exist.

Data for the proportion of salinity within subcatchments between sub regions and landscape units was initially tested for normality and homogenous variance in order to determine which statistical test was most applicable.

The Kolmogorov-Smirnov Test (Kolmogorov 1933; Smirnov 1939a, 1939b) was applied to determine normality of data. The Kolmogorov-Smirnov Test is commonly used to test for "*goodness of fit*". If the resulting p-value is less than 0.05 (95% confidence interval), then it is considered populations are not normally distributed, potentially causing bias to commonly applied statistical tests used for comparing paired samples and variance of populations.

The Shapiro-Wilk test (Shapiro and Wilk 1965) is a powerful statistical test for assessing normality. The Shapiro-Wilk test was applied as a follow up to the Kolmogorov-Smirnov Test for determining the "goodness of fit" of catchment salinity data identified for variance analysis.

Both the Kolmogorov-Smirnov and Shapiro-Wilk tests returned p-values of 0.000 for subcatchment salinity data for the sub regional analysis. Only 6 of the 23 landscape units were considered to have normally distributed data. It was determined that catchment salinity data is not normally distributed either at a sub regional or landscape scale for the purposes of subsequent analysis of variance.

A Levene's Test was used to test the equality of variance between samples. Levene's is a common statistical test used to determine if the variance between populations of different samples are equal (Levene 1960). If the resulting p-value of Levene's Test is less than 0.05 (95% confidence interval), then it is considered that the population of samples analysed is unlikely to be based on random sampling. The test is applied to determine which statistical tests should be used for assessing significance of variance between populations, as the outcome of some common statistical tests will be biased if applied to data that does not have equal variance between sample populations.

Result of the Levene's test of subcatchment salinity data for both sub regional and landscape unit analysis indicates there is no equality inferiors between samples, even considering a 99% confidence interval.

It was determined that salinity catchment data identified for analysis is neither normally distributed nor parametric, influencing the choice of tests used for comparing statistical difference between datasets.

A Kruskal Wallis test (α=0.05) was performed to determine if the proportion of saline land in each sub region and landscape unit had changed significantly for the period 1987 - 1992 to 1995 - 1998. A Kruskal Wallis test is commonly used for testing the significance of variation of population of nonparametric datasets (Kruskal and Wallis 1952). It is often referred to as analysis of variance by ranks. This test can be used in any situation where the parametric single factor analysis of variance (ANOVA) is applicable and will be 95% as powerful an ANOVA in determining differences in variance between populations (Zar 1984). Unfortunately, it cannot be used as a substitute for a two factor ANOVA. As a result variance between salinity recorded by Land Monitor in 1987 and 1996 was prepared separately to variations between individual sub regions and landscape units.

Mann-Whitney Tests (α=0.05) were performed on each pair of sub regions and landscape units to determine if significant differences exist between individual sub regions and landscape units. The Mann-Whitney test is a commonly used two sample ranked test for comparing differences between the dispersion or variance of two populations of non-parametric data (Mann and Whitney 1947). Testing for significance of nonparametric data is typically undertaken on ranked data, rather than on the actual raw data to negate issues arising from the non-parametric nature of the underlying data.

The Wilcox test was used to determine statistical differences between Land Monitor detected salinity for 1987 and 1996. The Wilcox test is a non-parametric analogue to the paired sampled *t*-test in the same way the Mann-Whitney test is a non-parametric procedure analogous to the two sampled *t*-test (Wilcoxon and Wicox 1964).

Based on the outcome of the Mann-Whitney Tests, sub regions were grouped by those found be most similar (no significant difference) with respect to the proportion of saline land for both time periods (1987 - 1992 and 1995 - 1998).

Results of the analysis undertaken are presented separately for primary and secondary catchments due to fundamental differences in the occurrence of salinity development between the two subcatchment categories.

Statistical analysis was restricted to assessment of salinity trends within secondary catchments, due to the small number of subcatchments contain within primary valley catchment areas. These results are presented in Section 5.4 and Appendix A.

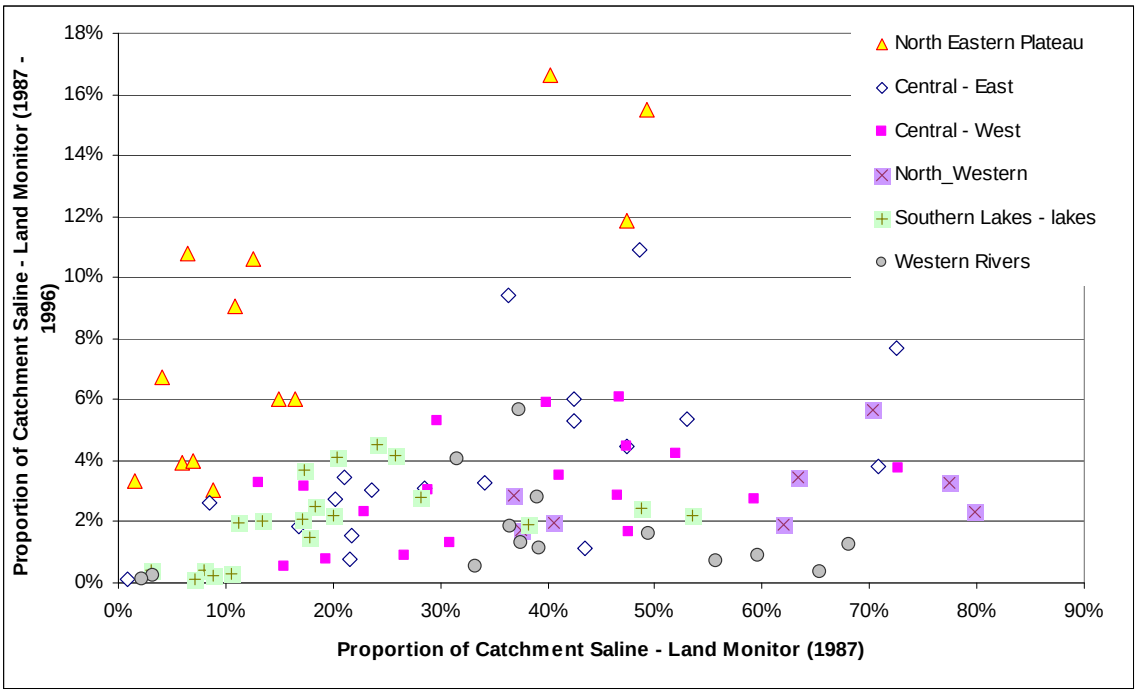
5.3 Results – Primary Valley Subcatchments

Salinity within *primary valley* subcatchments is typically well advanced throughout the region, with between 30% - 80% of primary valley catchment areas reported as saline in 1996 by Land Monitor.

The proportion of land impacted by Land Monitor as salinity in 1987 is compared with salinity occurring between 1987 and 1996 and presented in Figure 13. This analysis indicates differences in the spectrum of salinity development across sub regions. The following observations are offered:

- *Salinity within primary subcatchments of the North East Plateau appears to be progressing more rapidly than for other sub regions;*
- *Salinity within primary catchments of the Western Rivers catchments is progressing more slowly than in any other sub regions;*
- *Salinity within the central and southern sub regions appears to be developing at a similar rate; and*
- *Total salinity within primary catchments of the southern lakes sub region is less advanced than in other sub regions, potentially due to the large area of "primary salinity" (salt lakes) associated with the sub region.*

Figure 13 Salinity Detected by the Land Monitor for Primary Catchments



5.4 Results - Secondary Subcatchments

The proportion of secondary subcatchments impacted by salinity in 1987 is compared with salinity occurring between 1987 and 1996, and presented in Figure 14.

The salinity spectrum of subcatchments appears to differ between sub regions. The following observations are offered:

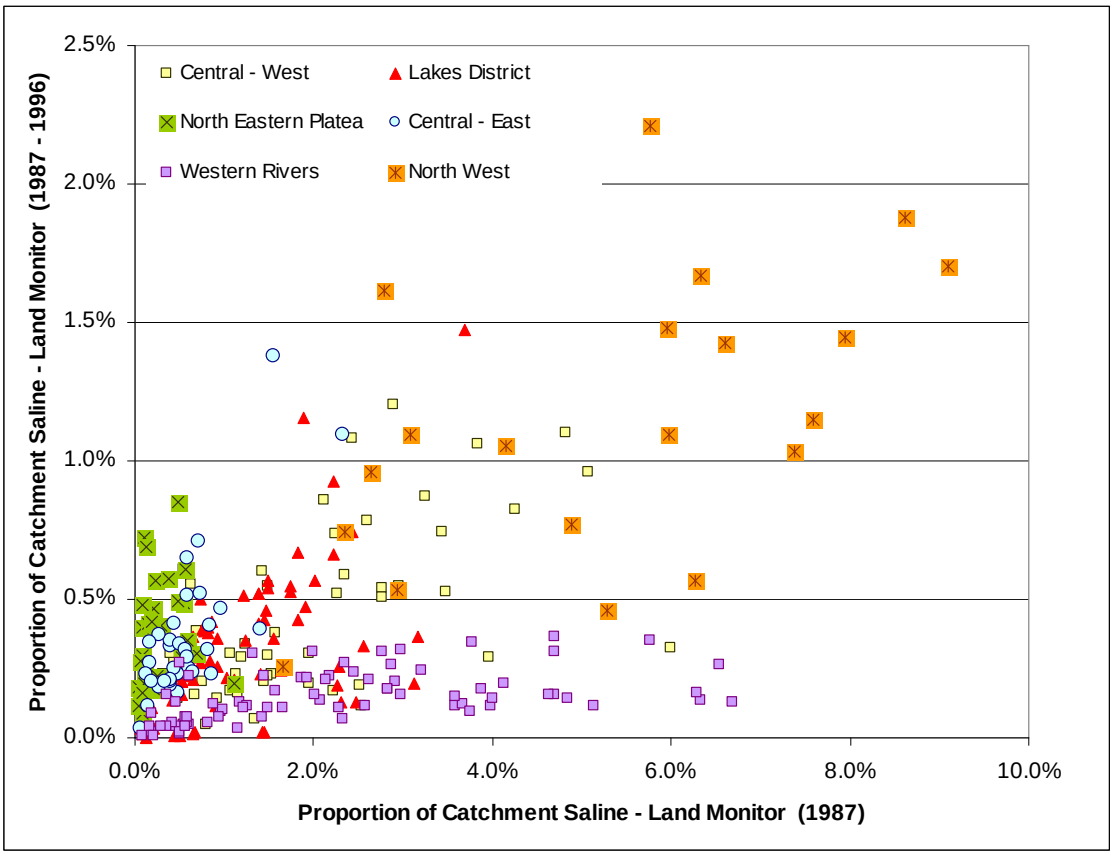
» *The proportion of salinity occurring within secondary subcatchments in 1987 was generally less than 7%, with the exception of subcatchments located within the North West sub region;*

» *The proportion of land affected salinity for the period 1987 – 1996 as a percentage of total salinity within secondary catchments was greatest for the North West sub region;*

» *The proportion of land affected salinity for the period 1987 - 1996 as a percentage of total salinity appears least within Western Rivers subcatchments; and*

» *Salinity is the least developed within secondary catchments of the North Eastern Plateau, however the proportion of land affected salinity for the period 1987 - 1996 as a percentage of total salinity appears consistent with other sub regions.*

Figure 14 Salinity Detected by the Land Monitor for Secondary Catchments



The results of statistical analysis undertaken to determine differences in the spectrum of salinity development between sub regions and landscape units for 1987 and 1996, are presented below.

5.4.1 Sub Regions

The Shapiro-Wilk test (α=0.05) indicated the underlying data is not normally distributed ($p<0.001$) (Appendix A).

A Levene's Test (α=0.05) indicated that the data had heterogeneous variance ($p<0.001$), indicating the data is nonparametric (Appendix A).

The Kruskal-Wallis Test (α=0.05) for Land Monitor mapped salinity in 1987 indicated there are significant differences between the proportion of salinity within sub regions ($p<0.001$).

The Wilcoxon Signed Ranks Test (α=0.05) indicated significant differences between the portion of saline land in 1987 and 1996 ($p=0.02$).

The Mann-Whitney Tests (α=0.05) conducted for Land Monitor 1987 – 1992 indicated the proportion of subcatchment salinity was significantly different between all sub regions, with the exception of the Central-West and Western Rivers sub regions (which were not significantly different at $p=0.525$).

The Kruskal-Wallis Test (α=0.05) for Land Monitor salinity mapped in 1996 indicated differences in the proportion of salinity between individual sub regions (p<0.001). Mann-Whitney Tests (α=0.05) indicated salinity development between 1987 and 1996 was similar (not significantly different) within the Central-East, Central-West, Southern Lakes and North Eastern Plateau sub regions. However, salinity development within the Western Rivers and North West sub regions was found to be significantly different in proportion to all other sub regions.

5.4.2 Landscape Units

The series of statistical tests used in Section 5.4.1 were applied to landscape units within the Avon River basin.

The Shapiro-Wilk test (α=0.05) indicated the landscape salinity data is not normally distributed (p<0.001). A Levene's Test (α=0.05) indicated the Landscape data has heterogeneous variance (p<0.001), suggesting that the data is nonparametric. Results of the analysis are presented in Appendix A.

A Wilcoxon Signed Ranks Test (α=0.05) indicated significant difference between the portion of saline land in 1987 when compared to 1996 (p<0.001). In further statistical analysis of salinity between landscape units, differences between the salinity in 1987 and 1996 were considered.

A Kruskal-Wallis test (α=0.05) was conducted on Land Monitor 1987 salinity extent and indicated differences in the portion of salinity within landscapes in 1987 (p<0.001). Mann-Whitney Tests (α=0.05) comparing individual landscapes indicated not all landscape units were significantly different from one another in saline proportions (Appendix A).

Groupings of adjacent landscape units with similar (not significantly different) Land Monitor mapped salinity percentages in 1987 are presented in Table 5. There are three instances where the Mann-Whitney test returned adjacent landscape units displaying similar salinity in 1987. These include Avon South and Avon East, both located on the eastern margin of the Western Rivers sub region. However, the Mann-Whitney test suggests significantly different values for Avon South and Avon East landscape units for Land Monitor mapped salinity in 1996. Newdegate and Lake King landscape units also returned a similar value (Mann-Whitney test) for Land Monitor mapped salinity in 1987, however returned different values for Land Monitor mapped salinity in 1996. This suggests that whilst salinity for these two pairs of landscape units were similar in 1990, the detected rates of change of salinity after 1990 was dissimilar.

Table 5 Similar Adjacent Landscape Units - Land Monitor 1987 – 1992 (Mann-Whitney P < 0.01)

Group	Landscape Units
1	Avon South, Avon East
6	Newdegate, Lake King
10	Beacon, Westonia, Bodallin, Muntagin

Table 6 Similar Adjacent Landscape Units - Land Monitor 1995 – 1998 (Mann-Whitney P < 0.01)

Group	*Landscape Units*
1	Kellerberrin (H), Nungarin (H)
3 - 4	Merredin, Muntagin, Nungarin (L)
10	Bodallin, Merredin, Muntagin,
12	Ejanding, Koorda, Kellerberrin (L), Merredin, Nungarin
14	Muntagin, Kulin – Holt Rock, Hyden

Table 5 indicates the North East Plateau landscapes of Beacon, Westonia, Bodallin, and the adjacent East Central landscape of Muntagin had similar (not significantly different) salinity values for Land Monitor mapped salinity in 1987. However, Table 6 indicates these landscapes did have significantly different salinity values for Land Monitor mapped salinity in 1996, with the exception of Bodallin and Muntagin, which were not significantly different.

Table 6 indicates that a range of adjacent landscapes, particularly those located throughout the central part of the region, exhibited similar rates of change of salinity after 1987 and before 1996. However, all except for the Bodallin and Muntagin landscape units exhibited different salinity values in 1987.

Salinity development within the Lake King landscape unit appears to have developed at a similar rate to that of the Newdegate landscape to 1987, however Land Monitor reports limited salinity development within all but one subcatchment for the period after 1987 and before 1996 for the Lake King landscape. It is not clear whether this apparent decline in the rate of salinity development is due to different geomorphology of the Lake King landscape, or whether it is a result of an anomaly within the 1996 Land Monitor salinity coverage.

5.5 Conclusions

The rate and extent of salinity development reported by Land Monitor within subcatchments appears to be a function of land form, reflecting underlying geological and geomorphologic differences between sub regions and landscape units.

All sub regions displayed significant differences in salinity development between the two timeframes tested (Land Monitor salinity mapping 1987 and 1996), indicating the severity of salinity increased throughout the region over the period 1987 - 1996.

The Western Rivers and Central West sub regions displayed similar salinity extent in 1987, however different rates of salinity development (or rather severity) between 1987 and 1996. The Central-East, Central-West, Southern Lakes and North Eastern Plateau displayed a similar rate of salinity development between 1987 and 1996, but significant differences in the overall proportion of land salinity is detected by Land Monitor.

Landscape units displayed different rates of salinity development when tested for both time periods, 1987 and 1996, with the exception of Bodallin and Muntadgin. Bodallin and Muntadgin were found to have similar (not significantly different) salinity extent for both periods tested (1987 and 1996).

Land Monitor indicates that the North West sub region displayed the highest proportion of salinity and the Central East and North East Plateau the least proportion of within the Avon River basin in 1996.

Land Monitor indicates that the greatest percentage of salinity development during the period 1987 – 1996 was recorded for the Wongan landscape unit, with the Kellerberrin and Ejanding landscapes (Central West), Nungarin (Central East), Lake Grace, Hyden, Kulin – Holt Rock (Southern Lakes) landscapes also recording above average increases in salinity for the period 1987 to 1996. The Avon Arc and Avon West landscapes (Western Rivers sub region) displayed the lowest increase in the severity of salinity for the period 1987 to 1996.

Additional Land Monitor coverages (ie. mapping of land impacted by salinity in 2006 and beyond) would allow a more comprehensive analysis to be undertaken and provide a more robust assessment of the development of salinity within the region.

6. Groundwater Monitoring Assessment

6.1 Background

The Department of Agriculture and Food (DAFWA) maintain a groundwater monitoring database (Ag Bores) representing the agricultural region of Western Australia. The database consists of clusters of observation wells and nested peiziometers, including over 600 bores, located in 22 subcatchments within the Avon River basin.

DAFWA have previously published groundwater trend data from the Ag Bores database for the Central Agricultural Region (CAR), with a geographic boundary similar to that of the Avon River basin (Nulson 1998, Ghuauri 2004). It is not the intention of this report to repeat the work previously undertaken by DAFWA, however the scope of the analysis undertaken was restricted by the detail of information provided by DAFWA.

6.2 Methodology

Groundwater rate of rise data presented in this study was supplied by DAFWA.

DAFWA undertook analysis of groundwater data and provided values for rates of rise of groundwater for individual bores within the Avon River basin. No actual groundwater levels or hydrographs were available in undertaking this study, due to perceived sensitivities arising from some groundwater bores being located on or near to private property.

Data fields provided with groundwater bore data included:

- *Bore Id;*
- *Catchment;*
- *Salinity (latest reading, average);*
- *pH;*
- *Latest water level;*
- *Rate of Rise 1980 -1990;*
- *Rate of Rise 1990 – 2000; and*
- *Rate of Rise 2000 – 2005;*

Previous published groundwater trend analysis undertaken by DAFWA included assessment using the Hydrograph and Rainfall Time Trend (HARTT) program (Fedowsian et al, 2001). HARTT is used to isolate the effects of rate of rise during the monitoring period and can be used to estimate the time delay between a rainfall event and ground response. However, rates of rise of groundwater bores provided by DAFWA for this project were derived from raw groundwater data only.

The extent of analysis undertaken within this project was restricted by the raw nature of groundwater supplied and lack of supporting information regarding the quality of

bore construction and reliability of monitoring undertaken. The analysis undertaken was restricted to:

- *Geographic assessment of groundwater trends at a sub regional and landscape scale;*
- *Comparison of rates of rise of shallow (water level 2 - 6 m below natural surface) and deeper (greater than 6 m below natural surface) groundwater trends;*
- *Preliminary assessment of groundwater trends for bores contained within significant areas of native remnant vegetation;*
- *Comparison of rates of rise of groundwater bores contained within and outside of the slope hazard area;*
- *A comparative analysis of groundwater rate of rise and Land Monitor salinity trends at a subcatchment scale; and*
- *Time series assessment of rate of rise for the periods 1980 – 1990, 1990 – 2000, and 2000 – 2005.*

Plot distribution analysis was undertaken to develop an understanding of the range and distribution of groundwater rise throughout the region, followed by numeric statistical analysis at a sub regional and landscape unit scale.

Groundwater rate of rise data was tested for normality and homogeneity of variance in order to determine whether the data is parametric or nonparametric and to determine appropriate statistical tests used in the analysis.

The Kolmogorov-Smirnov Test was applied to determine normality of data and Levene's Test was used to test the equality of variance between samples. Both tests applied a confidence interval of 95% (α=0.05).

Outcomes of the preliminary statistical analysis are presented in Appendix B. Groundwater data was shown to be nonparametric, in that samples were not considered to be normally distributed. Furthermore, populations tested, including orientation to sub regional and landscape unit boundaries, depth of latest water level and proximity of valley hazard, did not exhibit similar variance in sample populations. As a result nonparametric (ranked) statistical tests were applied in undertaking the analysis.

Mann-Whitney Tests (α=0.05) were performed on each data set to determine level of significance of rates of rise for groundwater bores located in the different combination of classes listed in Table 7.

Additional background of statistical tests used in the analysis is presented in section 5.2.4 of this report.

Table 7 Groundwater Classes used in Statistical Analysis

Class	*df*	*Descriptions*
Slope Hazard	2	» *Inside slope hazard area* » *Outside of slope hazard area*
Sub Regions	5	» *Western Rivers* » *Central West* » *Central East* » *North East Plateau* » *Southern Lakes*
Depth to groundwater	2	» *Shallow (between 2 – 6 m below natural surface)* » *Deep (greater than 6 m below natural surface)*

df – degrees of freedom

6.2.1 Slope Hazard Analysis

In determining the influence of *slope hazard* area on the rate of rise of groundwater, the data was separated into eight datasets by combining (5) *sub region* and (2) *depth-to-groundwater* class. However, the Western River sub region only had data for outside of the *slope hazard* area resulting in only eight datasets, rather than ten. A Mann-Whitney Test (α=0.05) was performed on each dataset to determine if there was a significant difference in the rate of rise of groundwater located in different *slope hazard* classes for each *sub region* and *depth-to-groundwater* combination.

6.2.2 Depth to groundwater Analysis

In determining significant difference in the rate of rise of groundwater in bores with different *depth to groundwater* classes (*2 - 6 m v's > 6 m below natural surface),* the rate of rise data was separated into nine datasets by *sub region* and *slope hazard* class combinations (note: no bores were located inside the slope hazard area for Western Rivers sub region).

A Mann-Whitney Test (α=0.05) was performed on each dataset to determine significance in the rate of rise of groundwater in bores with different *depth to groundwater* classes for each *sub region* and *slope hazard* combination.

The Mann-Whitney test is a commonly used two sample ranked test for comparing differences between the dispersion or variance of two populations of non-parametric data.

6.2.3 Sub regional Analysis

In determining potential significant differences in the rate of rise of groundwater within five *sub regions*, the data was divided into datasets representing each *depth to*

groundwater class and *slope hazard* area combination. However, only one sub region contained sufficient data for bores where the depth-to-groundwater was more than 6m below natural surface, therefore the analysis was restricted to three data sets. Separate Kruskal Wallis Tests (α=0.05) were applied to determine if the rate of rise of groundwater within paired *sub regions* was significant.

Mann-Whitney Tests (α=0.05) were then performed on each of the pairs of *sub regions* to determine which *sub regions* displayed different rates of rise of groundwater. The analysis provides an assessment of significance between *sub regions*, including differences in variance in *depth-to-groundwater* and orientation to *slope hazard*.

6.3 Discussion

DAFWA provided data for a total of 1,445 groundwater bores, including 512 contained within the Ag Bores network (managed by DAFWA) and a further 933 community bores (Figure 15). Community bores, which are funded by community landcare groups for the purpose of both investigation and monitoring, were identified by DAFWA in undertaking a review of groundwater bores in the region within the Groundwater Source Identification and Monitoring project for the Avon Catchment Council.

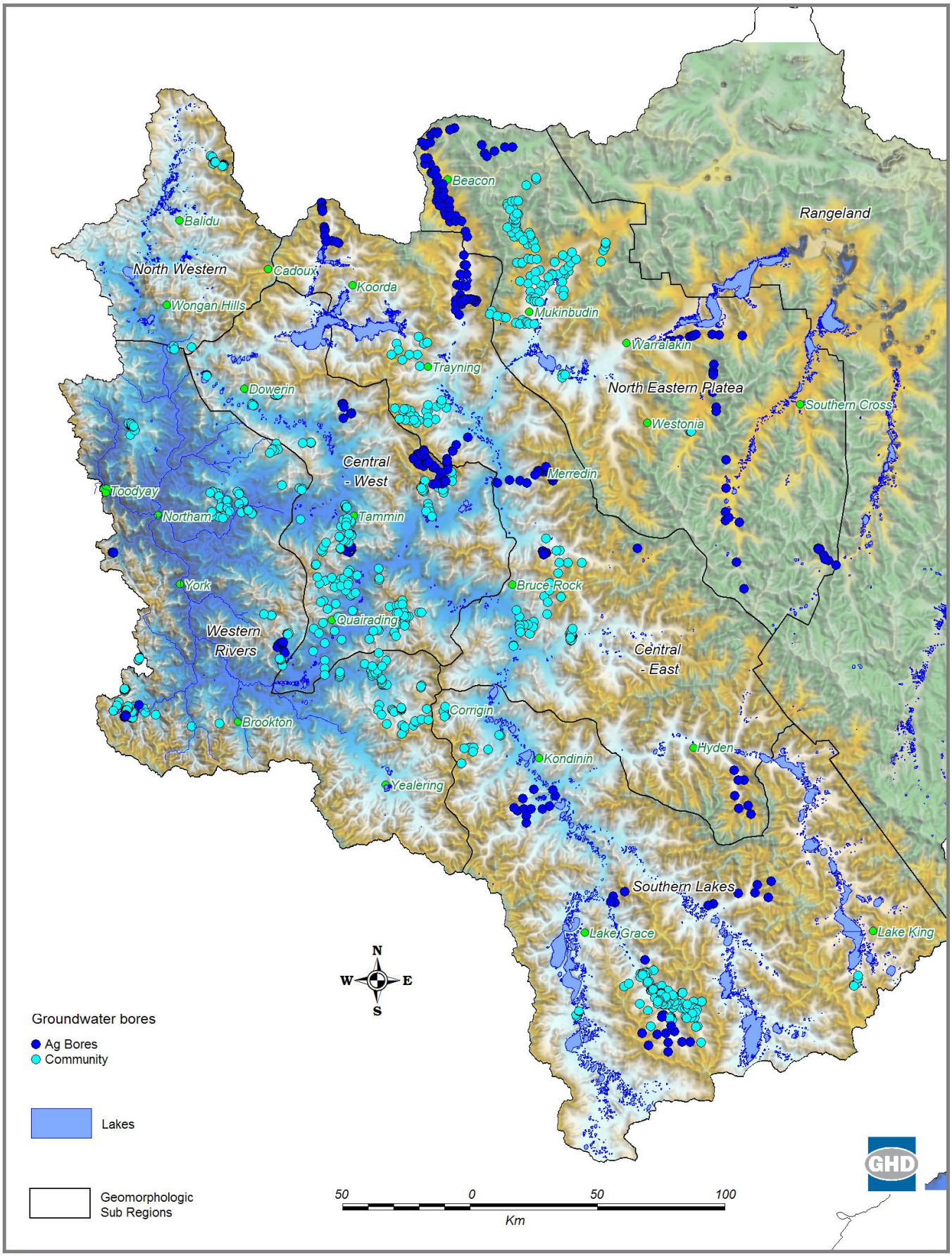
It was reported by DAFWA that no reliable rate of rise could be reasonably identified for the community bores identified in the study *(Smith pers. com.).* As a result discussion of groundwater trends within this report is by necessity restricted to the 512 bores contained within the Ag Bores network.

Table 8 Summary of Groundwater Bores - Avon River Basin

	Number of Groundwater bores	
Latest Recorded Groundwater Level	***All Bores***	***Trends Reported***
Less than 2 m BNS	221	170
2 - 6 m BNS	188	181
Greater than 6 m BNS	103	102
Total	***512***	***453***

** BNS: Below Natural Surface*

Of the 512 Ag Bore groundwater bores, 453 had groundwater trend data reported. Of these, 170 bores had their latest groundwater level reported less than 2 m below the surface. Groundwater bores with a standing water level less than 2 m below surface were excluded from the subsequent analysis of groundwater trends for this report, as it was considered that ground surface interactions with shallow water tables would have a negative effect on the reliability of the data. Rate of rise data for the remaining 283 groundwater bores was used in the analysis presented below.



Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 50

Figure 15. Groundwater Bores - Avon River Basin

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The decision to compare bores with depth to groundwater of 2 – 6 m and greater than 6 m below natural surface was based on the likely hazard of salinity development. Bores with recent groundwater levels within 6 m of the natural surface may present a short - medium hazard of salinity development. Assuming a base rate of rise of 0.1 – 0.2 m /year, these bores may present groundwater levels within 2 m of the natural surface over a 20 - 40 year period. Bores with recently reported groundwater levels of more than 6 m below natural surface present a much longer-term potential hazard of salinity development.

In addition, previous investigations undertaken by DAFWA indicated groundwater bores with water levels of more than 6 m below natural surface display a muted response to rainfall events, when compared to bores where the water table is within 6 m of the natural surface (Ghuauri 2004).

6.3.1 Native Vegetation

Development of salinity within the Avon River basin is generally considered to have been caused by the replacement of native vegetation with annual crops and pastures. A comparison of groundwater trends under both native vegetation and annual crops and pastures could provide an understanding of causal relationships associated with clearing of native vegetation over the development of salinity within the region.

The location of bores provided by DAFWA was overlaid with native vegetation areas of greater than two square kilometres to identify groundwater bores that were contained within significant areas of native vegetation. The distribution of bores contained within native vegetation is presented in Table 9.

Table 9 Depth to Groundwater of Bores Located within Native Vegetation

Sub Region	Catchment	Less than 2 m BNS	Between 2 - 6 m BNS	More than 6m BNS	Total
Central - East	Bulgin	13	1		**14**
Central - East	Merredin	2	4	1	**7**
Central - East	Newcarlebon Kulja	2	3	1	**6**
Central - West	Wallatin Ck	3	4	4	**11**
North Eastern Plateau	Beacon	7	1	1	**9**
Southern Lakes	Lake Bryde	2		2	**4**
Southern Lakes	Newdegate	2			**2**
	Total	**31**	**13**	**9**	**53**

In total 53 bores are contained within significant areas of native vegetation (> 2 km^2) over 17 locations throughout the region. It was found that 31 (58%) bores within native vegetation recorded the water level of less than 2 m below natural surface. As previous discussed, groundwater bores where water levels are less than 2 m below natural surface have been excluded from analysis, due to potential biasing associated with ground surface interactions resulting from capillary rise. After removal of these data, there remains only 22 bores contained within areas of native vegetation, including 13 with water levels between 2 and 6 m below natural surface and nine bores with water levels reported greater than 6 m below natural surface.

When sub regional distribution is taken into account only the Central East and Central West sub regions have more than two bores contained within native vegetation where reported water levels are more than 2 m below natural surface. No formal statistical analysis of these data was undertaken due to the small sample sizes.

Preliminary analysis indicates groundwater rate of rise within bores contained within areas of significant native vegetation generally reflect those recorded for the broader population of groundwater bores. Most groundwater bores constructed within areas of native vegetation appeared to be located within 100 m of the edge of the area of native vegetation, potentially introducing edge effects, biasing the results of native vegetation responses.

Figure 16 Rate of Rise Under Native Vegetation - Recent Groundwater Level Between 2 - 6 m Below Natural Surface

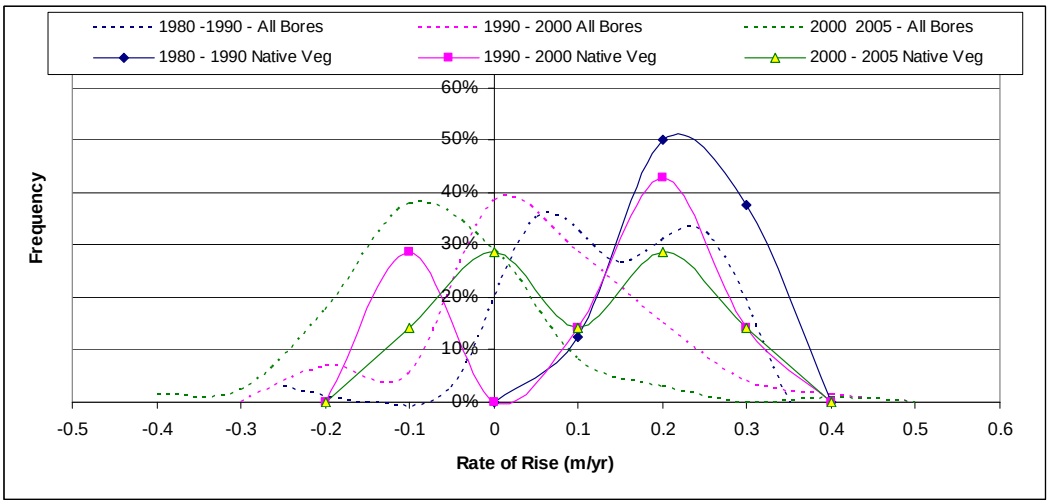
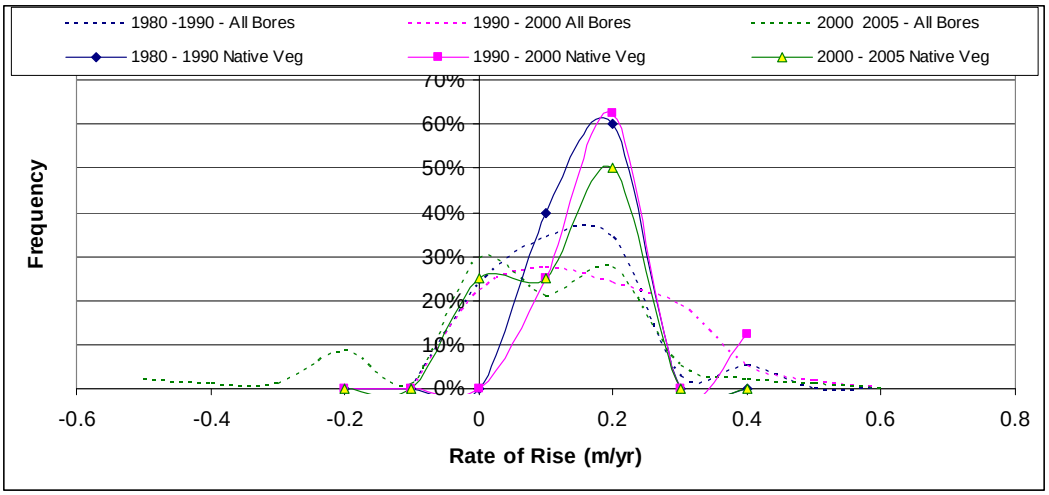


Figure 17 Rate of Rise Under Native Vegetation -Recent Groundwater Level more than 6 m Below Natural Surface



On the basis of the information supplied it is very difficult to draw conclusions regarding groundwater response of bores located within areas of significant native remnant vegetation. The low number and poor distribution of groundwater bores contained within significant areas of native vegetation, exacerbated by the apparent placement of bores near to the edge of blocks of native vegetation, appear to significantly limit the capacity to determine a *normal* groundwater response under native vegetation conditions. In addition, a high proportion of groundwater bores located within native vegetation display a recent water level of less than 2 m below natural surface, indicating a strong selective preference for sighting of bores in wet areas or areas adjacent to agricultural land impacted by salinity.

6.3.2 Depth to Groundwater

Understanding differences in response of groundwater bores with different depth to groundwater is important when interpreting groundwater responses to climatic variations. Groundwater rise for bores with a standing water level ~ 2 – 6 m below natural surface and those with a standing water level of greater than 6 m below natural surface, for the time periods 1980 - 1990, 1990 - 2000, 2000 - 2005 are presented in Table 10 and Table 11.

Table 10 Rate of Rise of Groundwater Bores - Water Level 2 – 6m Below Natural Surface.

	Rate of Rise (m/year)		
	1980 - 1990	**1990 - 2000**	**2000 - 2005**
Average	0.09	0.05	(- 0.08)
St dev	0.11	0.12	0.12
Count	34	73	135

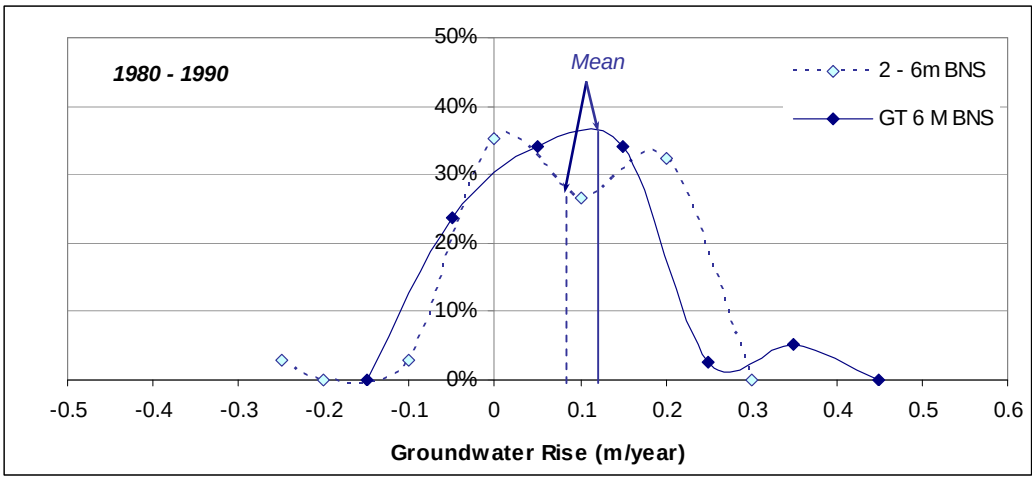
Table 11 Rate of Rise of Groundwater – Water Level more than 6M Below Natural Surface.

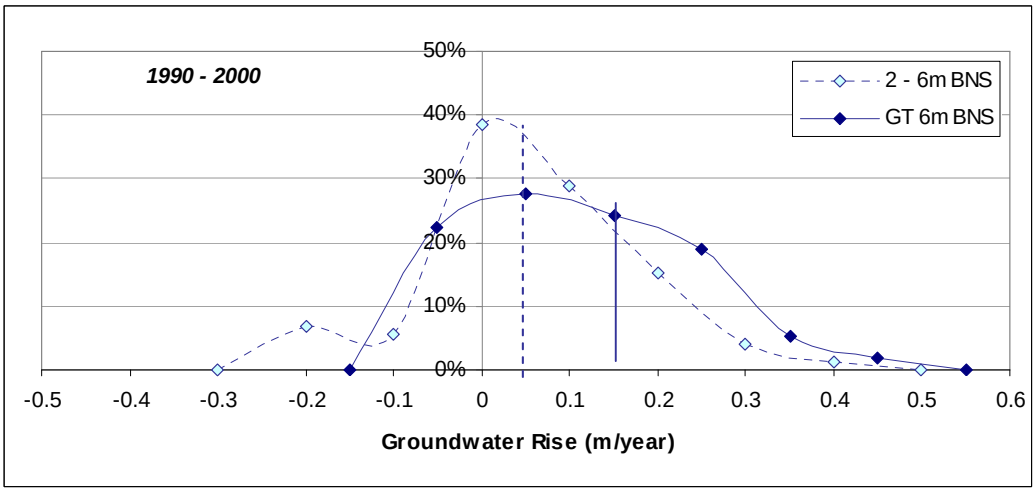
	1980 – 1990	**1990 2000**	**2000 - 2005**
Average	0.12	0.15	0.06
St Dev	0.10	0.13	0.20
Count	38	58	96

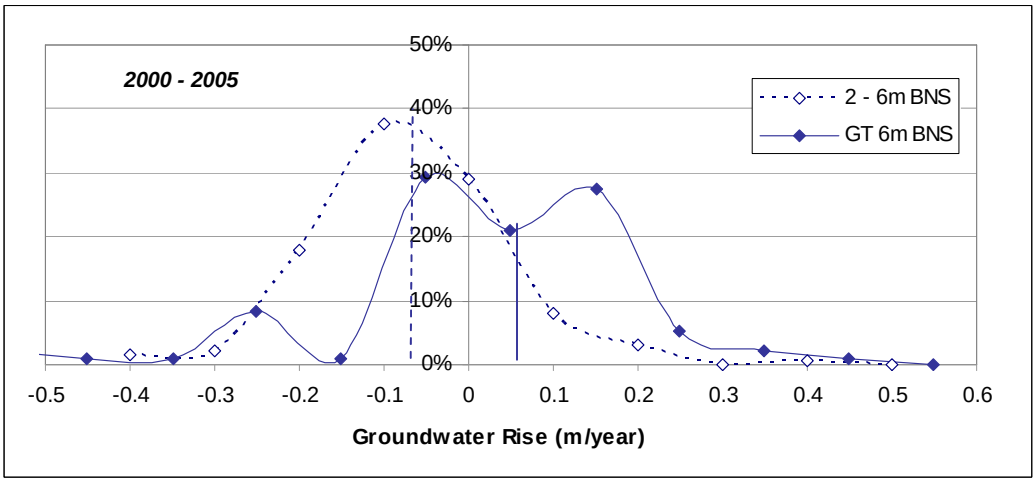
The results appear similar to those presented by DAFWA in the CAR groundwater trend analysis (Heath and George 2007). Heath and George (2007) reported average groundwater rise of 0.1 m/year for the periods 1980 - 1990 and 1990 – 2000, and 0.02 m/yr for the period 2000 – 2005, across 22 catchments within the CAR. Heath and George (2007) also reported that 40% of bores in the period 2000 – 2005 had no trend (zero groundwater rise/fall). This analysis was undertaken using a subset of 273 of the 600 bores within the CAR, with bores chosen based on quality of data, length of record, excluding those associated with *treatments* such as trees and drains; and filtered for sites where multiple bores existed (Heath and George 2007).

The analysis indicates groundwater bores with a shallow standing water level respond to short term climatic variations. Groundwater bores reporting recent standing water levels of greater than 6 m below natural surface demonstrate buffering to shorter term climatic variations, potentially indicating continued longer term hazard of salinity development.

Figure 18 Distribution Rate of Groundwater Rise 1980 – 1990, 1990 – 2000, 2000 - 2005







The rate of rise of all bores appears to exhibit a similar distribution in the period 1980 – 1990, however groundwater bores with a shallow depth of groundwater displayed a declining trend in rate of rise over the period 1990 – 2005. The water level in groundwater bores where the recent water level was reported less than 6 m below natural surface appeared to fall during the period 2000 – 2005 (Figure 18).

Groundwater bores where the recent water level was reported more than 6 m below natural surface displayed an increase in variance coupled with a slight decline in the rate of rise over the period 2000 – 2005.

Previous investigations indicate that summer rainfall patterns have a strong influence over groundwater response within the central agricultural region of Western Australia (Ghuauri 2004). The apparent decline in rate of rise of groundwater after 2000 is considered most likely to be caused by a combination of a decline in growing season rainfall (April – October) coinciding with a large episodic rainfall event in January 2000.

Growing season rainfall for the period 2000 – 2005 was typically between 10% and 25% below the long term average for most centres within the Avon River basin, in contrast to the period 1980 -1990, where growing season rainfall was typically between 5% below and 10% above long term averages for the region. Excess rainfall during periods of low evapo-transpiration during winter and spring and large episodic summer events are most likely to result in recharge of shallow groundwater tables.

Table 12 Mann-Whitney Tests Results Comparing Depth to Groundwater Classes

	Sub Region				
Slope Hazard Class	***Central-East***	***Central-West***	***Lakes District***	***North Eastern Plateau***	***Western Rivers***
Within Slope Hazard	SD	NS	NS	SD	-
Outside Slope Hazard	SD	NS	SD	SD	NS

SD: Significant Difference in the rate of rise for the particular Sub Region and Slope Hazard area Class combination (α=0.05).

NS: No Significant Difference in the rate of rise for the particular Sub Region and Slope Hazard area Class combination (α=0.05).

- : No statistical analysis done due to availability of data.

Mann-Whitney Tests (α=0.05) undertaken indicates significant differences in the rate of rise of groundwater in some sub regions within and outside of the slope hazard area (Table 12). Differences between bores with shallow and deeper standing water level appear most significant in the Central East and North East Plateau sub regions, with significant differences in the rate of rise of groundwater in the Lake District restricted to bores located outside of the valley hazard area. Statistical analysis indicates no significant difference between the rate of rise of groundwater bores with shallow and deeper standing water level located within the Central West, and Western Rivers sub

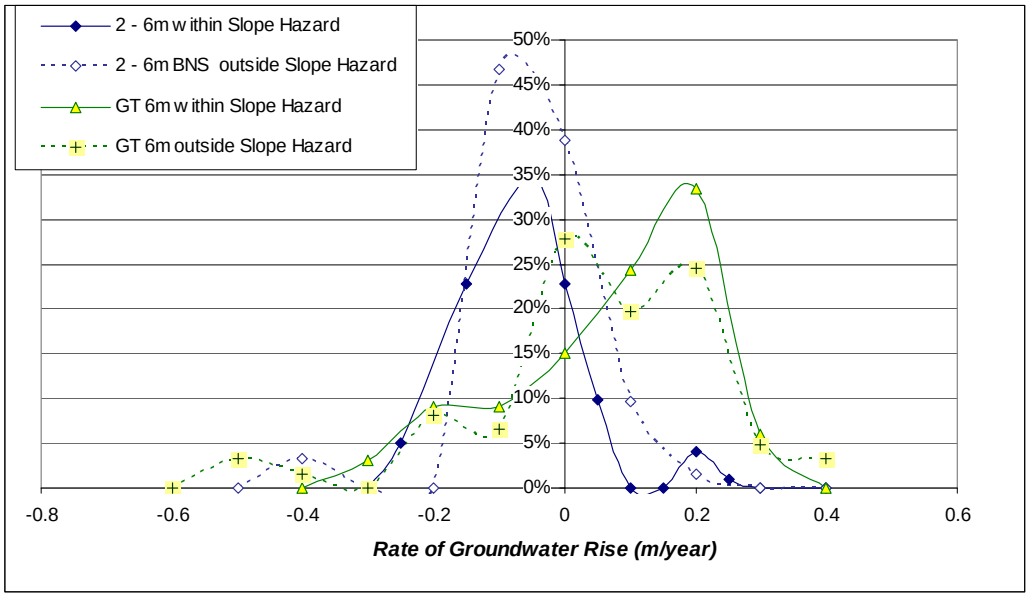
regions. No groundwater data is available for the North West sub region. Detailed results are presented in Appendix D.

The statistical analysis undertaken indicates that significant differences between groundwater rise for bores with different depths of groundwater are most significant in the eastern part of the region.

6.3.3 Slope Hazard Area Analysis

Frequency distribution of groundwater rate of rise within and outside of slope hazard areas indicates similar distribution when compared for shallow and deep groundwater bores (Figure 19).

Figure 19 Frequency Distribution of Groundwater Rise for Bores Located within and outside of Slope Valley Hazard Areas



Mann-Whitney Tests (α=0.05) undertaken indicate there was no significant difference in the rate of rise of the groundwater in bores located within and outside of the slope hazard area; with the single exception of a bore with a shallow depth to groundwater within the Central-East sub region only.

Data outputs from statistical analysis undertaken are presented in Appendix C.

6.3.4 Sub Regional Analysis

The relative distribution of groundwater trends for groundwater bores with a shallow depth to groundwater are presented for four sub regions in Figure 20. There are no groundwater bores located within the North West and limited groundwater bores located within the Western Rivers sub region. However, construction of new groundwater bores undertaken by DAFWA, under contract to the Avon Catchment Council, includes additional bores located within both the Western Rivers and North - West sub regions.

The analysis indicates normally distributed groundwater trends for the Central East and Central West sub regions, with a mean rate of rise of -0.05 m/year and 0.15 m/yr respectively. Groundwater data for the North Eastern Plateau is skewed to the left with a median rate of rise of approximately -0.15 m/year. The Southern Lakes sub region displays a split distribution with bores located within the Kulin – Holt Rock and Newdegate landscape units reporting different groundwater responses, with mediam values for rates of rise of 0.04 m/yr and -0.16 m/yr respectively.

Figure 20 Distribution of Groundwater Trends for Sub Regions (bores with a shallow depth to groundwater) 2000 – 2005

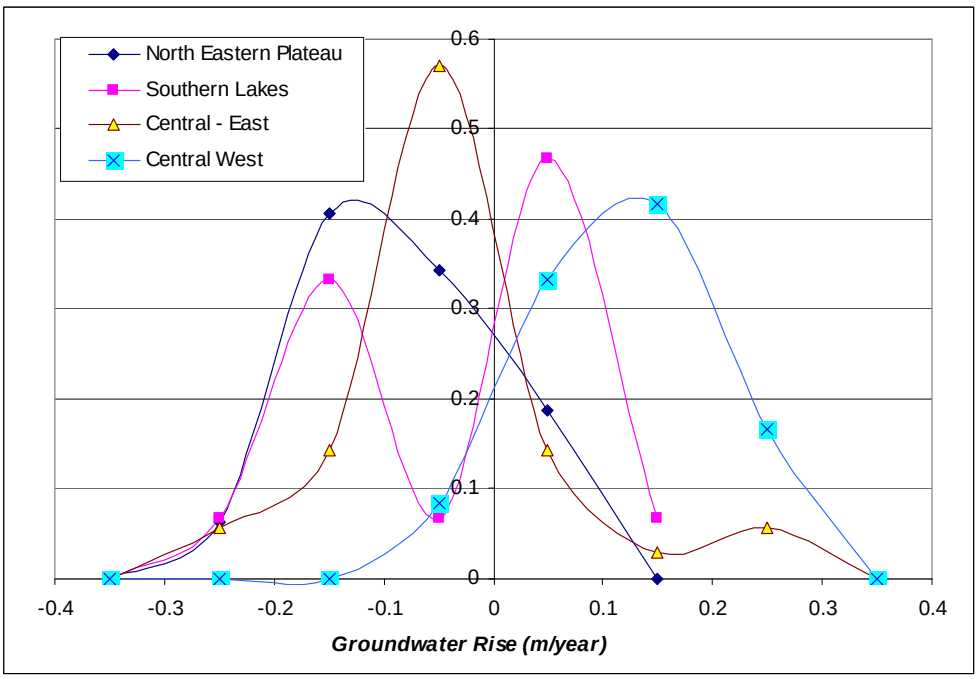
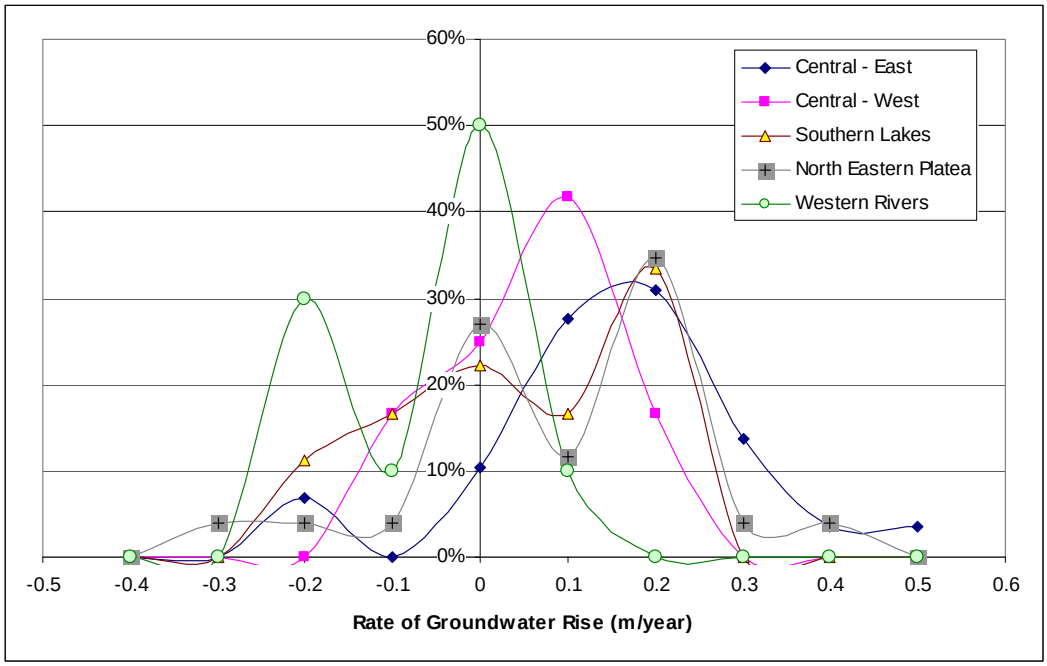


Figure 21 indicates frequency distribution of rate of rise of groundwater for bores with a standing water level of more than 6 m below the surface, is similar for those bores located within the eastern part of the Avon River basin (North East Plateau, Southern Lakes and Central East sub regions). However, the rate of rise of bores within the Central West and Western Rivers sub regions appear to differ from those located within eastern sub regions and from one another.

Figure 21 Distribution of Groundwater Trends for Sub Regions (deep groundwater bores) 2000 – 2005.



The Kruskal-Wallis Tests (α=0.05) undertaken indicate the rate of rise of groundwater in the five sub regions were not all the same.

Mann-Whitney Tests analysis (α=0.05) indicated the rate of rise of groundwater in the combinations listed below were similar to (not significantly different from) each other:

» *North East Plateau and River Catchments;*

» *Central-East and Lakes District; and*

» *North East Plateau and Lakes District.*

Mann-Whitney Tests (α=0.05) indicated that rates of rise of groundwater bores from the following sub regions are significantly different from one another:

» *Central-East and River Catchments; and*

» *Central-West and River Catchments.*

The remaining combinations of sub regions were found to be significantly different from one another in some combination of depth to groundwater or location of the bore with respect to slope hazard area, yet not significantly different in other combinations (Table 13). Detailed results of the statistical analysis are presented in Appendix E.

Table 13 Mann-Whitney Test (a=0.05) to Determine Significant Differences in the Rates of Rise across Sub Regions

Sub Region 1	Sub Region 2	SWL and Slope Hazard area Combination		
		Outside Slope Hazard area and Deep bores (GT 6m bns)	Outside Slope Hazard area and Shallow Bores (2 - 6m bns)	Inside Slope Hazard area and Shallow Bores (2 - 6m bns)
Central-East	Central-West	NS	SD	SD
	Lakes District	NS	NS	NS
	North Eastern Plateau	NS	SD	NS
	River Catchments	SD	SD	-
Central-West	Lakes District	NS	SD	NS
	North Eastern Plateau	NS	SD	SD
	River Catchments	SD	SD	-
Lakes District	North Eastern Plateau	NS	NS	NS
	River Catchments	SD	NS	-
North Eastern Plateau	River Catchments	NS	NS	-

SD: Significant Difference in the rate of rise for the particular Sub Region and Slope Hazard area Class combination (α=0.05).

NS: No Significant Difference in the rate of rise for the particular Sub Region and Slope Hazard area Class combination (α=0.05).

- : No statistical analysis done due to availability of data.

The statistical analysis of rate of rise of groundwater across different sub regions is inconclusive, however significant differences between the rates of groundwater rise between adjacent sub regions is prevalent. In addition, geomorphologically similar sub regions (including Lakes district and North East Plateau) appear to display similarities in the rate of groundwater rise.

In general, significant differences in the rates of groundwater rise between sub regions is more prevalent in bores with a groundwater level of 2 - 6 m below natural surface, when compared to bores with a groundwater level greater than 6 m below natural service, reflecting shallow groundwater responses to short-term climatic variations.

6.3.5 Time Series Analysis

When comparing the rate of rise of groundwater bores for time periods 1980 - 1990, 1990 - 2000, and 2000 - 2005, it should be noted that different groundwater bore numbers for each period were used in the analysis. The number of bores with a groundwater level between 2 and 6 m below natural surface with reported rates of rise of groundwater increased from 34 to 135 over the period 1980 – 2005.

Potential bias in reporting rates of groundwater rise may have occurred from accounting for bores that were not present over all three time periods. If the sample of groundwater bores reported is reduced to those with rate of rise data recorded for all three periods, then a steady groundwater rise 0.1 - 0.2 m/yr is apparent, with little or no distinguishable trend over the monitoring period. However, the sample size is considered too small to provide a reasonable representation of groundwater bores across the Avon River basin.

An alternate means of comparison was considered by comparing adjacent time periods of 1980 - 1990 with 1990 – 2000, and 1990 - 2000 with 2000 - 2005. Outcomes of this comparison are presented in Appendix D.

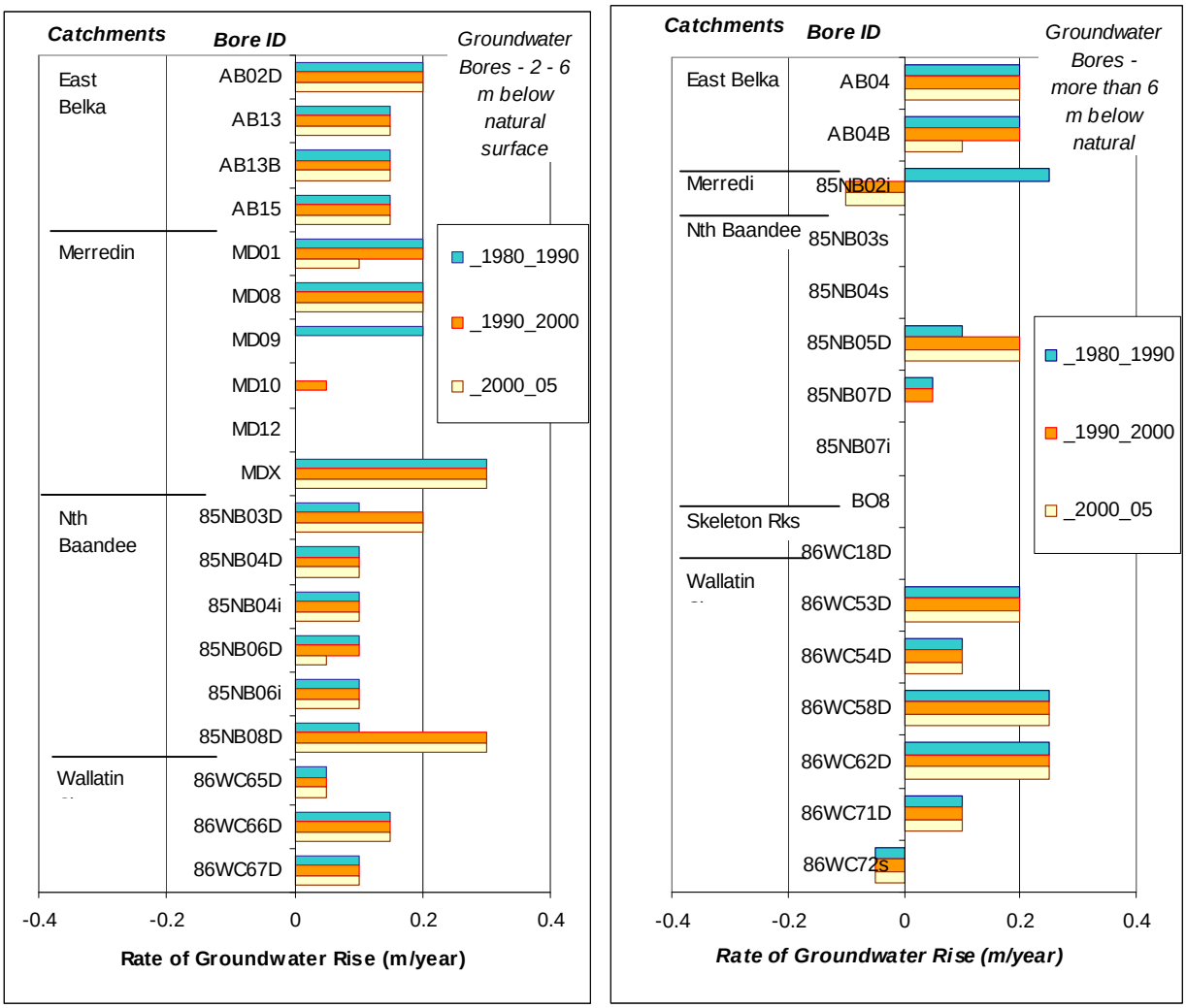
The time series analysis indicates little difference in groundwater rise for either shallow or deep groundwater bores for the periods 1980 - 1990 and 1990 - 2000, with the potential exception of the Merredin subcatchment where water levels in shallow groundwater bores appeared to decline significantly after 1990. This appears inconsistent with trends of other groundwater bores within the Central-East sub region or the Merredin – Narembeen landscape unit.

Groundwater bores monitored for the periods 1990 - 2000 and 2000 - 2005 indicate a consistent decline in the rate of groundwater rise in groundwater bores with a shallow depth to groundwater after 2000, with the exception of the Kellerberrin landscape unit (represented by groundwater bores within the Wallatin - O'Brien subcatchment). Bores located within the Wallatin - O'Brien subcatchment display a muted response to short term climatic impacts in groundwater rise recorded for shallow bores.

There was little or no change in rates of rise of bores with depth to groundwater of more than 6 m below natural surface for all landscape units, with the exception of Newdegate. Newdegate is represented by groundwater bores located within the Lake Bryde subcatchment, where a reduction from +0.2 m/yr to -0.2 m/yr was experienced in deep groundwater bores in the period 2000 - 2005 when compared to 1990 - 2000.

As no correction of rainfall had been undertaken for rates of rise of groundwater provided by DAFWA, it is entirely possible the time series analysis is heavily biased by a large rainfall event in January 2000. Given bores with a shallow depth of groundwater displayed a declining trend after 2000, which is generally not reflected in bores with a greater depth of groundwater, a shallow groundwater response to the January 2000 event appears likely. The extent to which this masks an overall decline depths of shallow groundwater tables within the region after 2000 is unclear.

Figure 22 Rates of Rise - Individual Groundwater Bores Monitored During All Periods (1980 - 1990, 1990 - 2000, 2000 - 2005)

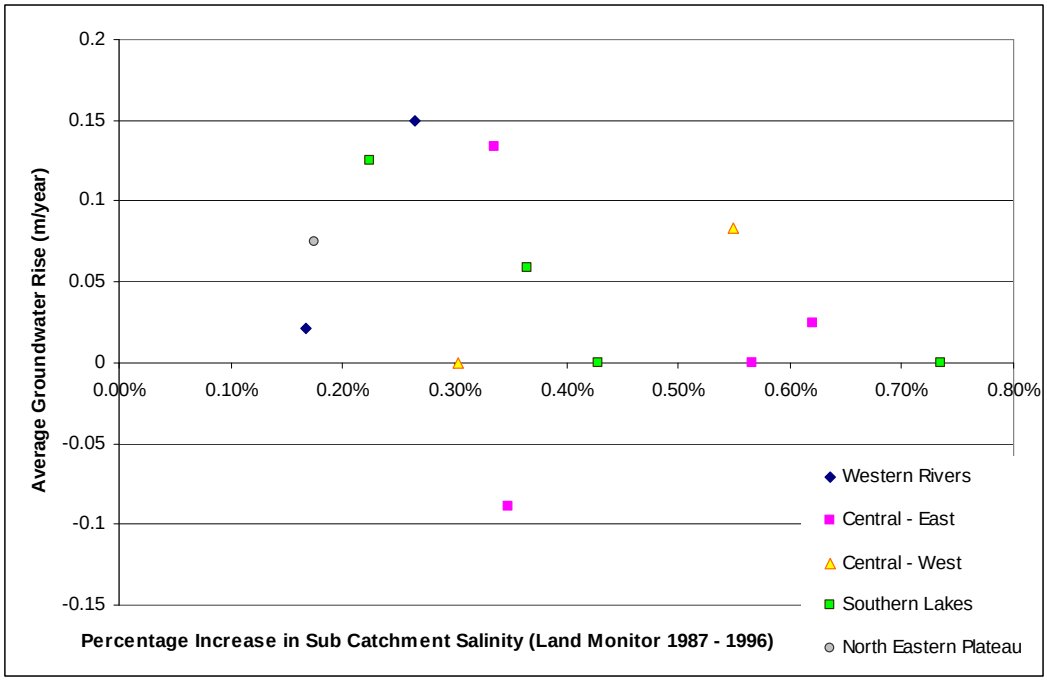


6.3.6 Land Monitor Analysis

A comparison of the rate of increase of salinity for the period 1987 – 1996, reported by Land Monitor and the rate of groundwater rise for the period 1990 - 2000 was undertaken at a subcatchment scale to determine correlation between the two datasets.

The analysis included estimating the proportion of the subcatchment to have become saline for the period 1987 - 1996 by Land Monitor for subcatchments where groundwater bore data existed (Figure 23). Groundwater data was restricted to bores with a SWL of between 2 and 6 m below natural surface and where there was a groundwater trend reported for the period 1990 - 2000.

Figure 23 Comparison of Increase in Salinity (Land Monitor) the Rate of Groundwater Rise - for Selected Subcatchments



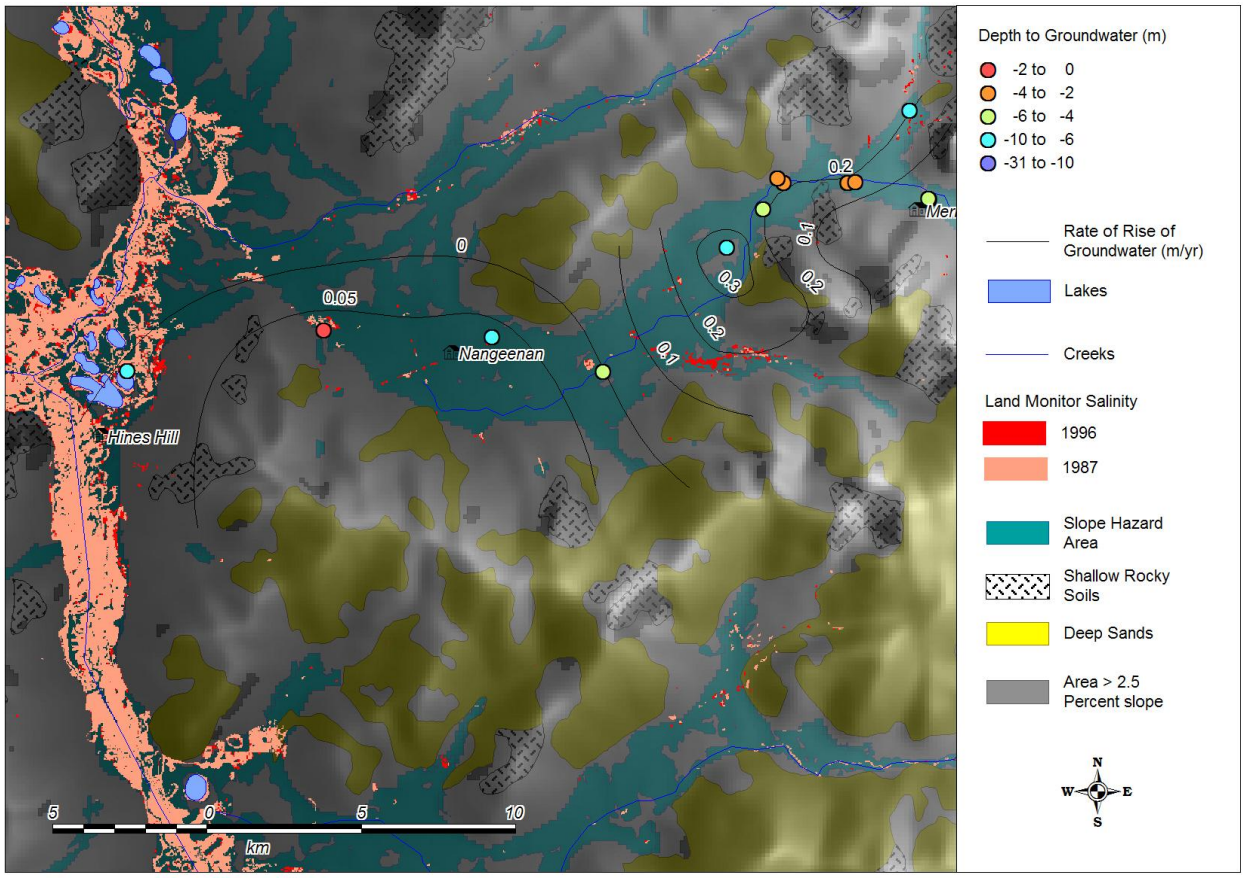
The analysis found no direct correlation between the increase in salinity estimated by Land Monitor and the recorded rate of rise of groundwater within selected subcatchments. This was not surprising, given intrinsic errors within Land Monitor, the lack of consistency in timeframes used in the analysis (1987 - 1996 for Land Monitor compared with 1990 – 2000 for groundwater rise), the relatively small bore data set available and lag time that exists between initial salinity development and detection by Land Monitor.

There is also significant variation in rates of rise of groundwater within individual catchments. The Wallatin – O'Brien and Merredin – Nangeenan catchments are the only subcatchments within the Avon River basin where sufficient number of bores are available to undertake an assessment of spatial variation in groundwater rise.

Contours for rates of rise of groundwater for these two subcatchments have been developed from groundwater data provided by DAFWA and mapped with recent depth to groundwater and Land Monitor mapped salinity for 1987 and 1996 (refer Figure 24 and Figure 25). The purpose of the assessment was to highlight drivers for and provide an indication of the spatial variability associated within groundwater trends.

Figure 24 and Figure 25 indicate a significant variation in rate of groundwater rise within the two mapped subcatchments. Where overlayed with depth to groundwater and the mosaic response of salinity development, it appears a simple analysis of average rate of rise of groundwater is unlikely to, in itself, provide a definitive assessment of the rate of spread of salinity.

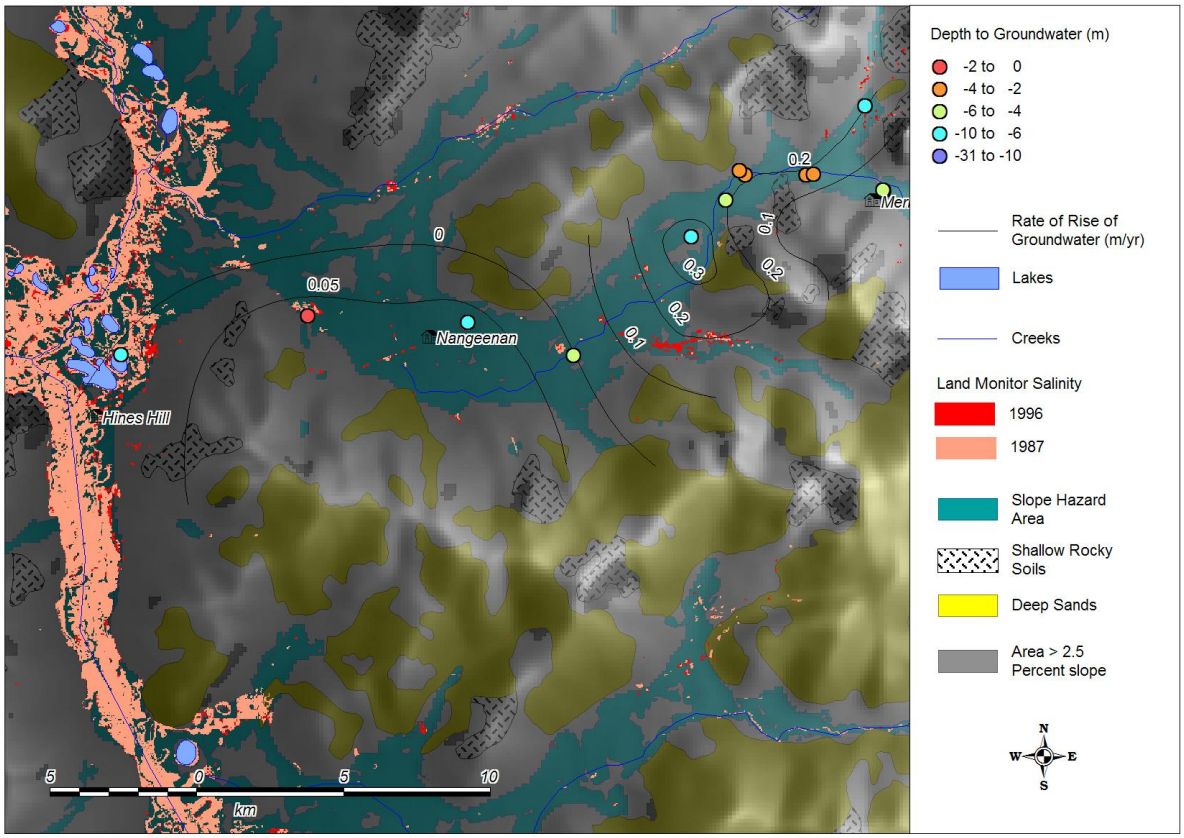
Figure 24 Land Monitor Salinity and Rate of Rise of Groundwater (1990 – 200) for the Wallatin – O'Brien Catchment



Patterns of salinity development are in part influenced by the geomorphology of the catchment, including orientation of shallow rock and associated high sloping surfaces, constrictions and confluences within drainage lines and changes in slope associated with the margins of valley flats. Deep sands may influence rates of recharge and in some cases may exacerbate the incidence of salinity development, however a range of factors clearly influence the rate of rise of groundwater and patterns of salinity development.

The recorded rate of rise of groundwater in the mid – lower Wallatin - O'Brien catchment is 0 – 0.05 m/yr for the period 1990 - 2000, whilst Land Monitor detected increasing severity of salinity in this part of the catchment for the period 1987 - 1996. This is consistent with Land Monitor detecting the development of salinity after profile saturation has occurred. The orientation of groundwater bores near to saline areas in the lower – mid catchment may not provide a true indication of the upward trend in groundwater within that part of the catchment.

Figure 25 Land Monitor Salinity and Rate of Rise of Groundwater (1990 – 200) for the Merredin – Nangeenan Catchment



Rates of groundwater rise in the Merredin catchment are variable with the orientation of shallow rock appearing to influence depth to groundwater in the mid part of the catchment. Salinity is less well developed in the Merredin catchment when compared to the Wallatin O'Brien catchment located to the west. However the development of salinity appears to be influenced by the orientation of shallow bedrock in particular and the confluence is a quarter courses and along the margins of valley flats.

No comparison of rate of rise of groundwater bores for the period 1980 - 1990 and Land Monitor data was possible due to insufficient groundwater bores with reported rates of rise for that period.

Although no direct correlation could be established between rate of rise of groundwater and increased salinity measured by Land Monitor at a sub regional scale, both datasets provided similar overall regional trends. These trends include a slowing of salinity development within the Western Rivers sub region and continued salinity development within the Central West. Both groundwater rise and Land Monitor data suggest subdued salinity development within the Central East and Southern Lake sub regions after 1990.

Analysis of both datasets provides a less clear indication of trends of salinity development within the North East Plateau, however Land Monitor indicates salinity may be an emerging issue within this sub region, with groundwater data indicating increasing trends in groundwater for deep and shallow bores throughout the 1990's, with a declining trend in shallow groundwater bores after 2000.

6.4 Conclusions

Significant differences between the rate of rise of bores with shallow (SWL 2-6 m below natural surface) and deeper (SWL > 6 m below natural surface) depth to groundwater were found to exist. A reduction in the rate of rise of bore with a shallow depth to groundwater appears to reflect the timing of large episodic rainfall events and a decline in growing season rainfall over the period 2000 – 2005, when compared to the period 1980 – 2000. The decline in rate of rise of bores with a shallow depth to groundwater appeared more pronounced in the eastern and southern areas of the region, with no significant difference between shallow and deep groundwater bores recorded within the Central West and Western River sub regions.

Bores with a shallow depth to groundwater appear more dynamic than bores with deeper groundwater levels, responding to short-term climatic variations. Bores with groundwater more the 6 m from the natural surface appear to display a muted response to changes to climatic conditions experienced for the period 2000 – 2005, with most deep groundwater bores continuing to rise throughout this monitoring period. Lake Bryde (*Southern Lakes*) was the only subcatchment to record consistent reductions in rate of rise of deep groundwater bores for the period 2000 – 2005.

No significant differences were found in the rate of rise of groundwater bores located within and outside the slope hazard area, except for within the Central East sub region. Significant differences within this sub region were restricted to differences in the rate of rise of shallow groundwater bores. It was concluded that location of the groundwater bore with respect to the slope hazard area generally had no influence over the rate of rise of groundwater.

No trend in groundwater rise within areas of native remnant vegetation could be established. Groundwater response in these areas appeared similar to rates of rise recorded for cleared cultural land. However the small number of bores and strong tendency to orientate bores in areas with shallow water tables and/or near to the edge of native vegetation blocks will almost certainly have introduced significant sampling bias. The lack of robust groundwater data under native vegetation conditions makes it difficult to effectively determine the impact of land clearing on the rate of rise of groundwater under agricultural land.

Sub regional analysis of trends in groundwater rise indicated differences between some sub regions, particularly for bores with groundwater 2-6 m below natural surface. The relatively small number of bores and their clustered distribution within isolated subcatchments may have resulted in sampling bias. However, the results indicate significant differences between groundwater rise between sub regions, except for the following pairs of sub regions: Southern Lakes and North East Plateau,

Southern Lakes and Central East, North East Plateau and West Rivers; where rates of groundwater rise were found to be similar.

No correlation was found between the rate of rise of groundwater and spread of land salinity detected by Land Monitor. However, overall spatial trends indicated by both datasets appear similar. Observations include a slowing of salinity development within the Western Rivers sub region, continued salinity development within the Central West, subdued salinity development within the Central East and Southern Lakes, with salinity development within the North East Plateau largely emerging after 1990.

The analysis undertaken within this report was greatly constrained by access to detailed groundwater data for the study area. The analysis undertaken relied heavily on basic rate of rise data provided by DAFWA. In addition, the choice of time frames used in the assessment of rate of rise may have resulted in bias, exacerbated by the uncorrected nature of rate of rise data provided by DAFWA.

In general, it is considered the groundwater monitoring within the region is in part compromised by the relatively small number of bores and poor spatial distribution of bores within the region. However, this could be overcome in part by more effective monitoring of community groundwater bores and will be improved by the construction of additional groundwater bores by DAFWA in 2008.

Restricted access to groundwater data is also considered to be a constraint to the effectiveness of groundwater monitoring, presenting difficulties in 3rd party analysis of groundwater data.

In some cases, bores are located in atypical subcatchments, or in areas of the catchment likely to be influenced by local geological features, and therefore less representative of "*regional*" groundwater trends. In addition, a high proportion of bores have been constructed in areas known to be saline or at immediate risk of becoming saline, resulting in additional sample bias.

Given the predominant influence of local hydrology over the development of salinity within the Avon River basin and landscape diversity, extrapolation of bore data beyond individual subcatchments where it was collected should be undertaken with caution.

7. Stream Flow Monitoring

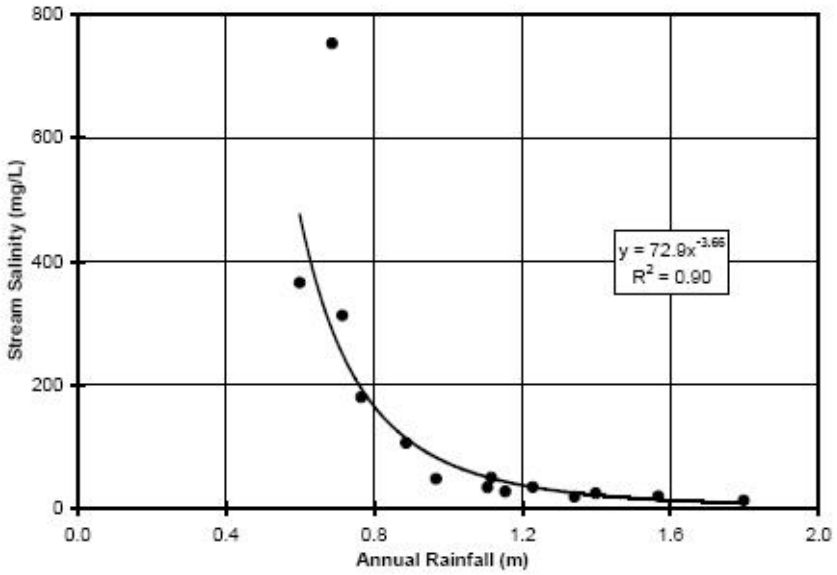
7.1 Background

The Avon Catchment Council adopts an asset based approach for prioritising investment. A salinity trend analysis of surface water flows within the Avon River basin was undertaken within the context of priority environmental assets. A preliminary environmental flow analysis undertaken for the Avon River identified river pools and riparian vegetation as key environmental assets associated with the Avon River and its major tributaries (GHD [4] 2008).

Streams function as a conduit for both surface water and groundwater flow can provide a surrogate for monitoring salinity within the catchment. Trend based approaches to salinity monitoring commonly incorporate stream salinity monitoring for assessing catchment salinity trends.

Stream flow monitoring for salinity trend assessment is typically adopted within relatively high rainfall environments. Figure 26 describes the correlation between stream salinity and average annual rainfall for 14 Victorian subcatchments. As average annual rainfall falls below 600 mm/year, stream salinity appears to become more variable.

Figure 26 Relationship between Long-Term Average Stream Salinity and Annual Rainfall for 14 Victorian Catchments *(Walker et. al.)*



Within the Avon River basin, defined rivers are restricted to the Western Rivers sub region, where average annual rainfall is generally greater than 400 mm/year.

Assessment of stream flow monitoring is largely restricted to assessment of trends within the Western Rivers sub region, principally because stream flow and salinity gauging is generally restricted to this sub region.

7.2 Methodology

Stream flow monitoring data used in the analysis was acquired from Department of Water gauging stations within the Avon River basin. The period over which recorded flow and salinity data is available for various sites are outlined in Table 14.

Table 14 Major Gauging Stations – Department of Water

Gauging Station	River	Period of Flow Monitoring	Start of Discrete Salinity Monitoring	Start of Continuous Salinity Monitoring
Northam Weir	Avon River	1973 – present	1978	1995
Brouns Farm	Avon River	1976 – 2001	NA	1992
Beverley Bridge	Avon River	1999 – present	NA	1999
Water Hatch Bridge	Dale River South	2000 – present	1997	2000
O'Driscolls	Mortlock River East	1974 – present	1974	NA
Fenches	Mortlock River North	1975 – present	1975	2003
Gairdners Crossing	Yilgarn River	1976 – present	1976	2003
Kwolyn Hill	Lockhart River	1976 – present	1973	1997
Qualandary Crossing	Salt River (Yenyening Lakes)	1983 - present	NA	1992
Yenyening Confluence	Avon River	1997 - present	1997	1997

The location of the Department of Water gauging stations is presented in Figure 29.

The gauging station at Brouns Farm was decommissioned in 2001, with Department of Water favouring sights at Beverley Bridge (Avon River) and Waterhatch Bridge (lower Dale River). Analysis indicates gauging stations at Beverley Bridge and Waterhatch Bridge provide a good correlation with flows at Broun's Farm for the period of overlap between gauging stations.

Data collected from gauging stations located on the Avon River upstream of the Yenyening Confluence and at Qualandary Crossing (measuring outflows from the Yenyneing Lakes) are considered unreliable. Whilst the Qualandary Crossing gauging station reports stage heights for the period 1983 – 2007, gauging of flows has only been undertaken for the period 1983 – 1992. No rating of the Qualandary Crossing gauging station has been undertaken after 1992, when an upgrade to the flow control structure at Qualandary Crossing was undertaken.

Flows reported for the gauging station located on the Avon River upstream of the Yenyening confluence are also considered unreliable. The lack of a low flow control structure and backwater influences resulting from discharge from the Yenyening Lakes make data from the Yenyening confluence (Avon River) difficult to interpret and therefore unreliable. Limited analysis of these two gauging stations was undertaken within this project.

Analysis reported herein focuses on the following gauging stations:

» *Northam Weir (Avon River upstream of confluence with the Mortlock River);*

» *O'Driscolls (Mortlock East River);*

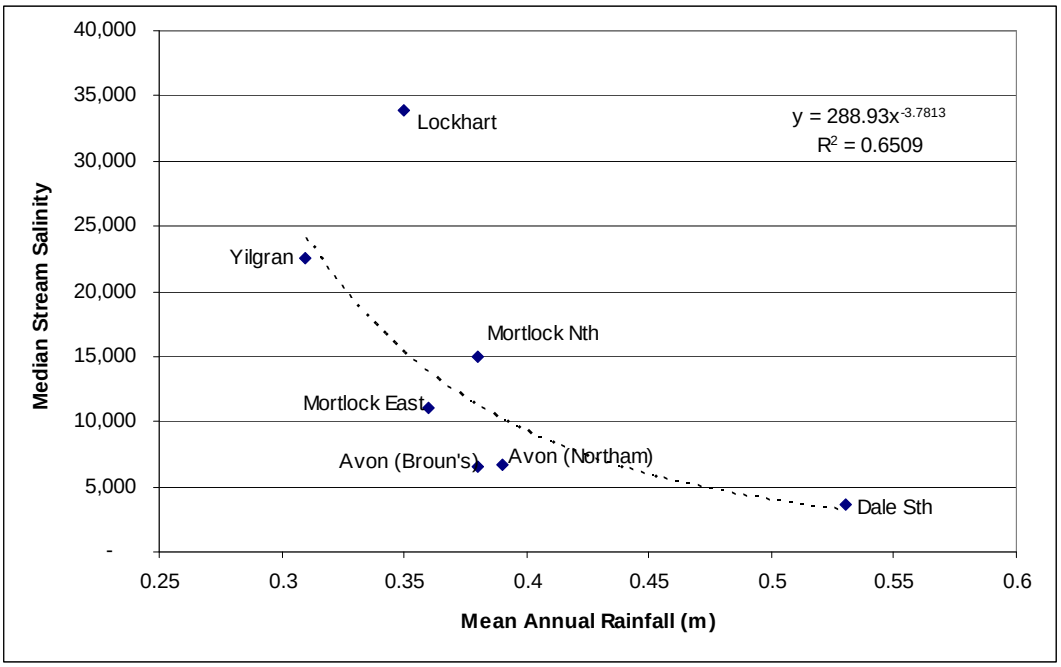
» *Frenches (Mortlock North River);*

» *Kwolyn Hill (Lockhart River); and*

» *Gairdners Crossing (Yilgarn River).*

The purpose of the analysis was to determine trends in stream salinity at key points within the Avon River basin within the context of important environmental assets, including river pools and riparian vegetation. Previously, salinity trend analysis for streams within Western Australia was undertaken by Mayer et al. (2005), focussing on median salinity at major gauging stations and an assessment of gross flow weighted salinity at Northam Weir. Median salinity and mean annual rainfall is presented in Figure 27, indicating a similar relationship to that presented by Walker et al. (2006) for Victorian rivers (Figure 26), however rivers of the Avon River basin are comparatively more saline.

Figure 27 Median Salinity at Key Sites on the Avon River



Source: Mayer et. al. (2005)

A simple exponential relationship exists between the mean annual rainfall and median stream salinity for key gauging stations considered within the study area; however the Lockhart River appears as a partial outlier, although included in the analysis presented in Figure 27.

Median salinity of the Lockhart and Yilgarn Rivers is influenced by the predominance of lakes which dominate the morphology of these watercourses. Lakes act as internal salt stores within the largely internally drained component of the Avon River basin. The volume of salt stored within lakes may also be influenced by "upwelling" of groundwater during dry lake phases. Lakes are significant contributors of salt mass within the Lockhart, Yilgarn and Salt Rivers during significant flow events. Medium to large scale lakes are particularly prominent within the Lockhart catchment, potentially contributing to higher-than-expected stream salinity when considering rainfall only. The very large lakes of the upper Lockhar and Yilgarn River are likely to have much less influence over salt flux during significant flow as these lakes rarely overflow due to there large capacity (CSIRO in press).

Surface water flow and salinity modelling was previously undertaken by CSIRO, through the development of LASCAM (LArge Scale CAtchment Model) for the Avon River basin. Modelling was primarily focussed on assessing impacts of climate change and regional drainage scenarios on flow and salinity with the Avon River basin *(CSIRO in press)*.

Analysis undertaken includes a brief review of existing analysis and the application of a digital recursive filter to flow data to determine base flow prior to assessment of flow weighted salinity. In addition, salinity for different flow classes (low, moderate and high flows) and for early winter and late winter - spring, was undertaken. Understanding salinity trends at different flow classes and throughout the flow period is important in the context of environmental assets and provides additional insights into hydrogeological processes influencing salinity development within the region.

7.2.1 Base flow Analysis

The National Land and Water Resources Audit describes base flow salinity as an effective indicator of catchment salinity (*nlwra.gov.au*). Stream flow may be comprised of a mixture of groundwater and surface water components. Base flow salinity is important because it indicates the relative contribution of groundwater salinity to total stream salinity. In rapidly - responding local groundwater flow systems, rising base flow salinities over time generally indicate an increasing groundwater contribution to the stream flow typically in response to rising watertables.

The base flow component of the streamflow time series can be separated using data processing or filtering procedures. Although these methods tend not to have a particular hydrological basis, they aim to generate an objective, repeatable and easily automated index that can be related to the base flow response of a catchment (Nathan and McMahon 1990).

Base flow weighted salinity was determined using the method described below. A digital recursive filter was applied to recorded stream flow data to filter out flow peaks

associated with rainfall events. Digital recursive filters are commonly used for determining base stream flow. The Lyne - Hollick algorithm was applied for flow data using the equation:

$$Q_{f(i)} = a\, Q_{f\,(i-1)} + (Q_{\,(i)} - Q_{\,(i-1)})\,(1 + a)/2$$

$$Q_b = Q - Q_f$$

Where:

$Q_{f(i)}$: is the filtered quickflow for the i^{th} sample.

$Q_{\,(i)}$: is the recorded flow for the i^{th} sample.

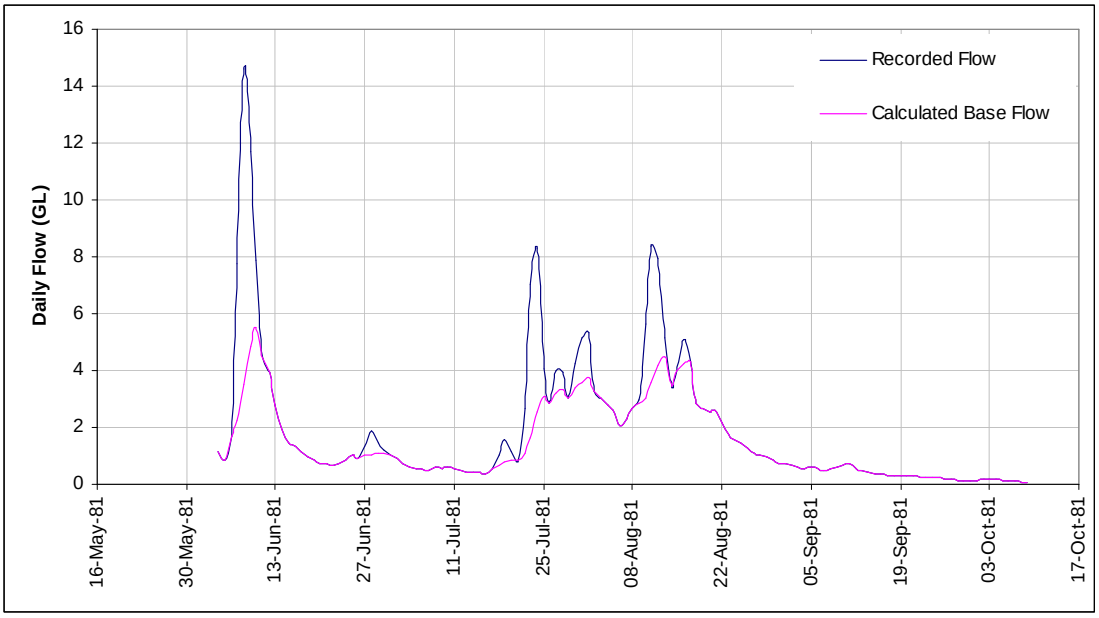
Q_b : is the calculated base flow.

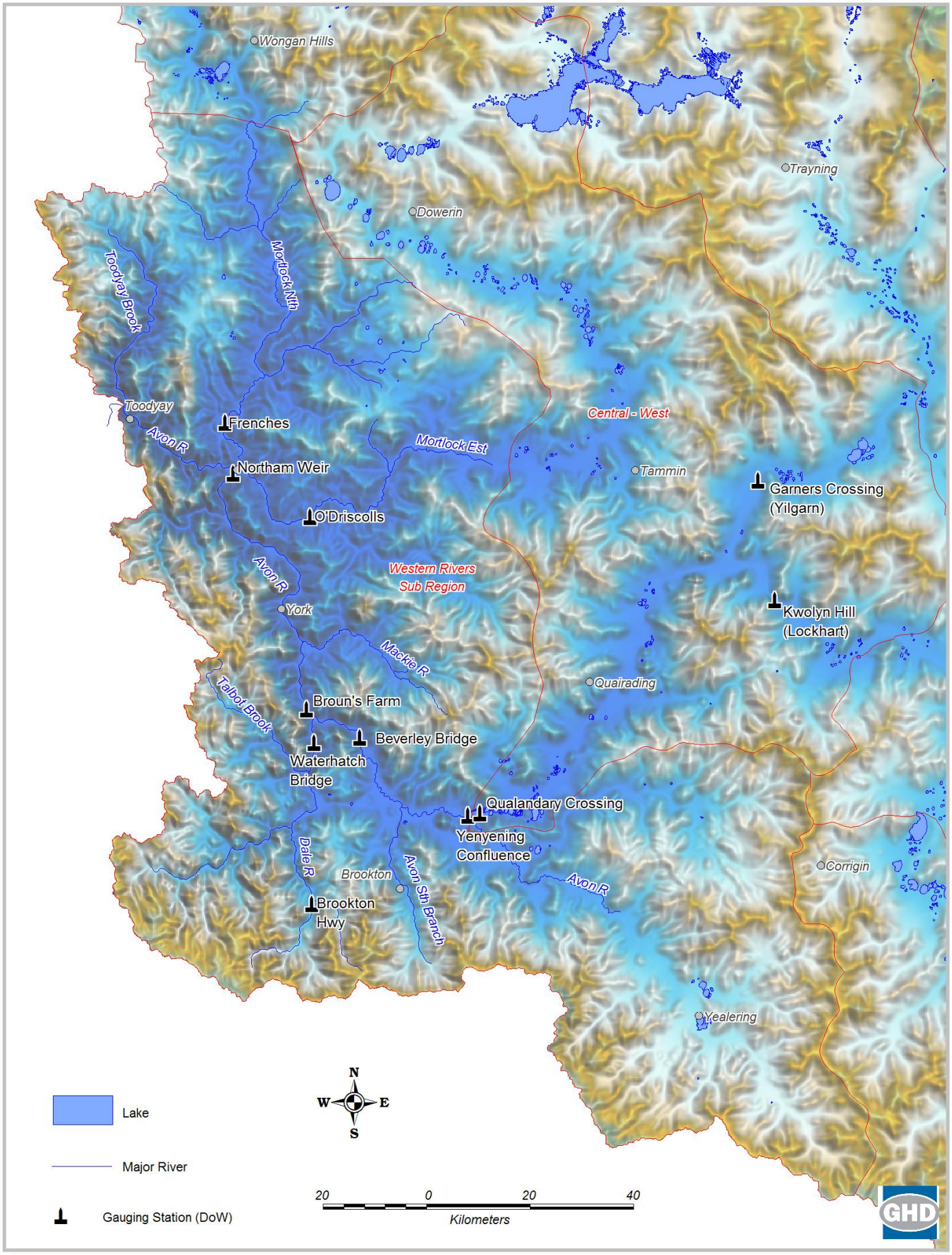
a : is a stream flow constant – 0.925 is typically used for daily flow and was applied in this instance.

(Lyne and Hollick 1979; Nathan and McMahan 1990)

The digital recursive filter was applied over three iterations as recommended by Nathan and McMahan (1990). An example of calculated base flow using the digital recursive filter employed is presented in Figure 28.

Figure 28 Example of Calculated Base Flow – Northam Weir (1981)





Map Projection: Universal Transverse Mercator
Horizontal Datum: Geocentric Datum of Australia 1994
Grid: Map Grid of Australia, Zone 50

Figure 29. Department of Water Gauging Stations

239 Adelaide Tce Perth 6000 Australia **T** 61 8 6222 8222 **F** 61 8 6222 8555 **W** www.ghd.com.au

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7.3 Discussion

Results and discussion of analysis undertaken within this project are presented for the Central West and Western Rivers sub regions separately.

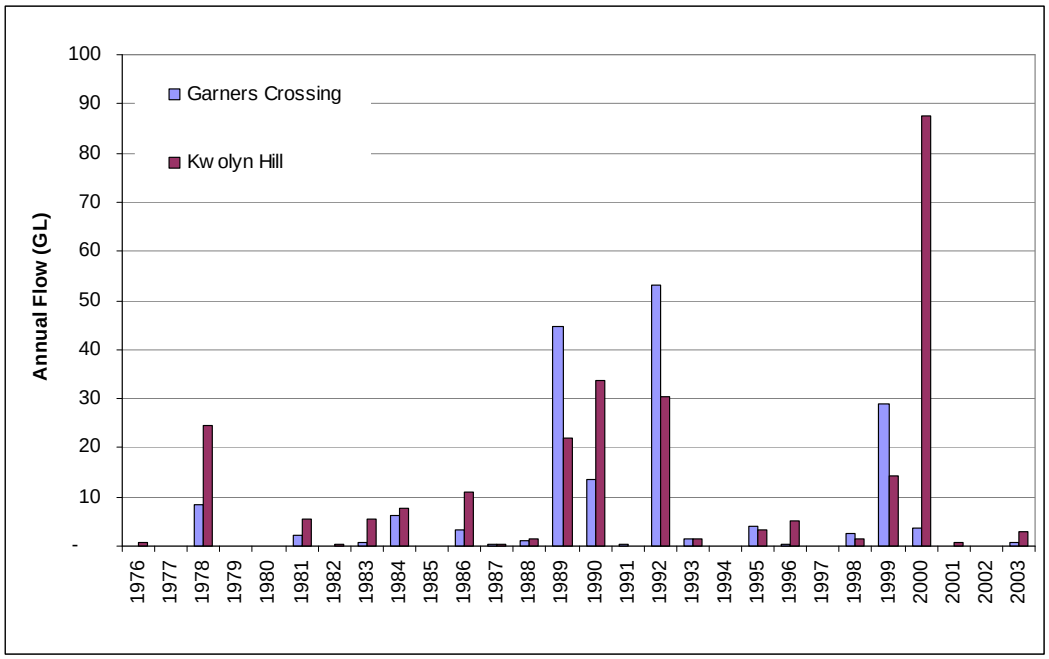
7.3.1 Central West

Gauging stations located within the Central West sub region are restricted to Gairdners Crossing (Yilgarn R.) and Kwolyn Hill (Lockhart R.). The Yilgarn and Lockhart Rivers are sluggish lake chains that join to form Salt River. Salt River discharges into the Avon River at Qualandary Crossing (Figure 29).

Flow at the Kwolyn Hill and Gairdners Crossing gauging stations is infrequent due to low landscape gradient (0.03 – 0.06 %), and massive flood plain storage associated with extensive lakes and alluvial flats. Long periods without flow are punctuated by large flows, such as 83 m^3/sec recorded at Kwolyn Hill in January 2000.

Presented in Figure 30 are annual flows recorded for the Kwolyn Hill and Gairdners Crossing gauging stations for the period 1976 - 2006, including extensive periods of relatively little flow for the early 1980s the mid 1990s and from 2000 - 2006.

Figure 30 Annual Flow for Gairdners Crossing and Kwolyn Hill



Larger flow events are generally associated with a sequence of particularly wet winters and/or large episodic rainfall events. The salinity of surface water flow is highly variable, depending on volume of flow and interaction with lakes. Flows associated with major lake chains of the Yilgarn and Lockhart are typically highly saline due to reactivation of salt stored within lakes, however flows of less than 10,000 mg/L can occur during significant flow events.

Base flow weighted salinity is presented for Gairdners Crossing and Kwolyn Hill. Base flow is expressed as a natural log, due to the large variations in base flow during the recorded period. Base flow weighted salinity is calculated by filtering the salinity of recorded flows that are in excess of the calculated base flow.

Figure 31 Base Flow Weighted Salinity for Gairdners Crossing (Yilgarn River)

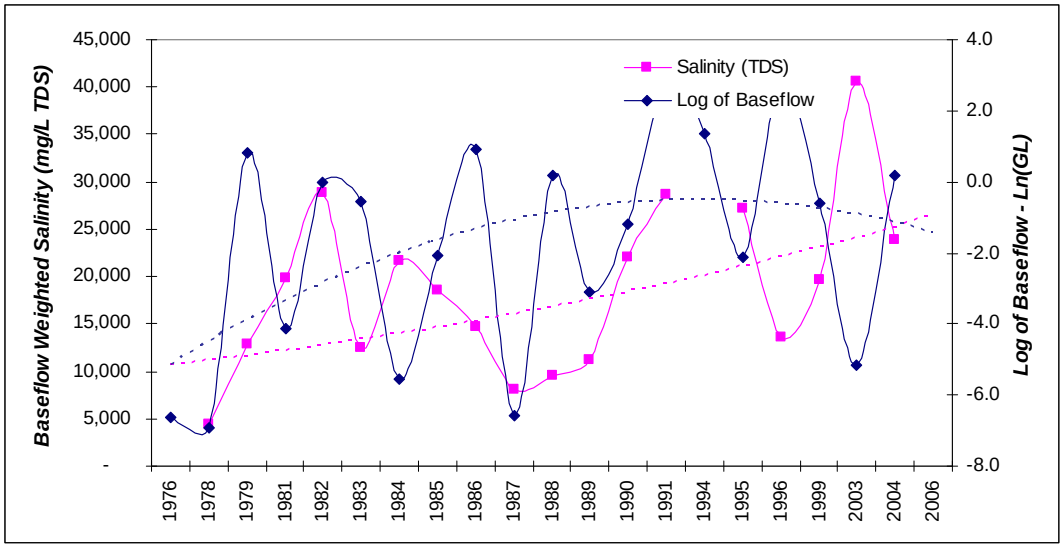
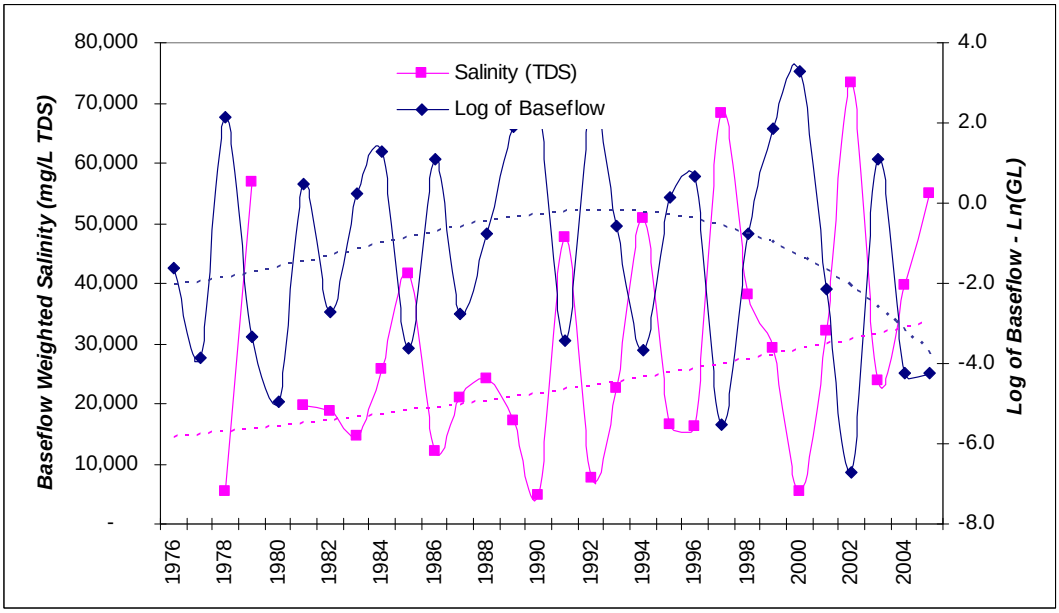


Figure 32 Base Flow Weighted Salinity for Kwolyn Hill (Lockhart River)



Salinity readings for Gairdners Crossing are restricted to snap shot readings prior to automatic recording of salinity in 2003. The median number of days where salinity readings were collected during base flow was three and the average number of recordings of salinity during base flow prior to 2003 was 4.1. As a result, flow weighted salinity analysis for Gairdners Crossing should be treated with caution due to the lack of available recorded salinity data. The period of monitoring for Kwolyn Hill

between 1976 – 1982 and 1988 – 1996 also had less than 10 salinity readings during calculated base flow periods, also potentially influencing the reliability of the analysis for this period.

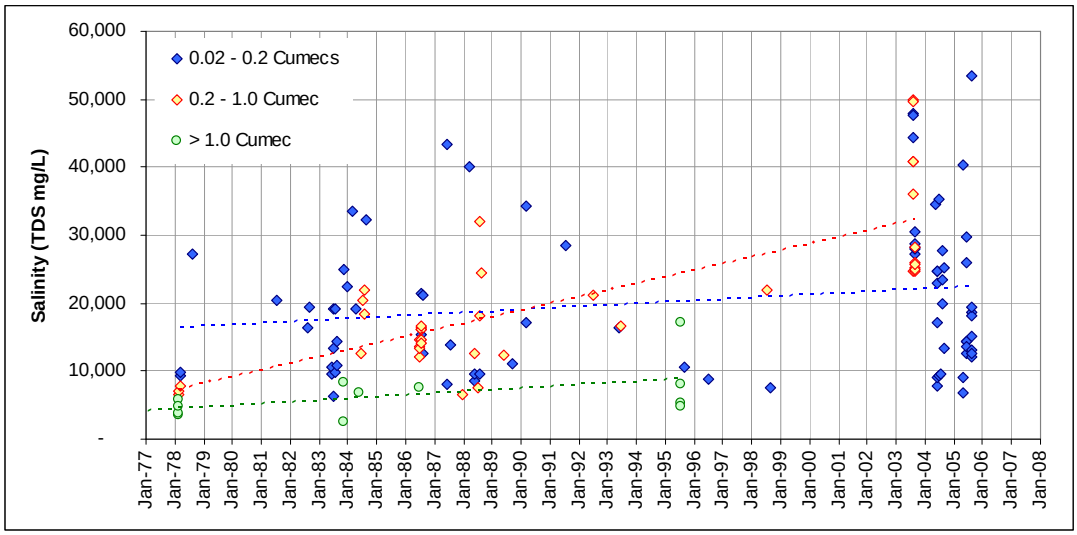
Analysis indicates variability in flow and salinity within both the Yilgarn and Lockhart Rivers. Figure 31 and Figure 32 indicate a gradual increase in the volume of base flow within both river systems up until the late 1990s, after which a period of depressed annual rainfall is reflected in reduced base flow. The analysis indicates rising groundwater levels in the upstream catchment prior to a slight reduction in groundwater levels after the late 1990s. This trend is generally reflected within monitoring of shallow groundwater bores undertaken within the Central West region.

Analysis of base flow weighted salinity indicates an increasing trend in salinity at both Gairdners Crossing and Kwolyn Hill throughout the monitoring period, with annual variations in base flow weighted salinity appearing to reflect annual variations within the volume of base flow.

Interestingly, base flow salinity appears to continue to increase despite a reclining volume of base flow after the late 1990s, indicating a potential lag time between declining groundwater and salt accumulation within the Lake systems of the Yigran and Lockhart Rivers. This is anticipated due to the large salt store contained within the extensive lake systems of these watercourses, resulting in a dampening of trends in base flow weighted salinity.

In largely internally drained catchments such as the Yilgarn and Lockhart, the larger the volume of flow, the further the flow originates from the point of measurement. Small flows are generated from the catchments immediately adjacent to the gauging station, with large flows generated from a more extensive catchment area. Recorded salinity for small, medium and large of flow at Gairdners Crossing and Kwolyn Hill gauging stations are presented in Figure 33 and Figure 34 respectively to provide additional insight into trends within the sub region. No assessment of base flow was able to be undertaken due to the relatively small number of recorded flows during calculated base flow periods.

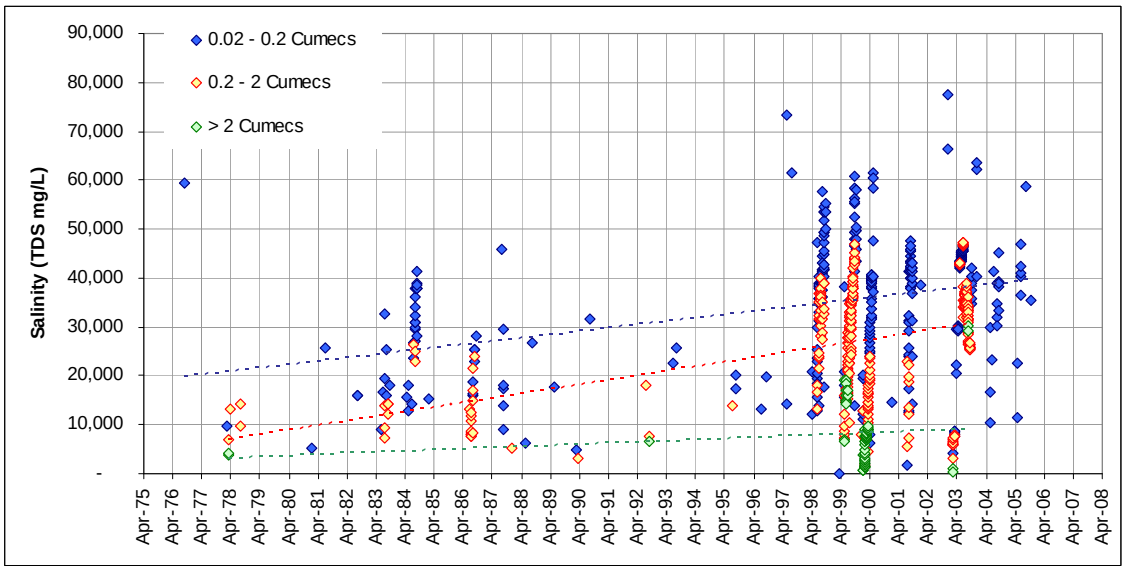
Figure 33 Salinity – Gairdners Crossing Gauging Station



The Gairdners Crossing gauging station reported a moderate increase in salinity of low flows (< 0.2 cumecs) for the monitoring period. Moderate flows at the Gairdners Crossing gauging station display an increase in salinity for the period 1977 - 2007, with flow appearing to approximately double in salinity over the recorded period. Large flows (greater than 1.0 cumecs) also increased in salinity over the period 1977 – 1996, with no significant large flows experienced after 1996.

The apparent large increase in salinity of moderate flows at Gairdners Crossing indicated in Figure 33, probably reflects sampling bias. However, the trend may in part reflect an increase in salinity within upstream subcatchments. Both Land Monitor and groundwater bore data indicate salinity in the area upstream of Gairdners Crossing increased at a greater rate than the surrounding landscape during the monitoring period.

Figure 34 Kwolyn Hill Gauging Station



Results indicate highly variable salinity for Kwolyn Hill gauging station for all flow classes, with a general increasing trend in the concentration of salinity. However, the potential for sampling bias due to the low number of salinity records prior to 1999 suggests that caution should be applied in interpreting salinity data presented.

7.3.2 Western Rivers

Analysis of flows at the Northam Weir and Frenches gauging stations are reported, reflecting salinity trends for the Avon and Mortlock Rivers respectively.

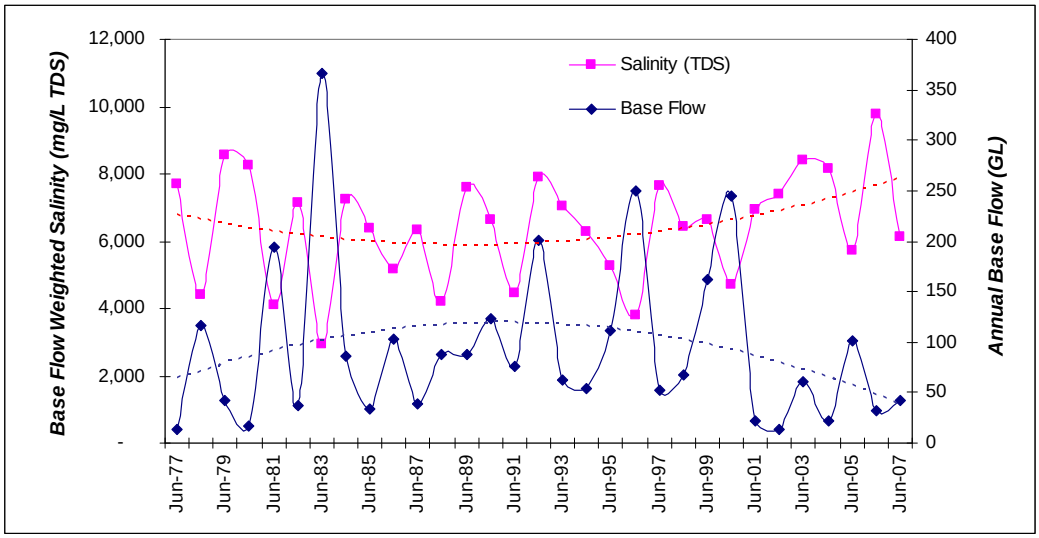
Northam Weir

Salinity trend analysis for Northan Weir was previously undertaken by Mayer et al. (2005). The study concluded there was no trend in the salinity of median flows within the Avon River for most of the recorded period, until an increasing trend in the 1990s. The study suggests Avon River flows were characterised by extreme variability, with median annual salinity ranging between 2000 and 8000 mg/L (TDS) and that trends were in part masked by variable contributions from different tributaries throughout the period of record. Analysis undertaken by Mayer et al. (2005) relied on raw annual flow weighted salinity and linear decadal trends for salinity at median flow.

Assessment of base flow weighted salinity is considered to provide a better indication of salinity trends relative to patterns of salinity development within the upstream catchment. The methodology applied to calculate base flow salinity is presented in section 7.2.1 of this report.

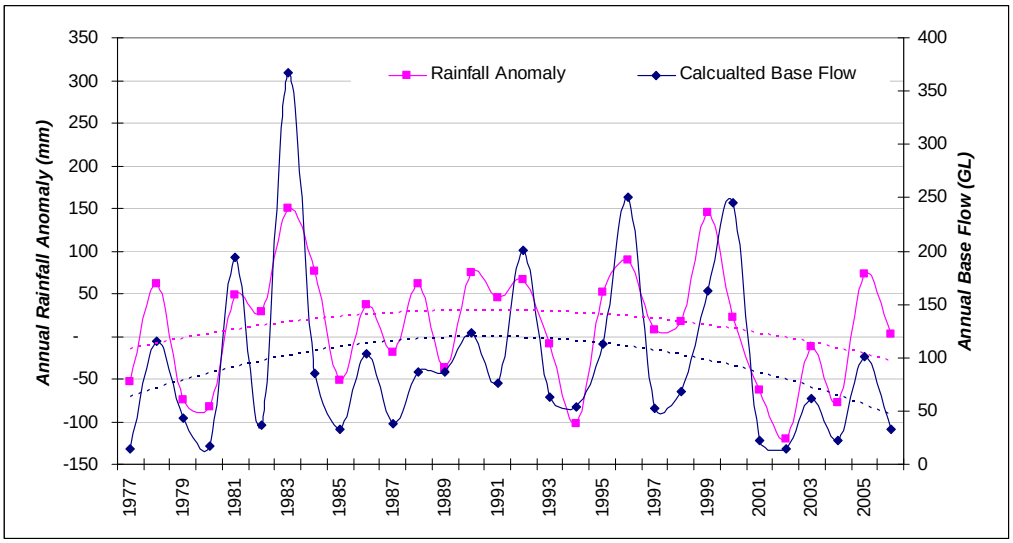
Consideration of annual base flow weighted salinity indicates no trend in salinity of base flows within the Avon River at Northam Weir. The analysis indicates variations within base flow weighted salinity are reflective of trends in the volume of base flow (Figure 35). Periods of higher base flow coincide with periods of lower base flow weighted salinity, indicating a dilution response, probably associated with increased fresh groundwater infiltration to the river during periods of higher rainfall.

Figure 35 Annual Base flow Weighted Salinity - Northam Weir



The volume of base flow salinity is plotted with the annual rainfall anomaly (as the annual variation from the annual mean over the period 1977 – 2006) for mean daily rainfall for evenly distributed long term rainfall gauges between Northam and Brookton. The trend in annual base flow appears to mimic rainfall anomaly, indicating base flow is largely responding to short term climatic variations.

Figure 36 Calculated Base Flow and Rainfall Anomaly – Northam Weir.



No trend in base flow weighted salinity nor base flow volume was found, suggesting little or no trend in groundwater levels within upstream catchments for the recorded period from 1977 - 2007. Trends within the relatively small number of groundwater bores contained within the Western Rivers sub region supports this conclusion.

Analysis of low, moderate and high volume early and late season base flows reported for Northam Weir gauging station was undertaken to provide additional insight into underlying trends in river salinity (presented in Figure 37 and Figure 38).

Figure 37. Early Season Base Flow (May - July) - Northam Weir

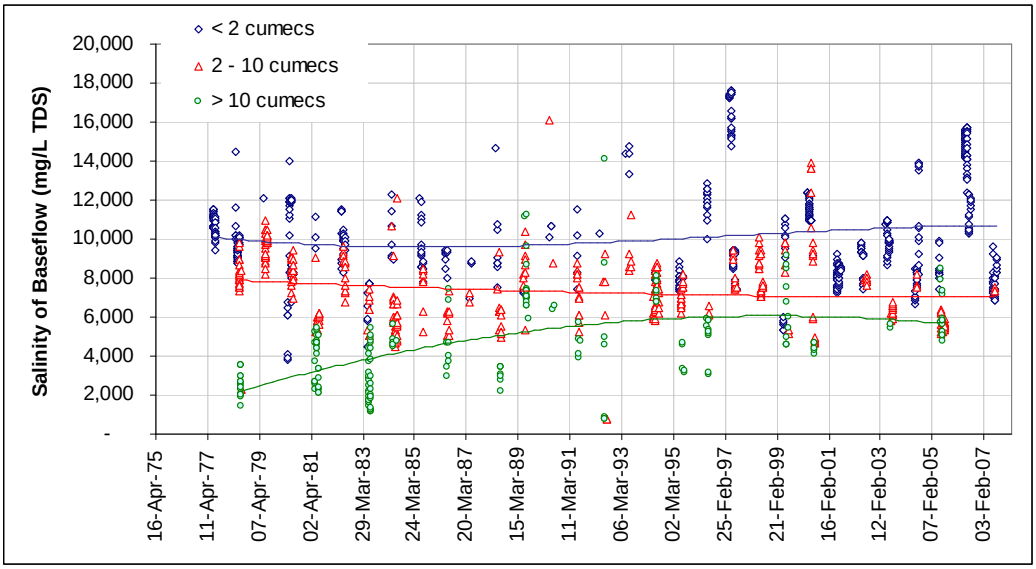
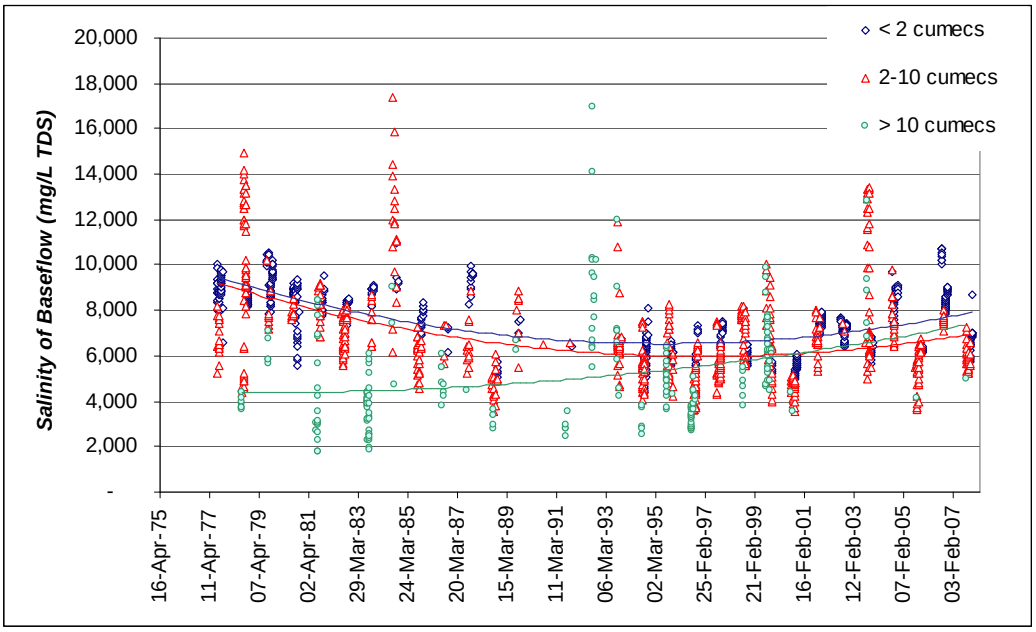


Figure 38. Late Season Base Flow - (Aug - Oct) Northam Weir

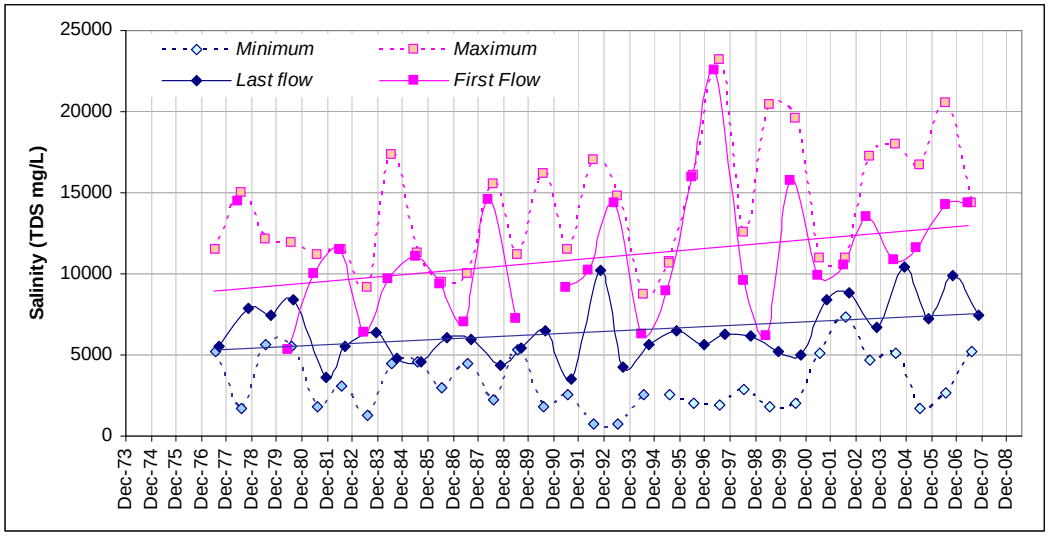


The analysis indicates early-season base flow is typically more saline and more dynamic than late season base flow. This is most likely reflective of early-season flows responding to stored surface salts within the upstream catchment, with late season base flows reflective of both fresh and saline groundwater influences.

Small early-season base flows appear more saline than moderate to high early-season base flows. The difference between the salinity of small and moderate base flows appears less apparent for late season flows.

No clear trend in either early or late season, low to moderate volume base flows (< 10 cumecs) was detected, however an increasing trend in both early and late season large base flows is evident prior to the mid 1990s. The different response pattern of low to moderate base flows when compared to large base flows potentially indicates a different response between the immediate catchment and the more extensive upstream catchment. Analysis and salinity trends reported by Land Monitor indicate salinity developed at a slower rate in the near river environment (Avon River landscape unit) when compared to the larger upstream contributing landscapes of the Avon Arc and South Avon and in upstream sub regions, in particular the Central – West sub region. The difference in the rate of development of salinity detected by Land Monitor may explain the difference in trend responses of low to moderate and high base flows evident at Northam Weir.

Figure 39 Salinity of Minimum, Maximum, First and Last Flows for Northam Weir



Analysis of minimum and maximum, first and last season flows for Northam Weir is present in Figure 39. This analysis indicates highly variable salinity of flows with the Avon River at Northam Weir ranging from 1000 mg/L to more than 20,000 mg/L. Variations of 10,000 mg/L within a single year are common with greatest variability occurring during early-season flows. Late season flows appear more stable, a likely response to fresh groundwater discharge from the near river environment during late winter and spring.

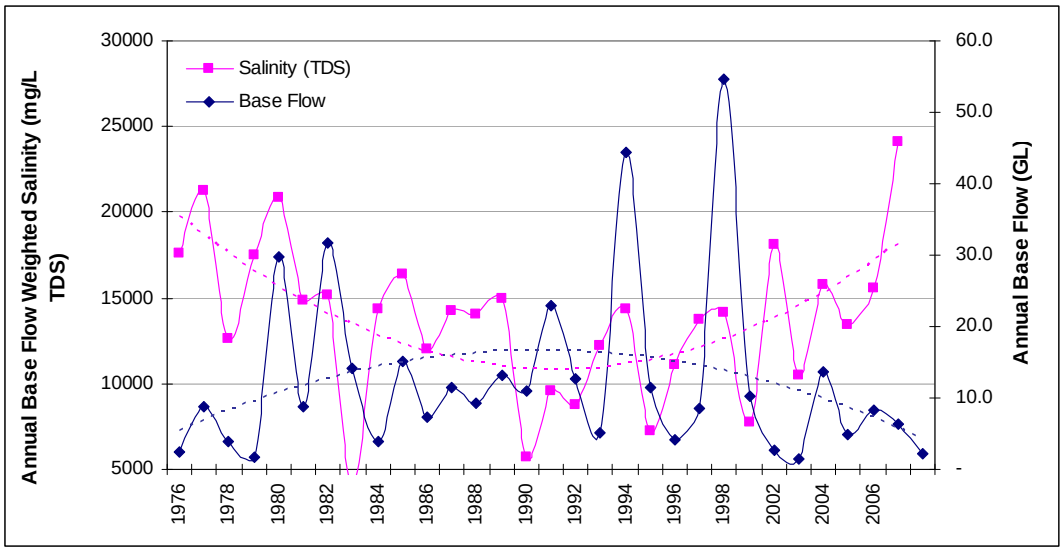
The increasing trend in salinity of early-season flow appears to reflect salt accumulation within upstream subcatchments resulting from capillary rise of salts over dryer summer months. Salts are dissolved in early flows and discharged from the catchment via the Avon River.

The slight increase in salinity reported for late season flows for the period 2001 – 2007 is likely due to a decline in base flow experienced at Northam Weir for that period (Figure 36).

Frenches (Mortlock Nth)

Frenches gauging station is located on the lower Mortlock North River. Base flow weighted salinity analysis indicates no overall trend in salinity of base flow within this major tributary to the Avon River, with variations in salinity reflecting trends in the volume of base flow (Figure 40).

Figure 40 Base flow Weighted Salinity for Frenches Gauging Station (Mortlock North)



A period of higher salinity base flow during the late 1970s and early – mid 1980s was followed by a period of declining salinity of base flow during the 1990s. A period of increasing salinity of base flow for the period after 2000 coincided with a period of declining base flow within the Mortlock North River.

There is currently little or no trend in base flow salinity within the Mortlock North River. No groundwater trend data is available for this river catchment. Land Monitor salinity data for subcatchments within the Mortlock North River catchment indicates relatively minor development of salinity over the period of monitoring.

Early and late season flow analysis reflects the dynamic nature of salinity discharge from the Mortlock North catchment (Figure 41 and Figure 42).

Figure 41 Frenches (Mortlock North) Flow Separated Salinity (May – July)

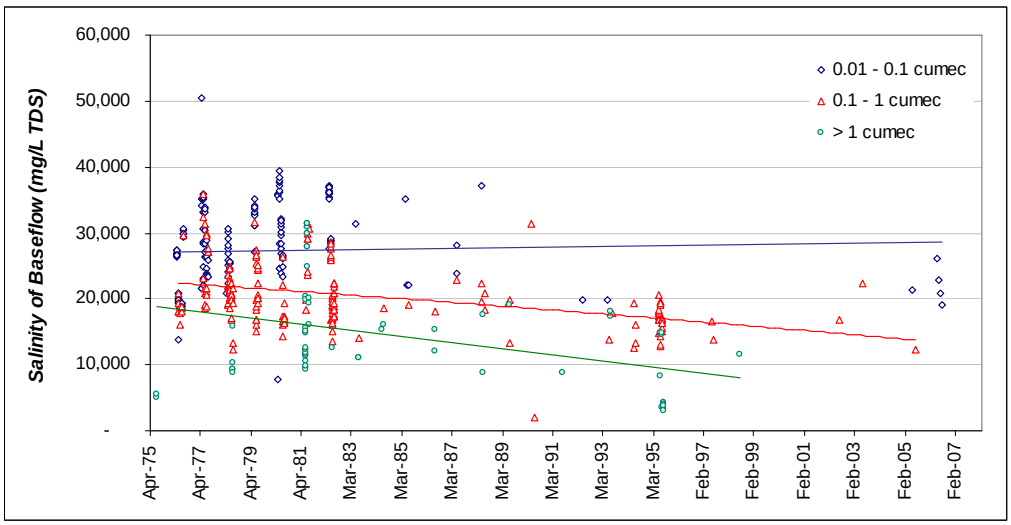
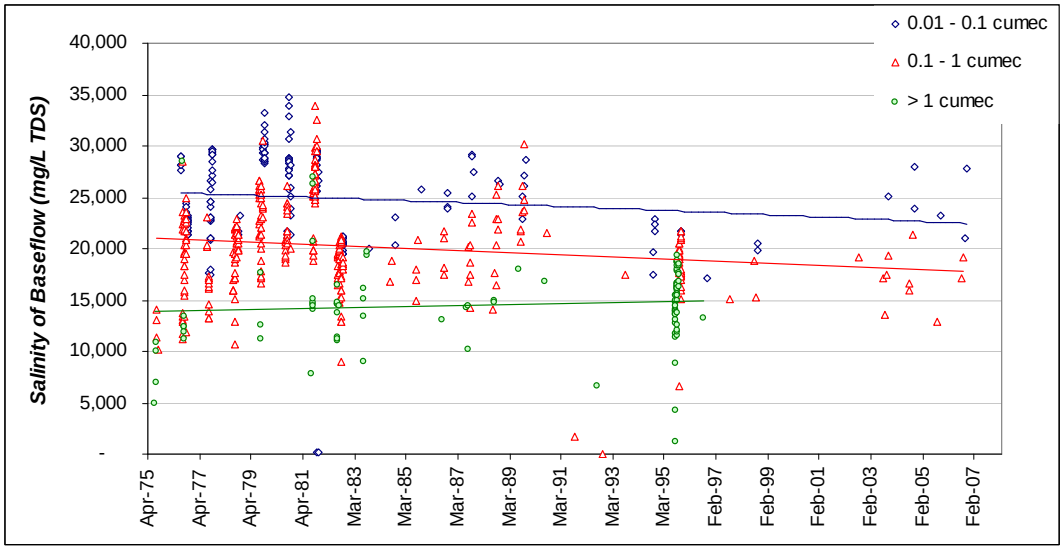


Figure 42 Frenches (Mortlock North) Flow Separated Salinity (Aug - Oct)



Salinity of flow at Frenches gauging station displays little or no trend over the period of monitoring; however significant fluctuations, particularly in salinity of early-season flow, are apparent (Figure 41). Variations in salinity appear to be most pronounced during the early season flow period (May – July), potentially suggesting flows are influenced by cyclic salt accumulation within the contributing catchment.

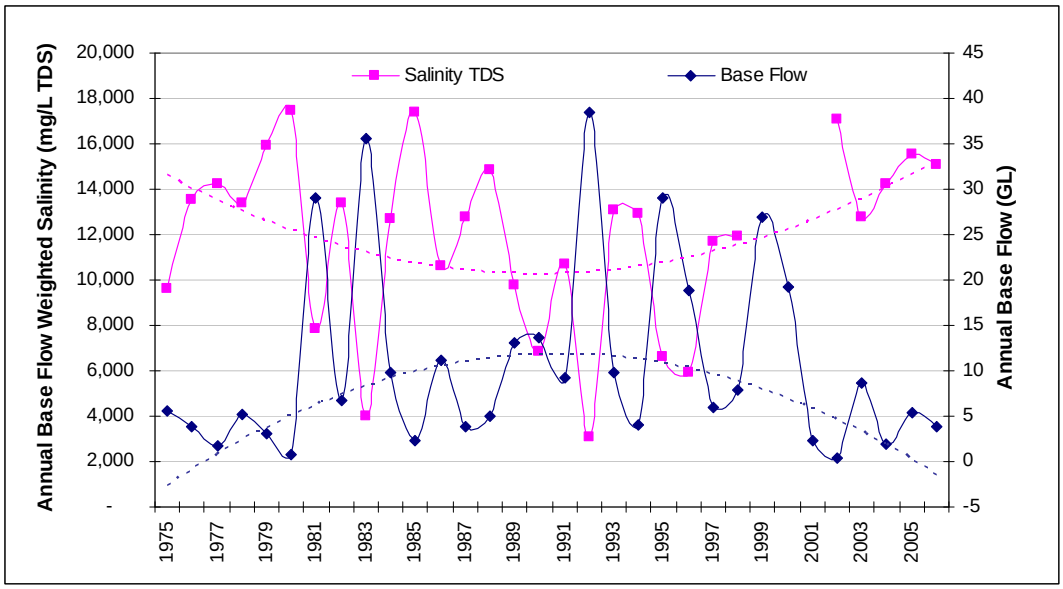
Late season flows are more likely to reflect the underlying groundwater contribution. There is no definitive trend in salinity of late season base flow within the Mortlock North River, indicating relatively stable groundwater levels within the catchment for the period of monitoring. This trend is generally supported by analysis of Land Monitor data, which indicates salinity within the North Mortlock catchment has not progressed significantly over the period of monitoring.

O'Driscoll's (Mortlock East)

O'Driscolls gauging station, located on the Mortlock East River, displayed similar trends to that for the Mortlock North River. The Mortlock East is a dynamic river recording large variations in base flow salinity over the recorded period. No trend in base flow weighted salinity was apparent, with salinity tending to mirror the volume of base flow.

Early and late season trends within the Mortlock East River were similar to those reported for the Mortlock North, displaying significant variations in early-season flow and a relatively stable late season flow.

Figure 43 Base flow Weighted Salinity for O'Driscoll's Gauging Station (Mortlock East)



7.4 Conclusions

Surface water monitoring provides an important component of monitoring within the Avon River basin, particularly for determining salinity trends in the Western Rivers sub region, where there is limited groundwater data available. Base flow analysis of the long term monitoring record for the Avon, Dale and Mortlock Rivers provides an important insight into progression of salinity within these river catchments.

Calibration issues influence the reliability of gauges in the upper reaches of the Avon River including those at the Yenyenning confluence (Avon River) and Qualandary crossing (Salt River). Both of these tributaries are likely to be important in future contributions of salinity to the Avon River, as indicated by trends within Land Monitor. Recalibration of the Qualandary Crossing gauge and relocation of the gauge upstream of the Yenyenning confluence are considered the highest possible priority.

Trends in stream flow salinity for Northam Weir appear consistent with monitoring of land salinity reported by Land Monitor. Both datasets indicate little or no trend in salinity development throughout much of the Western Rivers sub region for the monitoring period, except for within the South Avon landscape unit, where salinity development appears to be delayed when compared to the remainder of the Western Rivers sub region.

Gairdners Crossing and Kwolyn Hill gauging stations provide reasonable long-term sequences of flow and salinity monitoring for the Yilgarn and Lockhart Rivers respectively. However, salinity data from these gauging stations should be treated with caution due to the infrequent nature of snap shot salinity monitoring undertaken prior to installation of automatic salinity measurement in 1999 and 2003. Monitoring indicates a gradual increase in base flow at both stations prior to the late 1990s, after

which a slight decline of base flow is evident. The decline in base flow is consistent with groundwater monitoring undertaken within the Central West sub region and coincides with a decline in rainfall. Base flow weighted salinity increased throughout the monitoring at both gauging stations, consistent with an increasing trend in land salinity detected by Land Monitor. Base flow weighted salinity continued to increase during the period of depressed base flow after the late 1990s, indicating the important role lakes play in influencing the salinity of flows within the Central West sub region.

The general lack of reliable surface water flow data within the Central - West sub region limits the extent to which conclusions can be drawn from available flow monitoring data within this sub region.

Analysis of early and late season flows indicate a probable increasing trend in salinity of early-season flows, however environmentally important late season flows appear to remain relatively consistent throughout the monitoring period.

Although stream flow monitoring is restricted to the Central West and Western Rivers sub regions, it does provide significant supporting information of salinity trends.

8. Conclusions

The Avon Catchment Council is not responsible for undertaking resource condition monitoring, such as land salinity monitoring. The Avon Catchment Council's interest in salinity trend analysis is to better understand threats to key socio - environmental assets, to best inform priorities for investment and to evaluate the success of any subsequent investment made. Nevertheless, the analysis presented provides an important context regarding resource condition monitoring of salinity at a regional scale.

Conclusions presented relate to advice directly associated with Avon Catchment Council core business and to a lesser extent broader observations regarding salinity monitoring within the Avon River basin.

Previously the Avon Catchment Council set targets for salinity development within the Avon River basin within the Avon Regional Natural Resource Management (NRM) Strategy. Targets were primarily associated with rates of rise of groundwater and area impacted by salinity with reference to Land Monitor and stream flow monitoring as means of monitoring salinity development within the region (ACC 2005).

The Avon NRM Strategy states that 388,000 ha of 7.4 million ha of land available for agriculture was saline in 1996 (Land Monitor) and a total of 27.4% of land area is at risk of becoming saline (Land Monitor valley hazard mapping). Slope hazard mapping undertaken indicates the land potentially affected by salinity is likely to be less than the 27.4% reported by Land Monitor valley hazard mapping. Whilst it is considered that slope hazard mapping presented in this report is preliminary, there does appear to be potential to improve on currently published valley hazard mapping for the Avon River basin.

A summary of results derived from salinity trend analysis are presented together with recommendations to the Avon Catchment Council relating to monitoring and assessment within the Avon River basin.

8.1 Groundwater Monitoring

The Avon Natural Resource Management Strategy targets rely heavily on the rate of rise of groundwater as a means of monitoring salinity development within the region.

Salinity targets quoted with the Avon NRM Strategy included (ACC 2005):

> "*Reduction in average rate of groundwater rise on land in middle to upper catchment areas from 15 - 30 mm/year to 10 - 20 mm per year by 2025";*
> *and*
> "*The extent of valley floor salinity is less than 12% of land use for agriculture by 2025 (note the area currently affected is 5.4% this is expected to eventually increase to over 27%".*

For targets to be effective, they should account for underlying spatial and temporal variations and trends in salinity development within the region. The effectiveness of

the current groundwater monitoring network is considered constrained by the following issues:

- *Limited published information directly correlating rate of rise of groundwater to the rate of spread of salinity within the Western Australian wheat belt;*
- *No established correlation between rate of rise of groundwater and regionally based soil landscape units used for salinity classification;*
- *Poor integration of groundwater monitoring with other salinity monitoring programs, including Land Monitor and stream flow monitoring;*
- *Groundwater bores are often clustered within subcatchments of particular hydrogeological interest, not necessarily representative of the broader morphology/geomorphology of the region;*
- *Lack of adequate groundwater monitoring within native vegetation to provide a reasonable indication of groundwater rise under the "controlled" / natural vegetated environment;*
- *Lack of accessibility to groundwater data due to perceived sensitivities associated with salinity related data; and*
- *Lack of coordinated approach to monitoring of community bores resulting in community bores being excluded from analysis of rate of rise undertaken by DAFWA, principally due to the issues associated with consistency and data integrity.*

In particular, the limited geographic distribution of the bore monitoring network remains a key limitation to reliance on groundwater monitoring as a surrogate for understanding salinity trends within the Avon River basin. In general, it is considered a precautionary approach should be applied when extrapolating rate of rise of groundwater beyond the immediate environment in which the data was collected.

Recommendation 1. Better integrate groundwater monitoring network with complimentary monitoring programs including Land Monitor and surface water monitoring undertaken by the Department of Water.

Recommendation 2. A coordinated approach should be adopted for the monitoring of suitable quality community bores within areas with poor geographic coverage within the Ag bores network.

Recommendation 3. Undertake temporal analysis of rate of rise of groundwater consistent with timeframes used in complimentary monitoring programs including Land Monitor.

Recommendation 4. Better understand and remove data anomalies associated with surface water flows and rainfall anomaly from rate of rise analysis undertaken for groundwater data within the region.

Recommendation 5. Undertake additional groundwater monitoring within areas of native vegetation as a priority, to provide a better understanding of the response of groundwater under naturally vegetated conditions.

8.2 Land Monitor

Land Monitor has the advantage of providing a uniform temporal and spatial approach to salinity monitoring consistent with the underlying natural variations within the region. Land Monitor is capable of measuring variations in salinity at sub regional, landscape and subcatchment scales, consistent with the underlying geology and geomorphology of the region.

The compelling feature of Land Monitor is the use of archived satellite data for salinity mapping, where mapping can be refiled as knowledge of salinity processes and patterns of development within the region improves.

Land Monitor provides the advantage of a consistent spatial and temporal analysis of salinity trends within the region, however its effectiveness is constrained by a range of factors, including:

- *Ground truthing of salinity appears to be variable, with Land Monitor providing a more accurate assessment of salinity in some areas of the region than in others;*
- *Land Monitor tends to measure the increase in severity of salinity rather than the actual increase in area of new salinity, resulting in a delay in detection of salinity and some distortion in the measured rate of increase;*
- *Current time sequences of 1987 and 1996 constrain consideration of recent development of salinity;*
- *Valley hazard almost certainly over-estimates the area likely to be impacted by salinity in some areas of the region. Valley hazard tends to delineate an area outside of which salinity is less likely to occur rather than a salinity risk assessment tool in its own right; and*
- *Land Monitor does not cover the entire Avon River basin, with areas within the North East Plateau poorly represented.*

Not withstanding a range of issues limiting the capacity of Land Monitor as a definitive salinity monitoring tool, it does provide some distinct advantages over other salinity monitoring methodologies currently employed within the Avon River basin. Not least of all are the spatial / temporal capabilities of the technology and the potential development of an intelligent system that is able to incorporate new knowledge of salinity development within the region.

Land Monitor does appear to be constrained by a lack of an effective champion, with no particular agency with capacity to invest recurrent funding into its development. Land Monitor was developed within the Natural Heritage Trust program, and the lack of effective follow up investment appears to be constraining the development of this promising technology

Recommendation 6. Encourage further investment into the development of the Land Monitor program, including a salinity coverage for 2006 and better integration with groundwater and surface water monitoring programs.

Recommendation 7. Support additional ground truthing in areas where Land Monitor is least accurate, in particular within the North East Plateau sub region.

Recommendation 8. Revise salinity hazard mapping within the Avon River basin to determine a more accurate / realistic assessment of potential land at risk of salinity and in particular incorporate slope hazard analysis and geomorphic relationships as a potential salinity risk assessment tool.

8.3 Surface Water Monitoring

Base surface water flow analysis within the Avon River and significant tributaries provides a relatively robust mechanism for monitoring salinity trends within the Western Rivers sub region. However, the limited geographic distribution of gauging stations outside of the Western Rivers sub region limits the capacity of surface water monitoring as a salinity monitoring tool throughout the Avon River basin. This presents challenges when calibrating of surface water models for the region, including the LASCAM model. The current calibration sequence of LASCAM is heavily skewed towards the Western Rivers sub region, which is geomorphologically distinct from other sub regions within the Avon River basin, potentially causing bias within the model.

Large variations in flow and salinity in the Central West gauging stations of Kwolyn Hill and Gardens Crossing, coupled with the relatively incomplete record of salinity for these gauging stations presents difficulties in interpreting salinity trends. However, salinity and flow data from Kwolyn Hill and Gairdners Crossing gauges provides effective supporting information to other monitoring programs undertaken within their respective sub regions.

Recommendation 9. Encourage investment into additional surface water monitoring within the region, with particular emphasis on understanding the influence of key lakes on salt and water balance within internally drained sub regions.

Recommendation 10. Support the recalibration of the Qualandary Crossing gauging station and relocation of the Avon River (Yenyening confluence) gauging station to a more appropriate site.

Recommendation 11. Adopt seasonal base flow analysis as a surrogate monitoring and evaluation tool for assessing salinity status of key Avon River environmental assets.

8.4 Summary

Presented is a salinity trend analysis for the Avon River basin, incorporating elements of groundwater, surface water and Land Monitor salinity series monitoring data. In undertaking the analysis it became clear the lack of coordination associated with the design and implementation of these monitoring programs is an important constraint to integration of salinity monitoring within the region

Previous catchment scale modelling outside of the Avon River basin, have incorporating geomorphologic elements with a range of monitoring data. LASCAM modelling undertaken by CSIRO incorporated elements of groundwater and surface water monitoring, however failed to incorporate trends in salinity development within the region evident within the Land Monitor salinity series presented herein. Not withstanding this, LASCAM currently provides the only available mechanism for incorporating a range of salinity monitoring data sets at a regional scale. However, the current difficulties in accessing LASCAM data presents a significant obstacle to its incorporation into salinity monitoring programs.

The objective of the Avon Catchment Council in undertaking a salinity trend analysis was to identify trends within salinity development to inform strategic investment decisions and to inform further development of the monitoring and evaluation program.

It is considered Land Monitor provides a reasonable mechanism for describing underlying longer term trends in salinity development within the region, however caution needs to be applied in interpreting trends. Land Monitor detects the change of severity of salinity, rather than the changes to new salinity development, resulting in a delay in the identification of salinity by Land Monitor and some distortion in trends reported by Land Monitor. This, in addition to 1996 representing the most recent Land Monitor salinity series, means that Land Monitor currently presents an historic view of salinity within the region. Notwithstanding this, Land Monitor provides the most effective mechanism for understanding regional trends in salinity development because it incorporates both spatial and temporal aspects of salinity development and provides an effective geographic coverage of the region.

In the context of monitoring and evaluation, the most significant obstacle faced by the Avon Catchment Council is that current regional monitoring programs do not provide the resolution and sensitivity required to effectively evaluate the impact of individual projects. Due to the scale of investment generally undertaken by the Avon Catchment

Council, monitoring programs reviewed in this document have limited capacity for determining the effectiveness of investment.

Recommendation 12. Land Monitor provides an effective mechanism for undertaking trend analysis to support strategic investment decisions, however a precautionary approach needs to be applied due the historic nature of, and errors and inconsistencies contained within this data set.

9. References

ACC 2005 *Avon Regional Natural Resource Management Strategy*, Avon Catchment Council, Northam WA.

Allen & B. Beetson (1999) *The Land Monitor Project; A Multi-agency project of the Western Australian Salinity Action Plan supported by the Natural Heritage Trust*. Proceedings of WALIS Forum 1999, Perth, WA, March 1999, pp. 74-77.

Beard JS., (1998) *Position and Developmental History of the Central Watershed of the Western Shield Western Australia*. Journal Royal Society of Western Australia 81, pp 157 -- 164.

Caccetta, P. A., Allan, A. and Watson, I. (2000), *The Land Monitor project*, Proceedings of the Tenth Australasian Remote Sensing Conference.

Caccetta PA and Beetson B (2000), *Mapping and the Monitoring Salinity: Kellerberrin Landsat TMC (111 -- 082).* A report from the NHT funded Land Monitor project. CSIRO - Mathematical and Information Sciences, report number CMIS 2000/202.

Caccetta PA, Wallace JF, Beetson B And Crossley N: *Mapping Salinity in the Swan – Avon Region.* A report from the NHT funded Land Monitor Project. CSIRO 1999.

Cacetta P., Furby S., Wallace P. & Wheaton G., *Detecting and Monitoring Changes in Land Condition Through Time using Remotely Sensed Data,* A report from the LWRRDC project, CSIRO Mathematical and Information Sciences Agriculture Western Australia, Western Australia, September 2005

DAFWA AgET: *Water Balance Calculator* - Department of Agriculture and Food Western Australia, August 15, 2006. (www.agric.wa.gov.au/content/lwe/water/aget_index.htm).

DAFWA. Digital spatial information supplied by the Department of Agriculture and Food Western Australia, for Avon Catchment Council projects, 2007. Data supplied as Arc GIS shape files.

de Broekert P, Sandiford M. *Buried Inset Valleys in the Eastern Yilgarn Craton, Western Australia Geomorphology, Age, Allogenic Control*. The Journal of Geology, 2005, Volume 113, pp 471 – 493. University of Chicago.

DNRW, Salinity Hazard Mapping in Queensland Department of Natural Resource and Water Queensland Government, 2006

Dunne R, Caccetta P, Beetson B (2001). *Prediction of the Areas That the Risk of Salinity: the Central Districts and Eastern Wheatbelt.* Report number: CMIS 01/134. A report from the NHT funded land monitor project

Dunne R, and Beetson B, (2001). *Mapping and Monitoring Salinity: the Newdegate (Lake Grace) Landsat TM Scene (110/83).* A report from the NHT funded land

monitor project. CSIRO Mathematical and Information Sciences, report No. CMIs 2001/54.

DWNR: *Strategic Salinity Risk Assessment in the Condamine Catchment.* Land Management – Department of Natural Resources and Water Queensland Government – 2008.

Farmer D, Stanton S, Coles N (2002) *Lake Bryde Recovery Catchment, Surface Water Assessment and Recommendations,* Engineering Water Management Group Report, Department of Agriculture Western Australia.

Fedowsian R., Pannel DJ, McCaron C, Ryder A, Crossing L (2001): *Explaining Groundwater Hydrographs: Separating Atypical Rainfall Events from Time Trends*, Australian Journal for Soil Research 39: 861 – 875

Furby (2000) *Mapping Salinity in the Bencubbin Landsat TM Scene.* A report from the NHD fund project Land Monitor. CSIRO - Mathematical and Information Sciences.

Ghauri (2004) *Groundwater Trends in the Central Agricultural Region*, Resource Management Technical Report 269, Department of Agriculture - Western Australia. 2004.

GHD[1], (2008) *Salinity Target Setting* – ACC. A report by GHD for the Avon catchment Council. 2008. Northam, Western Australia.

GHD[2] (2008) *Preliminary Salinity Situations Statement for the Hotham Murray with Its Catchment Part 1: Conceptual Hydrogeological Analysis*. A report by GHD for the Peel Harvey atchment Council. Peel Harvey atchment Council Mandurah, Western Australia.

GHD [3] (2008) - *Detailed Risk Assessment Regionally Significant Road Avon River Basin Electromagnetic Survey.* GHD report to the Avon catchment Council. Protection transport assets project 2005 -- 2008 Investment Plan. Avon catchment Council, Northam, Western Australia.

GHD [4] (2008). *Preliminary Environmental Flow Assessment of the Avon River and Its Major Tributaries.* A GHD report for the Avon catchment Council, Water Management Self-Sufficiency Project, Avon catchment Council, Northam, Western Australia.

Heath R, George R (2007): *Groundwater Trends in the Central Agricultural Region*. Farm note: 208. Department of Agriculture and Food, Western Australia. January 2007

Hocking, RM. (1990). *Eucla Basin*. Geology and Mineral Resources of Western Australia. Geological Survey of Western Australia.

Kolmogorov, A. (1933). Sulla determinazione empirica di una legge di distribuzione. *Giornalle dell Instituto Italiano degli Attuari.* 4: 1-11.

Kruskall, W.H. and Wallis, W.A. (1952). Use of ranks in one-criterion analysis of variance. *J. Amer. Statist. Assoc.* 47: 583-621.

Levene, H. (1960). *Contributions to probability and statistics*. Pp 278-292. Stanford University Press, CA.

Lyne V and Hollick M, (1979). *Stochastic time-variable rainfall-runoff modelling*. Institute of Engineers Australia National Conference. Publ. 79/10, 89-93.

Mann, H.B. and Whitney, D.R. (1947). On a test of whether one of two random variables is stochastically larger than the other. *Ann. Math. Statist.* 18: 50-60.

Mayer E, Ruprecht J and Bari M. (2005). *Stream Salinity Status and Trends in South West Western Australia.* Department of Environment, Salinity and Land Use Impact Series, report no. SLUI 38, January 2005

Nathan RJ and McMahan TA, (1990). *Evaluation of automated techniques for baseflow and recession analysis.* Water Resources Research. 26(7):1465-1473.

(nrm.gov,au) Fact Sheet: *Area of land threatened by shallow or rising watertables: Groundwater salinity/baseflow salinity* http://www.nrm.gov.au/publications/factsheets/me-indicators/land-salinity/groundwater.html

(nlwra.gov.au). http://www.nlwra.gov.au/products/PN21230 Indicator protocols: Baseflow Salinity Areas Threatened by Shallow or Rising Water Tables

Robertson D, Massenbauer T, Paper GP (2005). *Spatial Water Balanced Model for Targeted Perennial Planting in South West Australian*, Department of Conservation and Land Management, Perth, Western Australia.

Searle, R. and Baillie, J. (1998) *Predictions of Landscape Salinity Hazard Using a Geographic Information System*, project report, Department of Natural Resources, Queensland.

Shapiro, S.S. and Wilk, M.B. (1965). An analysis of variance test for normality (complete samples). *Biometrika* 52: 591-611.

Short R, Farmer D, Whale P, Coles N. *Surface Water Assessment for the Buntine - Marchagee Recovery Catchment.* Department of Agriculture Western Australia. Resource Management Technical Report 299. State Government of Western Australia, 2006.

Smirnov, N.V. (1939a). Sur les ecarts de la courbe de distribution empirique. *Recueil Mathematique N.* 6: 3-26.

Smirnov, N.V. (1939b). On the estimation of the discrepancy between empirical curves of distribution for two independent samples. (In Russian). *Bull Moscow Univ. Intern. Ser. (Math.).* 2: 3-16.

Spies, B. and Woodgate, P. (2005). *Salinity Mapping Methods in the Australian Context.* Department of the Environment and Heritage; Agriculture, Fisheries and Forestry, June, 2005.

Tickell, G.W. (1994) *Dryland Salinity Hazard Map of the Northern Territory,* report 54/904D, Northern Territory Power and Water Authority, Darwin.

Walker G, Gordon I, Gilfedder M. (2006). *Salinity Hazard and Risk Assessment in Australia*. National Dryland Salinity Program, 2006.

Wallace (2003) *Mapping Salinity in the Southern Cross Landsat Scene.* A supplementary report to the NHD funded land monitor project. CSIRO Mathematical Information Sciences, CMIS Task Report No. 2003/15.

Wilcoxon, F. and Wilcox, R.A. (1964). *Some rapid approximate statistical procedures.* Lederle Laboratories, Pearl River, N.Y. 59 pp.

Xevi E and Khan S, (2007). *Integrating GIS and Modelling Surface Water and Crop Production.* CSIRO Land and Water, New South Wales, 2007

Zar JH (1984) *Biostatistical Analysis*, Second Edition. Department of Biological Sciences Northern Illinois University. Prentice Hall Inc, Englewood Cliffs, NJ 07632.

(DAFWA 2007)

(NLWRA 2001).

(MDBMC, 1999)

(DNRW, 2006)

Appendix A

Landscape - Land Monitor Statistical Analysis

Normality Test for Land Monitor Data - Grouped by Year of Scene Analysis

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Year	Statistic	df	Sig.	Statistic	df	Sig.
Proportion Saline	1987	.173	328	.000	.796	328	.000
	1995	.163	328	.000	.797	328	.000

a. Lilliefors Significance Correction

Normality Test – Catchments Grouped by Sub Region

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Sub Region	Statistic	df	Sig.	Statistic	df	Sig.
Proportion Saline	Central-East	.188	138	.000	.753	138	.000
	Central-West	.195	112	.000	.788	112	.000
	Lakes District	.185	142	.000	.843	142	.000
	North Eastern Platea	.136	68	.003	.910	68	.000
	River Catchments	.271	156	.000	.730	156	.000
	Wongan-Pithara	.199	40	.000	.863	40	.000

a. Lilliefors Significance Correction

Levene's Test for Land Monitor Data - Grouped by Year of Scene Analysis

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Salinity	Based on Mean	260.477	1	654	.000
	Based on Median	142.939	1	654	.000
	Based on Median and with adjusted df	142.939	1	351.168	.000
	Based on trimmed mean	208.247	1	654	.000

Levene's Test for data when grouped by Sub Region

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Salinity	Based on Mean	75.686	5	650	.000
	Based on Median	28.356	5	650	.000
	Based on Median and with adjusted df	28.356	5	305.666	.000
	Based on trimmed mean	60.573	5	650	.000

Normality Test for data when grouped by Year of Land Monitor Scene Analysis

Tests of Normality

	Year	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Salinity	1987	.174	323	.000	.795	323	.000
	1992	.164	323	.000	.796	323	.000

a. Lilliefors Significance Correction

Normality Test for data when grouped by Landscape

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Landscape	Statistic	df	Sig.	Statistic	df	Sig.
Salinity	Avon Arc	.323	36	.000	.793	36	.000
	Avon East	.304	8	.029	.782	8	.018
	Avon River	.265	18	.002	.814	18	.002
	Avon South	.259	28	.000	.799	28	.000
	Beacon	.332	8	.010	.755	8	.009
	Bodallin	.191	18	.083	.932	18	.208
	Corrigin	.239	24	.001	.821	24	.001
	Dalwallinu	.232	6	.200*	.921	6	.512
	Ejanding	.183	24	.037	.830	24	.001
	Hyden	.204	18	.047	.802	18	.002
	Keller High Saline	.178	36	.005	.891	36	.002
	Keller Low Risk	.173	50	.001	.876	50	.000
	Koorda	.166	24	.084	.842	24	.002
	Kulin Holt Rock	.208	46	.000	.868	46	.000
	Lake Grace	.162	18	.200*	.921	18	.133
	Lake King	.260	20	.001	.751	20	.000
	Merredin Narrembeen	.223	52	.000	.700	52	.000
	Muntagin Narrembeen East	.150	18	.200*	.906	18	.073
	Newdegate	.182	40	.002	.833	40	.000
	Nungarin	.185	14	.200*	.955	14	.644
	Nungarin High	.246	12	.043	.867	12	.060
	Avon West	.216	54	.000	.778	54	.000
	Westonia	.159	40	.012	.882	40	.001
	Wongan	.205	34	.001	.870	34	.001

a. Lilliefors Significance Correction

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Landscape	Statistic	df	Sig.	Statistic	df	Sig.
Salinity	Avon Arc	.323	36	.000	.793	36	.000
	Avon East	.304	8	.029	.782	8	.018
	Avon River	.265	18	.002	.814	18	.002
	Avon South	.259	28	.000	.799	28	.000
	Beacon	.332	8	.010	.755	8	.009
	Bodallin	.191	18	.083	.932	18	.208
	Corrigin	.239	24	.001	.821	24	.001
	Dalwallinu	.232	6	.200*	.921	6	.512
	Ejanding	.183	24	.037	.830	24	.001
	Hyden	.204	18	.047	.802	18	.002
	Keller High Saline	.178	36	.005	.891	36	.002
	Keller Low Risk	.173	50	.001	.876	50	.000
	Koorda	.166	24	.084	.842	24	.002
	Kulin Holt Rock	.208	46	.000	.868	46	.000
	Lake Grace	.162	18	.200*	.921	18	.133
	Lake King	.260	20	.001	.751	20	.000
	Merredin Narrembeen	.223	52	.000	.700	52	.000
	Muntagin Narrembeen East	.150	18	.200*	.906	18	.073
	Newdegate	.182	40	.002	.833	40	.000
	Nungarin	.185	14	.200*	.955	14	.644
	Nungarin High	.246	12	.043	.867	12	.060
	Avon West	.216	54	.000	.778	54	.000
	Westonia	.159	40	.012	.882	40	.001
	Wongan	.205	34	.001	.870	34	.001

*. This is a lower bound of the true significance.

Table 15 Levene's Test for data when grouped by Year Land Monitor Analysis

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Salinity	Based on Mean	256.192	1	644	.000
	Based on Median	139.368	1	644	.000
	Based on Median and with adjusted df	139.368	1	346.139	.000
	Based on trimmed mean	204.369	1	644	.000

Table 16 Levene's Test for data when grouped by Landscape

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Salinity	Based on Mean	45.903	23	622	.000
	Based on Median	14.602	23	622	.000
	Based on Median and with adjusted df	14.602	23	157.867	.000
	Based on trimmed mean	41.474	23	622	.000

Table 17 Landscapes grouped with those that did not have a significant difference in saline proportions in 1987

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11
Avon East										
	Avon River	Avon River								
Avon South	Avon South									
						Beacon	Beacon	Beacon	Beacon	Beacon
							Bodallin	Bodallin	Bodallin	Bodallin
	Corrigin		Corrigin							
Dalwallinu	Dalwallinu									
Ejanding	Ejanding									
						Hyden				
Keller High Saline										
				Keller Low	Keller Low					
		Koorda	Koorda	Koorda						
		Kulin-Holt Rock								
Lake Grace	Lake Grace									
					Lake King	Lake King	Lake King			Lake King
						Merredin – Narrembeen	Merredin – Narrembeen			
								Muntagin – Narrembeen East	Muntagin – Narrembeen East	Muntagin – Narrembeen East
					Newdegate					Newdegate
								Nungarin		
					Nungarin High	Nungarin High				
						Avon West				
									Westonia	

Table 18 Landscapes grouped with those that did not have a significant difference in saline proportions in 1995

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12	Group 13	Group 14
							Avon Arc						
					Avon River Margin	Avon River Margin					Avon River Margin		
							Avon River West	Avon River West					
												Avon South	
					Beacon	Beacon					Beacon		
	Bodallin	Bodallin	Bodallin						Bodallin	Bodallin	Bodallin		
						Corrigin	Corrigin						
Dalwallinu	Dalwallinu	Dalwallinu			Dalwallinu				Dalwallinu	Dalwallinu	Dalwallinu	Dalwallinu	Dalwallinu
		Ejanding		Ejanding	Ejanding	Ejanding			Ejanding		Ejanding	Ejanding	Ejanding
	Hyden	Hyden							Hyden				Hyden
Keller High Saline													
					Keller Low							Keller Low	
		Koorda	Koorda	Koorda	Koorda				Koorda		Koorda	Koorda	Koorda
		Kulin-Holt Rock	Kulin-Holt Rock	Kulin-Holt Rock	Kulin-Holt Rock				Kulin-Holt Rock				Kulin-Holt Rock
Lake Grace	Lake Grace												
			Merredin – Narrembeen	Merredin – Narrembeen	Merredin – Narrembeen						Merredin – Narrembeen	Merredin – Narrembeen	
		Muntagin – Narrembeen East	Muntagin – Narrembeen East	Muntagin – Narrembeen East	Muntagin – Narrembeen East				Muntagin – Narrembeen East		Muntagin – Narrembeen East	Muntagin – Narrembeen East	Muntagin – Narrembeen East
					Newdegate	Newdegate						Newdegate	
					Nungarin	Nungarin						Nungarin	
Nungarin High													
								Westdale		Westdale			
				Westonia	Westonia	Westonia						Westonia	Westonia

Appendix B

Groundwater Bores - Normality and Homogeneity of Variance Test Results

SPSS v.15 output tables

Sub Region

Tests of Normality

	Sub Region	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Rate of Rise	Central - East	.154	75	.000	.912	75	.000
	Central - West	.198	33	.002	.908	33	.009
	Lakes District	.164	53	.001	.943	53	.013
	North Eastern Platea	.160	72	.000	.957	72	.015
	River Catchments	.225	28	.001	.849	28	.001

a Lilliefors Significance Correction

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Rate of Rise	Based on Mean	5.179	4	256	.000
	Based on Median	4.102	4	256	.003
	Based on Median and with adjusted df	4.102	4	206.228	.003
	Based on trimmed mean	4.844	4	256	.001

Valley Hazard

Tests of Normality

	Slope Hazard	Kolmogorov-Smirnov(a)			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Rate of Rise	False	.159	167	.000	.932	167	.000
	True	.163	94	.000	.951	94	.001

a Lilliefors Significance Correction

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Rate of Rise	Based on Mean	1.131	1	259	.289
	Based on Median	1.107	1	259	.294
	Based on Median and with adjusted df	1.107	1	235.021	.294
	Based on trimmed mean	1.301	1	259	.255

SWL Class

Tests of Normality

		Kolmogorov-Smirnov(a)			Shapiro-Wilk		
	SWL CLass	Statistic	df	Sig.	Statistic	df	Sig.
Rate of Rise	GT 6m	.127	125	.000	.949	125	.000
	2 - 6m	.172	136	.000	.944	136	.000

a Lilliefors Significance Correction

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Rate of Rise	Based on Mean	13.344	1	259	.000
	Based on Median	10.990	1	259	.001
	Based on Median and with adjusted df	10.990	1	227.668	.001
	Based on trimmed mean	13.104	1	259	.000

Appendix C

Groundwater bores - Analyses of Slope Hazard Classes

SPSS v.15 output tables

Sub Region: Central-East

SWL Class: 2-6m

	Rate of Rise (Central-East 2-6m)
Mann-Whitney U	125.000
Wilcoxon W	590.000
Z	-2.525
Asymp. Sig. (2-tailed)	.012

a Grouping Variable: Valley (Central-East 2-6m)

	Rate of Rise (Central-West GT 6m)
Mann-Whitney U	7.500
Wilcoxon W	62.500
Z	-.553
Asymp. Sig. (2-tailed)	.580
Exact Sig. [2*(1-tailed Sig.)]	.606(a)

a Not corrected for ties.
b Grouping Variable: Valley (Central-West GT 6m)

Sub Region: Central-East

SWL Class: GT 6m

	Rate of Rise (Central-East GT 6m)
Mann-Whitney U	82.500
Wilcoxon W	173.500
Z	-1.185
Asymp. Sig. (2-tailed)	.236
Exact Sig. [2*(1-tailed Sig.)]	.245(a)

a Not corrected for ties.
b Grouping Variable: Valley (Central-East GT 6m)

Sub Region: Lakes District

SWL Class: 2-6m

	Rate of Rise (Lakes District 2-6m)
Mann-Whitney U	121.000
Wilcoxon W	374.000
Z	-.779
Asymp. Sig. (2-tailed)	.436
Exact Sig. [2*(1-tailed Sig.)]	.468(a)

a Not corrected for ties.
b Grouping Variable: Valley (Lakes District 2-6m)

Sub Region: Central-West

SWL Class: 2-6m

	Rate of Rise (Central-West 2-6m)
Mann-Whitney U	22.500
Wilcoxon W	37.500
Z	-1.551
Asymp. Sig. (2-tailed)	.121
Exact Sig. [2*(1-tailed Sig.)]	.153(a)

a Not corrected for ties.
b Grouping Variable: Valley (Central-West 2-6m)

Sub Region: Lakes District

SWL Class: GT 6m

	Rate of Rise (Lakes District GT 6m)
Mann-Whitney U	14.000
Wilcoxon W	29.000
Z	-1.864
Asymp. Sig. (2-tailed)	.062
Exact Sig. [2*(1-tailed Sig.)]	.075(a)

a Not corrected for ties.
b Grouping Variable: Valley (Lakes District GT 6m)

Sub Region: North Eastern Plateau

SWL Class: 2-6m

Sub Region: Central-West

SWL Class: GT 6m

	Rate of Rise (North Eastern Platea 2-6m)
Mann-Whitney U	261.500
Wilcoxon W	586.500
Z	-.023
Asymp. Sig. (2-tailed)	.982

a Grouping Variable: Valley (North Eastern Platea 2-6m)

Sub Region: North Eastern Plateau

SWL Class: GT 6m

	Rate of Rise (North Eastern Platea GT 6m)
Mann-Whitney U	43.000
Wilcoxon W	274.000
Z	-.625
Asymp. Sig. (2-tailed)	.532
Exact Sig. [2*(1-tailed Sig.)]	.569(a)

a Not corrected for ties.
b Grouping Variable: Valley (North Eastern Platea GT 6m)

Appendix D

Groundwater Bores - Analyses of Depth to Standing Water Level Classes

SPSS v.15 output tables

Sub Region: Central-East

Slope Hazard Class: False

	Rate of Rise (Central-East F)
Mann-Whitney U	59.000
Wilcoxon W	179.000
Z	-2.611
Asymp. Sig. (2-tailed)	.009
Exact Sig. [2*(1-tailed Sig.)]	.009(a)

a Not corrected for ties.
b Grouping Variable: SWL (Central-East F)

Sub Region: Central-East

Slope Hazard Class: True

	Rate of Rise (Central-East T)
Mann-Whitney U	28.000
Wilcoxon W	493.000
Z	-4.531
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000(a)

a Not corrected for ties.
b Grouping Variable: SWL (Central-East T)

Sub Region: Central-West

Slope Hazard Class: False

	Rate of Rise (Central-West F)
Mann-Whitney U	62.000
Wilcoxon W	117.000
Z	-1.025
Asymp. Sig. (2-tailed)	.305
Exact Sig. [2*(1-tailed Sig.)]	.363(a)

a Not corrected for ties.
b Grouping Variable: SWL (Central-West F)

Sub Region: Central-West

Slope Hazard Class: True

	Rate of Rise (Central-West T)
Mann-Whitney U	3.500
Wilcoxon W	18.500
Z	-.641
Asymp. Sig. (2-tailed)	.522
Exact Sig. [2*(1-tailed Sig.)]	.571(a)

a Not corrected for ties.
b Grouping Variable: SWL (Central-West T)

Sub Region: Lakes District

Slope Hazard Class: False

	Rate of Rise (Lakes District F)
Mann-Whitney U	60.500
Wilcoxon W	313.500
Z	-2.874
Asymp. Sig. (2-tailed)	.004
Exact Sig. [2*(1-tailed Sig.)]	.004(a)

a Not corrected for ties.
b Grouping Variable: SWL (Lakes District F)

Sub Region: Lakes District

Slope Hazard Class: True

	Rate of Rise (Lakes District T)
Mann-Whitney U	29.000
Wilcoxon W	44.000
Z	-.354
Asymp. Sig. (2-tailed)	.723
Exact Sig. [2*(1-tailed Sig.)]	.775(a)

a Not corrected for ties.
b Grouping Variable: SWL (Lakes District T)

Sub Region: North Eastern Plateau

Slope Hazard Class: False

	Rate of Rise (North Eastern Platea F)
Mann-Whitney U	118.000
Wilcoxon W	443.000
Z	-3.219
Asymp. Sig. (2-tailed)	.001

a Grouping Variable: SWL (North Eastern Platea F)

Slope Hazard Class: True

	Rate of Rise (North Eastern Platea T)
Mann-Whitney U	16.500
Wilcoxon W	247.500
Z	-2.400
Asymp. Sig. (2-tailed)	.016
Exact Sig. [2*(1-tailed Sig.)]	.015(a)

a Not corrected for ties.
b Grouping Variable: SWL (North Eastern Platea T)

Sub Region: River Catchments

Slope Hazard Class: False

	Rate of Rise (River Catchments F)
Mann-Whitney U	68.000
Wilcoxon W	239.000
Z	-1.112
Asymp. Sig. (2-tailed)	.266
Exact Sig. [2*(1-tailed Sig.)]	.308(a)

a Not corrected for ties.
b Grouping Variable: SWL (River Catchments F)

Sub Region: North Eastern Plateau

Appendix E

Groundwater - Analyses of Sub Regions

SPSS v.15 output tables

Slope Hazard: True SWL: 2-6m

Kruskal-Wallis Test

Ranks

	Sub Region (T & 2-6m)	N	Mean Rank
Rate of Rise (T & 2 - 6m)	Central – East	30	35.90
	Central - West	7	63.57
	Lakes District	18	45.31
	North Eastern Plateau	26	37.83
	Total	81	

Test Statistics(a,b)

	Rate of Rise (T & 2 - 6m)
Chi-Square	9.377
df	3
Asymp. Sig.	.025

a Kruskal Wallis Test
b Grouping Variable: Sub Region (T & 2-6m)

Mann-Whitney Tests

Sub Region Combination: Central-West and Central-East

	Rate of Rise (T & 2 - 6m)
Mann-Whitney U	27.500
Wilcoxon W	492.500
Z	-3.137
Asymp. Sig. (2-tailed)	.002
Exact Sig. [2*(1-tailed Sig.)]	.001(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (T & 2-6m)

Sub Region Combination: Lakes District and Central-East

	Rate of Rise (T & 2 - 6m)
Mann-Whitney U	205.500
Wilcoxon W	670.500
Z	-1.418
Asymp. Sig. (2-tailed)	.156

a Grouping Variable: Sub Region (T & 2-6m)

Sub Region Combination: North Eastern Plateau and Central-East

	Rate of Rise (T & 2 - 6m)
Mann-Whitney U	379.000
Wilcoxon W	844.000
Z	-.189
Asymp. Sig. (2-tailed)	.850

a Grouping Variable: Sub Region (T & 2-6m)

Sub Region Combination: Central-West and Lakes District

	Rate of Rise (T & 2 - 6m)
Mann-Whitney U	38.500
Wilcoxon W	209.500
Z	-1.537
Asymp. Sig. (2-tailed)	.124
Exact Sig. [2*(1-tailed Sig.)]	.141(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (T & 2-6m)

Sub Region Combination: Central-West and North Eastern Plateau

	Rate of Rise (T & 2 - 6m)
Mann-Whitney U	35.000
Wilcoxon W	386.000
Z	-2.507
Asymp. Sig. (2-tailed)	.012
Exact Sig. [2*(1-tailed Sig.)]	.012(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (T & 2-6m)

Sub Region Combination: Lakes District and North Eastern Plateau

	Rate of Rise (T & 2 - 6m)
Mann-Whitney U	196.500
Wilcoxon W	547.500
Z	-.909
Asymp. Sig. (2-tailed)	.363

a Grouping Variable: Sub Region (T & 2-6m)

Slope Hazard: False SWL: 2-6m

Kruskal-Wallis Test

Ranks

	Sub Region (F & 2 - 6m)	N	Mean Rank
Rate of Rise (F & 2 - 6m)	Central - West	15	58.23
	Central - East	16	80.91
	Lakes District	22	45.23
	North Eastern Platea	25	33.36
	River Catchments	18	36.61
	Total	96	

Test Statistics(a,b)

	Rate of Rise (F & 2 - 6m)
Chi-Square	36.179
df	4
Asymp. Sig.	.000

a Kruskal Wallis Test
b Grouping Variable: Sub Region (F & 2 - 6m)

Mann-Whitney Tests

Sub Region Combination: Central-East and Central-West

	Rate of Rise (F & 2 - 6m)
Mann-Whitney U	48.500
Wilcoxon W	168.500
Z	-2.964
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.004(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & 2 - 6m)

Sub Region Combination: Central-East and Lakes District

	Rate of Rise (F & 2 - 6m)
Mann-Whitney U	119.000
Wilcoxon W	372.000
Z	-1.482
Asymp. Sig. (2-tailed)	.138
Exact Sig. [2*(1-tailed Sig.)]	.161(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & 2 - 6m)

Sub Region Combination: Central East and North Eastern Plateau

	Rate of Rise (F & 2 - 6m)
Mann-Whitney U	82.000
Wilcoxon W	407.000
Z	-3.020
Asymp. Sig. (2-tailed)	.003
Exact Sig. [2*(1-tailed Sig.)]	.003(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & 2 - 6m)

Sub Region Combination: Central-East and River Catchments

	Rate of Rise (F & 2 - 6m)
Mann-Whitney U	69.000
Wilcoxon W	240.000
Z	-2.499
Asymp. Sig. (2-tailed)	.012
Exact Sig. [2*(1-tailed Sig.)]	.016(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & 2 - 6m)

Sub Region Combination: Central-West and Lakes District

	Rate of Rise (F & 2 - 6m)
Mann-Whitney U	36.500
Wilcoxon W	289.500
Z	-4.265
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & 2 - 6m)

Sub Region Combination: Central-West and North Eastern Plateau

	Rate of Rise (F & 2 - 6m)
Mann-Whitney U	24.000
Wilcoxon W	349.000
Z	-4.780
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & 2 - 6m)

Sub Region Combination: Central-West and River Catchments

	Rate of Rise (F & 2 - 6m)
Mann-Whitney U	12.500
Wilcoxon W	183.500
Z	-4.678
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & 2 - 6m)

Sub Region Combination: Lakes District and North Eastern Plateau

	Rate of Rise (F & 2 - 6m)
Mann-Whitney U	200.500
Wilcoxon W	525.500
Z	-1.626
Asymp. Sig. (2-tailed)	.104

a Grouping Variable: Sub Region (F & 2 - 6m)

Sub Region Combination: Lakes District and River Catchments

	Rate of Rise (F & 2 - 6m)
Mann-Whitney U	159.000
Wilcoxon W	330.000
Z	-1.104
Asymp. Sig. (2-tailed)	.270
Exact Sig. [2*(1-tailed Sig.)]	.299(a)

a Not corrected for ties.

b Grouping Variable: Sub Region (F & 2 - 6m)

Sub Region Combination: River Catchments and North Eastern Plateau

	Rate of Rise (F & 2 - 6m)
Mann-Whitney U	202.500
Wilcoxon W	527.500
Z	-.576
Asymp. Sig. (2-tailed)	.565

a Grouping Variable: Sub Region (F & 2 - 6m)

Slope Hazard: False SWL: > 6m

Kruskal-Wallis Test

Ranks

	Sub Region (F & GT 6m)	N	Mean Rank
Rate of Rise (F & GT 6m)	Central - East	17	47.00
	Central - West	10	32.45
	Lakes District	13	38.85
	North Eastern Platea	21	34.57
	River Catchments	10	20.15
	Total	71	

Test Statistics(a,b)

	Rate of Rise (F & GT 6m)
Chi-Square	11.600
df	4
Asymp. Sig.	.021

a Kruskal Wallis Test
b Grouping Variable: Sub Region (F & GT 6m)

Mann-Whitney Tests

Sub Region Combination: Central-East and Central-West

	Rate of Rise (F & GT 6m)
Mann-Whitney U	46.500
Wilcoxon W	101.500
Z	-1.955
Asymp. Sig. (2-tailed)	.051
Exact Sig. [2*(1-tailed Sig.)]	.052(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & GT 6m)

Sub Region Combination: Central-East and Lakes District

	Rate of Rise (F & GT 6m)
Mann-Whitney U	78.500
Wilcoxon W	169.500
Z	-1.356
Asymp. Sig. (2-tailed)	.175
Exact Sig. [2*(1-tailed Sig.)]	.183(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & GT 6m)

Sub Region Combination: Central-East and North Eastern Plateau

	Rate of Rise (F & GT 6m)
Mann-Whitney U	115.000
Wilcoxon W	346.000
Z	-1.878
Asymp. Sig. (2-tailed)	.060
Exact Sig. [2*(1-tailed Sig.)]	.064(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & GT 6m)

Sub Region Combination: Central-West and North Eastern Plateau

	Rate of Rise (F & GT 6m)
Mann-Whitney U	95.500
Wilcoxon W	150.500
Z	-.407
Asymp. Sig. (2-tailed)	.684
Exact Sig. [2*(1-tailed Sig.)]	.693(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & GT 6m)

Sub Region Combination: Central-East and River Catchments

	Rate of Rise (F & GT 6m)
Mann-Whitney U	32.000
Wilcoxon W	87.000
Z	-2.693
Asymp. Sig. (2-tailed)	.007
Exact Sig. [2*(1-tailed Sig.)]	.007(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & GT 6m)

Sub Region Combination: Central-West and River Catchments

	Rate of Rise (F & GT 6m)
Mann-Whitney U	23.000
Wilcoxon W	78.000
Z	-2.109
Asymp. Sig. (2-tailed)	.035
Exact Sig. [2*(1-tailed Sig.)]	.043(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & GT 6m)

Sub Region Combination: Central-West and Lakes District

	Rate of Rise (F & GT 6m)
Mann-Whitney U	50.500
Wilcoxon W	105.500
Z	-.915
Asymp. Sig. (2-tailed)	.360
Exact Sig. [2*(1-tailed Sig.)]	.376(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & GT 6m)

Sub Region Combination: Lakes District and North Eastern Plateau

	Rate of Rise (F & GT 6m)
Mann-Whitney U	117.000
Wilcoxon W	348.000
Z	-.701
Asymp. Sig. (2-tailed)	.483
Exact Sig. [2*(1-tailed Sig.)]	.506(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & GT 6m)

Sub Region Combination: Lakes District and River Catchments

	Rate of Rise (F & GT 6m)
Mann-Whitney U	30.000
Wilcoxon W	85.000
Z	-2.227
Asymp. Sig. (2-tailed)	.026
Exact Sig. [2*(1-tailed Sig.)]	.030(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & GT 6m)

Sub Region Combination: North Eastern Plateau and River Catchments

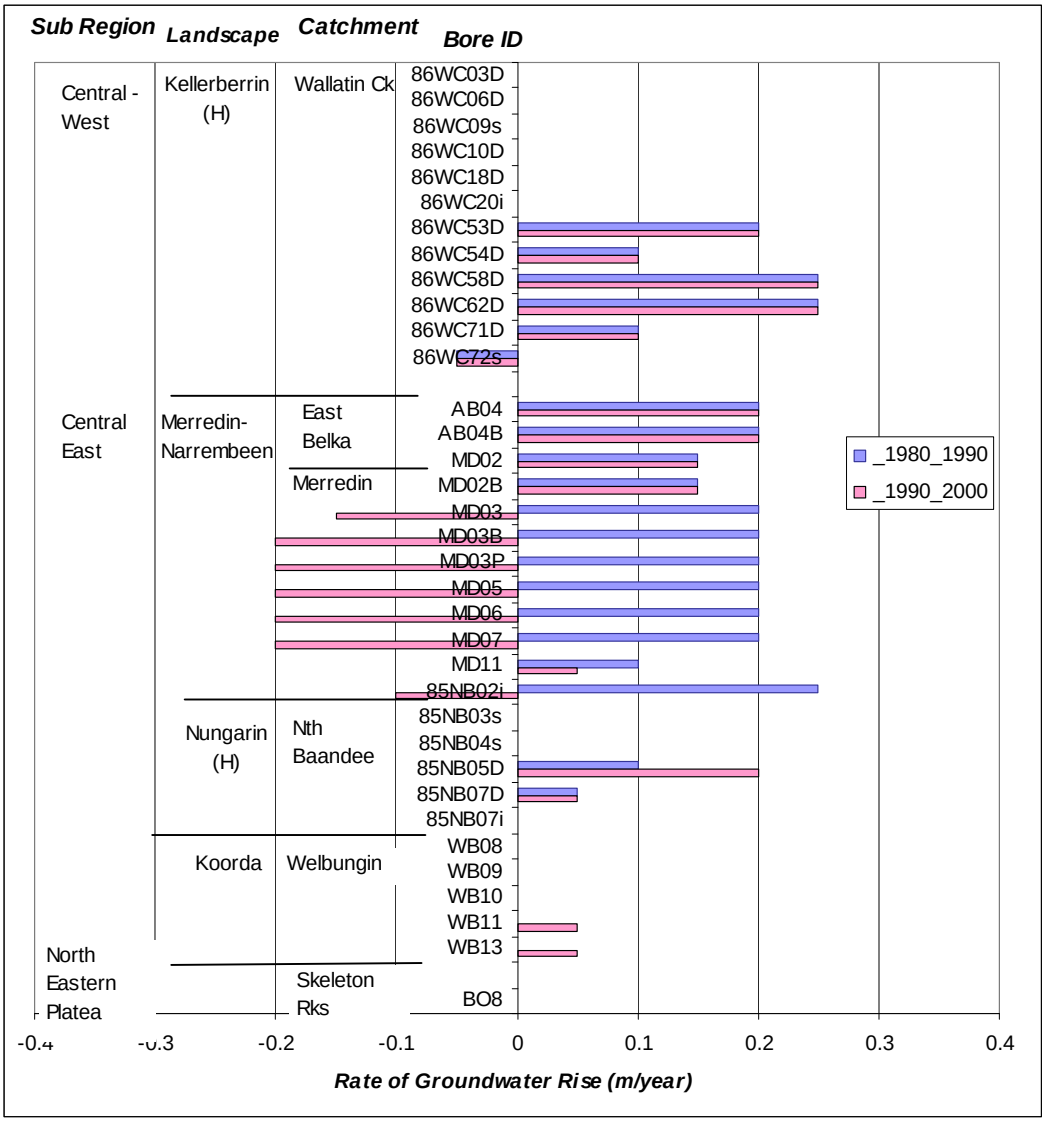
	Rate of Rise (F & GT 6m)
Mann-Whitney U	61.500
Wilcoxon W	116.500
Z	-1.885
Asymp. Sig. (2-tailed)	.059
Exact Sig. [2*(1-tailed Sig.)]	.065(a)

a Not corrected for ties.
b Grouping Variable: Sub Region (F & GT 6m)

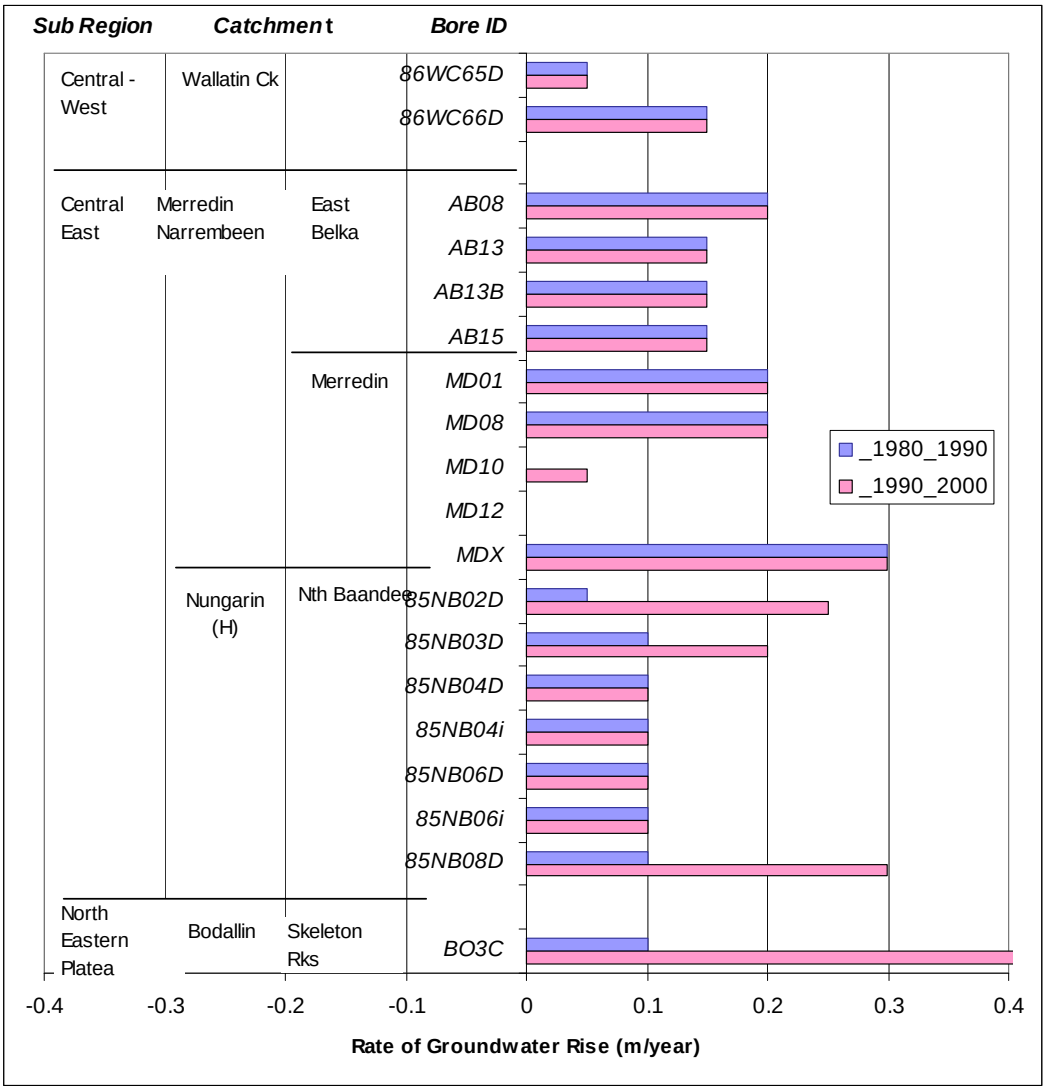
Appendix F

Groundwater Bores – Rate of Rise Charts (Sub Regions and Landscapes)

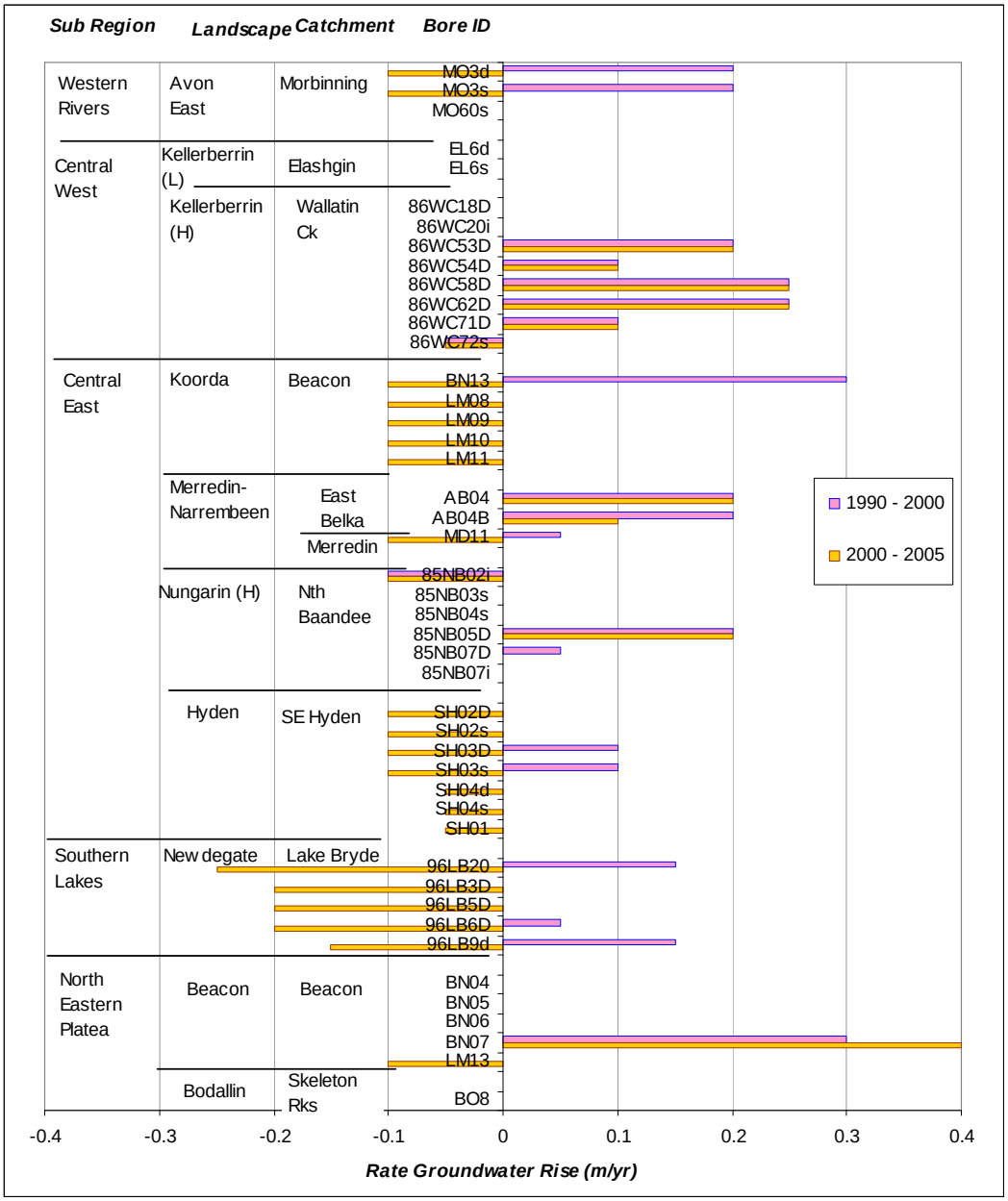
Comparison of Groundwater Levels 1980 -- 1990 with 1990 – 2000 - Groundwater Bores between 2 -- 6 M below the Surface



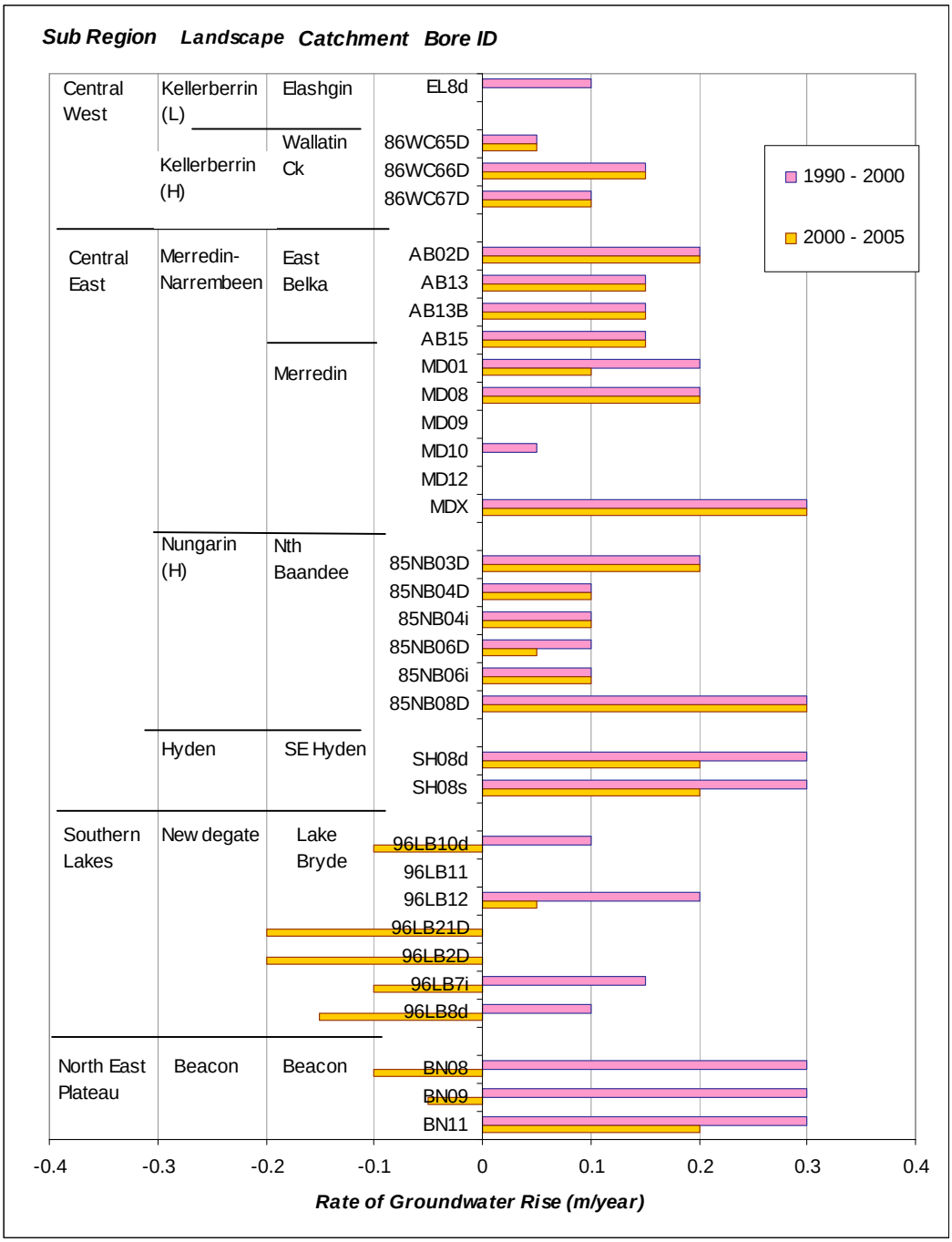
Comparison of Groundwater Levels 1980 -- 1990 with 1990 – 2000 - Groundwater Bores More than 6 M below the Surface



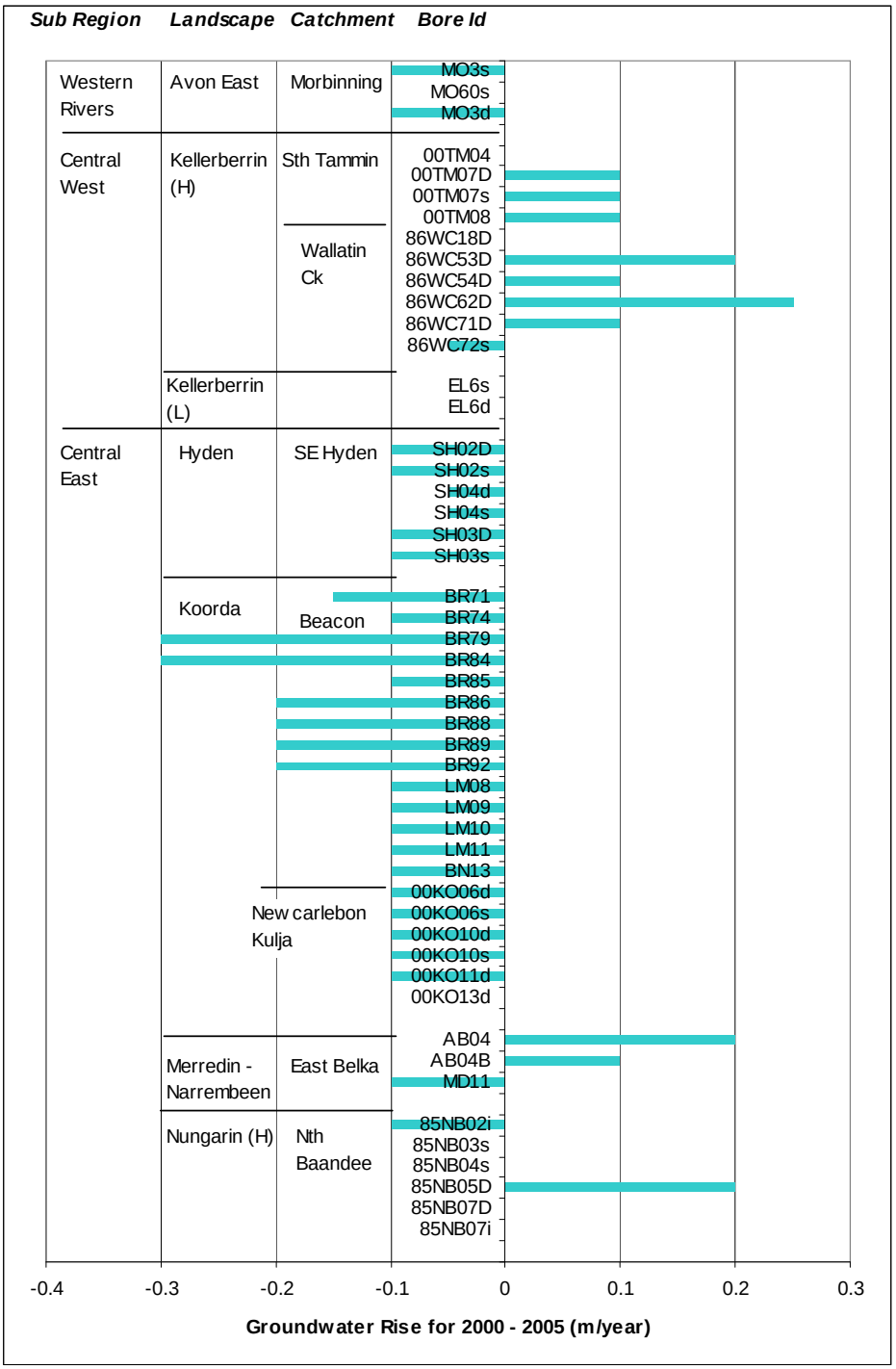
Comparison of Groundwater Levels 1990 – 2000 with 2000 – 2005 for Groundwater Bores with SWL 2m -- 6m Below Natural Surface



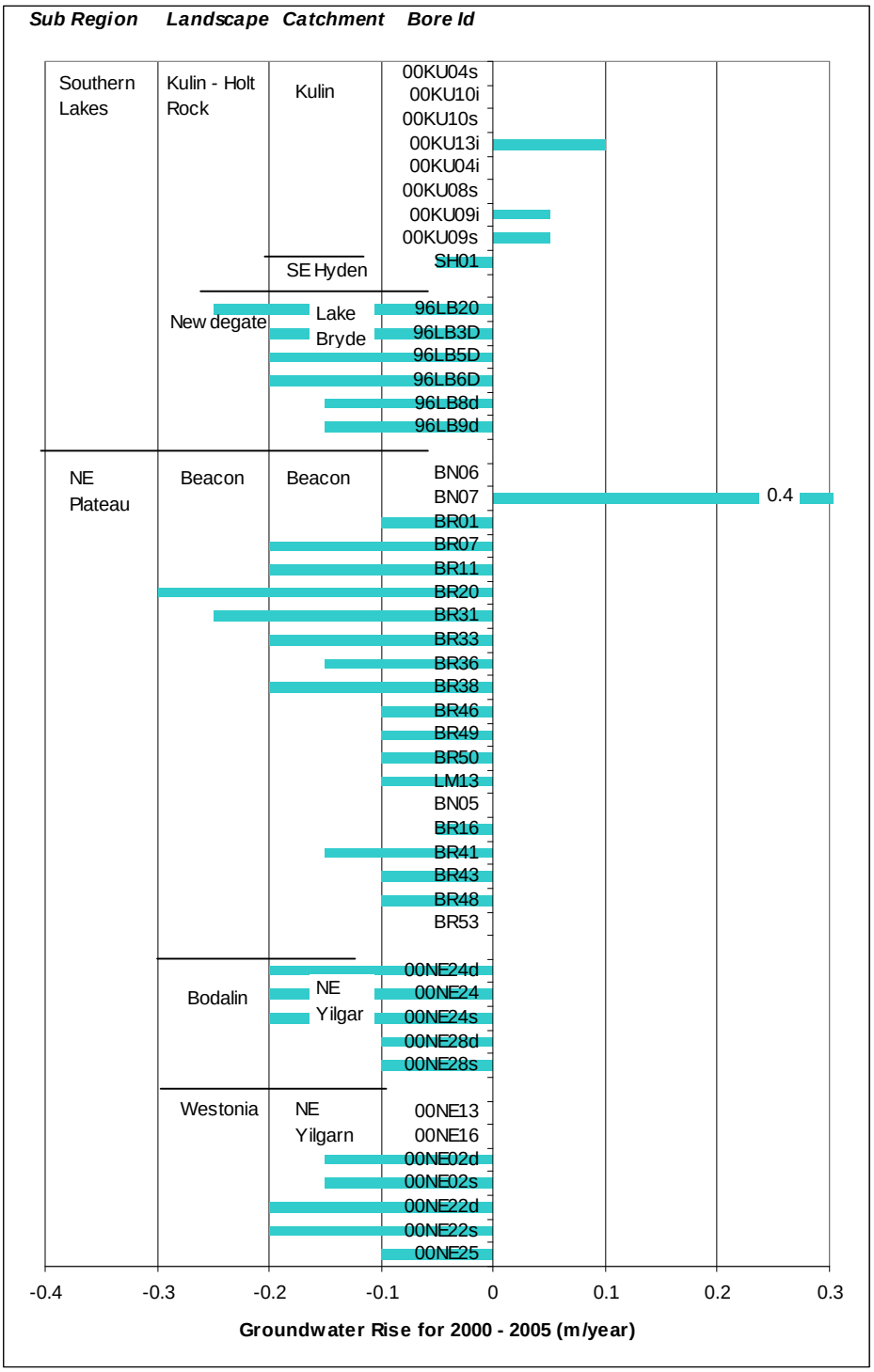
Comparison of Groundwater Levels 1990 – 2000 with 2000 – 2005 for Groundwater Bores More than 6 m Below Natural Surface



Rate of Rise Shallow Groundwater Bores Avon River Basin – Part 1



Rate of Rise Shallow Groundwater Bores Avon River Basin – Part 2



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