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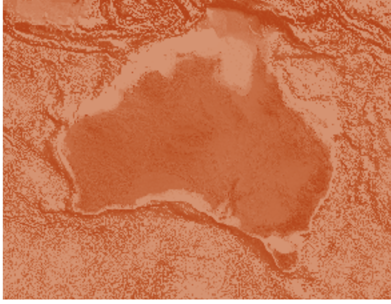

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Vulnerability Factor Analysis

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Australian Government
Geoscience Australia
National Water Commission

National Centre for Groundwater Research and Training
sustaining a vital water resource

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Executive Summary

Fresh groundwater stored in Australian coastal aquifers constitutes an important resource for humans and the natural environment. However, many Australian coastal aquifers are vulnerable to seawater intrusion (SWI) – the landward encroachment of seawater into coastal aquifers. SWI can significantly degrade water quality and reduce freshwater availability. The increasing demands for freshwater in coastal areas and the anticipated impacts of climate change (such as sea-level rise and reductions in rainfall recharge) may result in increases in the incidence and severity of SWI. Despite these threats, comprehensive investigations of SWI are relatively uncommon and the extent of monitoring and investigations specific to SWI are highly variable across the nation.

In response to the threat posed by SWI, Geoscience Australia (GA) and the National Centre for Groundwater Research and Training (NCGRT), in collaboration with state and territory water agencies, have undertaken a national-scale assessment of the vulnerability of coastal aquifers to SWI. This assessment aims to identify the coastal groundwater resources that are most vulnerable to SWI and considers the future consequences of over-extraction, sea-level rise, and recharge–discharge variations associated with climate change. The current study focuses on assessing the vulnerability of coastal aquifers, rather than that of surface water bodies, to the landward migration of the freshwater–saltwater interface. Project funding was provided through the Raising National Water Standards program, which is administered by the National Water Commission.

In order to achieve the project aims, the study comprised five technical assessments to analyse factors contributing to the vulnerability of coastal aquifers: (i) vulnerability factor analysis (VFA); (ii) coastal aquifer typology; (iii) mathematical analysis; (iv) SWI quantitative and qualitative vulnerability indexing; and, (v) future land surface inundation and population growth analysis.

This report covers the VFA component of the project which provides a first-pass, regional assessment of SWI vulnerability indicators in Australia's coastal areas based on state and territory groundwater datasets for individual groundwater bores. In total, more than 1.7 million groundwater levels and more than 1.1 million salinity measurements were compiled and evaluated as part of this project. This large dataset allowed analysis of a greater portion of Australia's coastline than has been assessed in previous studies and makes a significant contribution to the state of knowledge of SWI around the country.

Due to the scale of the VFA assessment and limits on the type of data available, it was not possible to include information on several important, site-specific parameters affecting SWI vulnerability including aquifer geometry, aquifer hydraulic properties, sea-aquifer connectivity and recharge rates. Consequently, the VFA cannot provide a definitive assessment of an area's vulnerability to SWI. Instead, the VFA indicators were used to identify priority areas of concern for further, site-specific analysis of SWI vulnerability and to inform the national vulnerability assessment reported in Ivkovic et al. (2012a).

Although additional factors are relevant when assessing vulnerability of groundwater systems to SWI, the VFA was restricted to a consideration of the following parameters due to constraints on data availability and the limitations of undertaking a national-scale analysis:

- groundwater levels in monitoring bores (minimum groundwater level, inter-decadal changes in minimum groundwater level and groundwater level trends);
- rainfall trends measured at BoM weather stations;
- groundwater salinity in monitoring bores (maximum salinity and inter-decadal changes in salinity); and
- groundwater extraction from production wells (locations and rates).

Values for each of the above parameters were separated into SWI vulnerability level indicator categories and plotted on a series of maps to facilitate spatial and temporal data analysis. Locations where indicators of high SWI vulnerability were present (e.g. low and/or decreasing groundwater levels, increasing salinity etc.) are highlighted in Sections 4 to 11 of this report.

Available data were analysed at both national and state levels in the VFA. The national-scale assessment highlights geographical areas where groups of three or more data points (boreholes) within a 5 km radius fall within the same SWI vulnerability indicator category for groundwater level and salinity data. This approach is useful for assessing the general vulnerability of large-scale areas and reducing the likelihood of classifications based on single anomalous measurements. The state-scale assessment presents data for all individual boreholes to provide a finer scale assessment than the national approach. Data in the state and territory analyses are summarised on the basis of groundwater management areas (GMAs) regulated by the state and territory authorities.

Areas where a relatively wide range of high SWI vulnerability indicators are present were identified in the VFA as priority areas for future, detailed assessment. Due to limitations to the usefulness of available rainfall and groundwater extraction data (discussed in Sections 3.4.3 and 3.4.4), only groundwater level and salinity data were considered in the prioritisation assessment. The classification criteria for VFA priority areas are detailed in Sections 4.5 and 5.5.

The national VFA identified the following localities (names refer to the general location and surrounding areas) as “national VFA priority areas” where a relatively wide range (>50% of seven key indicators- see Section 4.5) of high SWI vulnerability indicators were identified:

- Western Australia (WA): Carnarvon and the Swan Coastal Plain (including the following locations and surrounds: Mindarie, Perth, Munster, Peron, Peel Inlet, Harvey Estuary, Lake Preston and Abbey);
- Queensland (Qld): The area north of Cairns (around Holloways Beach), The Burdekin, Bowen, Pioneer Valley and Mackay, Bundaberg and Burnett Heads;
- Victoria (Vic): Koo Wee Rup; and
- South Australia (SA): Streaky Bay, Uley South, Northern Adelaide Plains, Adelaide, McLaren Vale, Aldinga Beach and Goolwa.

“State VFA priority GMAs” where a relatively wide range (>50% of seven key indicators- see Section 5.5) of high SWI vulnerability indicators were identified included (note that this assessment is somewhat dependent on GMA size and the results should be considered in the context of data locations presented on the maps throughout this document):

- WA: Arrowsmith, Bunbury, Busselton-Capel, Carnarvon, Cockburn, Gascoyne, Gingin, Murray, Perth, Stakehill, Southwest Coastal and Yanchep;
- Qld: Bowen, Bundaberg, Burdekin, Cairns Northern Beaches, Farnborough, Pioneer and Proserpine;
- Vic: Deutgam, Koo Wee Rup, Sale, Stratford and Tarwin; and
- SA: Baroota, Central Adelaide, Eastern Mount Lofty Ranges, Lower Limestone Coast, McLaren Vale, Northern Adelaide Plains, Southern Basins and Western Mount Lofty Ranges.

The VFA priority areas and GMAs listed above are shown on Figure A below. In addition to these areas, there are numerous other locations around Australia showing indicators of high SWI vulnerability and a lack of data in many areas (e.g. a lack of data in the Northern Territory, New South Wales and Tasmania precluded identification of priority VFA areas and GMAs in these states). Omission of locations from the lists of VFA priority areas, GMAs and Figure A should not be taken to imply that they are not highly vulnerable to SWI. The lists and figure simply highlight locations where a relatively wide range of high SWI vulnerability indicators are present where data are available around Australia’s coast. Sections 4 to 11 of this report should be consulted for the locations of SWI vulnerability indicators, for information on what data are available for a particular area, and to determine if there is sufficient information available to allow an assessment of likely SWI vulnerability level in an area.

The VFA results are incorporated into the holistic SWI vulnerability assessment in Ivkovic et al. (2012a). While it was developed with the specific intention of informing the National-Scale Vulnerability Assessment of Seawater Intrusion project, the VFA outlines a methodology suitable for evaluating groundwater data at both national and state scales to provide an indication of SWI vulnerability levels. Such an assessment can facilitate prioritisation of areas for further investigation and research should groundwater resources be developed or continue to be used. The VFA has also identified large areas around Australia’s coast where there are insufficient data to provide an indication of likely SWI vulnerability level and further investigation is recommended in these areas.

SWI vulnerability is dependent on a range of factors that vary over time (e.g. groundwater levels relative to sea level, climate, groundwater extraction relative to recharge etc.), and consequently the VFA assessment is time-dependent and requires revision as further data become available. While the VFA may serve as a useful model for future analysis, its methodology was developed to suit available data and should also be reconsidered as further information becomes available. One of the main drivers of SWI is extraction relative to recharge (see Norman et al., 2012), and an incorporation of some measure of this ratio into any future assessment would be valuable. However, it must be kept in mind that the VFA is a broad-scale approach to analysis and if such estimates require detailed, site-specific data, the VFA approach presented here is unlikely to remain relevant.

Figure A: *National VFA priority areas and State VFA priority GMAs (Note that due to a lack of sufficient data for priority area classification along the majority of the Australian coast, many other areas not classified on this figure may also have high SWI vulnerability as outlined in the preceding text)*

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1. Introduction

This vulnerability factor analysis (VFA) technical report forms part of a project entitled “A national-scale vulnerability assessment of seawater intrusion” that was completed by Geoscience Australia (GA) and the National Centre for Groundwater Research and Training (NCGRT) in collaboration with state and territory agencies. The aim of this project is to identify Australian coastal groundwater resources currently vulnerable to seawater intrusion (SWI), and potentially at risk in the future as a consequence of over-extraction, sea-level rise and/or recharge-discharge variations associated with climate change. A summary of the project findings is presented in the project summary report by Ivkovic et al. (2012c).

The introduction to this VFA report provides background information on SWI and includes the motivating context for the national-scale vulnerability assessment of SWI project. The concept of vulnerability is introduced in this chapter and the project aims and objectives are listed.

The national-scale vulnerability assessment of SWI project included five technical assessments that were undertaken to analyse various factors contributing to the vulnerability of coastal aquifers to SWI: (i) VFA; (ii) coastal aquifer typology; (iii) mathematical analysis; (iv) SWI quantitative and qualitative vulnerability indexing; and (v) future land surface inundation and population growth analysis. This technical report presents the VFA component of this project. The VFA was undertaken to provide a first-pass, regional assessment of SWI vulnerability indicators in Australian coastal areas based on nationally available datasets including groundwater levels, salinity, rainfall and extraction data. A summary of this report can be found in Chapter 4.2 of the project summary report (Ivkovic et. al, 2012a).

1.1. Background to the National-Scale Vulnerability Assessment of Seawater Intrusion Project

Fresh groundwater stored in Australian coastal aquifers is an important resource for the natural environment, as well as for urban, agricultural, rural residential and industrial activities. These aquifers may be vulnerable to SWI, which is the landward encroachment of seawater into fresh coastal aquifers. SWI can be caused by hydrologic changes, such as groundwater extraction, groundwater recharge variations, sea-level rise, or modifications to coastal surface water features. SWI poses a threat to the groundwater resources in all of Australia’s states and the Northern Territory. Yet despite this existing threat, comprehensive investigations of SWI are relatively uncommon and the extent of monitoring and investigations specific to SWI is highly variable across the nation (Werner 2010).

The vulnerability of Australia’s coastal aquifers to SWI is not only an area of current concern but also an area of increasing future concern. The increasing demands for freshwater in coastal areas and the anticipated impacts of climate change, such as sea-level rise and variations in rainfall recharge, may result in increases in the incidence and severity of SWI. An assessment is needed to address the paucity of knowledge of SWI vulnerability at the national-scale that considers the extensive and diverse aquifer systems of Australia’s coastal fringe (Werner 2010). An improved awareness and understanding of the key drivers for SWI, the current and emerging SWI vulnerable areas and possible future trends in SWI, will benefit decision makers and groundwater stakeholders across local, state and national levels. Development of a consistent approach for the assessment of SWI vulnerability will assist national, state and regional planning and management strategies.

The national-scale vulnerability assessment of SWI was developed to address the issues highlighted above. The project includes a number of technical reports focussing on various factors contributing to SWI vulnerability. The increased stresses being placed upon Australia's freshwater coastal aquifer systems and the reported threats of SWI within the states and the Northern Territory were strong motivating factors for development of the current project. It was funded by the National Water Commission under the Groundwater Action Plan.

1.2. Vulnerability Concept Clarification

The principal focus of this project is assessing the vulnerability of Australian coastal aquifers to SWI, and accordingly a discussion of the concept of vulnerability and its meaning are provided. Vulnerability has numerous definitions, conceptualisations and assessment methods in the literature found both across and within disciplines (Füssel, 2007). This project has utilised several vulnerability definitions that are appropriate for the multiple components of this national vulnerability assessment of SWI.

Füssel (2007) reviewed vulnerability definitions and found that four dimensions were fundamental to describe any vulnerable situation. These four dimensions included:

1. The **System** undergoing analysis;
2. The **Valued Attribute**(s) of the vulnerable (susceptible) system that is threatened by its exposure to a hazard;
3. **Hazard**: A potentially damaging influence on the system of analysis; and
4. **Temporal Reference**: The point in time or period of interest (current, future, number of years into future etc.).

Using these terms, this project can be described as an assessment of the vulnerability of Australian freshwater coastal aquifers (*system and attribute of concern*) to SWI as a consequence of over-extraction and sea-level rise and/or recharge-discharge variations associated with climate change (*hazards*) in the present, and future (*temporal reference*). This is consistent with the fact that SWI vulnerability is a function of the intrinsic characteristics of the aquifer and the management of the water balance in that aquifer.

The Intergovernmental Panel on Climate Change (IPCC) has defined vulnerability in the specific context of climate change as "*the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change*" (IPCC, 2007). Barnett et al. (2007), notes that "*While there is no consensus on the best approach to vulnerability assessment, in general they entail considering one or more of: exposure to climate risks, susceptibility to damage, and capacity to recover".* The essence of these definitions is captured by (Voice et al., 2006) who states "*vulnerability is a function of exposure, sensitivity and adaptive capacity"*.

By combining the above vulnerability definitions for the purposes of the current study, this report assesses aquifer SWI vulnerability as a function of:

- Exposure to hazards (SWI as a result of groundwater extraction and climate change);
- Sensitivity of the system (coastal aquifers) for attribute of concern (position of the freshwater-seawater interface);

- Time (current and future vulnerability); and,
- Adaptive capacity (monitoring and management specific to SWI).

1.3. Methodology of the National-Scale Vulnerability Assessment of Seawater Intrusion Project

In order meet the project objectives and to achieve a national-scale assessment of aquifer vulnerability to SWI for current and future conditions, the national-scale vulnerability assessment of SWI project adopted a methodology consisting of the following four work phases:

- Phase 1: Literature and data reviews provided a baseline assessment of the state of SWI investigations in Australia (presented in Ivkovic et al., 2012b);
- Phase 2: Five technical assessment components were developed to analyse factors contributing to the overall vulnerability of coastal aquifers to SWI:
  - Vulnerability Factor Analysis: a first-pass, broad-scale assessment of key observational elements of SWI vulnerability. The VFA is presented in this report.
  - Coastal aquifer typology: a characterisation of the hydrogeological settings of Australia's coastal aquifers based on principal aquifer types and climate groups (presented in Ivkovic et al., 2012c).
  - Mathematical analysis: a theoretical first-order assessment of steady-state SWI extent under current conditions as well as the propensity for change due to various future stresses (i.e. climate change and extraction). This work is detailed in the technical reports by Morgan et al. (2011) and Morgan et al. (2012a).
  - SWI vulnerability indexing: qualitative and quantitative SWI vulnerability indexing methodologies were developed to rank the relative vulnerability indicators in each CSA or aquifer. This work is detailed in the quantitative indexing technical report by Morgan and Werner (2012) and the qualitative indexing technical report by Norman et al. (2012).
  - Future land surface inundation and population growth analysis: consideration of the impacts of sea-level rise and population growth on SWI in the future. This work is detailed in the national summary report by Ivkovic et al. (2012a).
- Phase 3: The five technical components from phase 2 were integrated to provide an overall SWI vulnerability assessment for 27 case study areas (CSAs). A summary of this work is presented in Ivkovic et al. (2012a) with the detailed assessment provided in Marshall et al. (2012); and
- Phase 4: A national summary of SWI vulnerability around Australia was prepared based on the literature review (Phase 1), integrated vulnerability assessment (Phase 3) and VFA (Phase 2). This national summary is presented in Ivkovic et al. (2012a) where the VFA data were used to inform the SWI vulnerability assessment of case study areas (CSA) and infer SWI vulnerability outside of the CSAs at locations where sufficient data were available.

The following general approaches were adopted throughout this project:

1. SWI vulnerability analysis was restricted to areas within 15 km of the coast, including a limited selection of off-shore islands; areas further inland than this 15 km buffer zone were not considered likely to be vulnerable to SWI.

2. The areas of interest for detailed analysis within the CSAs are those where groundwater management units or equivalent groundwater management areas intersect the 15 km buffer zone and are connected to the coast.
3. The project focus is on SWI of coastal aquifer systems and there is limited emphasis on investigating the impacts of inundation to coastal environments and communities (human, ecological, infrastructure etc.).
4. Surface water processes are not specifically considered in any detail.
5. The project is restricted to the synthesis, analysis and interpretation of existing data and does not include new field data collection, local mapping or drilling.

2. VFA Approach and Background Information

2.1. VFA Project Aims and Focus

The VFA was undertaken to provide a first-pass, regional assessment of SWI vulnerability indicators in Australia's coastal areas (within 15 km of the coastline) based on state and territory datasets. Due to the scale of the VFA assessment and limits on data availability, it was not possible to include information on several important, site-specific parameters affecting SWI vulnerability including aquifer geometry, aquifer hydraulic properties, sea-aquifer connectivity and recharge rates. Consequently, the VFA cannot provide a definitive assessment of an area's vulnerability to SWI. Instead, the VFA indicators identify priority areas of concern that require further, site-specific assessment of SWI vulnerability. As an example, an aquifer with low water levels that is hydraulically isolated from the sea would not be vulnerable to SWI, but the VFA might identify it as an area containing vulnerability indicators since low groundwater levels suggest that SWI may occur.

Much of Australia's coastline is data poor, and the lack of SWI vulnerability indicators in these areas should not be taken to imply that they are unlikely to be vulnerable to SWI. The figures included in this report record where data were available for analysis, and no attempt has been made to infer conditions outside these areas. However, it is noted that data-rich regions coincide with areas of relatively high groundwater use and therefore areas where SWI may be of greater concern.

2.2. Known SWI sites

As part of the National-Scale Vulnerability Assessment of Seawater Intrusion project, Ivkovic et al. (2012b) undertook a literature review that identified locations where publicly available studies have documented the threat of SWI in Australia. In addition to the investigations highlighted by the literature review, relevant state and territory agencies identified several further sites that were potentially at threat of SWI but did not necessarily have investigated or reported SWI incidences. Collectively, these locations were referred to as "SWI sites". Their locations are listed in Table 2 below and mapped in Figure 1. These locations are marked on the maps included in the state and territory assessments in this report to highlight areas of known and suspected SWI issues for comparison with VFA SWI vulnerability indicators.

Table 1 *SWI Site Locations (where the threat of SWI is documented in literature or was identified by relevant state and territory agencies)*

Location	SWI Incidence Reported?
South Australia	
Eyre Peninsula	Yes
Le Fevre Peninsula (Adelaide)	Yes
Port MacDonnell	No
Willunga, SA	Yes
Adelaide Metropolitan	Yes
Victoria	
Werribee	Yes
Gippsland (Sale/Orbost region)	No
Nepean Bay*	No
Koo Wee Rup*	No
Moorabbin*	No
Nullawarre*	No
Yangery*	No
Western Australia	
West Kimberley Coast (Broome and Derby)	Yes
Cape Range	Yes
Carnarvon	Yes
Northern Swan Coastal Plain (Dongara, Leeman, Jurien)	No
Perth (other than Cottesloe)	No
Cottesloe Peninsula (Perth)	Yes
Rottnest Island	No
Bunbury	Yes
Busselton	No
Albany	No
Esperance	Yes
Northern Territory	
McMinns/Howard East (Darwin Rural Area)	No
Lambells Lagoon (Darwin Rural Area)	No
Milikapiti	No
Warruwi (Goulburn island)	No
Milingimbi	No
Ngukurr	No

Location	SWI Incidence Reported?
New South Wales	
Clarence River Floodplain	No
Stuarts Point	No
Botany Sands, Sydney	Yes
Stockton	No
Hat Head	No
Queensland	
Mitchell region, Cape York	No
Burdekin River Delta	Yes
Bowen	Yes
Pioneer Valley	Yes
Burnett Heads/Bundaberg	Yes
Bribie Island	Yes
Stradbroke Island	No
Pimpama Coastal Plain	No
Tasmania	
King Island	No
King Island, Grassy scheelite mine site	No
Woolnorth	No
Smithton* (Duck River, Montagu River, Welcome River Catchments)	No

* Public reports were not available for these SWI sites but they were highlighted by state and territory agencies during a project workshop

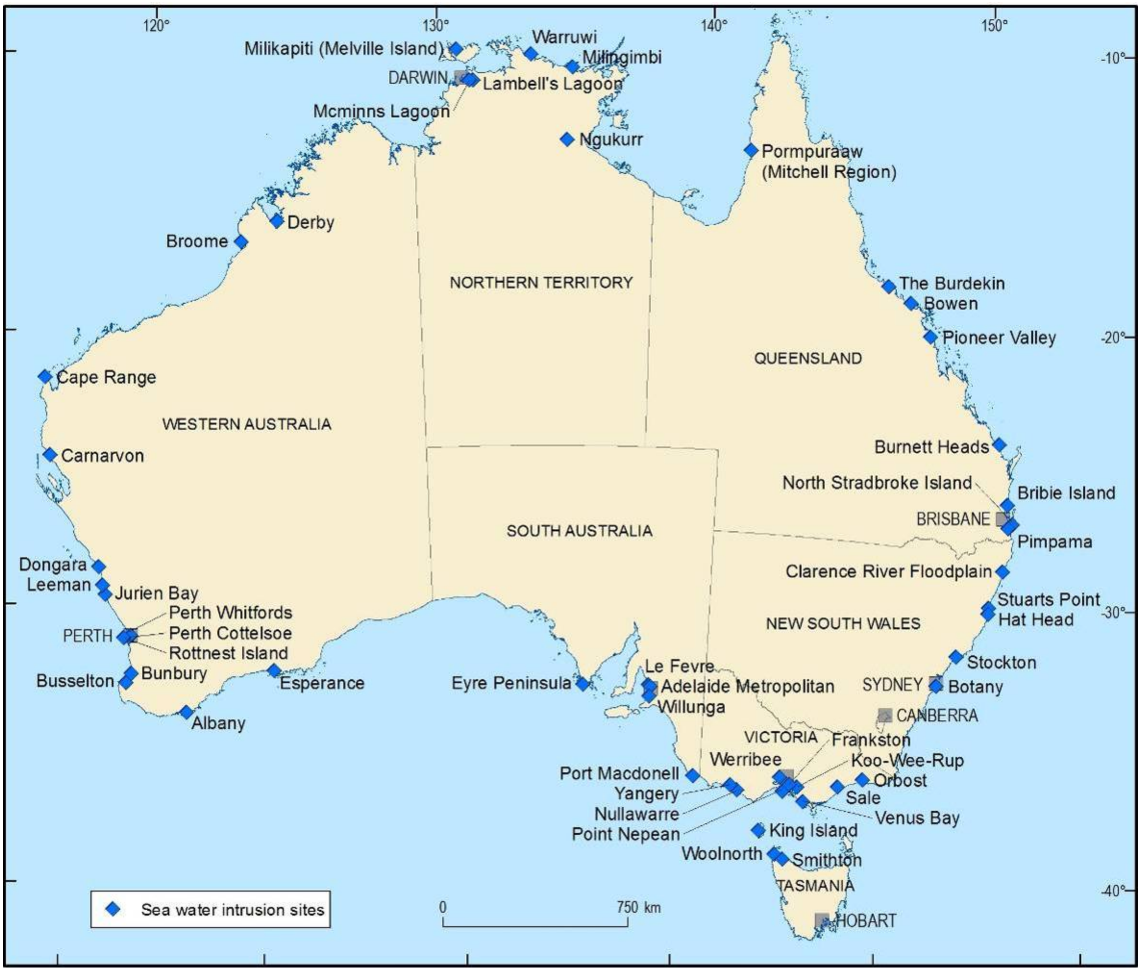


Figure 1 *Locations where the threat of SWI has been identified (as documented in Table 1)*

2.3. Reporting Areas

Within the individual state and territory sections of this report, results are reported on the basis of groundwater management zones defined by relevant water agencies. Such management zones are assigned different names in different states (e.g. “groundwater management areas” in Victoria and “prescribed wells areas” in South Australia). However, for the purposes of discussion, all state and territory regulated groundwater management zones are collectively termed groundwater management areas (GMAs) in this report.

Each GMA is based upon a physiographic or administrative boundary defining an area where groundwater use is regulated. The extents of coastal GMAs in each jurisdiction are presented in figures within Sections 5 to 11. There are 103 GMAs around Australia that lie within or partially within the 15 km coastal buffer (see Table 2). The GMAs are not continuous around Australia’s coastline and many areas fall outside of them. However, the GMAs are units that state/territory authorities use in their current management plans and reporting practices and hence reporting of results at this level can aid the communication and prioritisation of groundwater areas for future investigation, monitoring and research. In many instances the GMAs are aligned with the groundwater management units (GMUs) presented in Australian Water Resources 2005 (AWR, 2006) but this is not universally the case. Sustainable yield data presented in AWR 2006 are included in this report for comparison with recent extraction data within those parts of the GMAs within 15 km of the coast. Care in interpretation is needed, since the GMAs do not universally coincide with the GMUs (affected GMAs are detailed in appropriate sections) and the AWR (2006) sustainable yield data is for entire GMUs, not just those parts within 15 km of the coast.

Table 2 *Number of GMAs defined for each state or territory within Australia*

State or Territory	Number of GMAs Which Intersect the 15 km Coastal Buffer Zone
Western Australia	35
Northern Territory	3
Queensland	17
New South Wales	13
Victoria	26
Tasmania	0
South Australia	9
NATIONAL	**103**

3. VFA Methodology

The VFA follows a similar approach to Nation et al.'s (2008) SWI assessment of Australia's irrigation areas. However, the VFA includes an assessment of all available data around Australia's coastline using a significantly larger dataset (see Section 3.1). The VFA entailed spatial and temporal analysis of state and territory groundwater datasets as indicators of the level of SWI vulnerability of Australia's coastal aquifers. Although additional factors are relevant when assessing vulnerability of groundwater systems to SWI, the VFA was restricted to a consideration of the following parameters due to constraints on data availability:

- groundwater levels (minimum groundwater levels, inter-decadal changes in groundwater levels and groundwater level trends);
- rainfall trends;
- groundwater salinity (maximum salinity and inter-decadal changes in salinity); and
- groundwater extraction (locations and rates).

The VFA focused exclusively on areas situated within 15 kilometres of Australia's coastline since SWI impacts were considered unlikely to extend further inland in most areas.

Available data are analysed at both national and state levels in this report. The national-scale assessment highlights areas where groups of three or more data points (boreholes) within a 5 km radius satisfy the assessment criteria for groundwater level and salinity data. This approach is useful for assessing the general vulnerability of large scale areas and reducing the likelihood of classifications based on single anomalous measurements. In the national-scale assessment, all data are presented for individual boreholes in the state and territory analyses which provide a finer scale assessment than the national approach.

The general VFA methodology included data collection, data preparation, data filtering and data analysis. Each of these work steps is described in order below.

3.1. Data Collection

Available groundwater data were sourced from relevant state and territory water agencies and data points greater than 15 km from the coastline were removed from the database. Table 3 details the sizes of the state and territory datasets used in the VFA.

To supplement the state and territory data, extraction and sustainable yield information were compiled from Australian Water Resources 2005 (AWR, 2006) where state and territory GMAs coincided with AWR (2006) GMUs. In addition, historical monthly rainfall data were obtained from the Bureau of Meteorology (BoM) website for select locations around the Australian coast to assess past rainfall trends (focussing on the SWI site locations).

3.2. Data Preparation

The VFA required extensive data preparation. The structure of groundwater databases differed between jurisdictions and the level of data processing requirements varied accordingly. As part of the data preparation process, each measurement location (borehole) was assigned to a GMA for reporting purposes. The general data preparation steps included:

1. Attaching borehole location information (latitude, longitude and elevation) to groundwater level and water chemistry observations, ensuring consistency in coordinate systems (Geographics GDA94);
2. Extracting a subset of groundwater level and salinity data that lie within 15 km of the Australian coastline;
3. Calculating the distance of each borehole from the coastline for later analysis;
4. Converting measurements of depth to groundwater into groundwater elevations (in m AHD) using borehole survey information. As an exception, some borehole elevations in Qld were only known relative the Queensland State Datum (STD) and associated groundwater levels were thus reported to STD;
5. Converting salinity measurements into total dissolved solids (TDS) concentrations expressed in mg/L. Salinity measurements in the jurisdiction databases were variably measured as field electrical conductivity (EC), laboratory EC, and laboratory TDS concentrations by evaporation. Where multiple measurement types were presented for a sample, preference was given to laboratory EC over laboratory TDS by evaporation and to field EC over laboratory EC and TDS. This reflected the fact that the vast majority of salinity measurements were reported as field EC readings. TDS concentrations were estimated from EC measurements using the equation TDS (in mg/L) = 0.64 x EC (in µS/cm). Although factors such as temperature and ionic composition of groundwater affect EC readings making conversion to TDS concentrations inconsistent, this equation is considered to provide an approximation suitable for the current broad-scale analysis;
6. Generating a single data file for groundwater extraction rates ensuring consistent measurement units. As outlined further in Section 3.4.3, this data file includes extraction data from different years for different jurisdictions due to variability in the completeness of extraction records. Stock and domestic bores were not included in this data file which only incorporates bores classified by the jurisdictions as production bores (generally including irrigation, industrial and municipal supply bores); and
7. Generating a data file of production bore location information. This file includes all production bore locations, noting that the data file under point 6 above only includes bores where extraction information is available.

Table 3 *Number of groundwater measurements within 15 km of the coast analysed in the VFA*

Data Type	Data Subsets for Analysis	No. of Data Points
Groundwater levels	All relative standing water levels (RSWL)	1,788,532
	Minimum RSWL (all years)	24,409
	Minimum RSWL prior to 2000	19,954
	Minimum RSWL in the period 2000–2009	8482
	Calculations of inter-decadal change in minimum RSWL from 1990-99 to 2000-09	4237
	Groundwater linear trend analyses	1277
Groundwater salinity	All salinity measurements	1,160,916
	Maximum TDS (all years)	68,899
	Maximum TDS prior to 2000	38,174
	Maximum TDS in the period 2000–2009	10,185
	Calculations of inter-decadal change in maximum TDS concentration from 1990-99 to 2000-09	3438
Groundwater extraction	Bores with annual usage volumes in recent years used in analysis	2931

3.3. Data Filtering

Much of the VFA methodology focuses on data measurement extremes such as minimum recorded groundwater levels or maximum recorded TDS concentrations in a borehole. Since single anomalous measurements may therefore affect interpretation, filtering of the data was required to identify obvious spurious readings and remove them. The large number of data points precluded verification of each measurement and filtering focussed on those readings that were likely to affect interpretation. Filtering was undertaken on both groundwater elevation and salinity (TDS concentration) data.

3.3.1. Groundwater level data filtering

State and territory water agencies were consulted extensively on the validity of relatively high and low groundwater levels. The VFA groundwater level assessment below focuses on minimum recorded groundwater levels and changes in water levels over time. Minimum groundwater levels were thus extracted from the database for each borehole to highlight potential obvious anomalies. All artesian minimum water levels and water levels below -5 m AHD were highlighted and forwarded to the relevant water agencies for verification. Where measurements were confirmed as likely errors, the full datasets for the relevant boreholes were considered to establish if individual measurements or the entire dataset should be removed from the database.

In addition to the above filtering processes, relevant state and territory water agencies were consulted on boreholes showing the higher SWI vulnerability category groundwater level indicators (see Section 3.4.1) to assess their validity.

3.3.2. Salinity data filtering

The first step in TDS concentration filtering focussed on identification and removal of anomalously low TDS measurements. Although TDS concentrations below 10 mg/L are unusual in natural waters (including rainwater), such concentrations are possible so any measurements above 0 mg/L were kept in the database while those at or below 0 mg/L (noting that negative concentrations are not possible so were obviously incorrect) were removed.

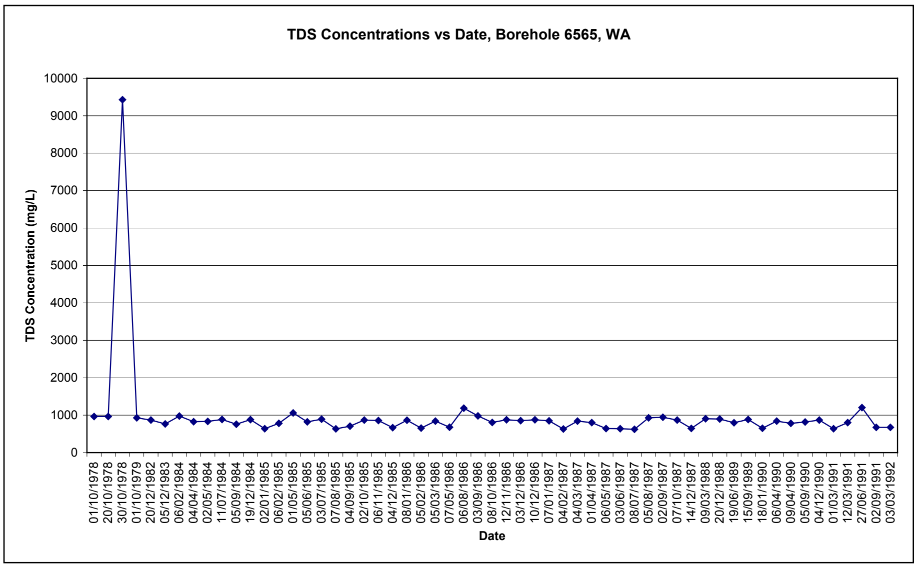
Following removal of low TDS measurements from the dataset, TDS measurements significantly higher than background concentrations were identified since they may indicate measurement errors. The checking of such measurements was important since the VFA salinity assessment below focuses on maximum TDS concentrations as indicators of vulnerability to SWI. For each dataset (borehole), the following calculation provided a relative measure of how much the maximum TDS concentration exceeded the mean by:

[Maximum TDS concentration – Mean TDS concentration] / Mean TDS concentration

The above calculation provides an indication of variability and is termed the relative deviation of the maximum (RDM) in this report. Resultant values >0.5 highlight instances where the maximum TDS concentration exceeds the mean by more than half of the mean TDS concentration. For the purposes of analysis, plots were made of TDS concentration over time for each borehole considered during the verification process. By consideration of several plots, it appeared that RDM values <0.5 generally indicated that maximum values were not obvious measurement errors and should therefore not be removed from the database. In contrast, boreholes with RDM values >0.5 commonly appeared to contain spurious maximum TDS concentrations and the higher the statistic, the greater the relative proportion of boreholes with anomalously high TDS readings. Since it was not feasible to check all salinity datasets due to the high number of measurement locations (boreholes), only those with an RDM value >0.5 were assessed to determine if they contained anomalous values that should be removed from the datasets.

TDS concentration datasets from 3453 boreholes had RDM values >0.5. Where these datasets had three or fewer data points they were deleted from the database since it was not possible to make a reasonable assessment of whether the maximum value was anomalously high or not. Where the maximum, mean and difference between maximum and mean TDS concentrations all fell below 1000 mg/L, the datasets were kept in the database since even if the maximum measurements were spurious, it would make no difference to interpretation as is evident from Section 3.4.2 below. For the same reason, datasets where maximum and mean TDS concentrations fell between 1000 mg/L and 3000 mg/L and the difference between maximum and mean TDS concentrations fell below 1000 mg/L were also retained. For the remaining datasets, plots were created of TDS concentrations over time for visual inspection and data filtering using the following rules:

1. Where maximum TDS concentration spikes consisted of only one measurement, they were deleted from the dataset. An example of this type of graph is shown below (borehole 6565 from Western Australia; the value >9000 mg/L appears to be anomalous and is not likely to indicate SWI- it was deleted from the dataset):



Where two or more measurements existed on a data spike, the maximum measurement was considered confirmed and was not deleted;

2. Where the dataset was highly variable and contained many spikes, it was not possible to tell if maximum concentrations were spurious and all readings were kept in the dataset;
3. Where initial measurements were high and declined to background levels over a short period (a few months or less) relative to the total monitoring period, they were deleted from the dataset since they were considered likely to have been impacted by drilling (e.g. introduction of drilling fluids etc.); and
4. Where initial measurements were low and increased over a short period (a few months or less) relative to the total monitoring period, they were deleted from the dataset since they were considered likely to have been impacted by drilling (e.g. introduction of freshwater).

Following the above process, TDS measurements were deleted from 576 datasets (boreholes).

For subsequent VFA analysis, the maximum TDS concentrations over several time intervals were extracted from the database as outlined in subsequent sections. The final filtering process involved an analysis of those datasets showing maximum TDS concentrations greater than that expected for seawater. Although average TDS concentration for seawater is typically reported to be around 35,000 mg/L, some authors (e.g. Hoang et. al., 2009) indicate it may be as high as 38,500 mg/L in certain areas around Australia. In addition, data from some states suggest that a conversion factor for EC to TDS of 0.55 may be appropriate in local areas compared to the value of 0.64 used in this report. An EC of 70,000 uS/cm equates to a TDS concentration of 38,500 mg/L using a conversion factor of 0.55 but to 44,800 mg/L using a conversion factor of 0.64. On this basis, TDS concentration measurements up to 45,000 mg/L were included in the VFA since higher values are likely to be either spurious readings or areas where TDS is not indicative of SWI but other salinity concentration mechanisms. It is noted that this approach may result in inclusion of high salinity water in the VFA that is not seawater and the requirement for site specific analysis when assessing SWI is emphasised.

In total, 386 boreholes contained maximum TDS concentrations >45,000 mg/L after the data processing steps outlined above. Most of these (358 in total) were deleted from the database since they contained both minimum and maximum TDS concentrations >45,000 mg/L and were therefore considered not to represent seawater. For the remaining 28 boreholes, plots of TDS concentration over time were examined to establish if the maximum concentrations were anomalous or not. Where the majority of measurements were <45,000 mg/L and less than three measurement spikes exceeded this value, the measurements >45,000 mg/L were removed from the datasets. For the remaining bores, measurements >45,000 mg/L were considered to be valid, the groundwater unlikely to be seawater-influenced, and the datasets were removed from the database.

In addition to the above filtering processes, relevant state and territory water agencies were consulted on boreholes showing the higher vulnerability category salinity indicators (see Section 3.4.2) to assess their validity.

3.4. Data Analysis

The initial stages of the VFA entailed identification of parameters that may indicate the level of an aquifer's SWI vulnerability and subsequent development of vulnerability indicator categories for each of these parameters. The parameters considered in the VFA and their associated SWI vulnerability level indicator categories are outlined for each of the main parameter classes in Sections 3.4.1 to 3.4.4 below.

Following presentation of the national results, locations (termed "national VFA priority areas") are highlighted where relatively large numbers and wide ranges of VFA vulnerability indicators are present suggesting high SWI vulnerability. A more detailed assessment and summary of VFA indicators is presented in the state and territory analyses that follow the national assessment, where "state VFA priority GMAs" are identified.

3.4.1. Groundwater levels

The groundwater level component of the VFA focuses on two parameter categories as indicators of SWI vulnerability:

1. Minimum recorded groundwater levels; and
2. Changes in groundwater levels over time.

These two indicator categories are discussed separately below.

3.4.1.1. Minimum groundwater levels

In general, lower groundwater levels indicate a greater potential for SWI. In the VFA, groundwater levels below mean sea level are considered to indicate the highest potential for SWI since freshwater will be insufficient to oppose the encroachment of seawater in these areas. Although mean sea level may deviate by tens of centimetres from the Australian Height Datum (AHD) in places, 0 m AHD was taken to be a reasonable approximation of mean sea level across the country for the purpose of analysis. As outlined in Section 3.2, some groundwater levels in Queensland were only known relative to STD. It is understood that there may be considerable error associated with conversion of water levels from STD to AHD away from measured benchmarks thus conversion of water levels was not undertaken. However, information supplied by the Qld Department of Environment and Resource Management (DERM) indicates that the difference between AHD and STD at known benchmarks near the coast is generally small (typically in the range 0 cm to 30 cm) in the areas of interest for this project. As such, water levels near the coast in STD are considered equivalent to water levels in AHD in this report (i.e. 0 m STD also appears to be a reasonable approximation of mean sea level in the areas of interest).

In coastal areas, tidal influence may result in elevated time-averaged water table elevations relative to mean sea level (Carey et al., 2009). Wave run-up and storm surges may also increase average water table levels. Inland of the coast, such tidal water table over-heights (TWOH) may cause inland movement of saltwater even where groundwater levels are above mean sea level. A literature search identified relatively few published studies on TWOH specific to Australia. However, Carey et al. (2009) identified TWOH of up to 2.41 m in the Pioneer Valley of Qld. Based on the geometry of the coastline and large tidal range in this area, the Pioneer Valley may be considered likely to have well above average TWOH compared to most other parts of Australia. In the VFA, groundwater levels above 2.5 m AHD were therefore considered less likely to be vulnerable to SWI.

Based on the above discussion, the VFA identifies locations where the lowest groundwater levels fall into one of the following groundwater level classes over the periods of interest (recent decade [2000-2009] levels are considered separately from historic data):

- <0 m AHD;
- 0–2.5 m AHD; and
- >2.5 m AHD.

These same categories were used by Nation et al. (2008) when assessing vulnerability of Australia's coastal aquifers in irrigation areas to SWI. It is noted that they do not take account of up-coning or migration of the saltwater wedge that may take place even where minimum water levels are above 2.5 m. An analysis of such processes would require site specific information that is beyond the scope of the VFA, which only serves as a first pass, broad scale assessment of SWI vulnerability indicators. However, it is emphasised that SWI may still occur where groundwater levels are above 2.5 m AHD.

The state and territory-scale analyses also highlight the maximum inland extent of groundwater level measurements in the <0 m AHD and 0-2.5 m AHD classes as a measure of the extent of potentially higher SWI vulnerability areas.

3.4.1.2. Groundwater level changes

Declining groundwater levels near the coast may be caused by decreases in recharge (including rainfall) and/or increases in groundwater discharge (usually extraction). They may indicate vulnerability to SWI since if water levels fall sufficiently where aquifers are connected to the sea, SWI may occur.

Changes in groundwater levels are assessed by two different methods in the VFA:

1. Inter-decadal change: To provide an indication of the magnitude of groundwater level changes, the minimum groundwater level measured in the decade 2000-2009 was subtracted from the minimum groundwater level measured in the decade 1990-1999; and
2. Linear trend analysis: For boreholes with sufficient time-series groundwater level data, a straight line was fitted through the data points to provide a measure of yearly change in groundwater levels. Trends were only included where greater than five data points existed, monitoring periods were greater than one year, and the correlation coefficient (R2) between the straight line trend and measured data points was greater than or equal to 0.5.

Groundwater levels may display short term fluctuations in response to a variety of factors including atmospheric pressure changes, rainfall events, changes in surface loading and intermittent pumping. Such short term fluctuations may affect the inter-decadal change assessment and suggest greater declines than average conditions may show. Analysis of longer term groundwater level trends tends to remove the influence of short term fluctuations when assessing groundwater level increases or declines.

The inter-decadal change analysis is useful since it provides a total estimate of groundwater level change. However, the linear trend analysis identifies sustained trends in groundwater level changes and, unlike the inter-decadal change method, it is not based on single extreme measurements that may not be indicative of normal conditions. It is therefore useful to consider the results of both analyses together when assessing groundwater level change as an indicator of vulnerability to SWI.

For the purposes of analysis, inter-decadal changes in minimum groundwater level are classified according to the following subjective categories in the VFA (in order of decreasing vulnerability indicator level):

- >5 m decline;
- 2.5 – 5 m decline;
- 0 – 2.5 m decline;
- 0 – 1 m increase; and
- >1 m increase.

Although the inter-decadal change analysis method is prone to skewing by extreme or anomalous measurements, across the relatively large dataset spatial category clusters are considered likely to be indicative of general area trends. In the analysis, large inter-decadal declines in groundwater levels are considered to highlight areas that may be vulnerable to SWI or become vulnerable if water levels continue to fall. Reductions in storage indicated by decreasing water levels may also suggest that current groundwater extraction rates are unsustainable without impacting on groundwater availability and quality. However, since groundwater level declines may also be caused by decreases in recharge, interpretation of results is complicated and consideration should also be given to other datasets during SWI vulnerability assessment.

For the purposes of analysis, groundwater level trends are classified according to the following subjective categories in the VFA (in order of decreasing vulnerability indicator level):

- >1 m/year decreasing trend;
- 0.5 – 1 m/year decreasing trend;
- 0.25 – 0.5 m/year decreasing trend;
- 0 – 0.25 m/year decreasing trend; and
- Increasing trend.

In the VFA, decreasing groundwater level trends are considered to highlight areas that may potentially be vulnerable to SWI or become vulnerable if water levels continue to fall. Similarly to inter-decadal declines in groundwater levels, decreasing water level trends may indicate groundwater extraction above sustainable rates but could also be a result of decreases in recharge. Although at the current rates of decline, areas with small yearly declines are likely to be more easily managed than areas with greater decreasing trends, SWI may still become an issue in these areas over a longer timeframe. However, it is noted that if groundwater levels are currently low, small decreasing trends will take on greater significance.

3.4.2. Groundwater salinity

The groundwater salinity component of the VFA focuses on two parameters as indicators of SWI vulnerability:

1. Maximum recorded salinity (expressed as TDS concentration in mg/L); and
2. Changes in groundwater salinity over time.

These two parameters are discussed separately below.

3.4.2.1. Maximum salinity measurements

Maximum groundwater TDS concentrations are grouped in the VFA into the following categories:

- <1000 mg/L. Freshwater that is suitable for most uses including drinking water, domestic uses, stock watering, irrigation (not all species) and industrial processes (e.g. the Australian Drinking Water Guidelines 2004 suggest that water with TDS concentrations >1,000 mg/L is unpalatable to humans).
- 1000 – 3000 mg/L. Generally unsuitable for drinking water but suitable for most stock watering (e.g. ANZECC 2000 indicates that even less salt-tolerant stock should adapt to such waters without loss of production), irrigation of some salt tolerant crops and some domestic and industrial purposes.
- 3000 – 10,000 mg/L. Suitable for limited stock watering and industrial processes; and
- >10,000 mg/L. Although some limited industrial processes and temporary sheep watering may use water with TDS concentrations >10,000 mg/L, it is generally unsuitable for most uses and ANZECC (2000) indicates that loss of production can be expected in all livestock above this concentration.

In the VFA, recent decade (2000-2009) TDS concentrations are considered separately from historic data. Areas where higher use groundwater resources (in the <1000 mg/L and <3000 mg/L categories) exist are highlighted. As an indicator of SWI vulnerability, the VFA identifies areas where groundwater with low maximum salinity (TDS concentrations <3000 mg/L) is close to (defined here as within 1 km) groundwater with high maximum salinity (TDS concentrations >10,000 mg/L). In such areas, extraction of low salinity groundwater could cause intrusion of higher salinity water identified nearby.

It is noted that this analysis method does not include information on whether salinity measurements are within the same aquifer systems or whether migration from an area of high salinity to an area of low salinity is hydraulically possible. Nearby high and low salinity measurements may not indicate high vulnerability to SWI in areas where migration is implausible, and the results should therefore be considered in conjunction with site-specific information to assess vulnerability to SWI (consideration of such site specific information was beyond the scope of the VFA which only provides a first pass assessment of available data).

3.4.2.2. Changes in maximum salinity measurements

Increases in groundwater TDS concentrations may indicate the occurrence of SWI in coastal environments. They are considered to serve as indicators of SWI vulnerability level since, if TDS concentrations have increased in an area, further SWI may occur without appropriate management. It is noted that when salinity in groundwater bores increases due to SWI, the bores are often abandoned which could result in under-reporting of TDS increases.

To provide an indication of the magnitude of recent TDS concentration changes, the maximum TDS concentration measured in the decade 1990 to 1999 was subtracted from the maximum TDS concentration measured in the decade 2000 to 2009 for boreholes where data were available. Inter-decadal TDS concentration changes were categorised according to the same ranges for maximum salinity measurements in Section 3.4.2.1 above. Increases >3000 mg/L were considered to be particularly significant since SWI will typically lead to relatively large increases in TDS concentrations over time and such large increases may dramatically affect the usability of water resources. However, it is stressed that even increases <1000 mg/L may have large detrimental effects on high quality drinking and irrigation water.

3.4.3. Groundwater extraction

Groundwater extraction rate relative to aquifer recharge is a key indicator of vulnerability to SWI. Where groundwater is extracted at a rate greater than recharge, groundwater levels will fall and, in coastal areas, SWI may result. Recharge data at a suitable scale were not available nationally for the VFA (local information on recharge is required to assess if local extraction rates exceed recharge volumes). In many instances, the VFA could therefore only focus on groundwater extraction rate to highlight areas of high groundwater use that could result in SWI. However, the limitations of not incorporating recharge estimates into the VFA assessment are emphasised. Where sustainable yield values are available for specific areas, they have been considered in the context of extraction rates for the individual state and territory analyses in Sections 5 to 11.

The VFA focussed on groundwater bores classed as “production bores” by the states and NT. The datasets specifically exclude stock and domestic supply bores, focussing on large volume extractors. Groundwater extraction data provided by the states and NT were the least complete and consistent of the data available for the VFA. The time periods that extraction records cover are variable and groundwater extraction data for individual bores were only available for Western Australia, Queensland, Victoria and South Australia. For the purposes of assessment, extraction volumes for the most recent year when a reasonably complete dataset of groundwater extraction was available were selected for each of the four states considered:

- Western Australia: 2010–11 financial year;
- Queensland: 2009–2010 financial year;
- Victoria: 2009–10 financial year; and
- South Australia: 2007–2008 (Lower Limestone Coast) and 2008–2009 (elsewhere) financial years.

Extraction rates in the VFA are classified according to the following subjective categories:

- <50 ML/year;
- 50–250 ML/year;
- 250–500 ML/year;
- 500–1000 ML/year; and
- >1000 ML/year.

As outlined above, in the context of SWI it is difficult to attach significance to extraction rates in the absence of recharge data. The extraction information presented in the VFA is best considered at a site specific level in conjunction with other available information. However, areas containing individual production bores with particularly high extraction rates >500 ML/year are highlighted in the VFA.

To provide a measure of cumulative groundwater extraction rates, a 5 km grid was overlain on the production bore extraction data and the extraction volumes of production bores falling within each grid cell were summed. Although the final extraction rate (and category) for each cell is somewhat dependent on where the grid is positioned, the results provide a good indication of cumulative extraction rates in the relevant sections below. Cumulative extraction rates within specific GMAs where sustainable yield information is also available are presented in the state and territory assessments as well.

3.4.4. Rainfall trends

Change in rainfall volume over time may be a useful indicator of potential changes to recharge, which can in turn affect groundwater levels. Although it is acknowledged that confined aquifers may have recharge zones distant from the areas they underlie, changes in rainfall volumes in an area commonly affect recharge to underlying aquifers and hence groundwater levels. In addition to directly changing groundwater levels through recharge, changes in rainfall volume can affect the availability of surface water and thereby affect groundwater extraction. In this way, rainfall changes can also indirectly affect groundwater levels. When both direct and indirect impacts are included, it is considered that rainfall may be a useful indicator of stress to groundwater systems and therefore vulnerability to SWI.

To assess increasing or decreasing trends in rainfall volumes in Australia’s coastal areas, historical monthly rainfall data were obtained from the Bureau of Meteorology for selected weather stations along the coastal margin. Cumulative deviation of monthly rainfall from long term average monthly rainfall (calculated as the cumulative sum of monthly rainfall less long term average rainfall) was plotted for the period 2000-2009. An increasing trend to the cumulative plot indicates times when rainfall was greater than average, and conversely, a decreasing trend signifies lower than average rainfall periods.

Although rainfall trends may be useful indicators of SWI vulnerability, drought around the country has eased in 2010 and 2011, and a reversal in rainfall trends is evident in some areas. As such, the rainfall trends presented in the VFA for the decade 2000-2009 may not remain good indicators of SWI vulnerability and should be updated in future assessments.

4. Vulnerability Factor Analysis Results: National-Scale

As outlined above, the national-scale VFA focuses on locations where three or more measurements within a 5 km radius fall within the same analysis categories developed in Section 3.4. Individual measurements are considered in the state and territory analyses that follow this section. Figure 2 provides a reference map for localities discussed throughout this chapter. Due to the large number of data points in areas along Australia's coast, the place descriptions in Sections 4.1 to 4.5 are necessarily general; they refer to the locality as well as surrounding areas. Reference should be made to the state and territory analyses for more precise locations of vulnerability indicators.

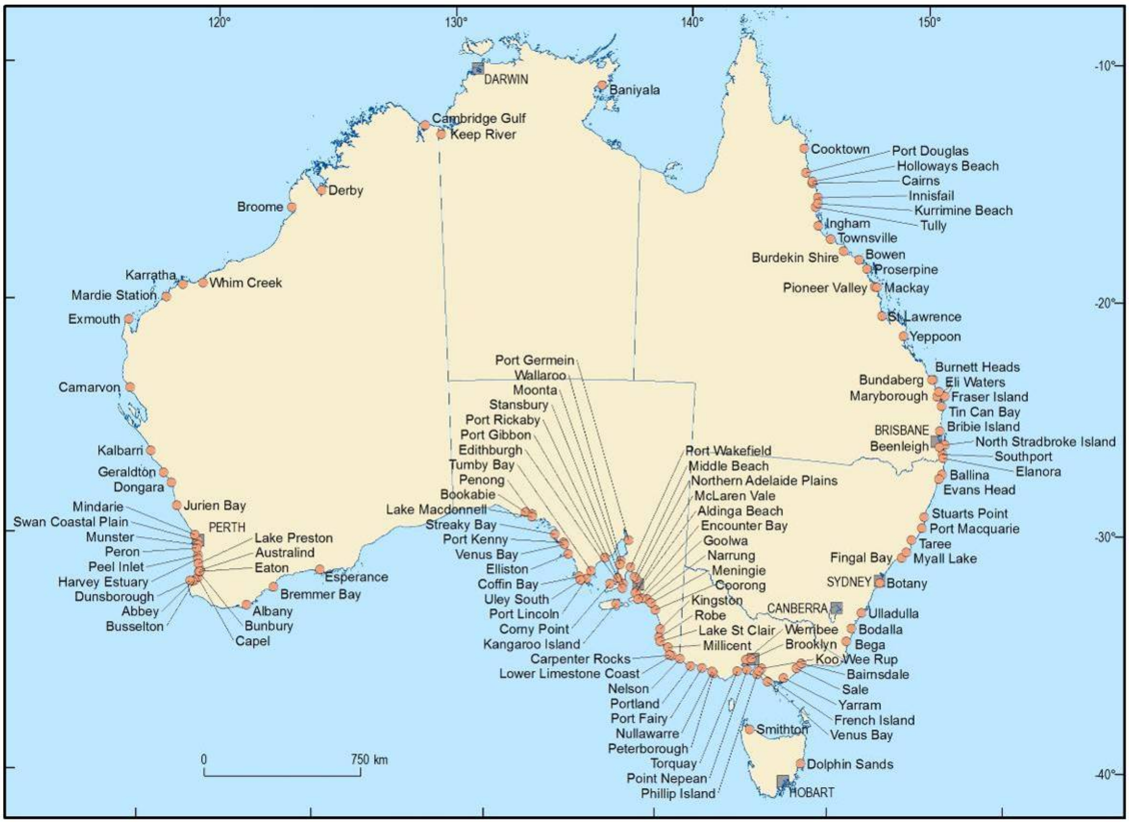


Figure 2 National VFA locality reference map

4.1. National Groundwater Level Analysis

4.1.1. Minimum groundwater levels

The discussion below focuses on areas showing the highest SWI vulnerability indicator category of water levels <0 m AHD. However, water levels between 0 and 2.5 m AHD on Figure 3 and Figure 4 may also suggest some vulnerability to SWI.

Groundwater level data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data to highlight areas that have recently shown groundwater level indicators of vulnerability. However, the lack of recent vulnerability indicators cannot be used to infer a reversal in vulnerability trends in many areas since they may in part be due to a lack of recent data. A more appropriate consideration of changes in water level over time is given in Section 4.1.2.

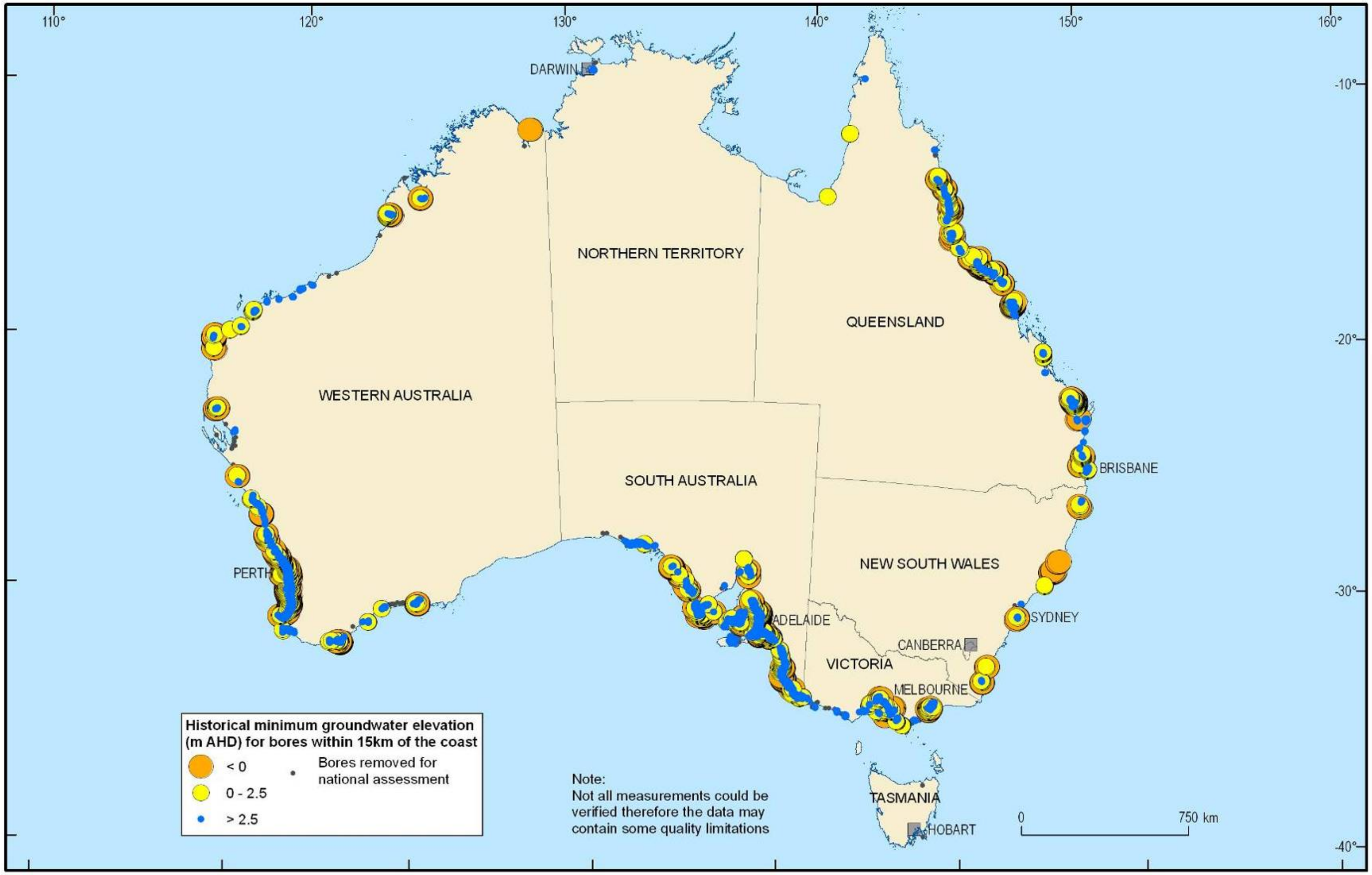


***Figure 3** Historical minimum groundwater levels measured prior to 2000 (only data points where three or more boreholes within a 5 km radius fall into the same category are classified)*

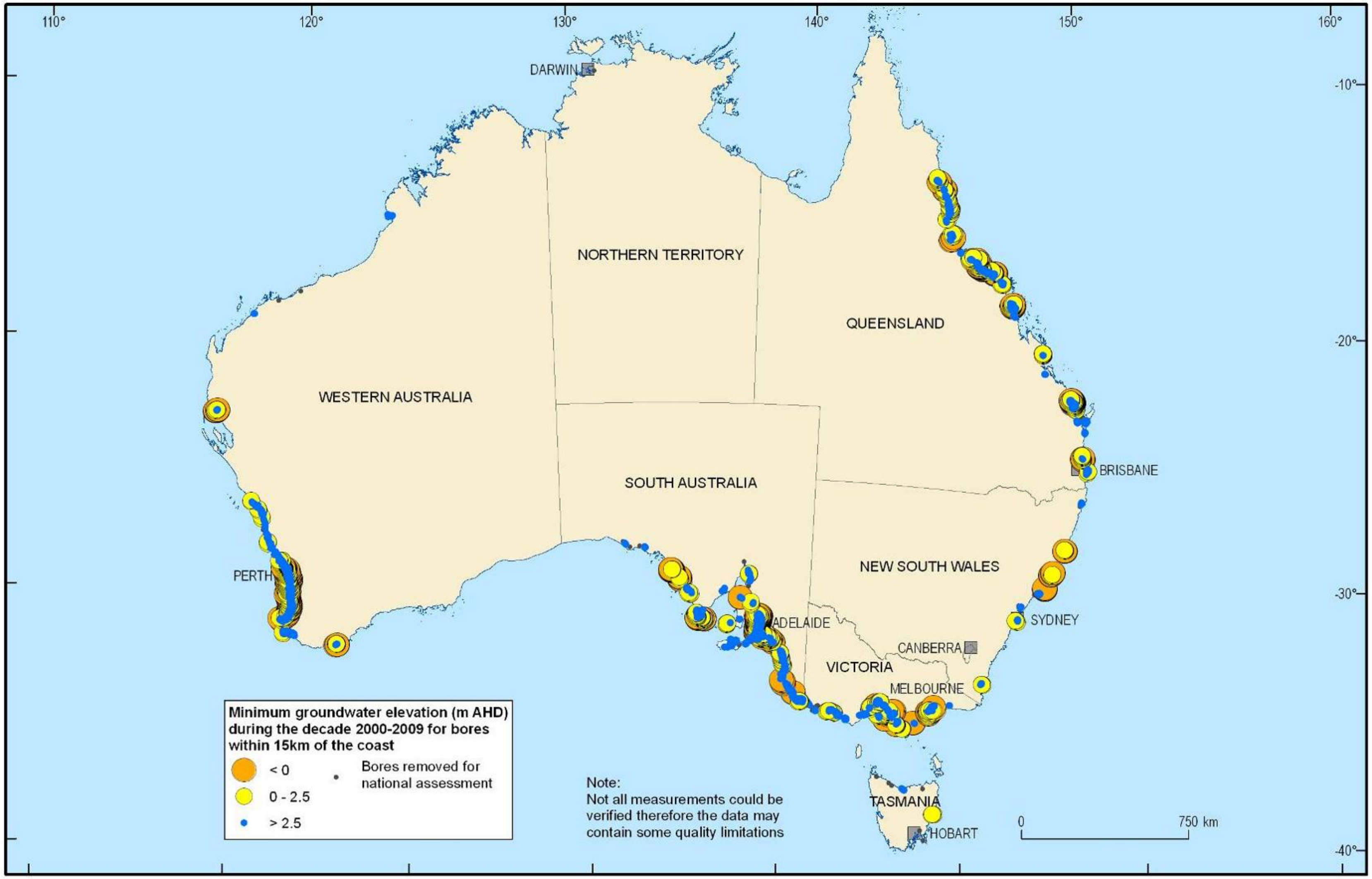


Figure 4 *Minimum groundwater levels measured between 2000 and 2009 (only data points where three or more boreholes within a 5 km radius fall into the same category are classified)*

4.1.1.1. Historical minimum groundwater levels

Minimum groundwater levels reported prior to 2000 are summarised on Figure 3. Where data were available, the general areas (and surrounds) showing boreholes with minimum groundwater levels <0 m AHD, indicating the possibility of high vulnerability to SWI, included:

- Western Australia (WA): Cambridge Gulf (east head), Derby, Broome, Exmouth (and an area around 50 km south of Exmouth), Carnarvon, Kalbarri, around 15 km south of Dongara, several areas on the Swan Coastal Plain (including several places between Jurien Bay and Mindarie, Perth, Munster, the land around Peel Inlet, Harvey Estuary and Lake Preston, Australind, Eaton, Bunbury, several areas between Capel and Busselton, and several areas between Abbey and Dunsborough), Albany and Esperance;
- Queensland (Qld): Port Douglas, north of Cairns (Holloways Beach), Innisfail, Kurrimine Beach, Ingham, The Burdekin, Bowen, Proserpine, Pioneer Valley and Mackay, Bundaberg and Burnett Heads, Maryborough, Bribie Island and Brisbane;
- New South Wales (NSW): Evans Head, around 20 km southwest of Port Macquarie, Taree and surrounds, Botany, Bodalla and Bega;
- Victoria (Vic): Brooklyn, Koo Wee Rup, Phillip Island and Sale; and
- South Australia (SA): Streaky Bay, Port Kenny, Venus Bay, Elliston, Coffin Bay and surrounds, Uley South, the Port Lincoln Area, Port Germein, Edithburgh, Stansbury, Northern Adelaide Plains, Adelaide, McLaren Vale, Aldinga Beach, Encounter Bay, Goolwa, Narrung, Kingston, the area from Robe to Lake St Clair and around 14 km southeast of Millicent.

4.1.1.2. Minimum groundwater levels, 2000–2009

Minimum groundwater levels reported for the most recent decade (2000 to 2009) are summarised on Figure 4. Where data were available for the period, the areas showing boreholes with minimum groundwater levels <0 m AHD, indicating the possibility of high vulnerability to SWI, included:

- WA: Carnarvon and the Swan Coastal Plain (including Mindarie, Perth, Munster, Peron, the land around Peel Inlet, Harvey Estuary and Lake Preston, Australind, Eaton, Bunbury, Capel, Abbey and Dunsborough);
- Qld: Port Douglas, north of Cairns (Holloways Beach), Ingham, The Burdekin, Bowen, Pioneer Valley and Mackay, Bundaberg and Bribie Island;
- NSW: Stuarts Point , Taree and the Myall Lake area;
- Vic: Werribee, Phillip Island, French Island, the Koo Wee Rup area, Venus Bay, Yarram, Sale and Bairnsdale; and
- SA: Streaky Bay, Uley South, Port Lincoln, Northern Adelaide Plains, Adelaide, McLaren Vale, Aldinga Beach, Goolwa, Narrung, Meningie, the area from Robe to Lake St Clair and around 14 km southeast of Millicent.

4.1.2. Groundwater level changes

Changes in groundwater levels over time are plotted on Figure 5 (inter-decadal decline in minimum groundwater levels from 1990-1999 to 2000-2009) and Figure 6 (linear trends in groundwater levels) and discussed in the following text.

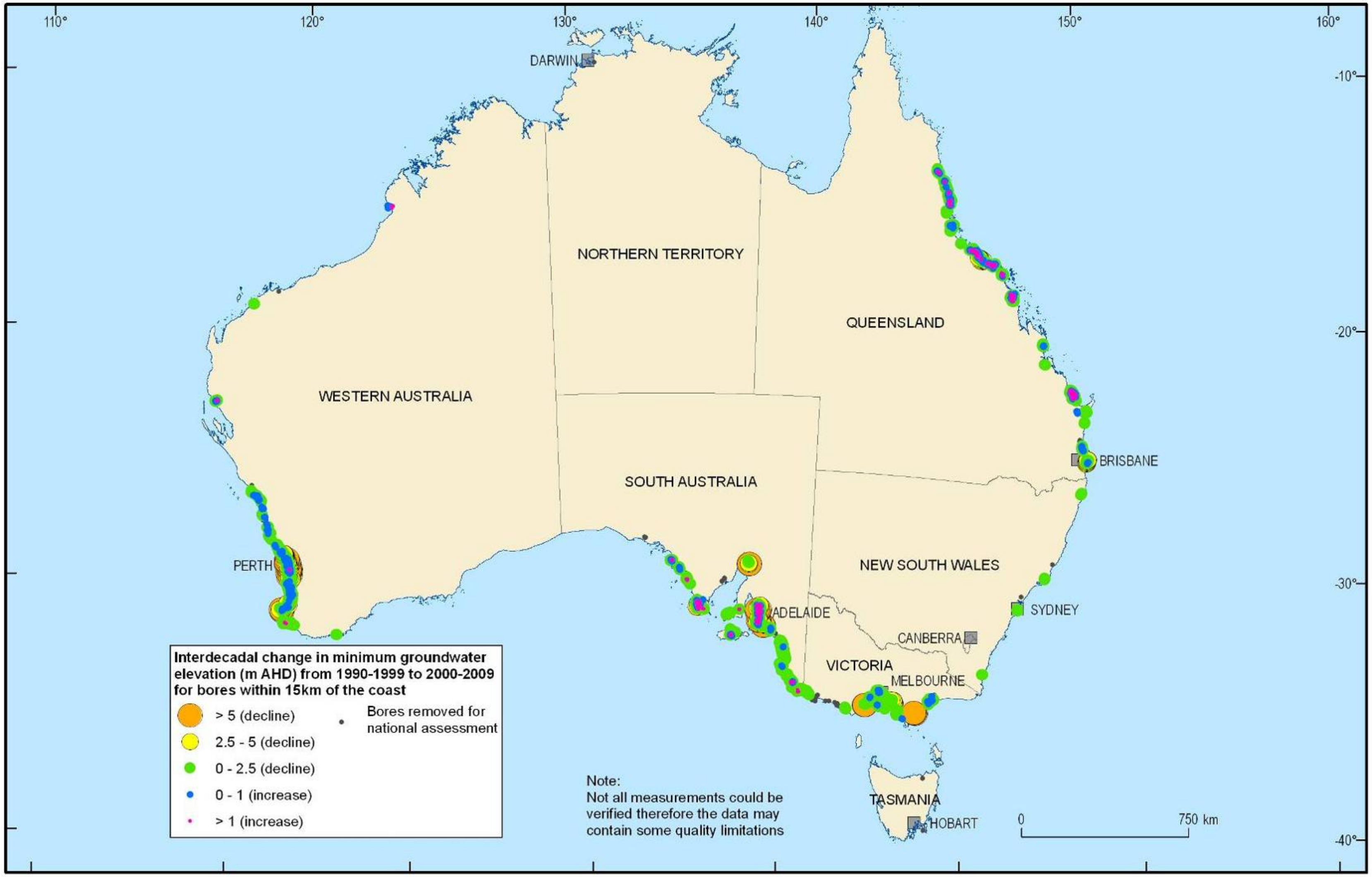


***Figure 5** Inter-decadal changes in minimum groundwater levels from 1990-1999 to 2000-2009 (only data points where three or more boreholes within a 5 km radius fall into the same category are classified)*

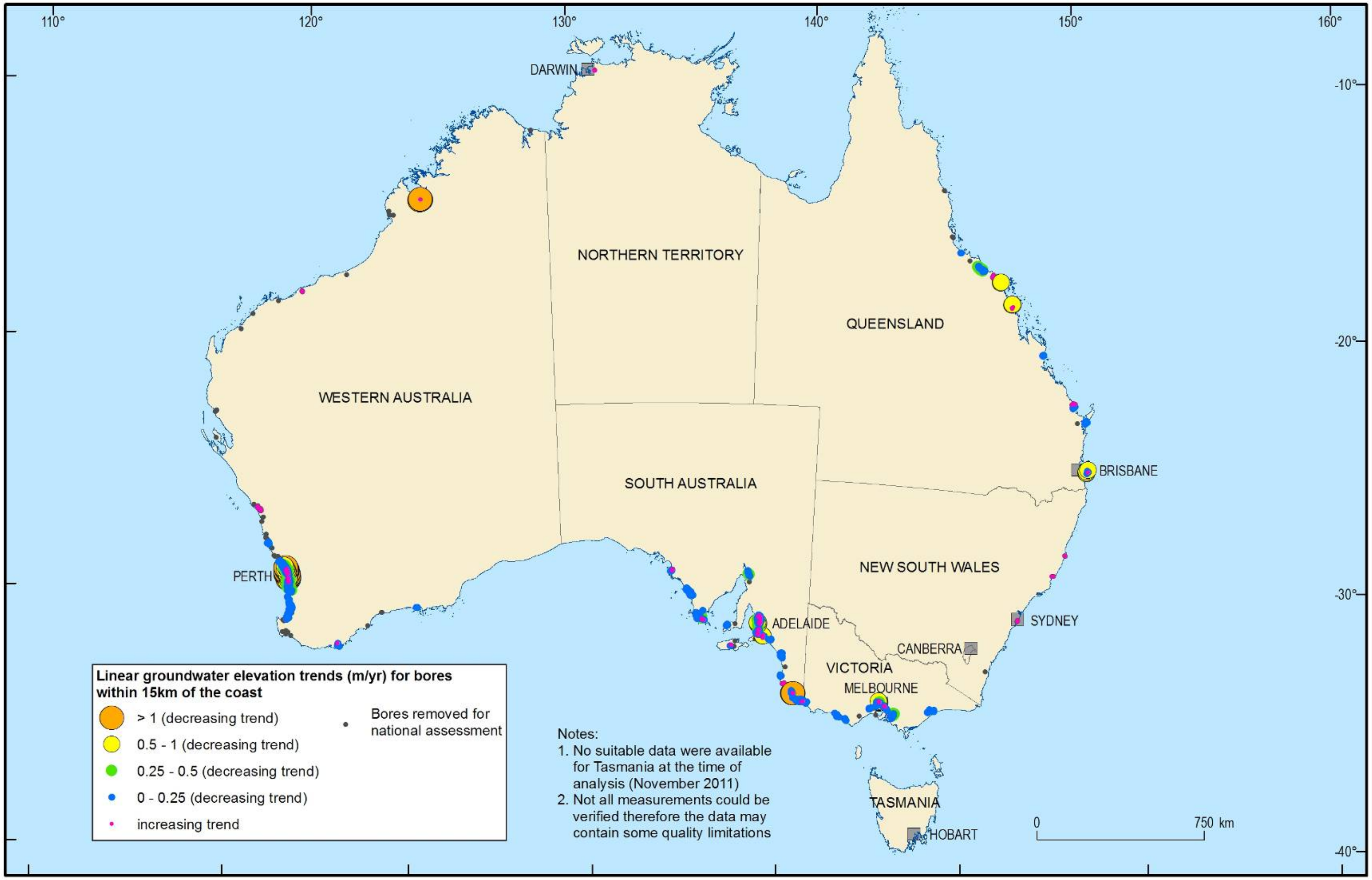


Figure 6 *Linear groundwater level trends (only data points where three or more boreholes within a 5 km radius fall into the same category are classified)*

4.1.2.1. Inter-decadal changes in minimum groundwater levels

Figure 5 indicates that the greatest inter-decadal declines in minimum groundwater levels (> 5 m) occurred in the following areas:

- WA: The Swan Coastal Plain (including from Mindarie to Perth, from the Munster to Peron area and surrounds, and between Abbey and Dunsborough);
- Vic: Torquay and Yarram; and
- SA: Port Germein, Adelaide, McLaren Vale and Goolwa.

In addition to the above localities, the following areas showed considerable inter-decadal declines in minimum groundwater levels of between 2.5 and 5 m:

- WA: The Swan Coastal Plain (including the area around the Peel Inlet and around Capel);
- Qld: The Burdekin and North Stradbroke Island;
- Vic: Koo Wee Rup; and
- SA: Uley South, the Northern Adelaide Plains and Aldinga Beach.

4.1.2.2. Groundwater level trends

Figure 5 shows that, under the national analysis, no groundwater elevation trends were available for Tasmania and relatively few data points were present in New South Wales and the Northern Territory, both of which showed increasing groundwater level trends. In the remaining states, although some boreholes showed increasing trends in groundwater levels, most areas where information was available showed decreasing groundwater levels in a number of places. Strong declining groundwater level trends of more than 0.5 m/year were identified at several locations including:

- WA: Derby (trends >1 m/year were recorded here) and the Swan Coastal Plain (from Mindarie to Perth and surrounds had trends >1 m/year, other areas with trends >0.5 m/year included the area up to 15 km north of Mindarie and from Munster to Peron);
- Qld: Proserpine, Pioneer Valley and Mackay and North Stradbroke Island;
- Vic: Brooklyn; and
- SA: Adelaide, Goolwa, and around 15 km southeast of Millicent (trends >1 m/year were recorded here).

Areas with decreasing groundwater level trends between 0.25 and 0.5 m/year not identified above included:

- WA: The Swan Coastal Plain from Peron to the Peel Inlet;
- Qld: The Burdekin;
- Vic: Koo Wee Rup; and
- SA: Uley South and Port Lincoln area, Port Germein, Northern Adelaide Plains and McLaren Vale.

Several areas on Figure 6 show declining groundwater level trends <0.25 m/year. Although at the current rates of decline these areas are likely to be more easily managed than areas with greater decreasing trends, these smaller trends may still be indicators of high SWI vulnerability. SWI may become an issue in these areas over a longer timeframe although, if groundwater levels are currently low (see Figure 4), they may take on greater significance.

4.2. National Groundwater Salinity Analysis

4.2.1. Maximum salinity measurements

Historical maximum salinity measurements made prior to 2000 are considered separately from 2000-2009 data below.

4.2.1.1. Historical maximum salinity measurements

Historical maximum TDS concentrations are shown on Figure 7. Of particular interest in the VFA are those areas where groundwater has TDS concentrations <3000 mg/L since it is suitable for a wide range of uses. Such groundwater is more likely to be exploited than more saline groundwater and as such it may be more prone to SWI.

Areas where groundwater with maximum TDS concentrations <3000 mg/L was within 1 km of groundwater with maximum TDS concentrations >10,000 mg/L included:

- WA: Broome, Karratha, Carnarvon, the Swan Coastal Plain (near Mindarie and Perth and in several areas south of Perth including Munster, Peron, land around the Peel Inlet, Harvey Estuary, and Lake Preston, Eaton, Bunbury and Abbey) and Rottnest Island;
- Northern Territory (NT): The area south of Keep River, the area northeast of Darwin and in the Baniyala area;
- Qld: Port Douglas, north of Cairns (Holloways Beach), The Burdekin, Bowen, Pioneer Valley and Mackay, Yeppoon, Bundaberg, Burnett Heads, Maryborough, Brisbane and Elanora;
- NSW: East and west of Taree and southeast of Bega;
- Vic: Sale; and
- SA: Bookabie, Penang and Lake MacDonnell (and surrounding areas, noting that Lake MacDonnell has a history of salt production) typically recorded high maximum TDS concentrations >10,000 mg/L with relatively few maximum TDS concentrations <3000 mg/L. A greater proportion of maximum TDS concentrations <3000 mg/L were present near Streaky Bay, Port Kenny, Venus Bay, in many areas between Elliston and Coffin Bay, Port Lincoln, Tumby Bay inland from Port Gibbon, in the area around Port Germein, Moonta, from the Port Rickaby area in many locations around the peninsular to around 15 km north of Stansbury, from the Northern Adelaide Plains around the coast to Goolwa, Narrung and in the Meningie – Coorong area. The majority of maximum TDS concentrations were <3000 mg/L with relatively few maximum TDS concentrations >10,000 mg/L in Uley South, in the area of Kingston, in several places from Robe to Millicent, Carpenter Rocks and on Kangaroo Island.

4.2.1.2. Maximum salinity measurements, 2000-2009

Figure 8 shows the maximum TDS concentrations measured during 2000–2009. Attention is drawn to those areas displaying groundwater with maximum TDS concentrations <3000 mg/L which is likely to be suitable for a wide range of uses. Areas where groundwater with maximum TDS concentrations <3000 mg/L was within 1 km of groundwater with maximum TDS concentrations >10,000 mg/L included:

- WA: Whim Creek, Exmouth, Carnarvon, the Swan Coastal Plain (Including Mindarie, Perth and Lake Preston), Bremmer Bay;

- Qld: North of Cairns (Holloways Beach), The Burdekin, Bowen, Pioneer Valley and Mackay, Yeppoon, Bundaberg, Burnett Heads and Eli Waters and surrounds;
- NSW: Southwest of Port Macquarie; and
- SA: Streaky Bay, Wallaroo, Northern Adelaide Plains, Adelaide, McLaren Vale, Aldinga Beach, Kangaroo Island, Goolwa and Meningie.

4.2.2. Inter-decadal changes in maximum salinity measurements

Changes in maximum TDS concentrations between the decades 1990-1999 and 2000-2009 are shown on Figure 9. Only the Mindarie area (Swan Coastal Plain) in Western Australia and Streaky Bay in South Australia showed increases in the maximum TDS concentration by more than 10,000 mg/L in some bores. Carnarvon and Perth in Western Australia and The Burdekin, Bowen, Pioneer Valley and Mackay areas of Queensland showed maximum TDS concentration increases in the range 3,000 mg/L to 10,000 mg/L.

Maximum TDS concentration increases in the range 1000–3000 mg/L are also considered to be significant and areas showing inter-decadal increases in that range not listed above included:

- WA: The Harvey Estuary Area (Swan Coastal Plain)
- Qld: The Bundaberg and Burnett Heads area
- Vic: Koo Wee Rup
- SA: Northern Adelaide Plains and McLaren Vale.

Although the above areas have shown larger increases in maximum TDS concentrations, even concentration increases of more than 1000 mg/L can be significant since water with TDS concentrations above 1000 mg/L is considered in many areas to be unsuitable for human consumption. The general water use in an area should therefore be taken into account when assessing the significance of the increases in TDS concentration shown in Figure 9.

4.2.3. Time-series salinity measurements

As outlined in Section 3.3.2, part of the data filtering process for salinity measurements entailed plotting TDS concentrations over time to facilitate identification of anomalous readings. Only borehole salinity time series with an RDM value >0.5 were examined. During this process, a number of boreholes were identified that showed strong indications of possible SWI in their measurements (e.g. dramatic increases in TDS concentration over time with multiple confirmatory measurements).

Since such analyses were only undertaken on a small subset of the salinity data and the total number of TDS time series precluded analysis of all measurement points, it was not considered appropriate to present the data in the context of the national assessment. Presentation of the data here would place unjustifiable emphasis on the locations where time series TDS analysis was undertaken. However, the TDS time series plots for boreholes showing indications of SWI are included for reference purposes in Appendix 1.

It is noted that the plots in Appendix 1 are not definitive indications of SWI since such an assessment would require interpretation in the context of site specific information.

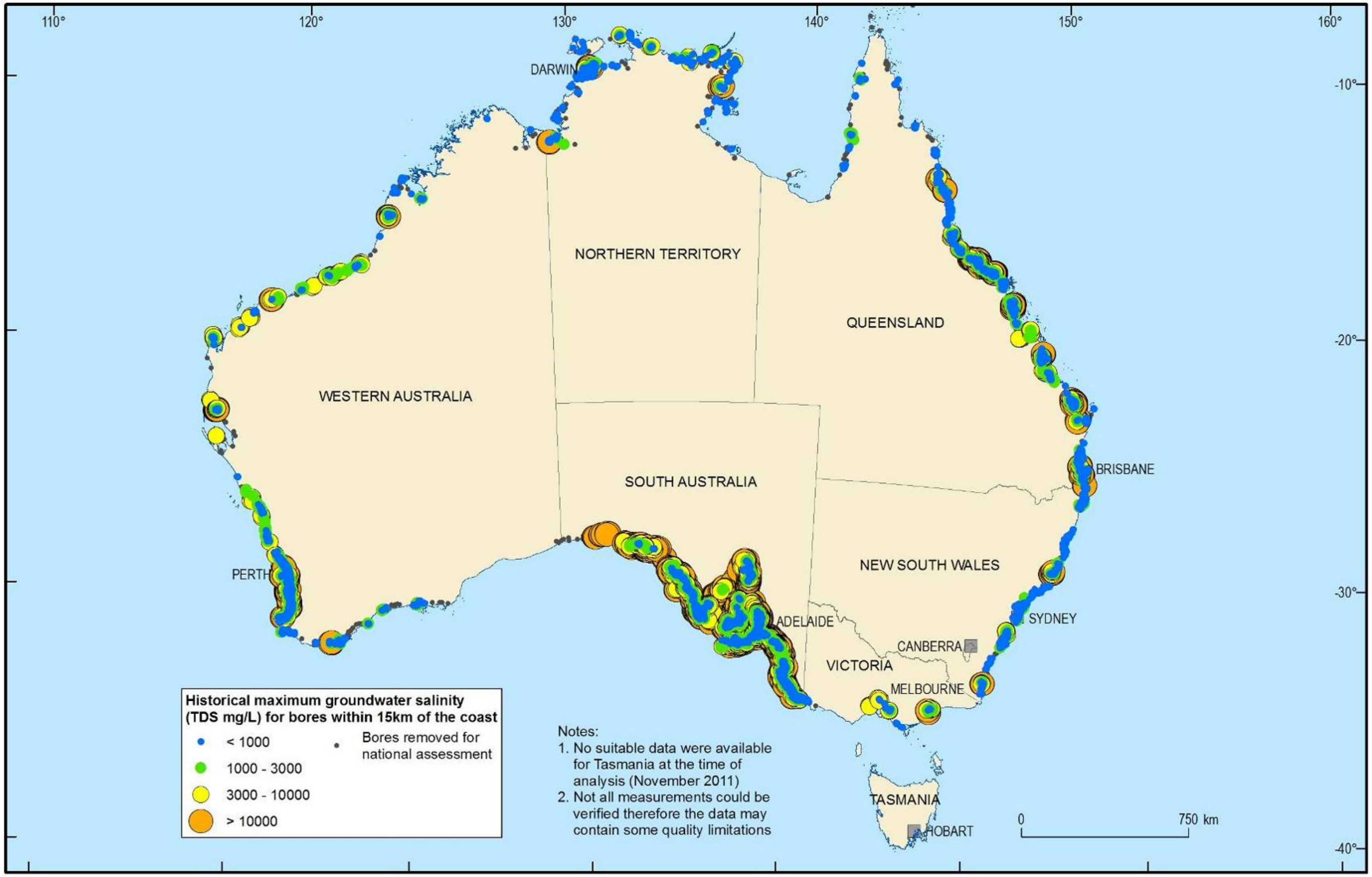


Figure 7 *Historical maximum TDS concentrations measured prior to 2000 (only data points where three or more boreholes within a 5 km radius fall into the same category are classified)*

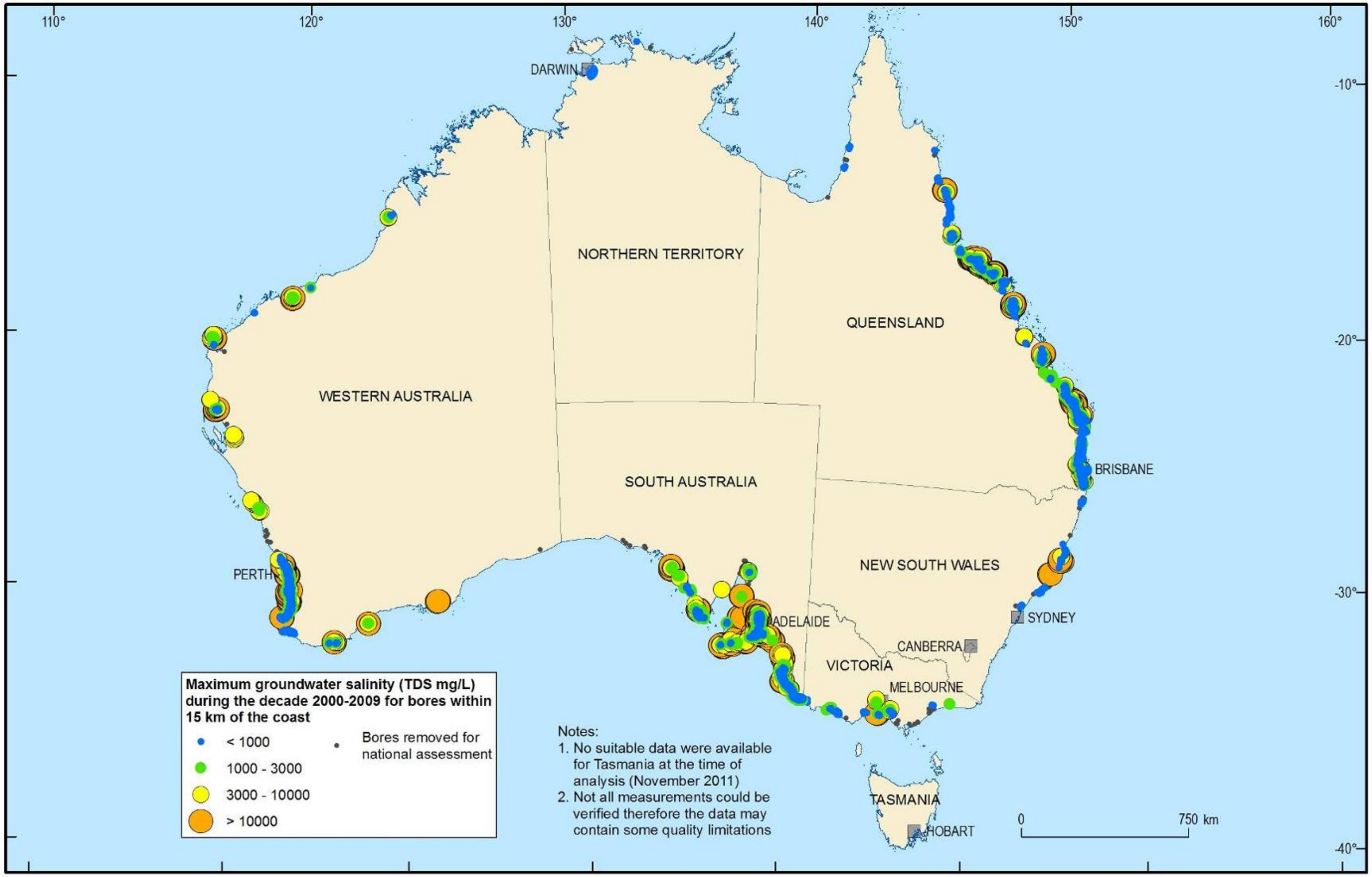


Figure 8 *Maximum TDS concentrations for the period 2000-2009 (only data points where three or more boreholes within a 5 km radius fall into the same category are classified)*

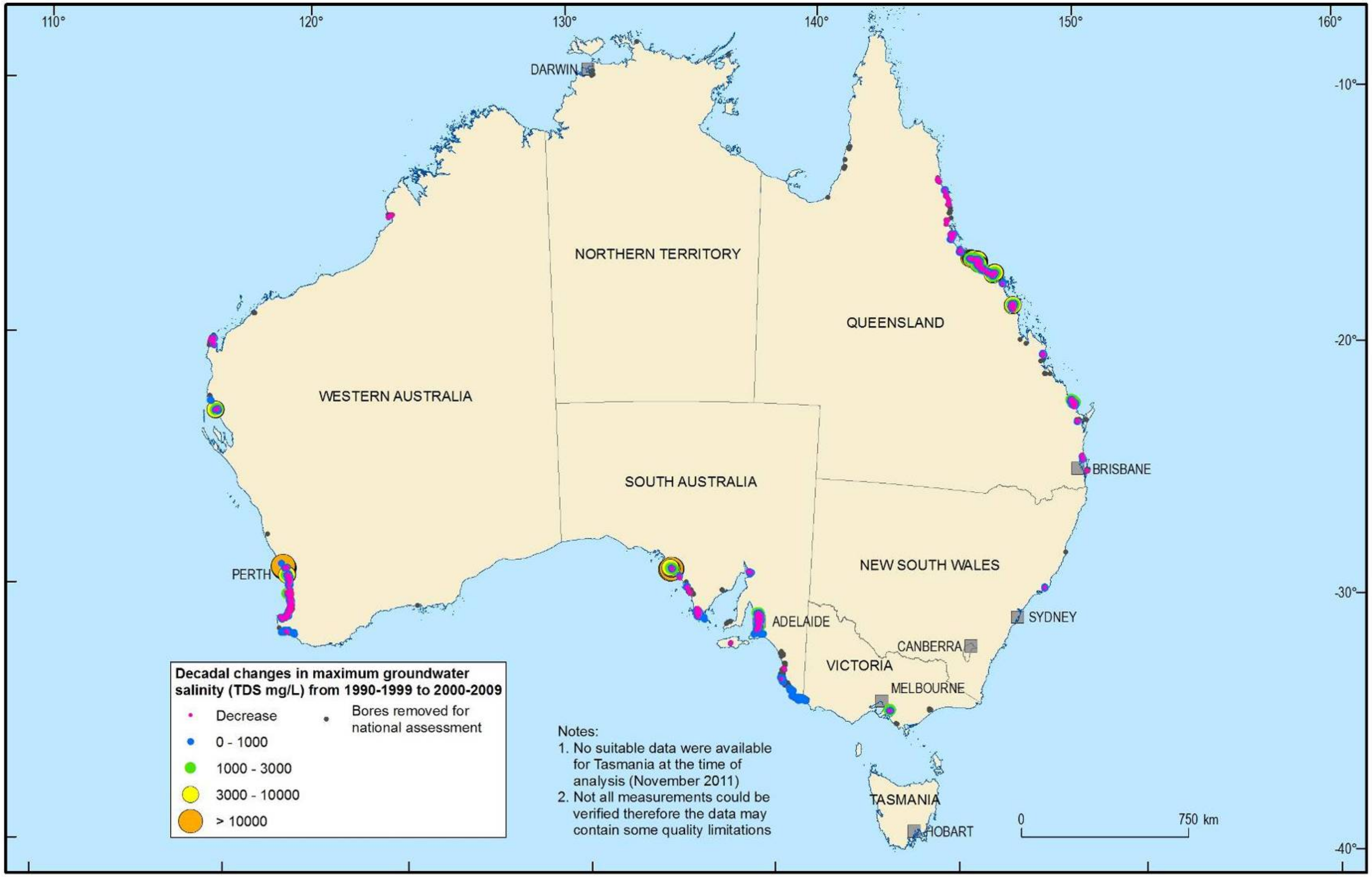


Figure 9 *Inter-decadal change in maximum TDS concentrations from 1990-1999 to 2000-2009 (only data points where three or more boreholes within a 5 km radius fall into the same category are classified)*

4.3. National Groundwater Extraction Analysis

4.3.1. Distribution of production bores

Figure 10 shows the location of production bores and their extraction rates over the time periods indicated. Water agencies in Tasmania and New South Wales were unable to provide locations of production bores across the state 15 km coastal buffers thus no extraction data is presented for these areas. Although the locations of extraction bores were provided for the Northern Territory, no extraction rates were available and no distinction was made between production bores and those used for stock and domestic purposes so the results are not included in this analysis either. It is emphasised that extraction does occur along the coast in these states so the lack of data should not be taken to mean that extraction does not take place.

4.3.2. Groundwater extraction rates

As outlined in Section 3.4.3, in the context of SWI it is difficult to attach significance to extraction rates in the absence of recharge data. The information presented is best considered at a site specific level in conjunction with other available information. However, the following areas contained individual production bores with particularly high extraction rates > 1000 ML/year:

- Western Australia: The area around 20 km north of Dongara, the Swan Coastal Plain (near Mindarie, Perth, Munster, Australind and Eaton);
- Queensland: The Burdekin, Pioneer Valley and Mackay and Bundaberg;
- Victoria: Portland, the area near Torquay, Yarram and Sale; and
- South Australia: Uley South.

Areas containing production bores with extraction rates in the range 500–1000 ML/year that are not listed above include:

- Victoria: The area between Portland and Port Fairy as well as Nullawarre; and
- South Australia: Port Germein, Le Fevre Peninsular and Adelaide and the Lower Limestone Coast.

4.3.3. Cumulative groundwater extraction rates

The above analysis does not take into account the cumulative impacts of multiple extraction bores. It is apparent from Figure 10 that several areas around the coastline contain relatively large numbers of production bores that fall into the lower extraction categories. In Figure 11, a 5 km grid has been overlain on the production bore extraction data from Figure 10, and the extraction volumes of production bores falling within each grid cell have been summed. The final category that each cell falls into is somewhat dependent on where the grid is positioned, but in general the information shows that the following areas contain cumulative pumping within 25 km^2 grid cells >1000 ML/year:

- Western Australia: Broome, the area around 20 km north of Dongara, the Swan Coastal Plain (near Mindarie, Perth, Munster, Australind, Eaton and Bunbury) and Albany;
- Queensland: The Burdekin, Pioneer Valley and Mackay, Bundaberg and Burnett Heads;
- Victoria: Portland, the area near Port Fairy, Torquay, Point Nepean, Yarram and Sale; and
- South Australia: Uley South, Adelaide and the Lower Limestone Coast.

Areas containing 25 km^2 grid cells with cumulative pumping in the range 500–1000 ML/year not listed above include:

- Western Australia: Derby, Dunsborough and Esperance;
- Queensland: Bowen;
- Victoria: Nullawarre; and
- South Australia: McLaren Vale and Aldinga Beach.

4.4. National Rainfall Trend Analysis

Linear rainfall trends for the period 2000-2009 are shown on Figure 12. It is apparent that most areas around the Australian coast experienced lower than average rainfall over this period. In these areas, lowered recharge may have contributed to decreasing groundwater levels and may also have resulted in increases in groundwater extraction, leading to further groundwater level decline. However, it is noted that drought around the country has eased in 2010 and 2011, and a reversal in rainfall trends is evident in some areas. As such, the rainfall trends on Figure 12 may not remain good indicators of vulnerability and should be updated in future assessments. They are included here as useful background information and an example of how rainfall trends over time may be analysed for inclusion in an assessment of vulnerability but they are not explicitly used for assessing SWI vulnerability in this document.

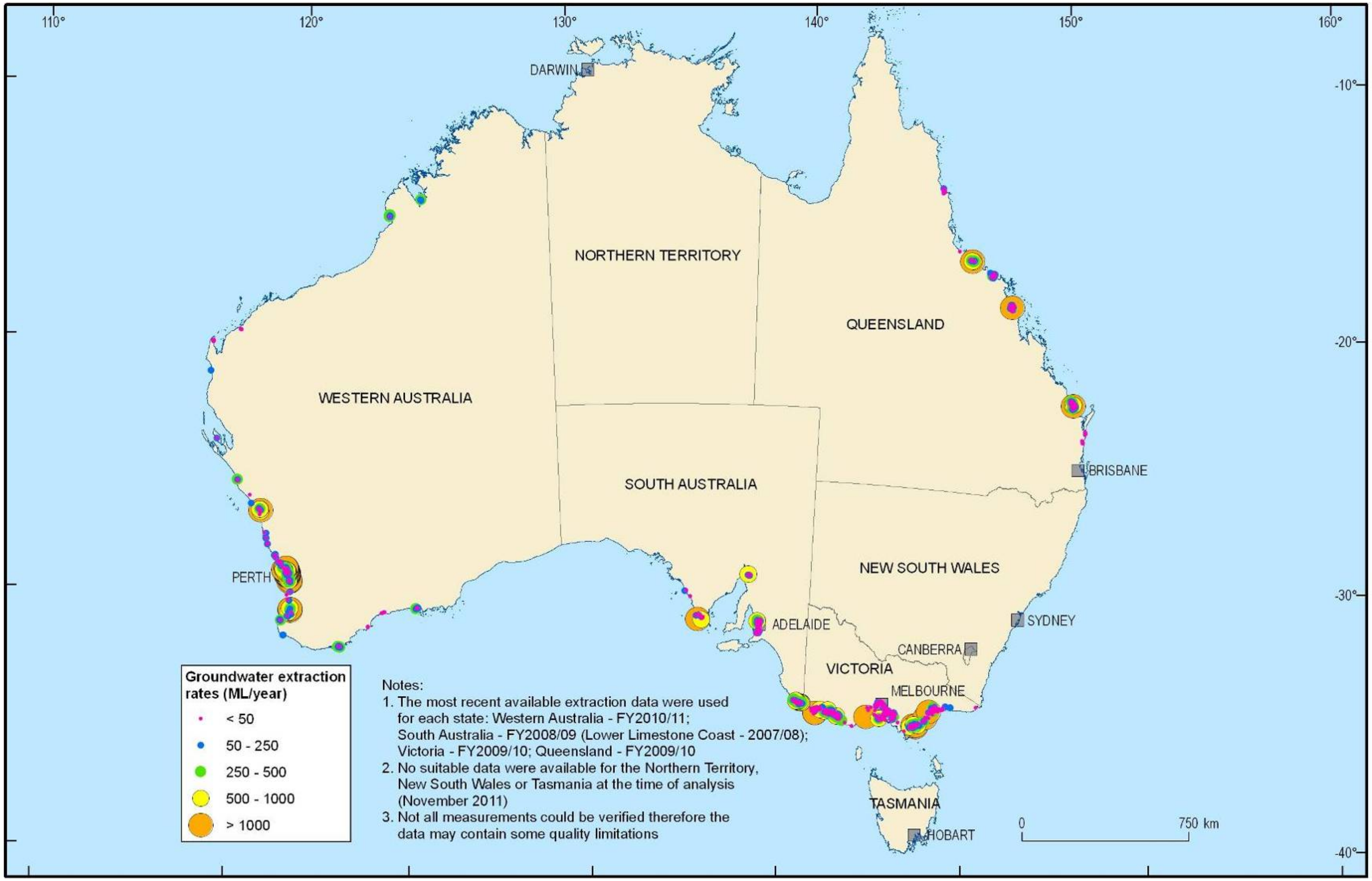


Figure 10 *Groundwater production bore locations and extraction rates*

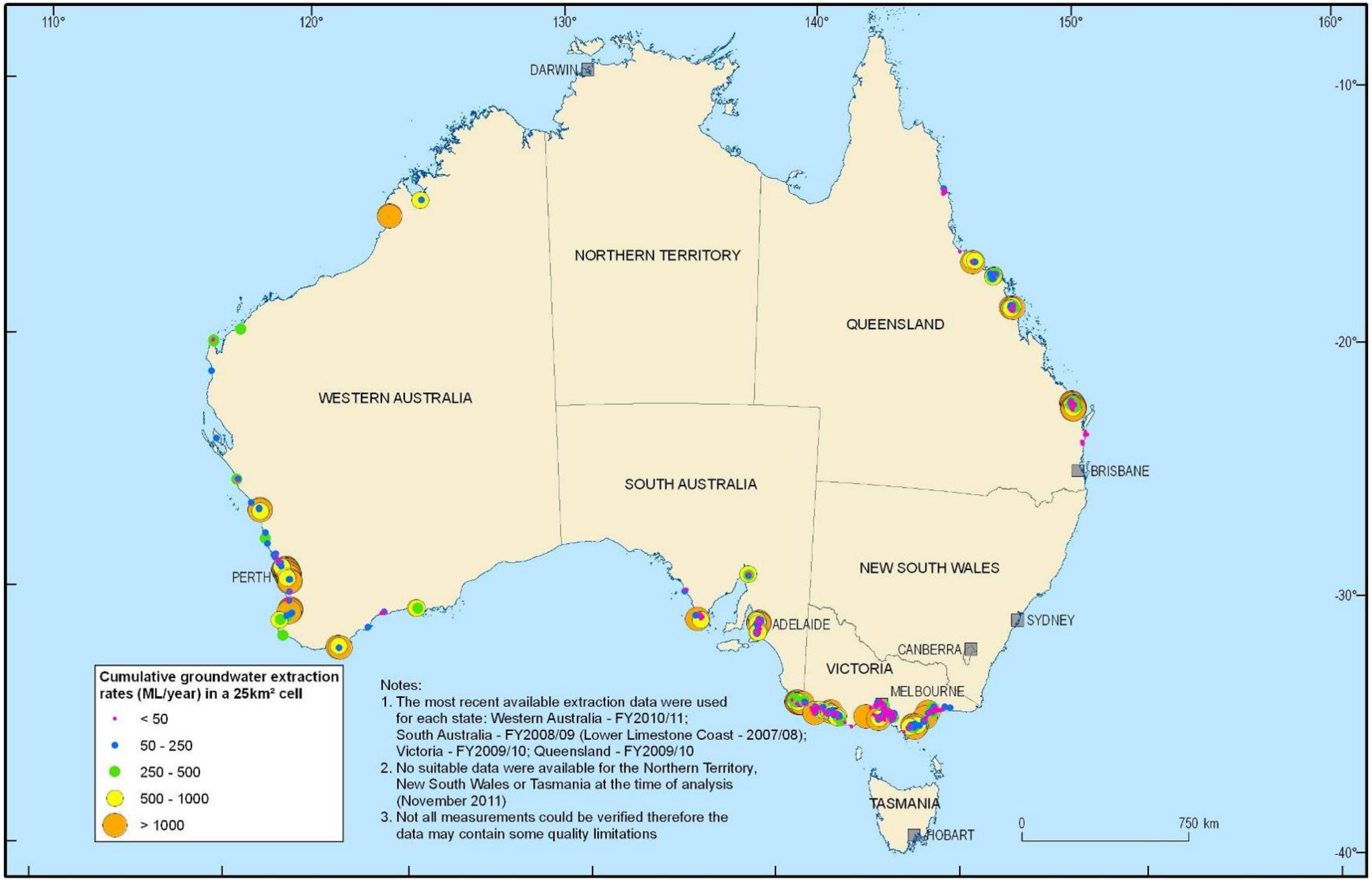


Figure 11 *Cumulative groundwater extraction rates within 5x5 km grid cells*

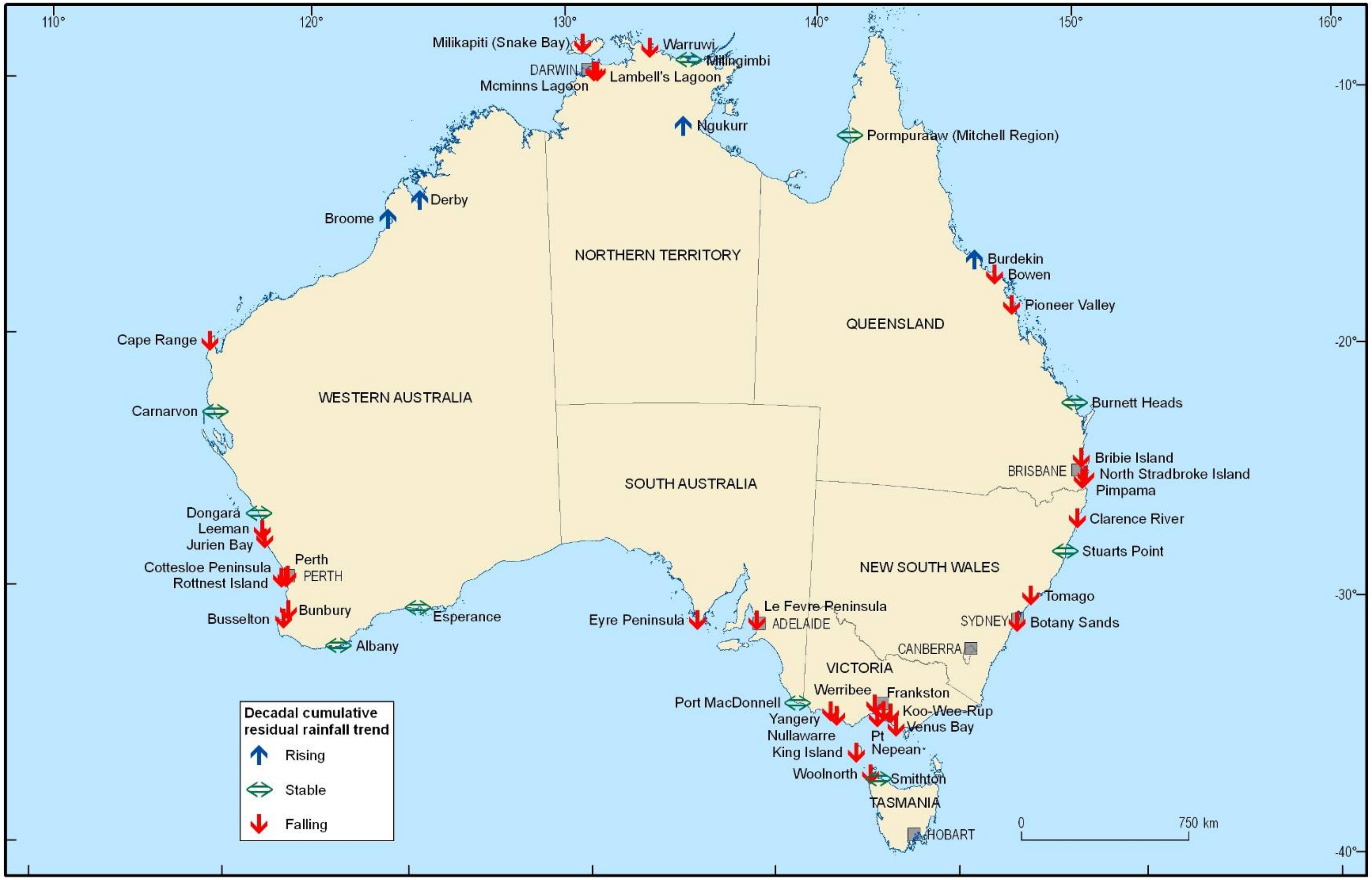


Figure 12 *Trends in cumulative deviation of monthly rainfall from long term averages for the period 2000-2009*

4.5. National VFA Summary and Priority Areas

There are no or limited VFA data around much of Australia's coast. A single VFA indicator of high vulnerability in an area may correspond to an area with high SWI vulnerability and some high SWI vulnerability areas may have no data at all. However, it is useful to identify locations where numerous high vulnerability indicators are present as a mechanism to prioritise areas for further investigation and management if groundwater resources are to be developed or groundwater use is to continue.

Given the limitations with respect to rainfall and groundwater extraction data outlined above, only groundwater level and salinity data were considered in this prioritisation assessment. The following seven categories of VFA parameters were considered to indicate high vulnerability:

1. Historic minimum groundwater levels <0 m AHD (pre 2000);
2. Recent minimum groundwater levels <0 m AHD (2000-2009);
3. Inter-decadal decline in groundwater levels between 1990-1999 and 2000-2009 >2.5 m;
4. Declining groundwater level trends >0.5 m/year;
5. Historic maximum TDS concentrations >10,000 mg/L located within 1 km of maximum TDS concentrations <3000 mg/L (pre 2000);
6. Recent maximum TDS concentrations >10,000 mg/L located within 1 km of maximum TDS concentrations <3000 mg/L (2000-2009); and
7. Inter-decadal increase in maximum TDS concentrations >1000 mg/L between 1990-1999 and 2000-2009.

Table 4 summarises the above category results for all areas where at least one high category VFA indicator is identified in the national VFA analysis. Locations showing greater than 50 per cent (4 or more) of the above category indicators and at least one indicator from both groundwater level (any of the indicators listed in points 1 to 4 above) and salinity (any of the indicators listed in points 5 to 7 above) categories were classified as priority VFA areas containing a significant proportion and range of VFA indicators. Such areas include (place names refer to the general area of interest):

- Western Australia: Carnarvon and the Swan Coastal Plain (including the following locations and surrounds: Mindarie, Perth, Munster, Peron, Peel Inlet, Harvey Estuary, Lake Preston and Abbey);
- Queensland: The area north of Cairns (around Holloways Beach), The Burdekin, Bowen, Pioneer Valley and Mackay, Bundaberg and Burnett Heads;
- Victoria: Koo Wee Rup; and
- South Australia: Streaky Bay, Uley South, Northern Adelaide Plains, Adelaide, McLaren Vale, Aldinga Beach and Goolwa.

It is reiterated that there are other areas around Australia showing indicators of high SWI vulnerability and a lack of data in many areas. Omission of locations from the above list should not be taken to imply that they are not significantly vulnerable to SWI. The list simply highlights locations where considerable numbers of high SWI vulnerability indicators are present where data are available around Australia's coast.

Although the national VFA identifies locations where regionally available data suggest that areas may have high SWI vulnerability, it does not provide sufficient details to conclusively determine if areas are vulnerable to SWI or not. For a full assessment of vulnerability to SWI, additional site-specific factors require consideration. Such an approach is undertaken in Ivkovic et al. (2012a), where the results of all technical aspects of the national SWI vulnerability assessment project are collated.

Table 4 *National VFA summary (national VFA priority areas are indicated by *)*

Area	Groundwater levels				Groundwater salinity		
	Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS concentrations of <3000 mg/L within 1 km >10,000 mg/L		TDS concentration changes
	Pre-2000	2000-2009	Inter-decadal declines >2.5 m	Declining trends >0.5 m/year	Pre 2000	2000-2009	Inter-decadal increase >1000
WESTERN AUSTRALIA							
Cambridge Gulf (East Head)	Y						
Derby	Y			Y			
Broome	Y				Y		
Whim Creek						Y	
Karratha					Y		
Exmouth	Y					Y	
50 km south of Exmouth	Y						
*Carnarvon	Y	Y			Y	Y	Y
Kalbarri	Y						
15 km S of Dongara	Y						
WESTERN AUSTRALIA SWAN COASTAL PLAIN							
Jurien Bay	Y						
*Mindarie	Y	Y	Y	Y	Y	Y	Y
*Perth	Y	Y	Y	Y	Y	Y	Y
Rottnest					Y		
*Munster	Y	Y	Y	Y	Y		
*Peron		Y	Y	Y	Y		

Area	Groundwater levels				Groundwater salinity		
	Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS concentrations of <3000 mg/L within 1 km >10,000 mg/L		TDS concentration changes
	Pre-2000	2000-2009	Inter-decadal declines >2.5 m	Declining trends >0.5 m/year	Pre 2000	2000-2009	Inter-decadal increase >1000
*Peel Inlet	Y	Y	Y		Y	Y	
*Harvey Estuary	Y	Y			Y	Y	Y
*Lake Preston	Y	Y			Y	Y	
Australind	Y	Y					
Eaton	Y	Y			Y		
Bunbury	Y	Y			Y		
Capel	Y	Y	Y				
Busselton	Y						
*Abbey	Y	Y	Y		Y	Y	
Dunsborough	Y	Y	Y				
Bremmer Bay						Y	
NORTHERN TERRITORY							
South of Keep River					Y		
Northeast of Darwin					Y		
Baniyala area					Y		
QUEENSLAND							
Port Douglas	Y	Y			Y		
*N of Cairns (Holloways Beach)	Y	Y			Y	Y	
Innisfail	Y						

Area	Groundwater levels				Groundwater salinity		
	Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS concentrations of <3000 mg/L within 1 km >10,000 mg/L		TDS concentration changes
	Pre-2000	2000-2009	Inter-decadal declines >2.5 m	Declining trends >0.5 m/year	Pre 2000	2000-2009	Inter-decadal increase >1000
Kurrimine Beach	Y						
Ingham	Y	Y					
*The Burdekin	Y	Y	Y		Y	Y	Y
*Bowen	Y	Y			Y	Y	Y
Proserpine	Y			Y			
*Pioneer Valley and Mackay	Y	Y		Y	Y	Y	Y
Yeppoon					Y	Y	
*Bundaberg	Y	Y			Y	Y	Y
*Burnett Heads	Y				Y	Y	Y
Eli Waters						Y	
Maryborough	Y				Y		
Bribie Island	Y	Y					
Brisbane	Y				Y		
North Stradbroke Island			Y	Y			
Beenleigh					Y		
NEW SOUTH WALES							
Evans Head	Y						
Stuarts Point		Y					
±20 km SW of Port Macquarie	Y					Y	

Area	Groundwater levels				Groundwater salinity		
	Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS concentrations of <3000 mg/L within 1 km >10,000 mg/L		TDS concentration changes
	Pre-2000	2000-2009	Inter-decadal declines >2.5 m	Declining trends >0.5 m/year	Pre 2000	2000-2009	Inter-decadal increase >1000
Taree and surrounds	Y	Y			Y		
Myall Lake Area		Y					
Botany	Y						
Bodalla	Y						
SE of Bega	Y				Y		
VICTORIA							
Torquay			Y				
Werribee		Y					
Brooklyn	Y			Y			
Phillip Island	Y	Y					
French Island		Y					
*Koo Wee Rup area	Y	Y	Y				Y
Venus Bay		Y					
Yarram		Y	Y				
Sale	Y	Y			Y		
Bairnsdale		Y					
SOUTH AUSTRALIA							
Bookabie					Y		
Penang					Y		
Lake MacDonnell					Y		

Area	Groundwater levels				Groundwater salinity		
	Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS concentrations of <3000 mg/L within 1 km >10,000 mg/L		TDS concentration changes
	Pre-2000	2000-2009	Inter-decadal declines >2.5 m	Declining trends >0.5 m/year	Pre 2000	2000-2009	Inter-decadal increase >1000
*Streaky Bay	Y	Y			Y	Y	Y
Port Kenny	Y				Y		
Venus Bay	Y				Y		
Elliston	Y				Y		
Coffin Bay	Y				Y		
*Ulley South	Y	Y	Y		Y		
Port Lincoln area	Y	Y			Y		
Tumby Bay					Y		
Port Gibbin					Y		
Port Germein	Y		Y		Y		
Wallaroo						Y	
Moonta					Y		
Port Rickaby					Y		
Corny Point					Y		
Edithburgh	Y				Y		
Stansbury	Y				Y		
±15 km north of Stansbery					Y		
*Northern Adelaide Plains	Y	Y	Y		Y	Y	Y
*Adelaide	Y	Y	Y	Y	Y	Y	
*McLaren Vale	Y	Y	Y		Y	Y	Y

Area	Groundwater levels				Groundwater salinity		
	Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS concentrations of <3000 mg/L within 1 km >10,000 mg/L		TDS concentration changes
	Pre-2000	2000-2009	Inter-decadal declines >2.5 m	Declining trends >0.5 m/year	Pre 2000	2000-2009	Inter-decadal increase >1000
*Aldinga Beach	Y	Y	Y		Y	Y	
Encounter Bay	Y				Y		
*Goolwa	Y	Y	Y	Y	Y	Y	
Narrung	Y	Y			Y		
Meningie		Y			Y	Y	
Coorong					Y		
Kingston	Y				Y		
Robe	Y	Y			Y		
Lake St Clair	Y	Y			Y		
Millicent					Y		
±14 km Southeast of Millicent	Y	Y		Y			
Carpenter Rocks					Y		
Kangaroo Island					Y	Y	

5. Vulnerability Factor Analysis Results: Western Australia

In WA, groundwater is managed on the basis of defined groundwater management areas and groundwater subareas. The boundaries for these regulatory units were obtained from the Western Australia Department of Water for use in the VFA (see Figure 13). As outlined above, these regulatory units are referred to as GMAs below.

The total area of each GMA and the proportion of each GMA lying within 15 km of the coastline are provided in Table 5 which also indicates which of the WA GMAs coincide with the GMUs defined in AWR (2006). There are 35 GMAs in WA that are wholly or partially within 15 km of the coast and 25 contained data for consideration in this state assessment. A total of 16 GMAs had more than 90% of their total areas within 15 km of the coastline, suggesting that SWI vulnerability may be highly relevant to their overall groundwater management. The VFA results are reported on the basis of GMAs in summary form in Section 5.5.

Table 6 provides details of the number of measurements collected and analysed for the VFA in WA.

5.1. Groundwater Level Analysis

5.1.1. Minimum groundwater levels

Consistent with the national analysis in Section 4, the discussion below focuses on areas showing the highest SWI vulnerability indicator category of water levels <0 m AHD. However, water levels between 0 and 2.5 m AHD on Figure 14 and Figure 15 may also suggest some vulnerability to SWI.

Groundwater level data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data to highlight areas that have recently shown groundwater level indicators of vulnerability. However, the lack of recent vulnerability indicators cannot be used to infer a reversal in vulnerability trends in many areas since they may in part be due to a lack of recent data. When making such an assessment, Figure 14 and Figure 15 should be considered together.

5.1.1.1. Historical minimum groundwater levels

Minimum groundwater levels reported in monitoring wells prior to 2000 are summarised on Figure 14. Several areas around WA contained water level measurements for this period <0 m AHD. Many of these locations were between Geraldton and Dunsborough within the Swan Coastal Plain. In addition, a number of locations between Cape Range and Derby and between Albany and Esperance also recorded minimum groundwater levels in this category. Figure 14 should be consulted for the locations of all water level measurements <0 m AHD.

5.1.1.2. Minimum groundwater levels, 2000–2009

Minimum groundwater levels reported in monitoring wells for the period 2000-2009 are summarised on Figure 15. Although there are less measurement locations (probably due to a shorter monitoring period), minimum water levels show a similar distribution to those measured historically. Several areas along the WA coast contained water level measurements for this period <0 m AHD including many locations between Geraldton and Dunsborough within the Swan Coastal Plain. Water levels <0 m AHD were also encountered near Carnarvon and Albany. Figure 15 should be referred to for precise locations of all water level measurements <0 m AHD. The distribution of these water levels relative to the coastline is discussed in Section 5.1.4 below.

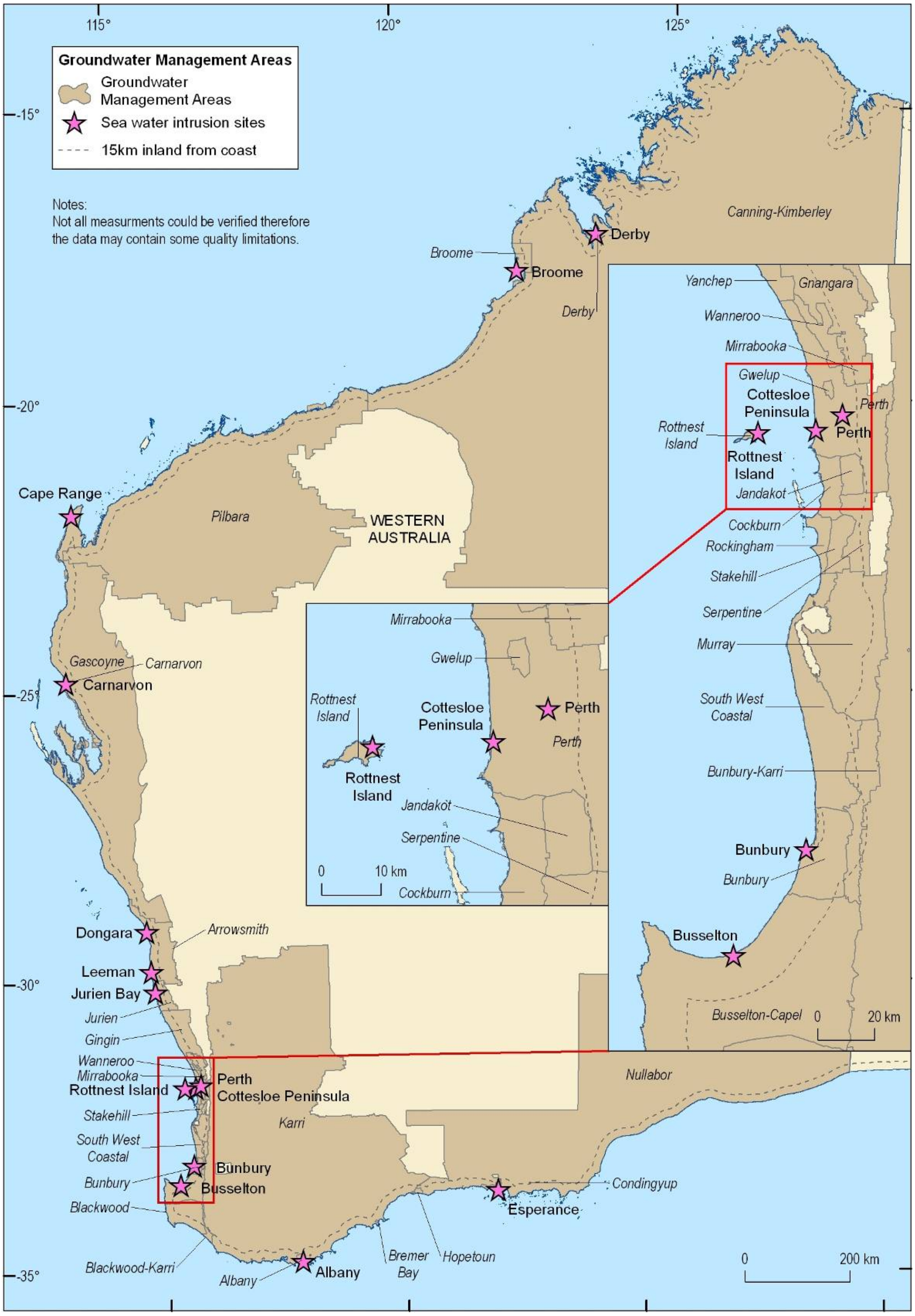


Figure 13 *GMAs in WA that intersect the 15 km coastal buffer zone.*

Table 5 *Total WA GMA areas that are wholly or partially within 15 km of the coast and percentage of total GMA areas within 15 km of the coast*

GMA name	Total GMA area (hectares)**	Percentage of GMA within 15 km of coast
Bremer Bay*	2,166	100
Cockburn*	15,548	100
Derby*	3,378	100
Gwelup*	1,666	100
Hopetoun*	14,543	100
Jandakot*	10,140	100
Rockingham	9,424	100
Stakehill†	13,749	100
Yanchep*	11,374	100
Albany*	21,264	99
Esperance	34,579	99
Wanneroo*	15,567	99
Carnarvon*	4,611	97
South West Coastal	79,986	95
Rottnest Island*	1,805	94
Bunbury*	46,519	91
Blackwood-Karri	37,918	70
Murray*	103,008	68
Perth*	96,072	61
Broome*	174,700	60
Blackwood*	326,341	47
Busselton-Capel*	313,135	47
Gnangara*	71,677	43
Bunbury-Karri	40,064	38
Serpentine	40,704	35
Mirrabooka*	8,515	34
Condingyup*	854	23
Arrowsmith	1,011,530	22
Gingin	632,912	22
Jurien	491,014	18
Gascoyne	20,590,700	8
Nullabor	17,234,248	8
Canning-Kimberley*	70,793,540	6
Karri	16,007,450	5
Pilbara	21,430,400	5

† Not listed in AWR 2006 where it is combined with Rockingham

*Generally matches AWR 2006 GMU

**Areas calculated based on the GDA1994 datum using a Lambert Conformal Conic Projection

Table 6 Groundwater data utilised in the VFA for WA

Data Type	Data Subset	No. of Measurements
Groundwater levels	All relative standing water levels (5/1901–12/2010)	374,245
	Minimum RSWL (all years)	4,940
	Minimum RSWL Pre 2000	4,315
	Minimum RSWL 2000–2009	1,573
	Calculations of inter-decadal change in minimum RSWL from 1990-99 to 2000-09	1,244
	Groundwater linear trend analyses	538
Groundwater salinity	All salinity measurements	191,879
	Maximum TDS (all years)	5,394
	Maximum TDS Pre 2000	4,306
	Maximum TDS 2000–2009	1,643
	Calculations of inter-decadal change in maximum TDS from 1990-99 to 2000-09	769
Groundwater extraction	Bores with annual usage volumes in recent years used in analysis	364

5.1.2. Groundwater level changes

Changes in groundwater levels over time are plotted on Figure 16 (inter-decadal decline in minimum groundwater levels from 1990-1999 to 2000-2009) and Figure 17 (linear trends in groundwater levels) and discussed below.

5.1.2.1. Inter-decadal changes in minimum groundwater levels

Figure 16 indicates that the majority of declines in minimum groundwater level in excess of 5 m from 1990-1999 to 2000-2009 occurred in the central (Perth and surrounds) and southern parts of the Swan Coastal Plain. In addition to increasing risk of SWI, the large reduction in storage over this period also indicates current groundwater extraction rates are unsustainable without impacting on water availability and quality. The majority of sites that exhibited greater than 10 m declines were located upon the Gnangara mound. At Cottesloe, it is understood that local stormwater managed aquifer recharge sites have been established in an effort to reduce SWI.

5.1.2.2. Groundwater level trends

Figure 17 shows that the majority of decreasing groundwater level trends >1 m/year were identified on the Swan Coastal Plain near Perth. Isolated occurrences of decreasing trends >1 m/year were recorded in several other places including Derby, Onslow, Denham, Dongara and Binningup. Areas showing declining trends in the range 0.5 – 1 m/year include Scott River, Bremer Bay and Esperance.

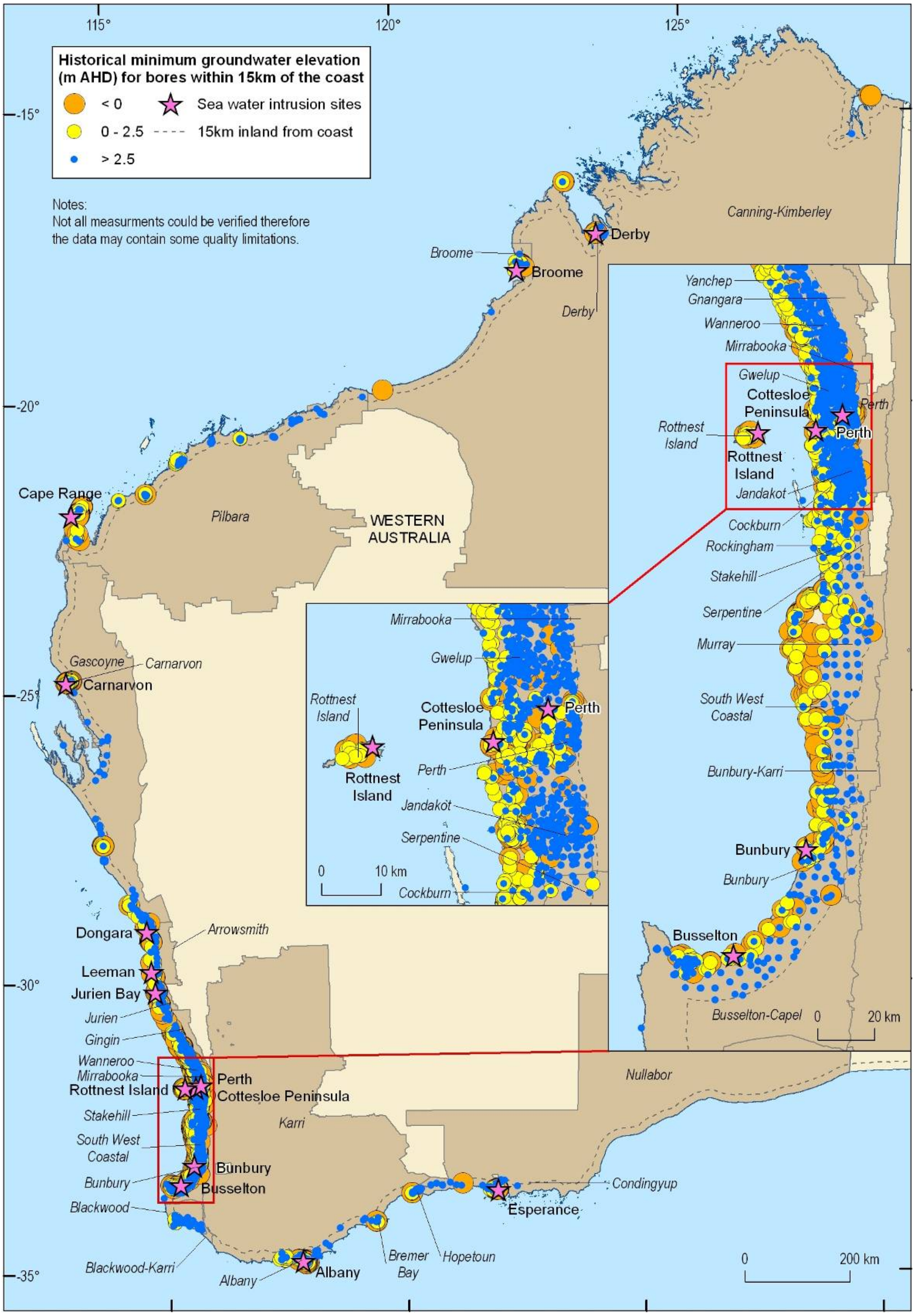


Figure 14 *Historical minimum groundwater levels measured prior to 2000,WA.*

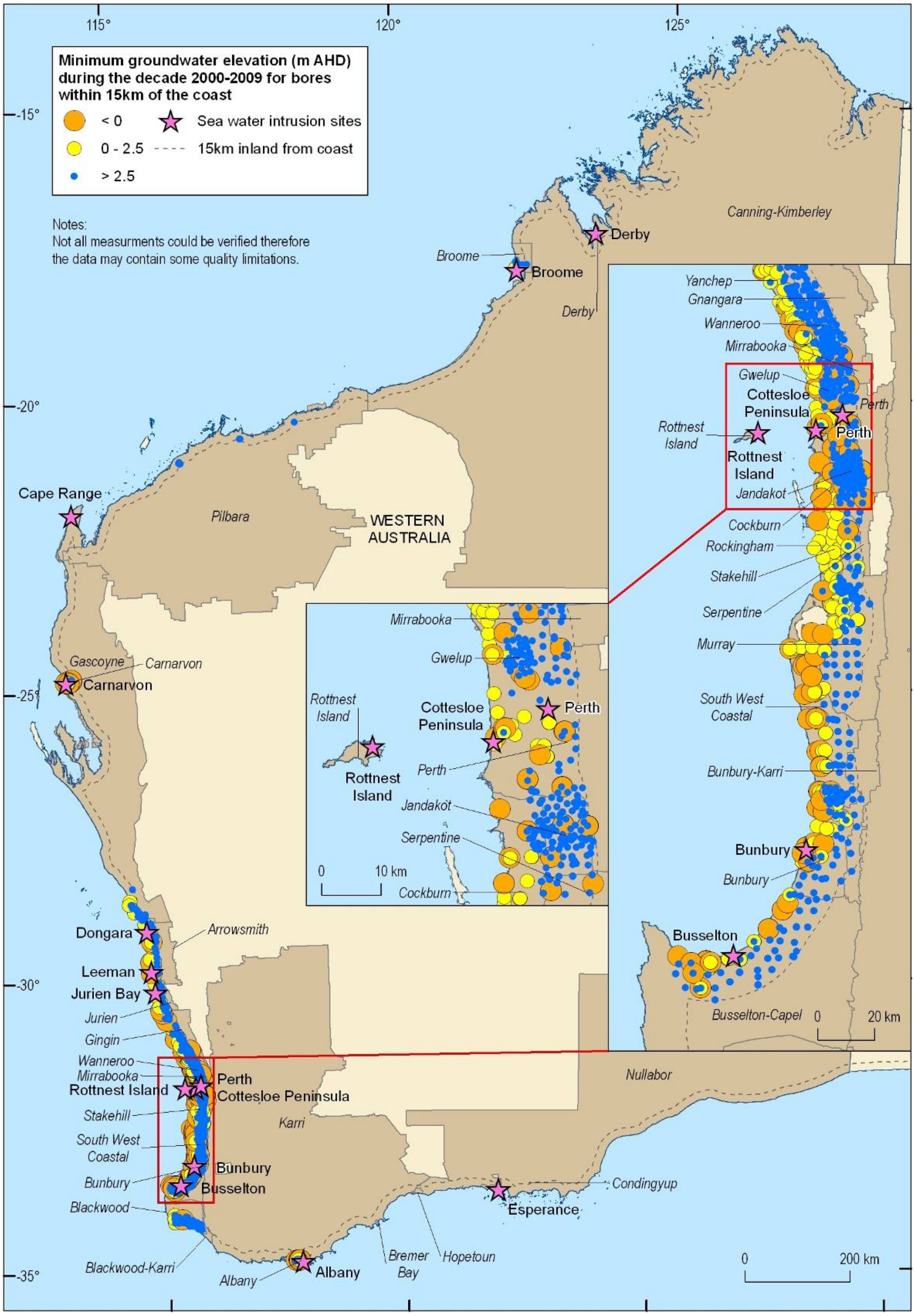


Figure 15 *Minimum groundwater levels measured in the period 2000-2009, WA.*

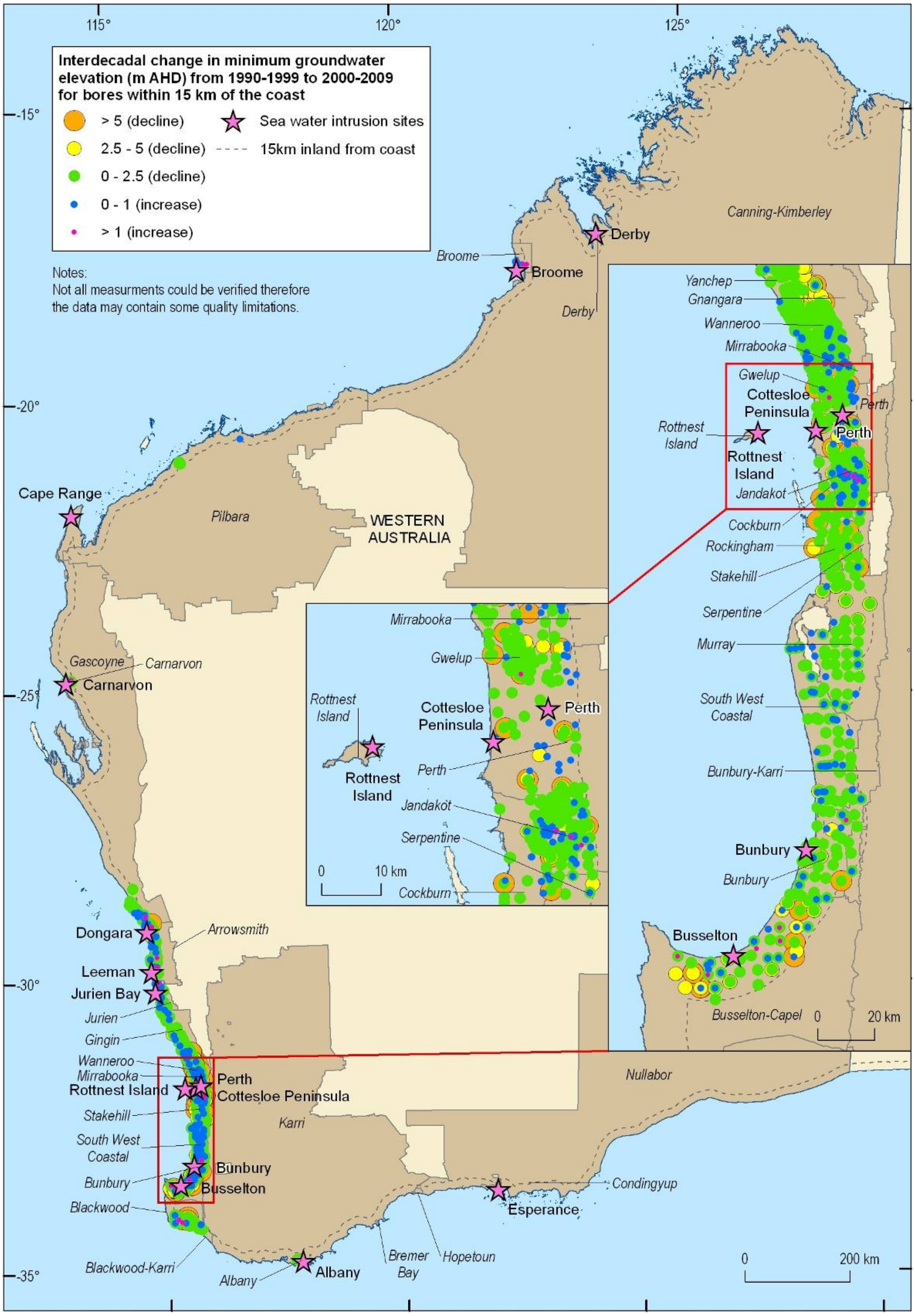


Figure 16 *Inter-decadal changes in minimum groundwater levels from 1990-1999 to 2000-2009, WA.*

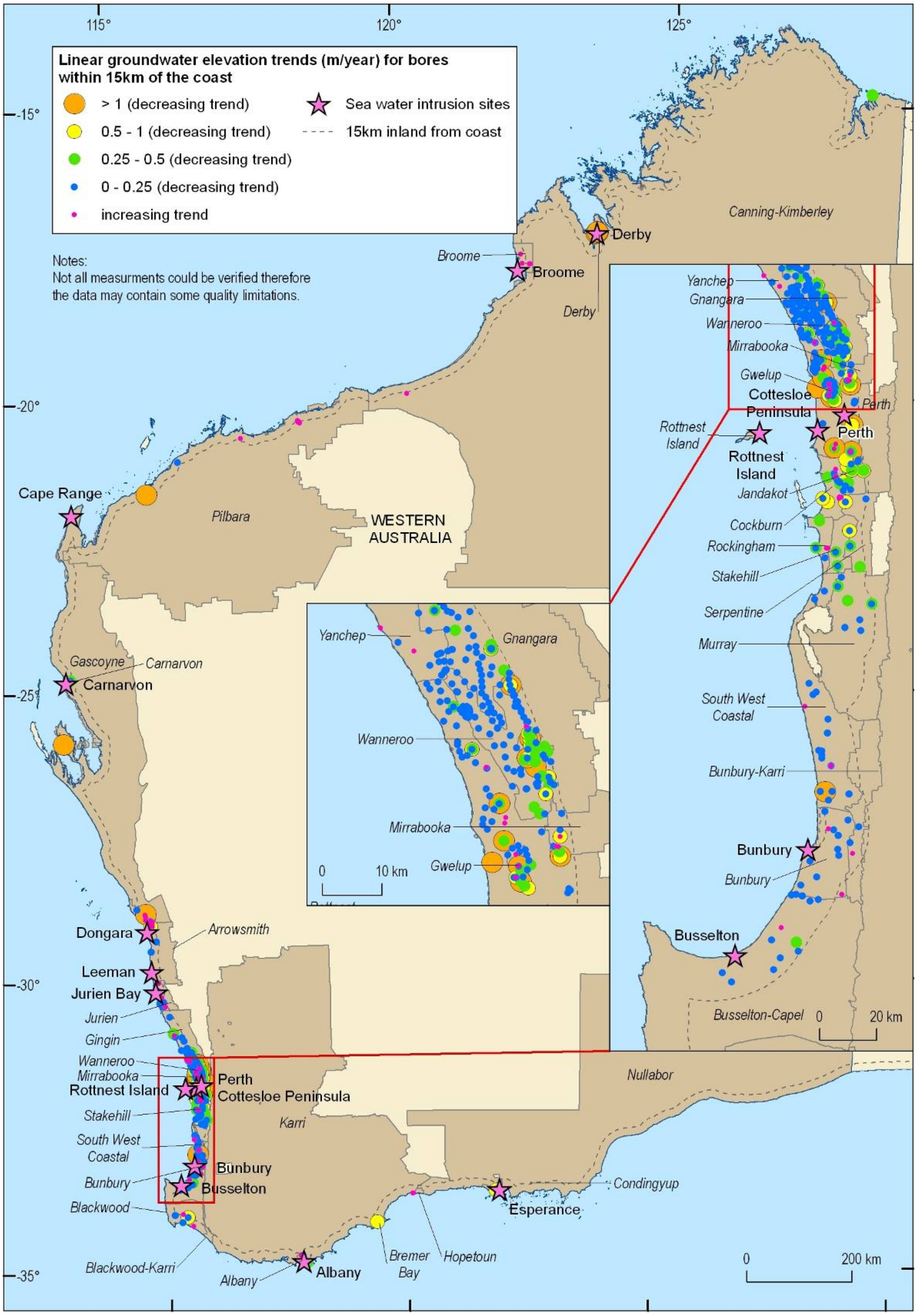


***Figure 17** Linear groundwater level trends in WA.*

5.1.3. Summary of groundwater level SWI vulnerability indicators

Figure 18 shows the high SWI vulnerability indicator categories for each of the groundwater level parameters presented in Section 5.1 above. It is apparent on the figure that the Swan Coastal Plain in Perth and surrounds contains a relatively high number and density of boreholes showing low minimum groundwater levels, large inter-decadal declines in groundwater levels and high decreasing trends in groundwater levels. The southern parts of the Swan Coastal Plain between Busselton and Bunbury also contain a range of high category SWI vulnerability indicators. Collectively these groundwater level parameters suggest that these areas may have high vulnerability to SWI and further detailed consideration is warranted. However, it is noted that the presence of fewer or no SWI vulnerability indicators in other areas may reflect a lack of data and high vulnerability in these areas cannot be ruled out.

5.1.4. Spatial distribution of low groundwater level observations

The maximum distances that groundwater levels <0m AHD and <2.5 m AHD extend inland from the coast are presented for each GMA in Table 7. The data shown are based on minimum groundwater levels measured in boreholes over the decade 2000-2009. SWI may be anticipated to extend further inland in areas where low groundwater levels extend further from the coast. Minimum groundwater levels <0 m AHD were measured further inland than 14 km in both the Serpentine and Jandakot GMAs on the Swan Coastal Plain near Perth. Several other GMAs recorded minimum groundwater levels <0 m AHD over 10 km from the coast including Busselton-Capel, Carnarvon, Gascoyne, Mirrabooka, Perth, Rockingham, and Wannaroo. Although whether SWI occurs in these areas is dependent on many other factors in addition to groundwater levels, if SWI does occur in these areas groundwater level distributions may be such that SWI could extend a considerable distance inland if not appropriately managed.

The boundaries of some GMAs do not extend far inland from the coast thus Table 7 should be considered in conjunction with Figure 13 if assessing potential impacts to individual GMAs rather than total distance from the coast.

It is noted that the discussion above does not take into account all water levels in the GMAs, and if higher water levels are present between the coast and low water levels further inland (i.e. low water levels are localised), SWI may not be hydraulically possible. Minimum water levels for the entire monitoring period (historic and recent) in each monitoring bore are plotted against distance from the coast in Appendix 2 for each GMA. As anticipated, the plots indicate that water levels typically increase away from the coast. In some GMAs such as Perth, many low water levels have been recorded extending relatively far inland from the coast suggesting that, if SWI were to occur here, groundwater levels may facilitate extensive impacts. In contrast, GMAs such as Hopetoun show a more marked increase in groundwater levels with distance from the coast suggesting that impacts would be more likely to be confined to more coastal areas if SWI was to occur there.

5.2. Rainfall Trend Analysis

Plots of cumulative deviation of monthly rainfall data from long term averages are included in Appendix 3 for locations near the SWI sites and summarised for WA on Figure 19 for the period 2000-2009. Figure 19 shows that although rainfall generally increased near Derby and Broome in the northwest, much of WA experienced declining rainfall trends over the period 2000-2009. Although additional groundwater pressures may be anticipated where rainfall has decreased, it is emphasised that drought around the country has eased in 2010 and 2011, and a reversal in rainfall trends is evident in some areas. As such, the rainfall trends on Figure 19 may not remain good indicators of vulnerability and should be updated in future assessments.

***Table 7** Maximum inland extent within 15 km of the coast of minimum groundwater levels <0 m AHD and <2.5 m AHD based on 2000-2009 monitoring data reported for WA GMAs*

GMA	Maximum Inland Distance of <0 m AHD Groundwater Levels (km)	Maximum Inland Distance <2.5 m AHD Groundwater Levels (km)
Albany	2.99	4.29*
Arrowsmith	3.91	7.31
Blackwood	7.45	11.78
Blackwood-Karri	No elevation data	No elevation data
Bremer Bay	No elevation data	No elevation data
Broome	All levels > 0m AHD	1.37
Bunbury	3.05	7.90
Bunbury-Karri	All levels > 0m AHD	All levels > 2.5m AHD
Busselton-Capel	10.68	10.70
Canning-Kimberley	No elevation data	No elevation data
Carnarvon	12.68	13.00*
Cockburn	4.36	6.67
Condingyup	No elevation data	No elevation data
Derby	No elevation data	No elevation data
Esperance	No elevation data	No elevation data
Gascoyne	13.19	13.19
Gingin	1.46	14.28
Gnangara	All levels > 0m AHD	6.39
Gwelup	5.60	5.60
Hopetoun	No elevation data	No elevation data
Jandakot	14.53*	14.53*
Jurien	All levels > 0m AHD	6.25
Karri	No elevation data	No elevation data
Mirrabooka	12.74	12.74
Murray	3.10	9.70
Nullabor	No elevation data	No elevation data
Perth	12.63	12.63
Pilbara	All levels > 0m AHD	All levels > 2.5m AHD

GMA	Maximum Inland Distance of <0 m AHD Groundwater Levels (km)	Maximum Inland Distance <2.5 m AHD Groundwater Levels (km)
Rockingham	4.29*	2.24
Rottnest Island	No elevation data	No elevation data
Serpentine	14.59*	14.59*
South West Coastal	5.41	6.72
Stakehill	10.93	10.93
Wanneroo	12.74	12.74
Yanchep	1.02	5.07
OTHER (non GMA)	1.73*	1.73*

*Furthest inland water level measurement. Low water levels may extend further inland.

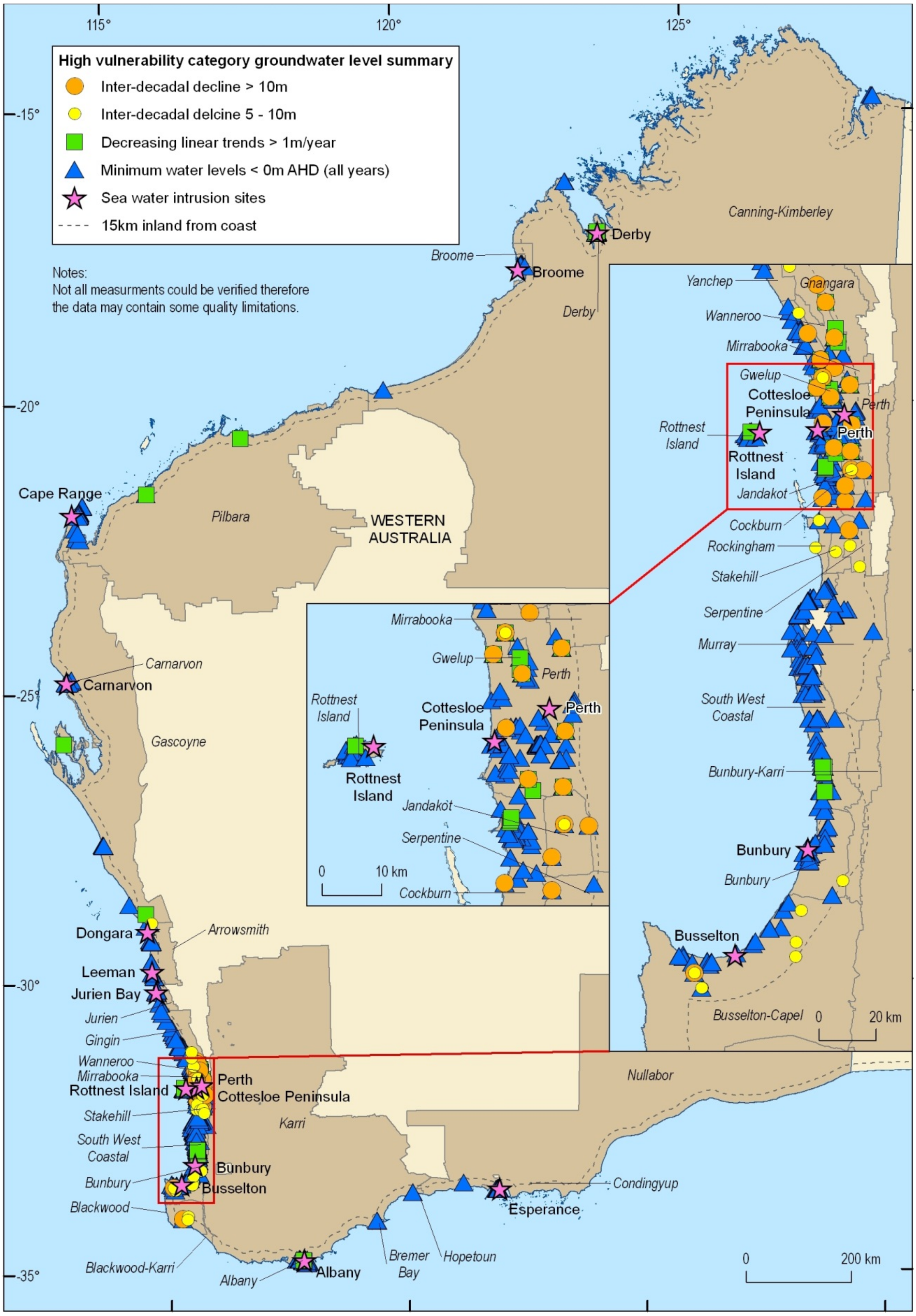


__Figure 18__ Summary of groundwater level indicators of high SWI vulnerability, WA.

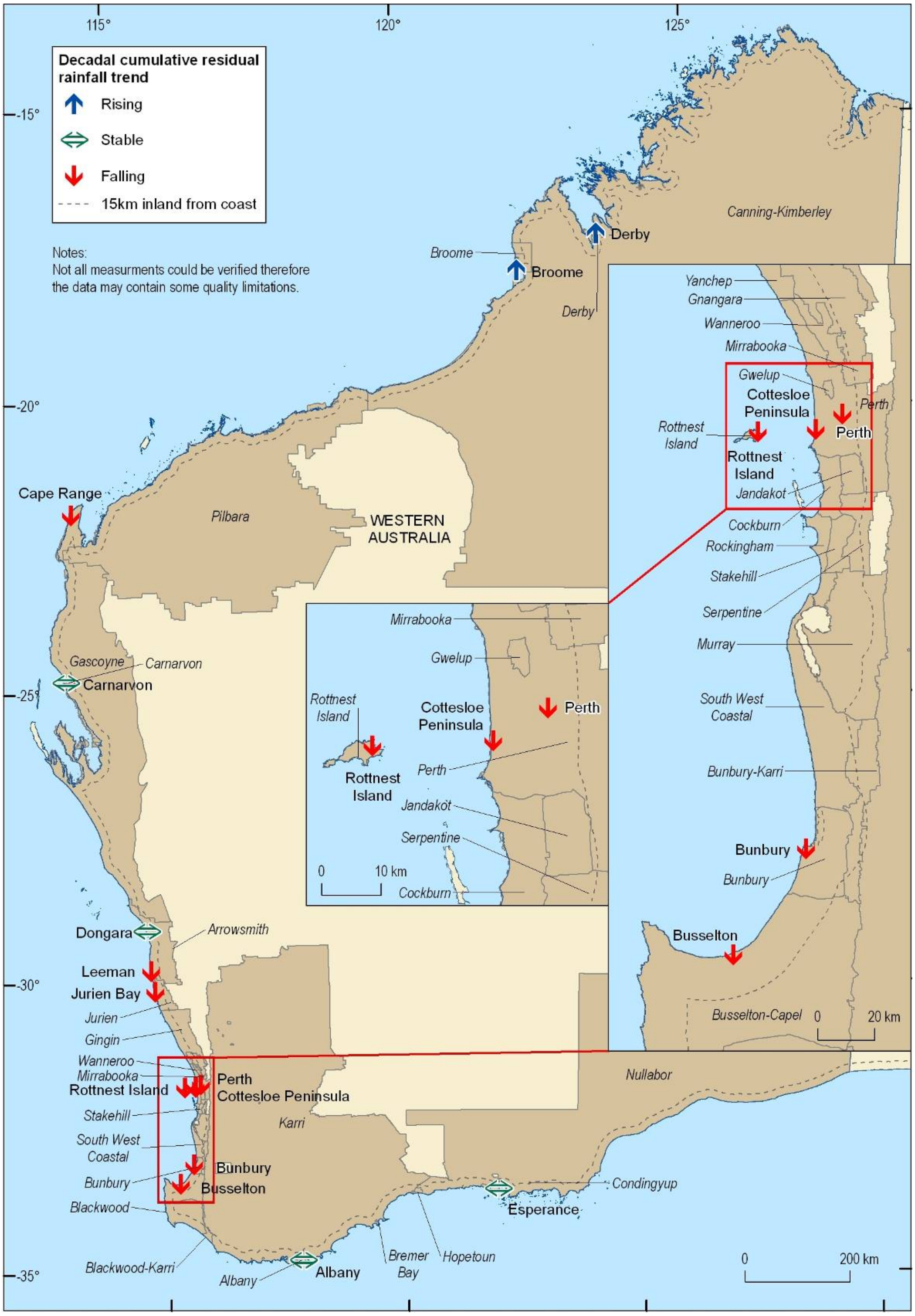


Figure 19 *Trends in cumulative deviation of monthly rainfall from long term averages for the period 2000-2009, WA.*

5.3. Groundwater Salinity

5.3.1. Maximum salinity measurements

Groundwater salinity data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data to highlight areas that have recently shown groundwater salinity indicators of SWI vulnerability. However, the lack of recent vulnerability indicators cannot be used to infer a reversal in vulnerability trends in many areas since they may in part be due to a lack of recent data. When making such an assessment, Figure 20 and Figure 21 should be considered together.

5.3.1.1. Historical maximum salinity measurements

Historical maximum TDS concentrations are shown on Figure 20. Groundwater with TDS concentrations <3000 mg/L has been identified in many places in WA. Such groundwater is suitable for a wide range of uses and represents an important resource. The Swan Coastal Plain shows a particularly high number of low TDS concentrations relative to high TDS concentrations. Areas where groundwater with maximum TDS concentrations <3000 mg/L is located near groundwater with maximum TDS concentrations >10,000 mg/L are also of interest since they suggest that without appropriate management, pumping of low salinity groundwater may induce intrusion of high salinity water.

5.3.1.2. Maximum salinity measurements, 2000-2009

Maximum TDS concentrations measured during the period 2000-2009 are shown on Figure 21. Although the data show a similar spatial distribution to the historic measurements, a smaller proportion of lower salinity groundwater measurements appear to have been recorded over the recent decade. It is difficult to assess the significance of such changes since they are likely to be influenced by the number and location of monitoring points between the different time periods. Section 5.3.2 provides a more appropriate assessment of inter-decadal changes in salinity measurements.

5.3.2. Inter-decadal changes in maximum salinity measurements

Changes in maximum TDS concentrations between the decades 1990-1999 and 2000-2009 are shown on Figure 22. It is apparent that the majority of locations where data are available in WA experienced a decrease or only a slight increase in maximum salinity measurements over this time. Notable exceptions included Exmouth, Carnarvon and parts of the Swan Coastal Plain including the Perth and Southwest Coastal GMAs.

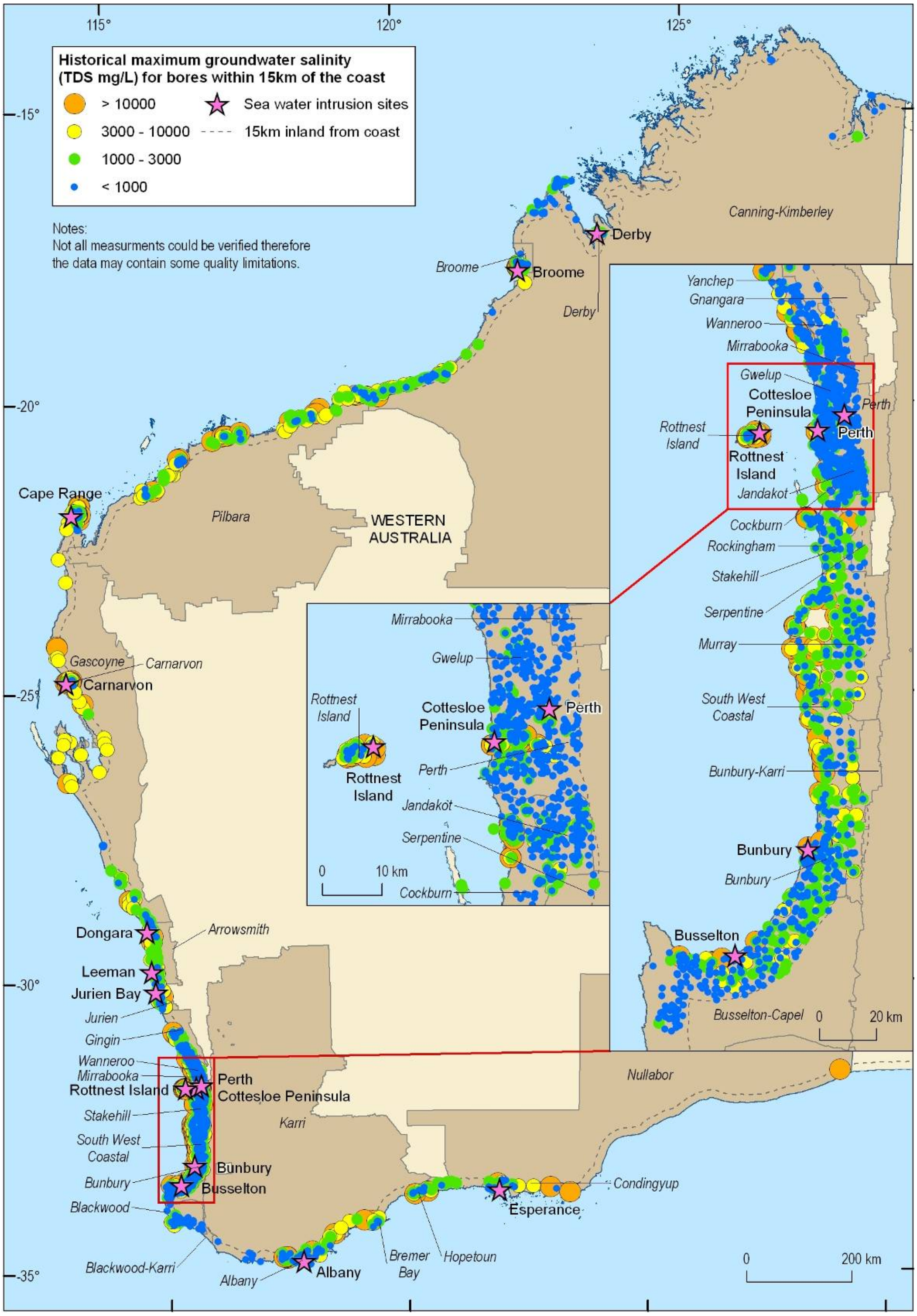


Figure 20 *Historical maximum TDS concentrations measured prior to 2000, WA.*

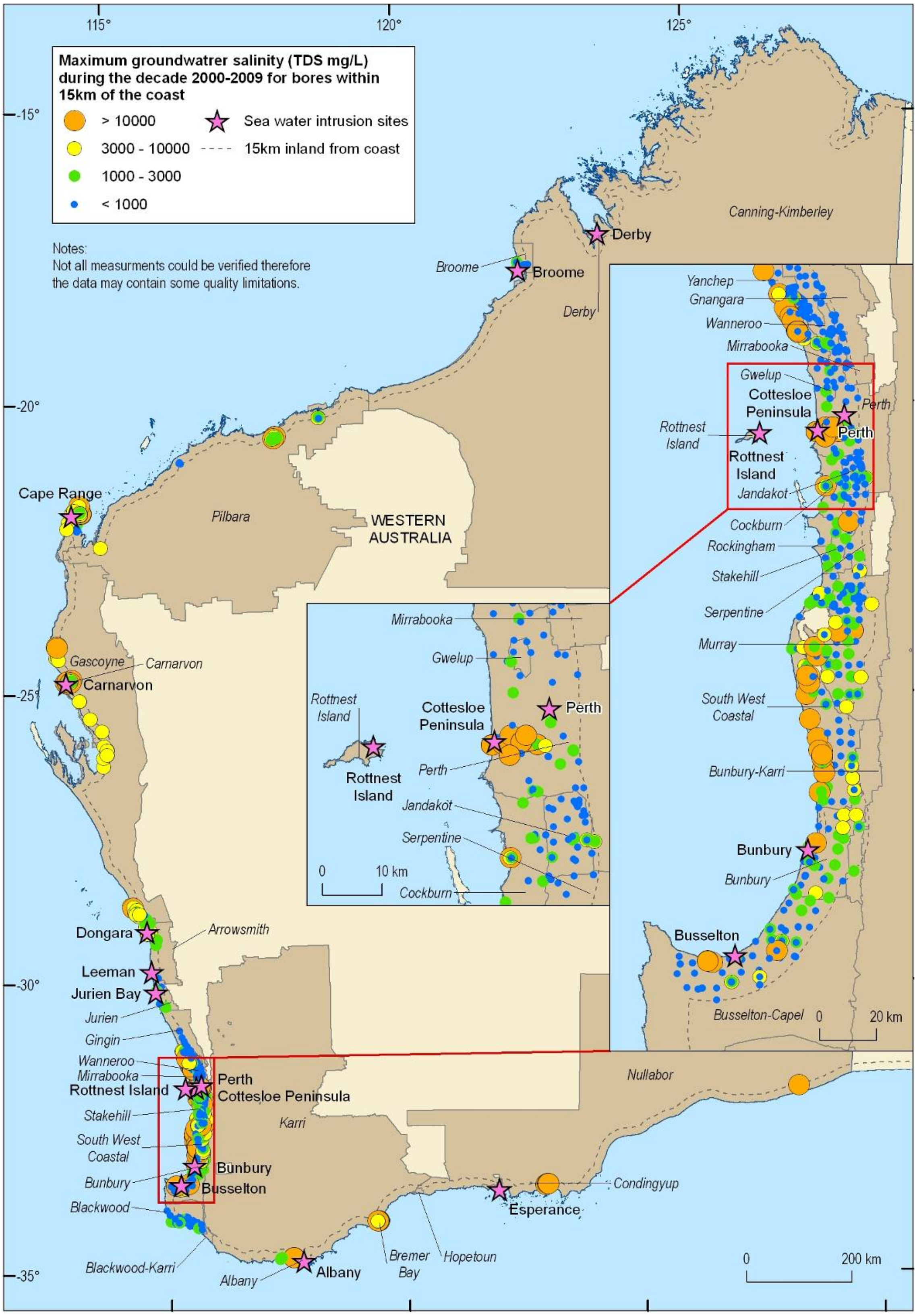


Figure 21 *Maximum TDS concentrations for the period 2000-2009, WA.*

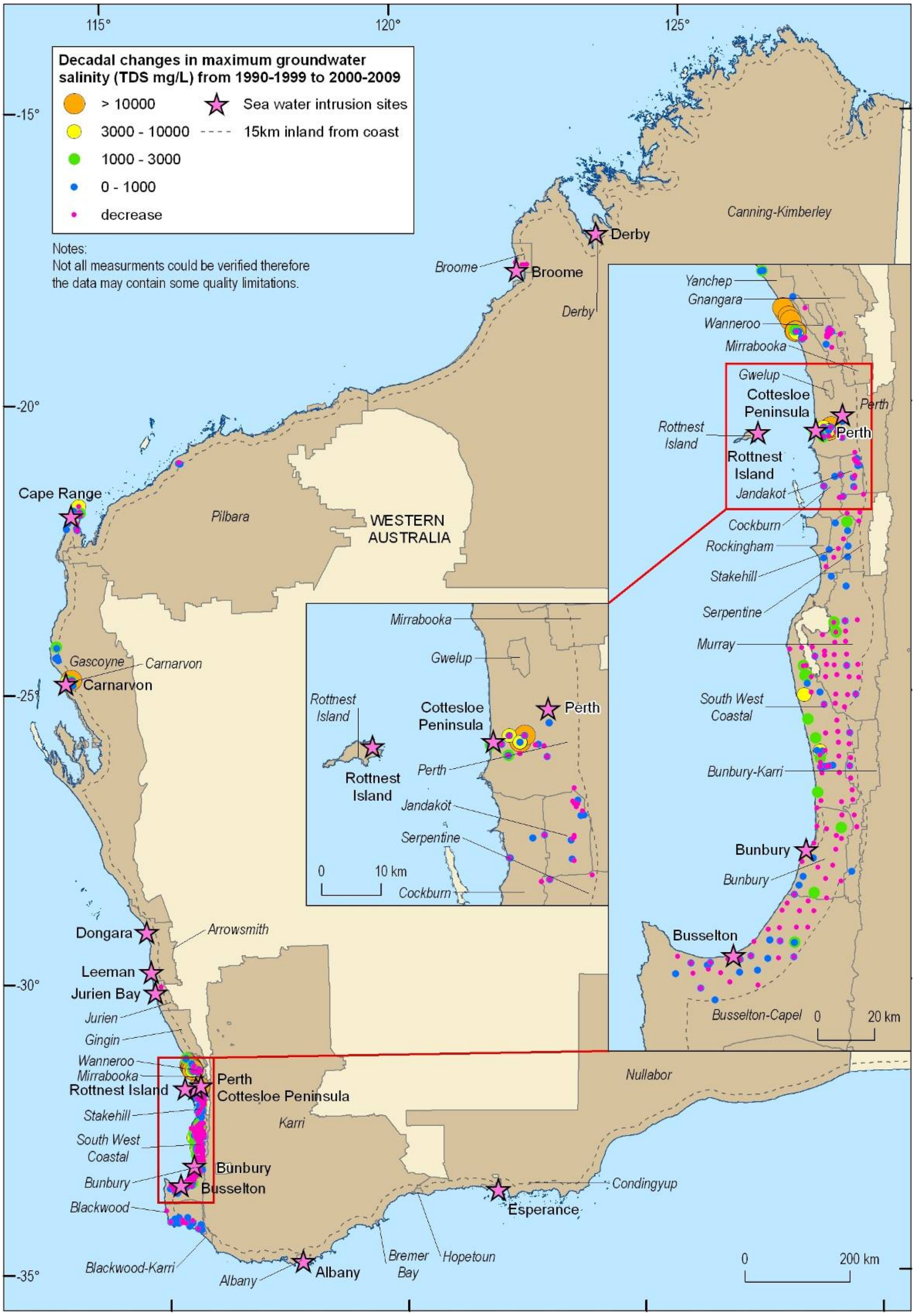


Figure 22 *Inter-decadal change in maximum TDS concentrations from 1990-1999 to 2000-2009, WA.*

5.4. Groundwater Extraction

5.4.1. Distribution of production bores

Production bore locations and groundwater extraction data were provided by relevant water agencies in WA. Production bore locations are presented on Figure 23 (private stock and domestic supply bores are not included). It is apparent from the figure that the majority of groundwater production bores are located in the central and southern parts of the Swan Coastal Plain.

5.4.2. Groundwater extraction rates

Figure 24 presents the recorded groundwater extraction rates in coastal WA for the 2010-2011 financial year. As outlined in Section 3.4.3, in the context of SWI it is difficult to attach significance to extraction rates in the absence of recharge data. The information presented is best considered at a site specific level in conjunction with other available information. Figure 24 indicates that relatively high extraction rates are associated with production bores near Dongara and on the Swan Coastal Plain in the Perth and Bunbury areas.

5.4.3. Cumulative groundwater extraction rates by area

Figure 25 presents cumulative groundwater extraction rates in 5 x 5 km grid cells in coastal WA based on Figure 24 data. The final category that each cell falls into is somewhat dependent on where the grid is positioned, but in general the information shows that in addition to those areas with high individual bore extraction rates listed above, Albany and Broome have relatively high cumulative extraction rates.

5.4.4. Groundwater extraction rates by GMA

Figure 26 summarises groundwater extraction rates within 15 km of the coast within GMAs from 2001-2011. Although highest in 2010-2011, the figure shows that groundwater extraction has remained relatively stable since 2006. The addition of 17 GMAs in 2006 (to a total of 24) saw the total WA extraction volume increase by approximately 30 GL/yr due to the inclusion of previously unaccounted areas.

Extraction volumes for those portions of the GMAs within 15 km of the coast for the 2010-2011 financial year are presented in Table 9 where they are compared to the sustainable yield estimates for the GMUs in AWR (2006). The AWR (2006) GMUs do not directly correspond to the WA GMAs in all instances thus care in interpretation is required (further details are included in Table 9).

Table 9 shows the percentage of AWR (2006) extraction for 2004-2005 relative to sustainable yield. Where extraction rates are high relative to sustainable yield, impacts on groundwater levels may occur resulting in SWI. Although this data is several years old, it provides an indication of which GMAs may be stressed. Extraction at 50% of sustainable yield is taken to be a reasonable distinction between relatively low extraction rates and relatively high extraction rates. Of the GMAs for which data are available, Albany, Bremer Bay, Bunbury, Busselton-Capel, Carnarvon, Cockburn, Hopetoun, Jandakot, Mirrabooka, Perth, Pilbara, Wannaroo and Yanchep had extraction rates exceeding 50% of estimated sustainable yield for 2004-2005. Although it is acknowledged that sustainable yield estimates and extraction rates may change over time, further investigation and detailed management of these areas would be prudent.

The above discussion does not take into account the spatial distribution of groundwater extraction in each GMA. Where a high proportion of extraction relative to sustainable yield occurs close to the coast, SWI may occur in shorter timeframes. Table 9 includes the proportion of extraction in each GMA from 2010-2011 within 15 km of the coast relative to the AWR (2006) sustainable yield data for the entire GMU. It indicates that several GMAs have extraction rates within 15 km of the coast that exceed 50% of estimated sustainable yield for the entire GMA, including Albany, Hopetoun and Jandakot. The figures suggest that these GMAs may be particularly susceptible to SWI (noting that those GMAs with a high proportion of their areas within 15 km of the coast are more likely to show higher values). However, groundwater levels near the coast depend on local extraction and recharge conditions that may be unrelated to sustainable yield for the entire GMA and therefore many of the other GMAs in Table 9 may also be at risk on the basis of this analysis. Such detailed consideration is beyond the scope of the VFA which offers a broad scale assessment of available data. The requirement for further site specific investigation is emphasised.

5.5. VFA Summary: Western Australia

As outlined in the national analysis in Section 4, a single VFA indicator of high vulnerability in an area may correspond to an area with high SWI vulnerability and some high SWI vulnerability areas may have no data or high category indicators at all. However, it is useful to identify locations where numerous high vulnerability indicators are present as a guide to prioritising areas for further investigation and management if groundwater resources are to be developed or groundwater use is to continue.

Under the state and territory analyses, the following seven categories of VFA parameters were considered to indicate that areas may have high SWI vulnerability (other VFA parameters were not included for reasons outlined in the national VFA discussion):

1. Historic minimum groundwater levels <0 m AHD, pre 2000;
2. Minimum groundwater levels <0 m AHD, 2000-2009;
3. Inter-decadal decline in groundwater levels >2.5 m between 1990-1999 and 2000-2009;
4. Declining groundwater elevation trends >0.5 m/year;
5. Historic maximum TDS concentrations >10,000 mg/L located within 1 km of maximum TDS concentrations <3000 mg/L, pre 2000;
6. Maximum TDS concentrations >10,000 mg/L located within 1 km of maximum TDS concentrations <3000 mg/L, 2000-2009; and
7. Inter-decadal increase in maximum TDS concentrations >1000 mg/L between 1990-1999 and 2000-2009.

The VFA findings for WA are summarised in Table 9 for each GMA. Locations showing greater than 50 per cent (4 or more) of the above category indicators and at least one indicator from both groundwater level (any of the indicators listed in points 1 to 4 above) and salinity (any of the indicators listed in points 5 to 7 above) categories are considered to show a particularly high proportion and range of VFA indicators. Such GMAs are termed “state VFA priority GMAs” and include: Arrowsmith, Bunbury, Busselton-Capel, Carnarvon, Cockburn, Gascoyne, Gingin, Murray, Perth, Stakehill, Southwest Coastal and Yanchep.

It is reiterated that there are other areas in WA showing indicators of high SWI vulnerability and a lack of data in many areas. Omission of locations from the above list should not be taken to imply that they are not highly vulnerable to SWI. The list simply highlights locations where considerable numbers of high SWI vulnerability indicators are present where data are available. Some GMAs cover large areas compared to others thus reporting at the GMA level is somewhat inconsistent. The data presented above should be considered on a case by case basis at a scale commensurate with the area of interest.

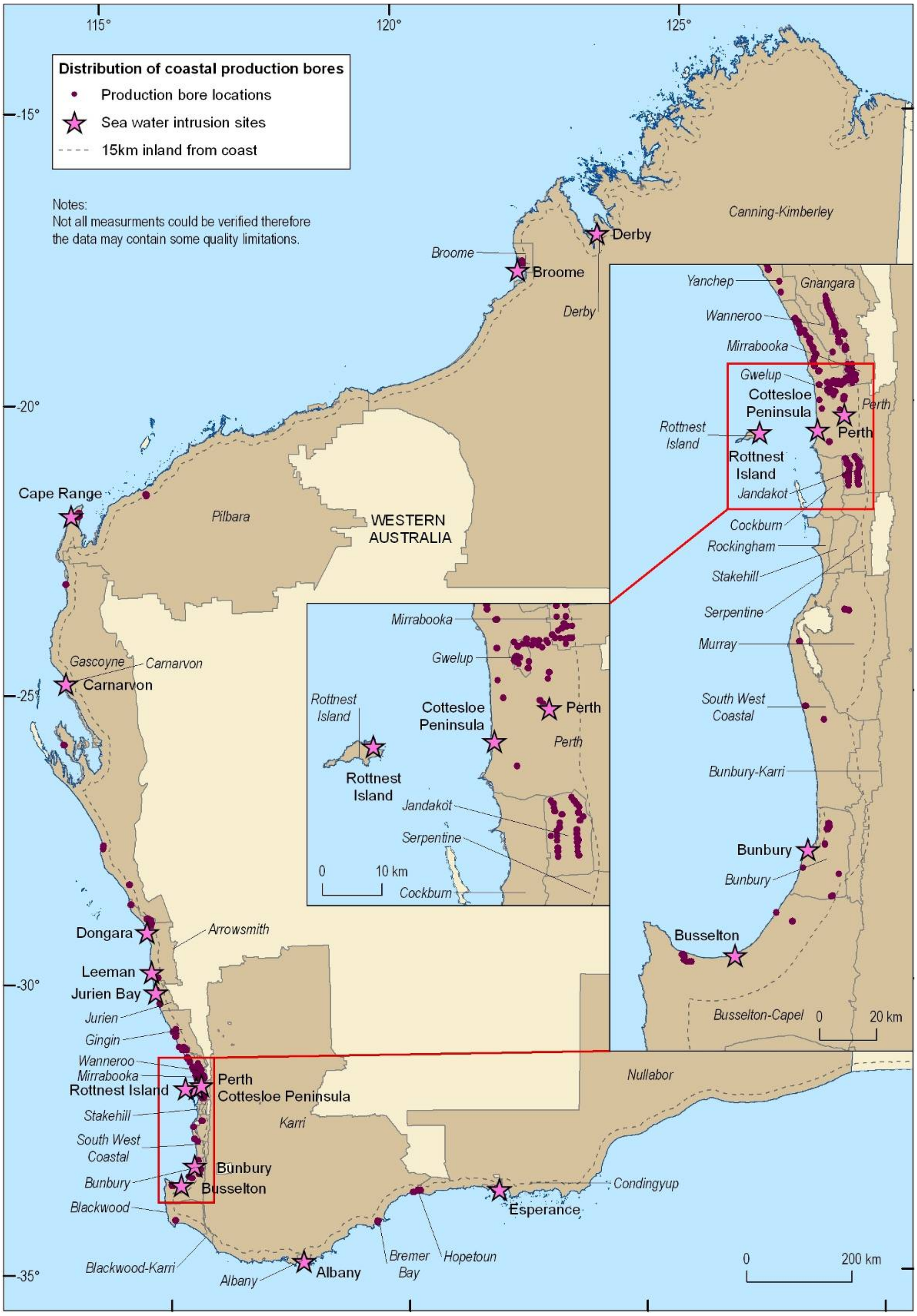


***Figure 23** Distribution of recorded production bores, WA.*

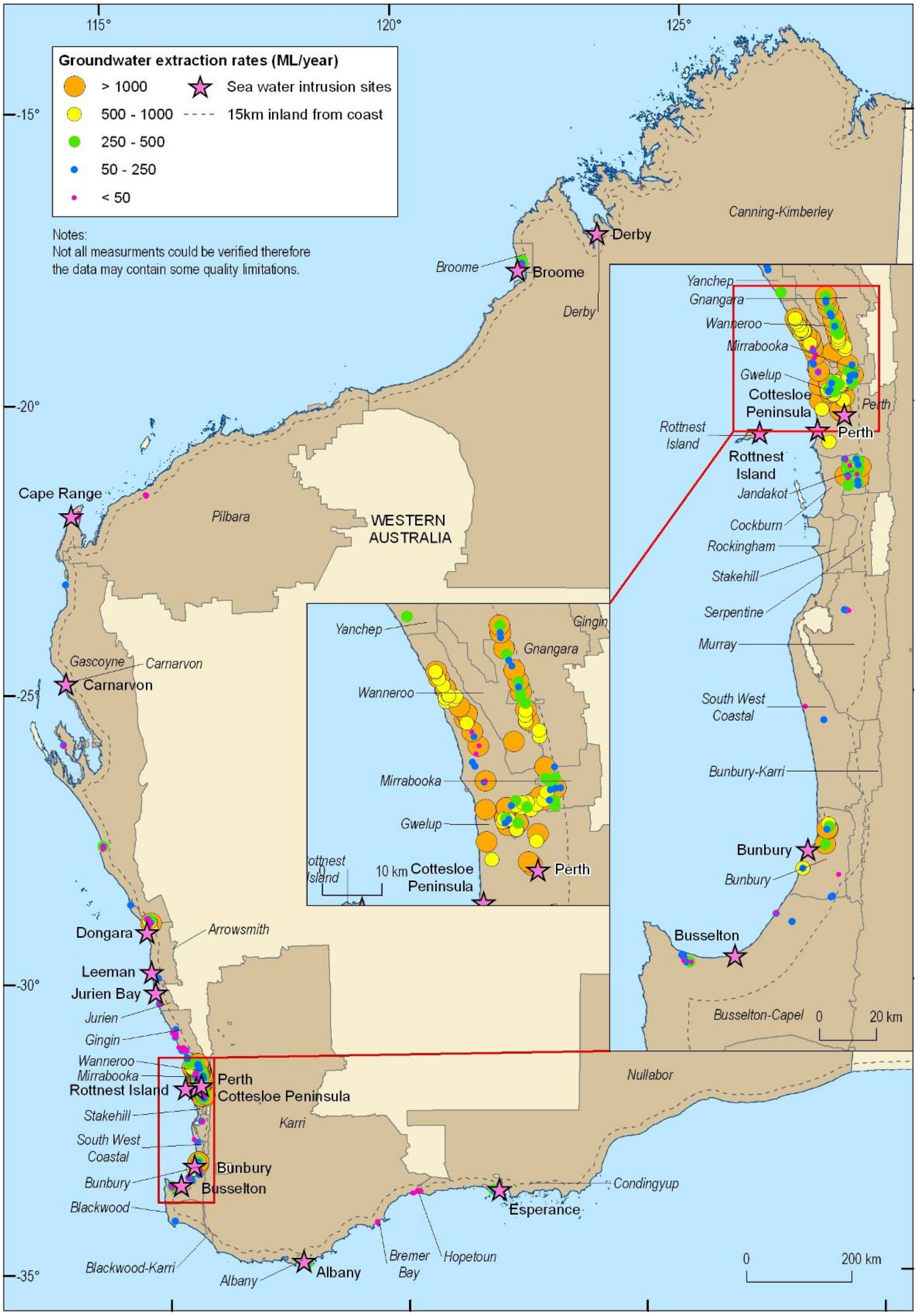


Figure 24 *Groundwater extraction rates for the 2010/11 financial year, WA (source: WA Water Corporation).*

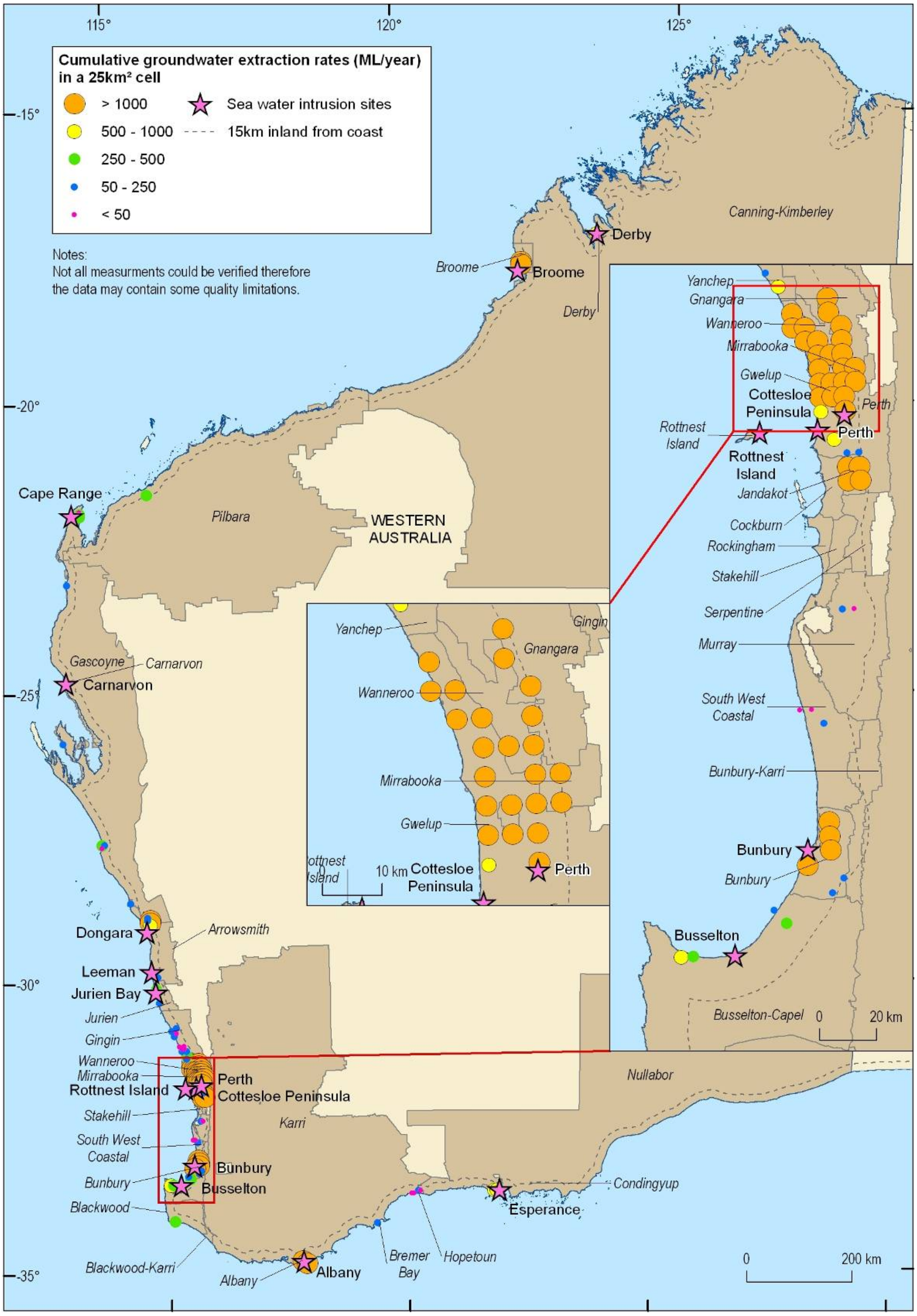


Figure 25 *Cumulative groundwater extraction rates within 5x5 km grid cells, WA.*

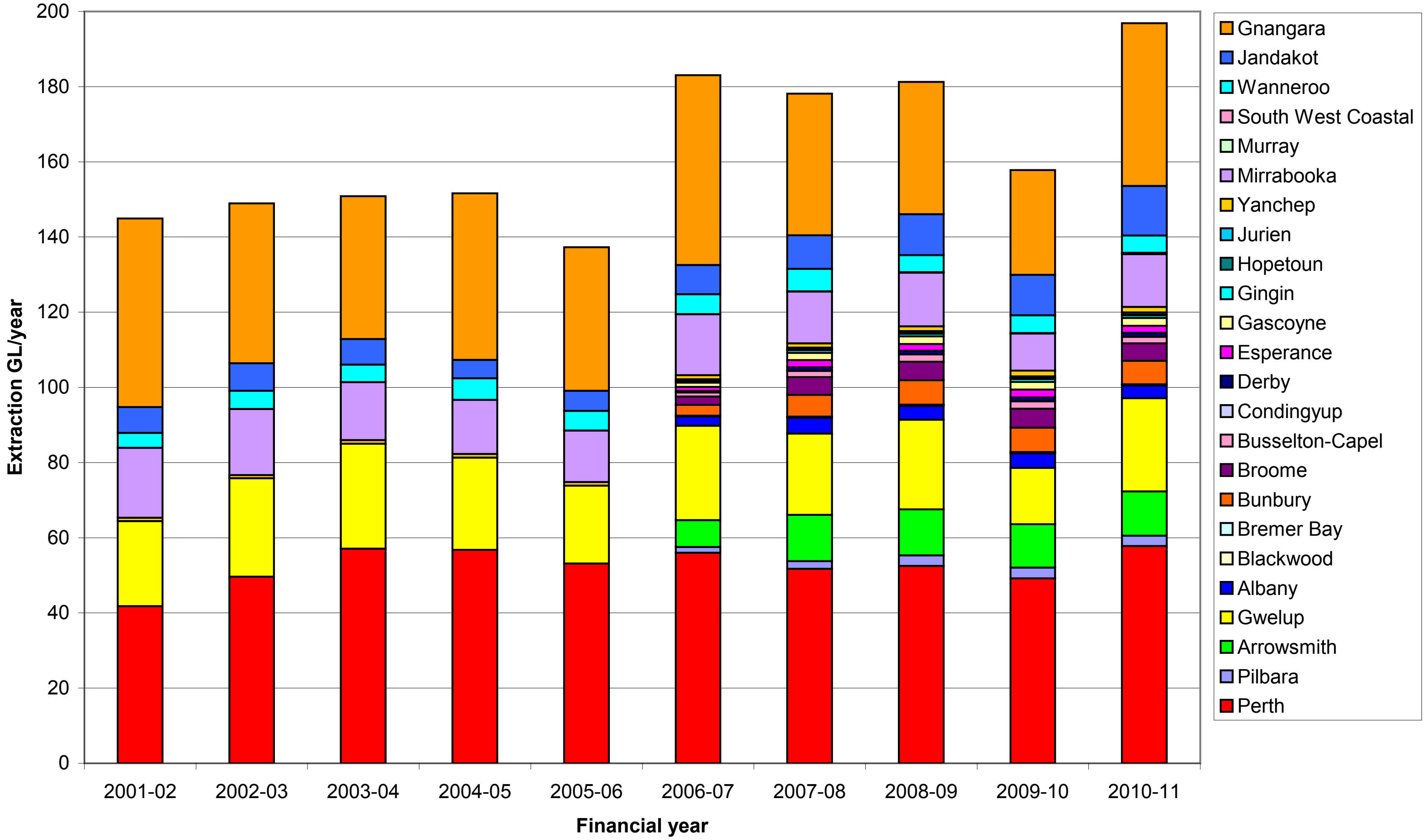


***Figure 26** Annual groundwater extraction (GL/year) within 15 km of the coast in each GMA for WA (source: WA Water Corporation)*

Table 8 *Summary of extraction and sustainable yield (SY) data, WA*

GMA	AWR 2005 2004-2005 Extraction† (ML/yr)	AWR 2005 SY† (ML/yr)	2010-2011 Extraction within 15 km of coast (ML/yr)	AWR 2005 Groundwater use relative to SY	2010-2011 Extraction within 15 km relative to SY
Albany	5036	4210	3386.05	120%	80%
Arrowsmith**	50194	183700	4802.04	27%	3%
Blackwood	13491	27510	263.95	49%	1%
Blackwood-Karri***	-	-	-	-	-
Bremer Bay	142	240	56.94	59%	24%
Broome	7916	56659	4665.45	14%	8%
Bunbury	33787	54600	6214.59	62%	11%
Bunbury-Karri***	-	-	-	-	-
Busselton-Capel	73844	131850	1748.12	56%	1%
Canning-Kimberley	52659	358758	-	15%	-
Carnarvon	10612	11100	-	96%	-
Cockburn	37736	45340	-	83%	-
Condingyup	20	70	-	29%	-
Derby	2537	6169	1053.7	41%	17%
Esperance**	2186	7870	1825.97	28%	23%
Gascoyne**	31872	138360	1482.72	23%	1%
Gingin**	130115	338570	741.63	38%	0%
Gnangara	27000	61755	25014.28	44%	41%
Gwelup	-	-^	24773.34	-	-
Hopetoun	140	260	185.72	54%	71%
Jandakot	20848	25440	13195.76	82%	52%
Jurien**	14496	90100	528.38	16%	1%
Karri	165	-	-	-	-
Mirrabooka*	27024	34660	12021.35	78%	35%
Murray	9517	69970	246.84	14%	0%
Nullabor**	-	-	-	-	-
Perth	167430	160155	57837.5	105%	36%
Pilbara**	236894	334930	261.05	71%	0%
Rockingham*	19667	42732	-	46%	-
Rottnest Island	5272	35500	-	15%	-

GMA	AWR 2005 2004-2005 Extraction† (ML/yr)	AWR 2005 SY† (ML/yr)	2010-2011 Extraction within 15 km of coast (ML/yr)	AWR 2005 Groundwater use relative to SY	2010-2011 Extraction within 15 km relative to SY
Serpentine**	15893	50290	-	32%	-
South West Coastal**	30055	72320	108.67	42%	0%
Stakehill***	-	-	-	-	-
Wanneroo	40523	40950	4575.45	99%	11%
Yanchep	2143	11270	1469.74	19%	13%

†Source: AWR (2006) for GMUs, noting that the GMU boundaries differ from GMA boundaries as indicated.

*Source: available extraction data from WA water corporations.

**GMA boundary supplied by WA water corporations differs substantially from GMU in AWR (2006).

***GMA not listed in AWR (2006).

^Gwelup SY in AWR (2006) is reported to be 245 ML/year. This value is not consistent with state data and the National Land and Water Resources Audit (NLWRA) 2000-02 and is not included in the analysis above.

- = no data

*__Table 9__ Summary of VFA indicators by GMA for Western Australia (State VFA Priority GMAs are indicated by *)*

GMA	SWI Sites	Groundwater Levels				Groundwater Salinity (TDS Concentration in mg/L)		
		Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS <3000 within 1 km >10,000		TDS conc. changes
		2000-2009	Pre 2000	Inter-decadal decline >2.5 m	Declining trend >0.5 m/yr	Pre 2000	2000-2009	Inter-decadal increase >1000
Albany	Albany	Y	Y	N	N	N	N	-
*Arrowsmith	Dongara, Leeman	Y	Y	Y	Y	Y	N	-
Blackwood	-	Y	N	Y	Y	N	N	N
Blackwood-Karri	-	-	-	-	-	-	-	-
Bremer Bay	-	-	Y	-	Y	N	-	-
Broome	Broome	N	Y	N	N	Y	N	N
*Bunbury	Bunbury	Y	Y	Y	N	Y	N	Y
Bunbury-Karri	-	Y	N	N	N	N	N	N
*Busselton-Capel	Busselton	Y	Y	Y	N	Y	Y	Y
Canning-Kimberley	-	-	Y	-	Y	N	-	-
*Carnarvon	Carnarvon	Y	Y	N	N	Y	Y	Y
*Cockburn	-	Y	Y	Y	Y	Y	N	N
Condingyup	-	-	-	-		-	-	-
Derby	Derby	-	Y	-	Y	N	-	-
Esperance	Esperance	-	Y	-	Y	Y	-	N
*Gascoyne	Cape Range	Y	Y	N	Y	Y	Y	Y
*Gingin	-	Y	Y	Y	N	Y	N	-

GMA	SWI Sites	Groundwater Levels				Groundwater Salinity (TDS Concentration in mg/L)		
		Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS <3000 within 1 km >10,000		TDS conc. changes
		2000-2009	Pre 2000	Inter-decadal decline >2.5 m	Declining trend >0.5 m/yr	Pre 2000	2000-2009	Inter-decadal increase >1000
Gnangara	-	N	N	Y	Y	N	N	N
Gwelup	-	Y	Y	Y	Y	N	N	-
Hopetoun	-	-	Y	-	N	N	-	-
Jandakot	-	Y	Y	Y	Y	N	N	N
Jurien	Jurien Bay	N	Y	N	N	N	N	N
Karri	-	-	Y	-	N	N	Y	-
Mirrabooka	-	Y	Y	Y	Y	N	N	-
*Murray	-	Y	Y	Y	N	Y	Y	Y
Nullabor	-	-	Y	-	-	N	N	-
*Perth	Cottesloe Peninsula, Perth	Y	Y	Y	Y	Y	Y	Y
Pilbara	-	N	Y	N	Y	Y	Y	N
Rockingham	-	Y	N	Y	N	Y	N	N
Rottnest Island	Rottnest Island	-	Y	-	-	Y	-	-
Serpentine	-	Y	Y	Y	Y	N	N	N
*South West Coastal	-	Y	Y	Y	Y	Y	Y	Y
*Stakehill	-	Y	Y	Y	Y	N	N	Y
Wanneroo	-	Y	Y	Y	Y	N	N	N
*Yanchep	-	Y	Y	N	N	Y	Y	Y

6. Vulnerability Factor Analysis Results: Northern Territory

There are three GMAs that lie within or partially within 15 km of the coast in NT. The boundaries for these regulatory units were obtained from the NT Department of Natural Resources, Environment, The Arts and Sport (NRETAS) and are shown on Figure 27. It is apparent that most of the coastline is covered by a large, unincorporated area that is not designated as a groundwater management unit. None of the GMA boundaries provided by NRETAS match the GMUs presented in AWR (2006).

The total area of each GMA and the proportion of each GMA lying within 15 km of the coastline are provided in Table 10. The Gove Water GMA had 100 % of its area contained within 15 km of the coast suggesting that SWI vulnerability may be highly relevant to its overall management.

Table 11 summarises the number of measurements collected and analysed for the VFA in NT.

The VFA results for NT are discussed below and summarised on the basis of GMAs in Section 6.5.

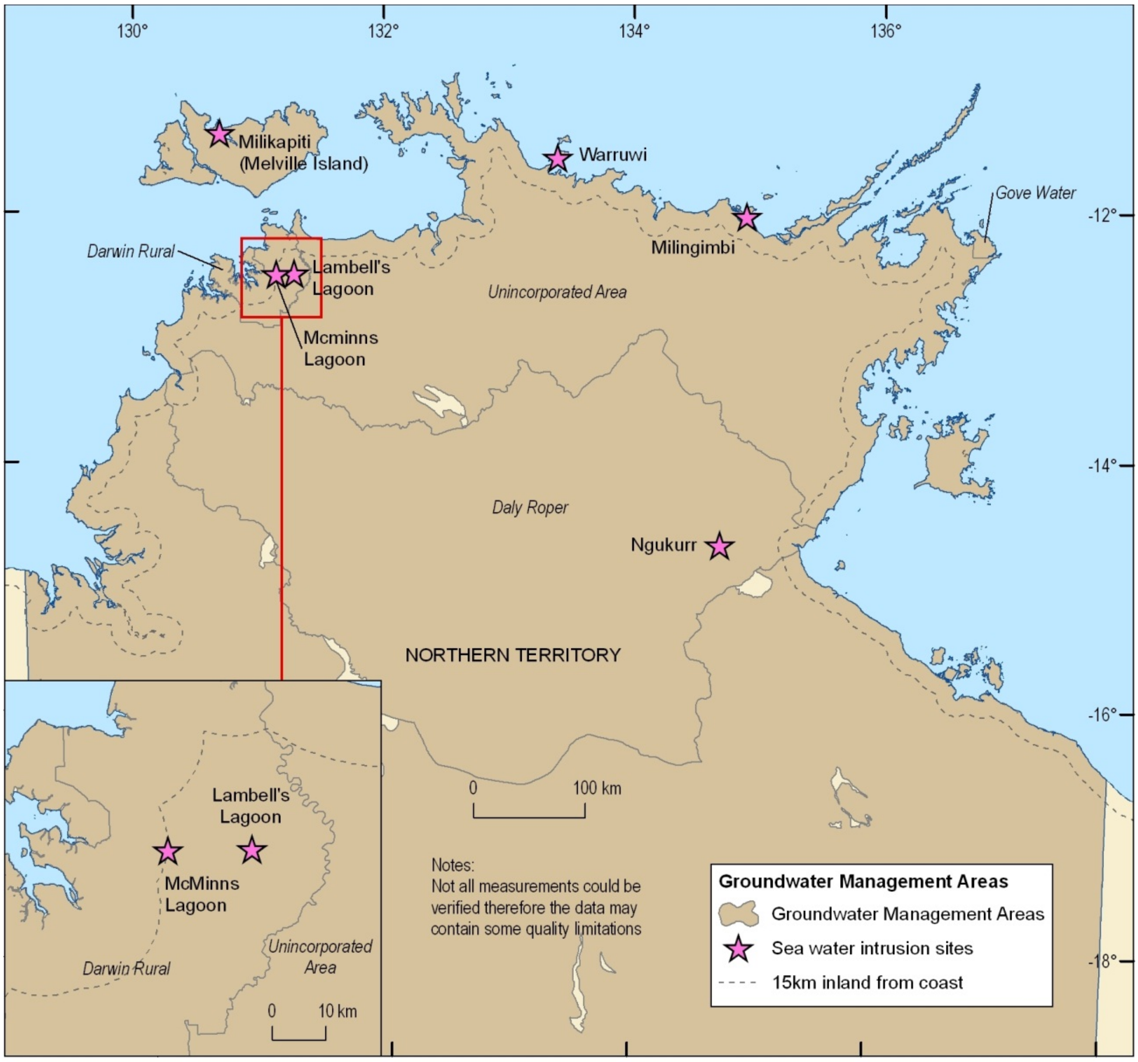


Figure 27 *GMAs in NT that intersect the 15 km coastal buffer zone.*

Table 10 *Total NT GMA areas that are wholly or partially within 15 km of the coast and percentage of total GMA areas within 15 km of the coast*

GMA Name	Total GMA Area (Hectares)*	Percentage of GMA Within 15 km of Coast
Gove Water	37,680	100
Darwin Rural	445,053	56
Unincorporated Area	87,407,351	6
Daly Roper	13,708,870	1

*Areas calculated based on the GDA1994 datum using a Lambert Conformal Conic Projection

Table 11 Groundwater data utilised in the VFA for NT

Data type	Data subset	No. of measurements
Groundwater levels	All relative standing water levels	2851
	Minimum RSWL (all years)	15
	Minimum RSWL Pre 2000	12
	Minimum RSWL 2000–2009	15
	Calculations of inter-decadal change in minimum RSWL from 1990-99 to 2000-09	12
	Groundwater linear trend analyses	1
Groundwater salinity	All salinity measurements	15,689
	Maximum TDS (all years)	2921
	Maximum TDS Pre 2000	2,693
	Maximum TDS 2000–2009	54
	Calculations of inter-decadal change in maximum TDS from 1990-99 to 2000-09	6
Groundwater extraction	Bores with annual usage volumes in recent years used in analysis	0*

*Annual usage volumes were not available

6.1. Groundwater Level Analysis

6.1.1. Minimum groundwater levels

Minimum groundwater levels measured in monitoring bores in NT are shown on Figure 28 and Figure 29. Groundwater level data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data to highlight areas that have recently shown groundwater level indicators of vulnerability. However, the lack of recent vulnerability indicators cannot be used to infer a reversal in vulnerability trends in many areas since they may in part be due to a lack of recent data. When making such an assessment, on Figure 28 and Figure 29 should be considered together.

6.1.1.1. Historical minimum groundwater levels

Minimum groundwater levels reported in monitoring wells prior to 2000 are shown on Figure 28. Data are only available for the Darwin Rural Area GMA. Most minimum groundwater levels remained above 2.5 m AHD and no levels were recorded in the highest vulnerability indicator category of <0 m AHD.

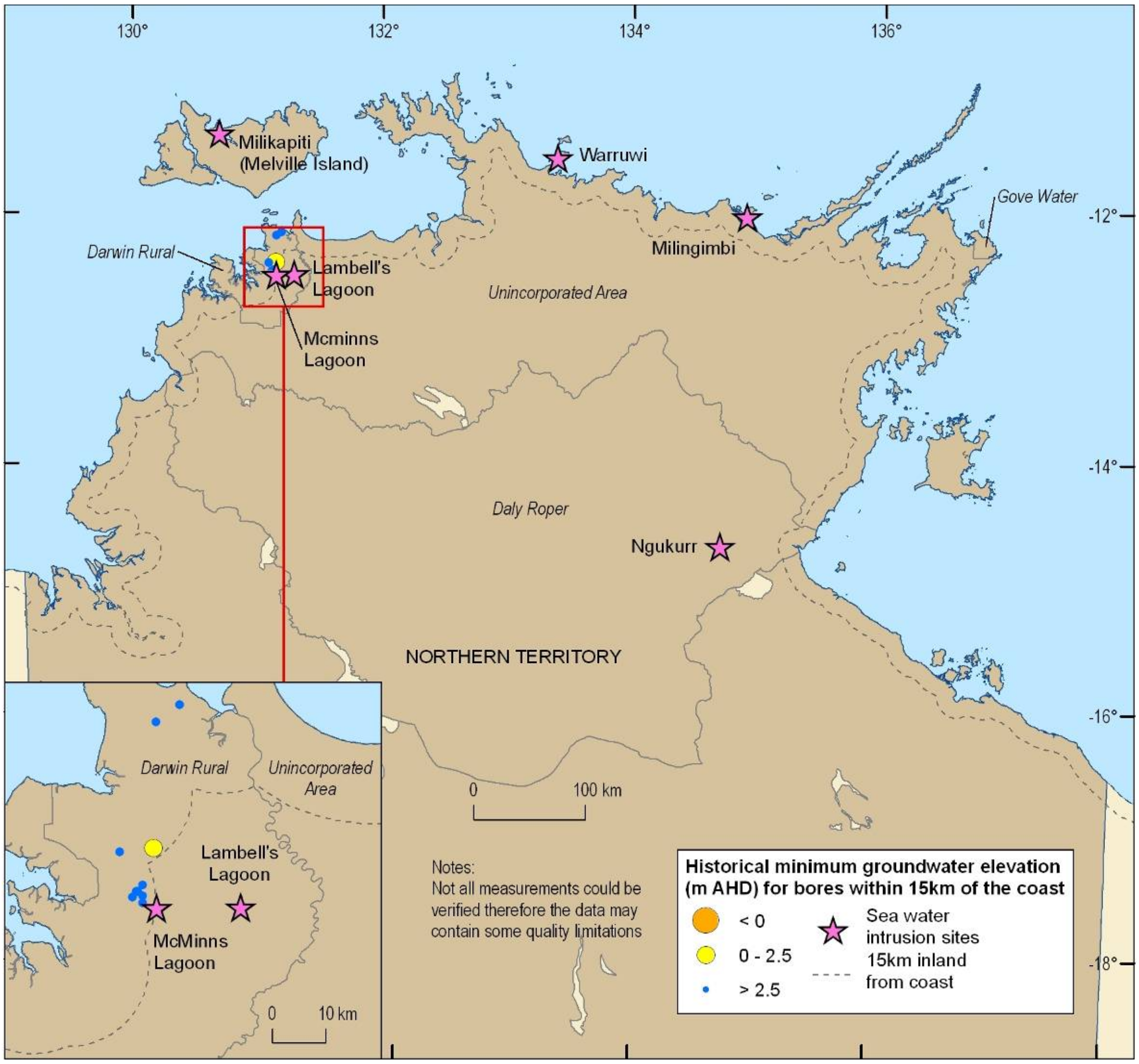


Figure 28 *Historical minimum groundwater levels measured prior to 2000, NT.*

6.1.1.2. Minimum groundwater levels, 2000–2009

Minimum groundwater levels measured between 2000 and 2009 are shown on Figure 29. Similarly to the historic data, measurements were only available for the Darwin Rural area. Most results fell into the >2.5 m AHD category with a single reading near the coast <2.5 m AHD.

6.1.2. Groundwater level changes

Changes in groundwater levels over time are plotted on Figure 30 (inter-decadal decline in minimum groundwater levels from 1990-1999 to 2000-2009) and Figure 31 (linear trends in groundwater levels) and discussed in the following text.

6.1.2.1. Inter-decadal changes in minimum groundwater levels

Inter-decadal changes in minimum groundwater levels are shown on Figure 30 where data are only available for the Darwin Rural GMA. Although some bores showed an increase in minimum water level between decades, more showed a decline in the range 0-2.5 m.

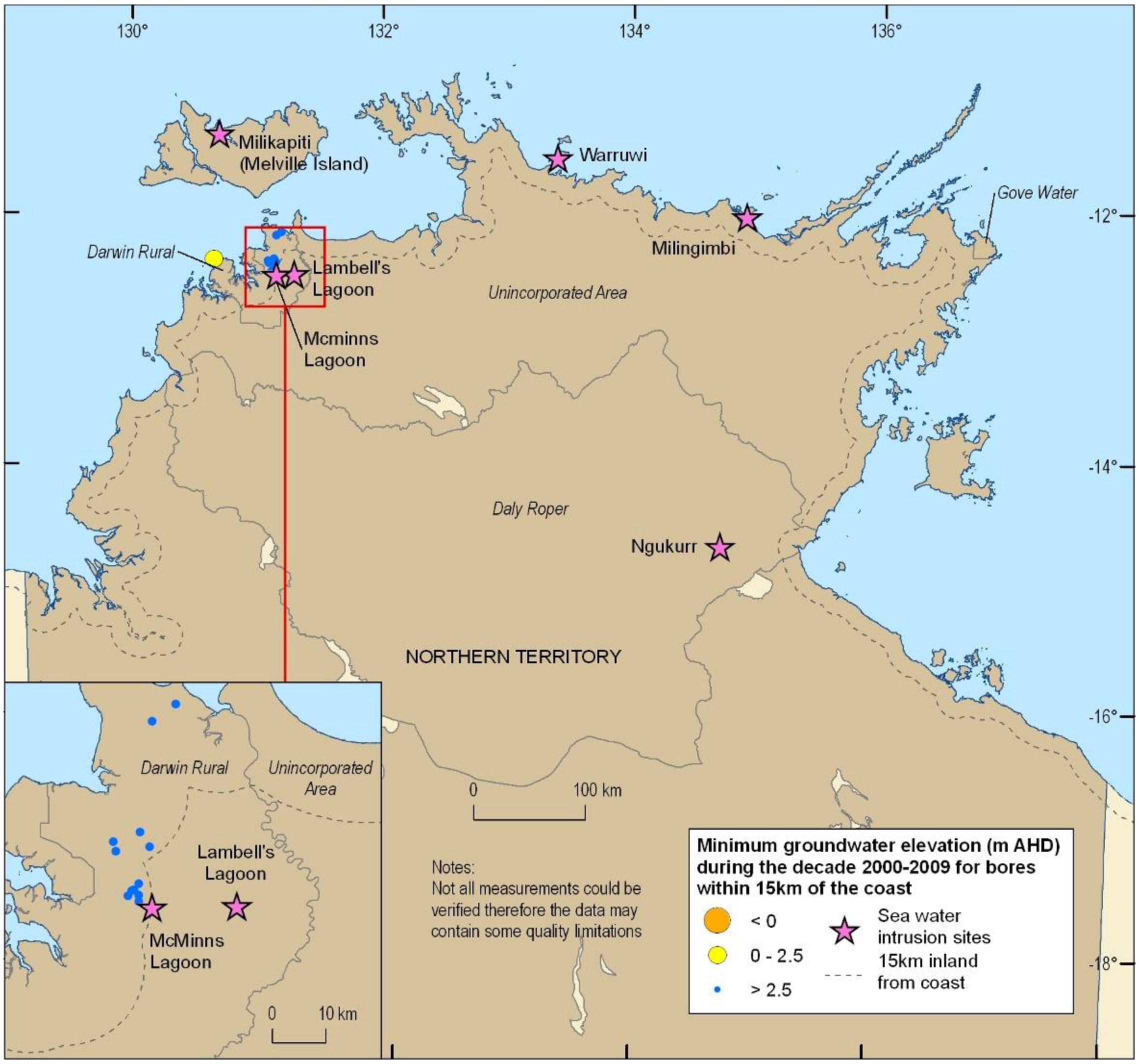


Figure 29 *Minimum groundwater levels measured in the period 2000-2009, NT.*

6.1.2.2. Groundwater level trends

A linear groundwater level trend could only be calculated for a single borehole from the data available in the NT within 15 km of the coast. Its location is shown on Figure 31 in the Darwin Rural area where an increasing groundwater level trend was identified.

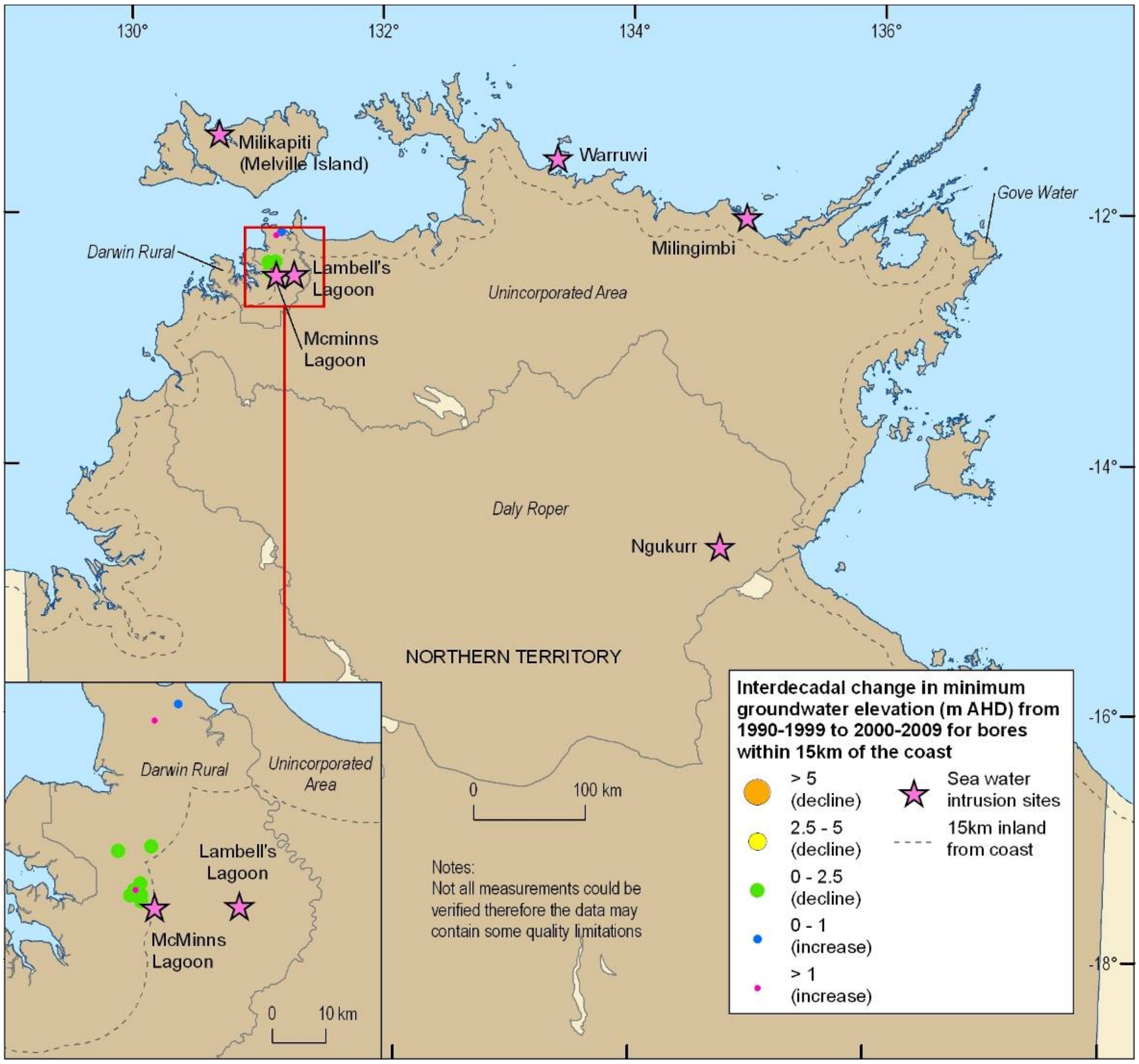


Figure 30 *Inter-decadal changes in minimum groundwater levels from 1990-1999 to 2000-2009, NT.*

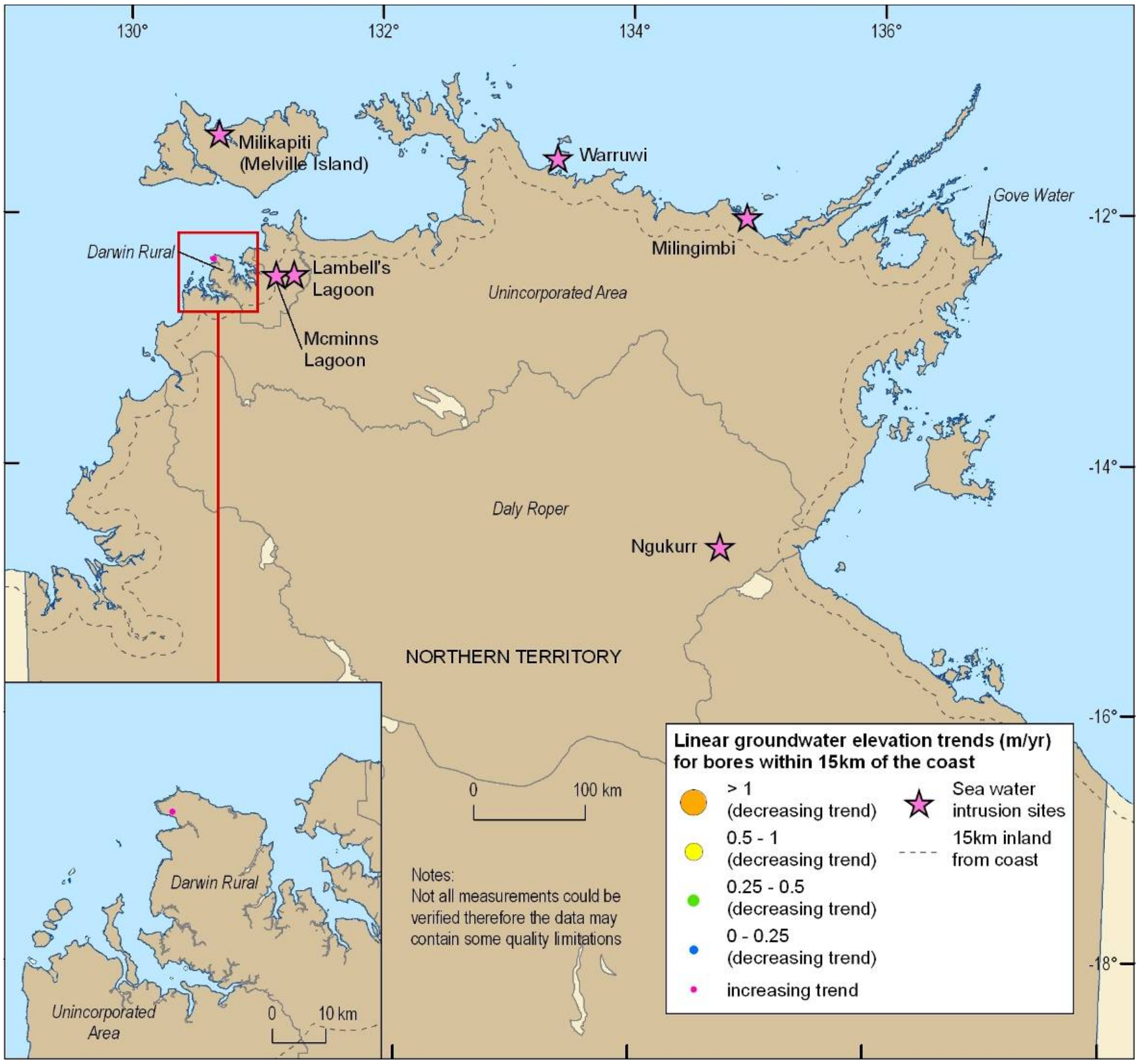


Figure 31 *Linear groundwater level trends in NT.*

6.1.3. Spatial distribution of low groundwater level observations

No groundwater levels below 2.5 m AHD were present in the NT database thus no analysis of groundwater level data relative to distance from the coast was undertaken.

6.2. Rainfall Trend Analysis

Plots of cumulative deviation of monthly rainfall data from long term averages are included in Appendix 3 for locations near the SWI sites and summarised for NT on Figure 32 for the period 2000-2009. Figure 32 shows that although rainfall generally increased near Ngukurr in the southeast, much of NT experienced declining rainfall trends over the period 2000-2009. Although additional groundwater pressures may be anticipated where rainfall has decreased, rainfall trends presented may not remain good indicators of vulnerability and should be updated in future assessments.

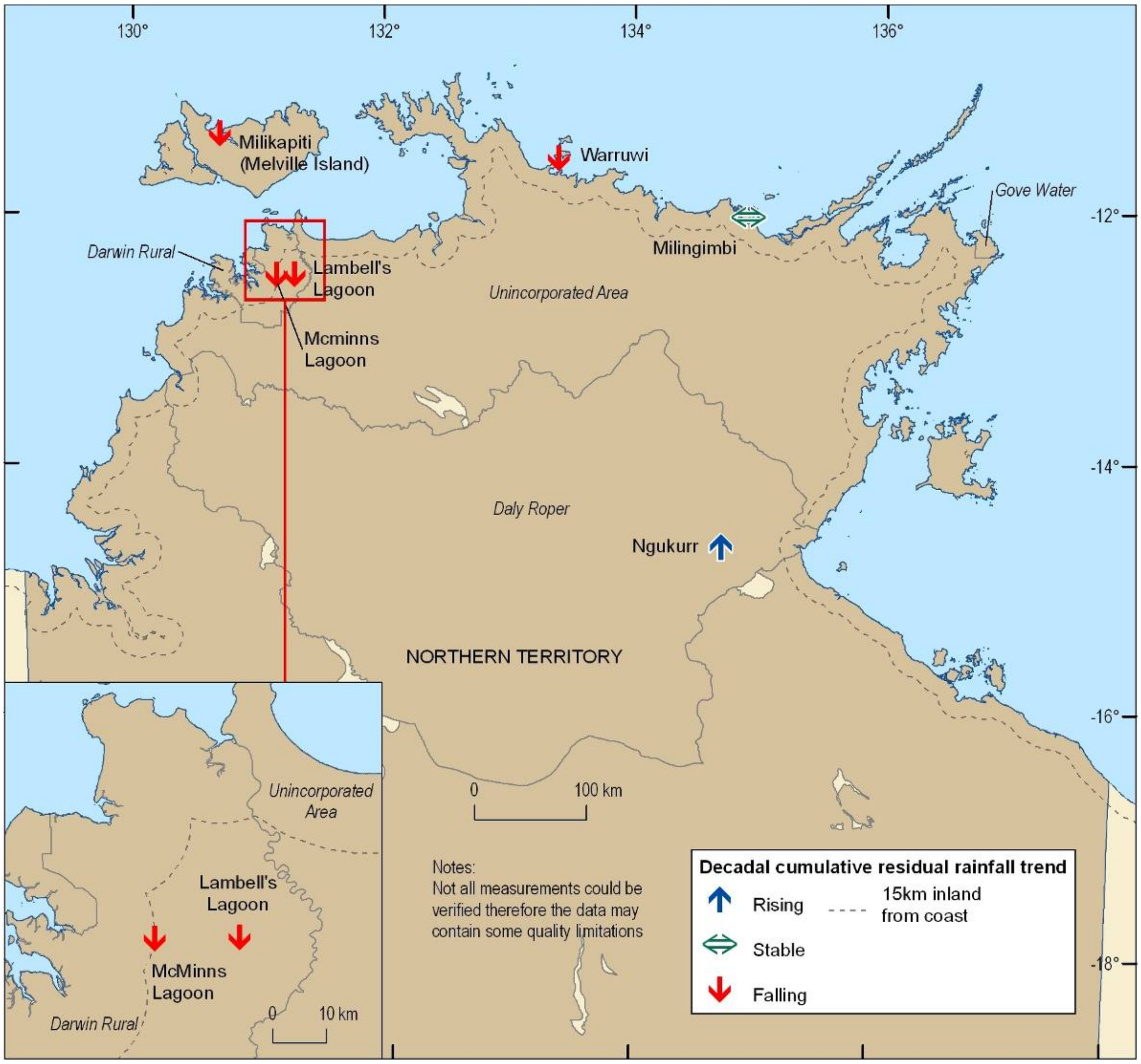


Figure 32 *Trends in cumulative deviation of monthly rainfall from long term averages for the period 2000-2009, NT.*

6.3. Groundwater Salinity

6.3.1. Maximum salinity measurements

Maximum TDS concentrations measured in monitoring bores in NT are shown on Figure 33 and Figure 34.

6.3.1.1. Historical maximum salinity measurements

Historical maximum TDS concentrations are shown on Figure 33. Groundwater with maximum TDS concentrations <3000 mg/L has been identified in many places within 15 m of the coast in NT. Such groundwater is suitable for a wide range of uses and represents an important resource. The Darwin Rural GMA showed a relatively high number and concentration of TDS measurements in this category. Some instances of high salinity groundwater situated close to low salinity groundwater are evident in Figure 33.

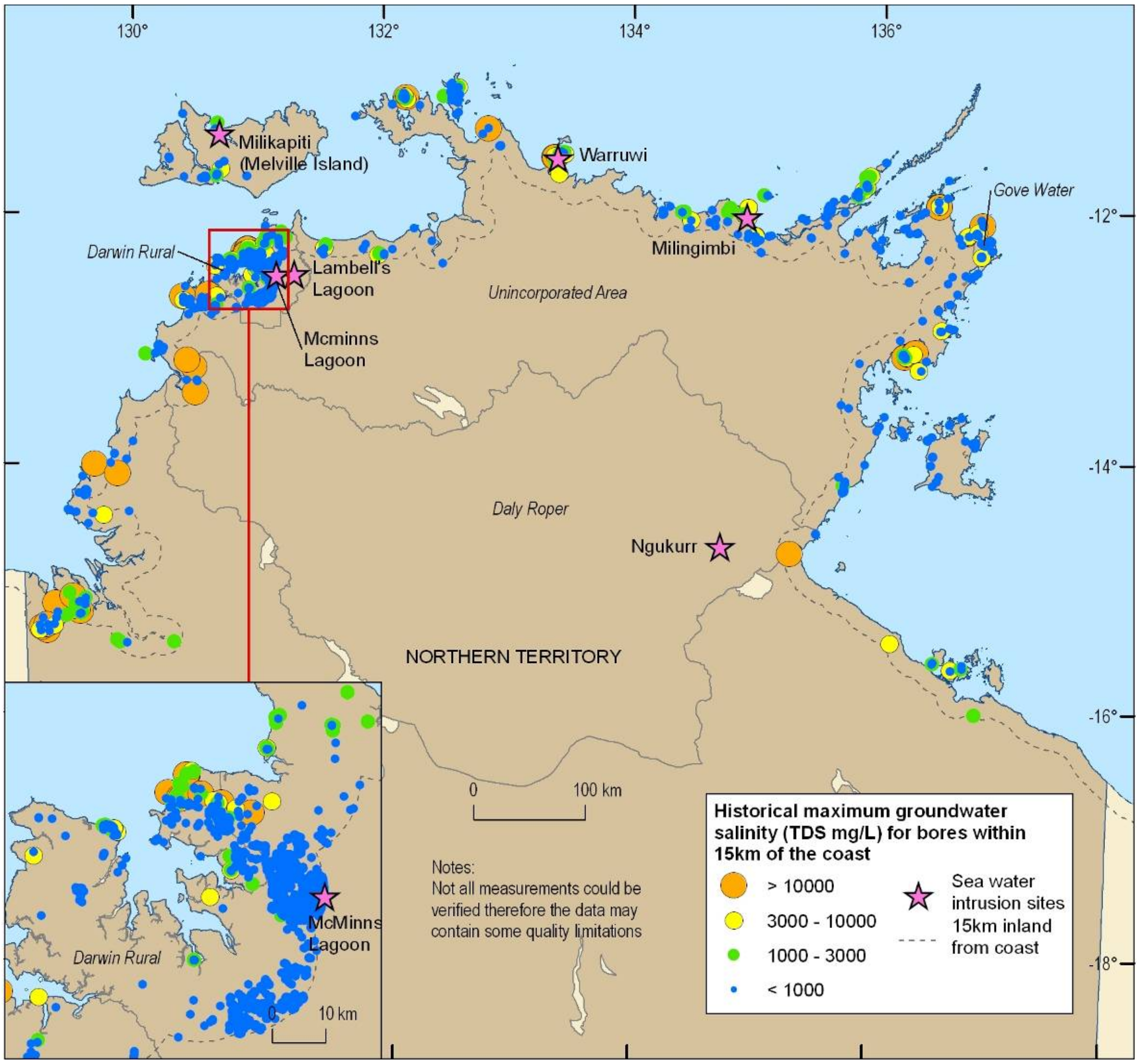


Figure 33 *Historical maximum TDS concentrations measured prior to 2000, NT.*

6.3.1.2. Maximum salinity measurements, 2000-2009

Maximum TDS concentrations measured during the period 2000-2009 are shown on Figure 34. There were only limited data for this period, all measurements being situated within the Darwin Rural GMA and showing maximum TDS concentrations <1000 mg/L.

6.3.2. Inter-decadal changes in maximum salinity measurements

Changes in maximum TDS concentrations between the decades 1990-1999 and 2000-2009 are shown on Figure 35. Due to the limited number of measurements available for the 2000-2009 decade, it is difficult to assess changes in salinity over this period. Inter-decadal changes could only be calculated for a few bores in the Darwin Rural GMA which showed either decreases in salinity over time or small increases of <1000 mg/L.

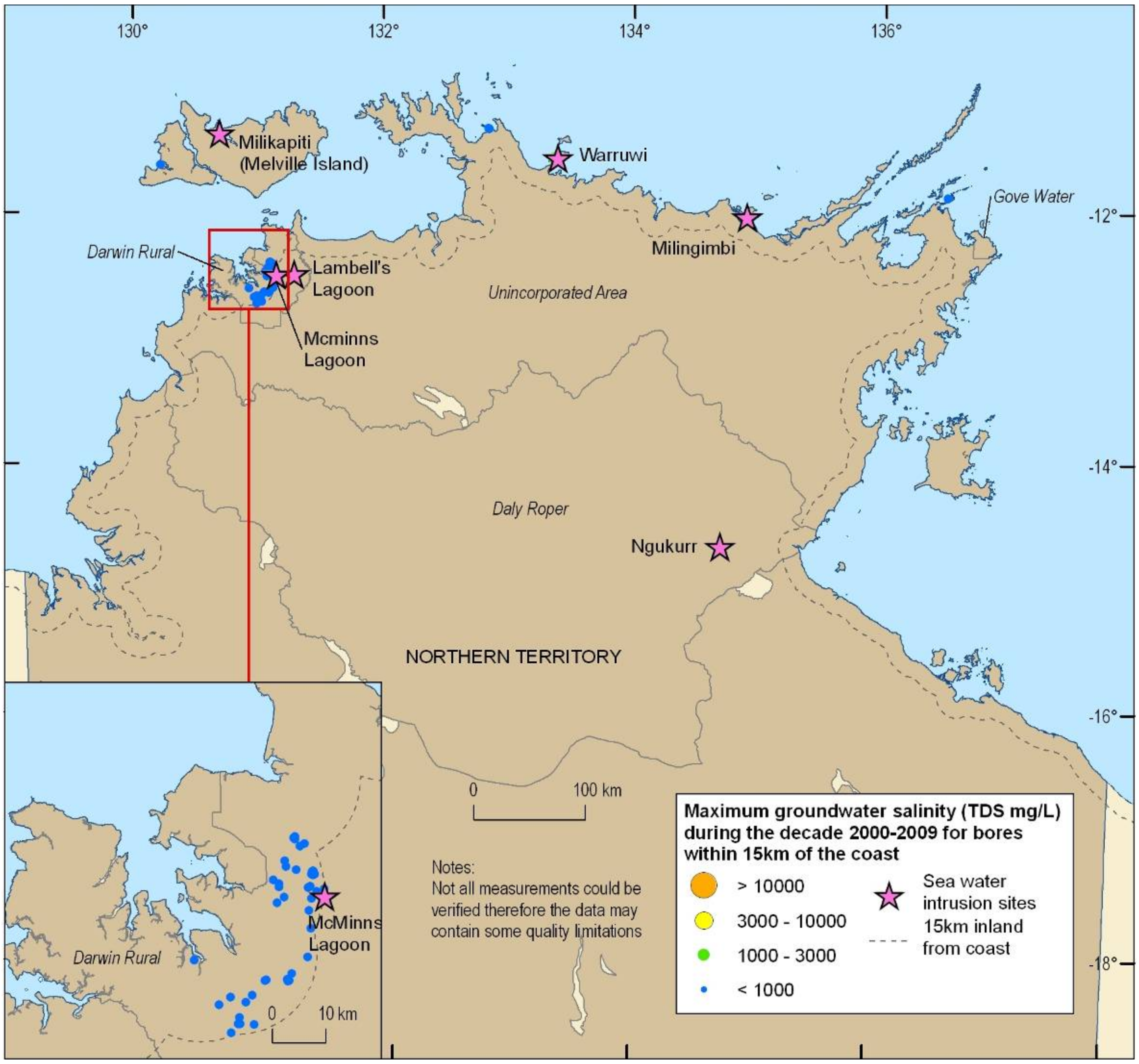


Figure 34 *Maximum TDS concentrations for the period 2000-2009, NT.*

6.4. Groundwater Extraction

6.4.1. Distribution of production bores

Although a database of active production bores was not available for the NT, bore attribute and location data were used to identify likely groundwater extraction bores as shown on Figure 36. It is noted that whereas only production bores are presented for the other states, Figure 36 may include stock and domestic extraction bores as well. Particularly high densities of extraction bores were identified in the Darwin area, in the Gove Water GMA and towards the Western Australia border.

6.4.2. Groundwater extraction rates

No groundwater extraction volume data for the NT were made available to the authors at the time of preparing this report.

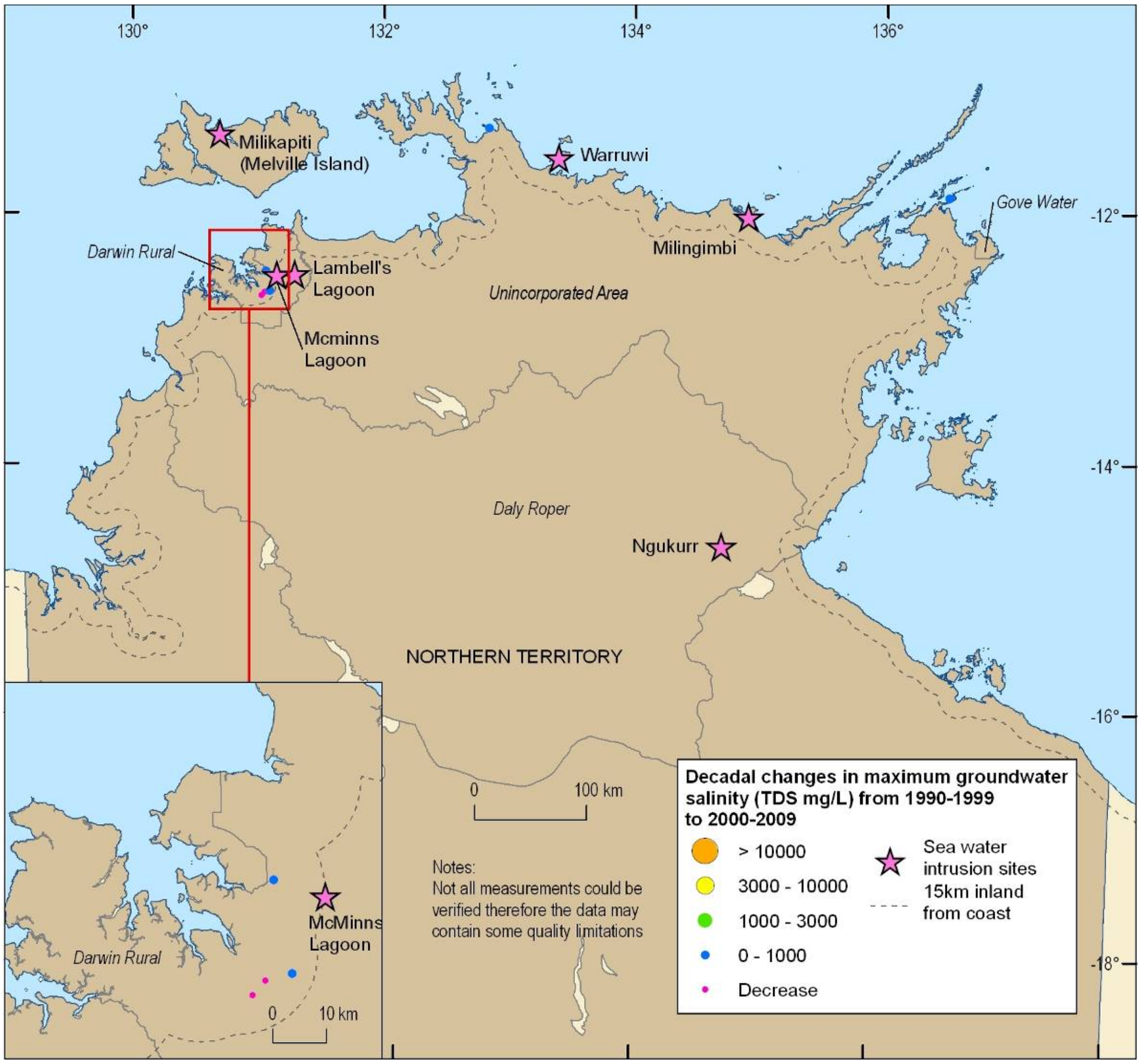


Figure 35 *Inter-decadal change in maximum TDS concentrations from 1990-1999 to 2000-2009, NT.*

6.5. VFA Summary: Northern Territory

Only limited groundwater data were available for NT for consideration in the VFA. Consequently, it is difficult to draw conclusions on the likelihood of SWI around the coast. As further data become available, their incorporation into the dataset and analysis following the methods presented above will provide useful indications of potential for high SWI vulnerability.

The VFA parameter categories identified in NT GMAs are summarised in Table 12. However, no state VFA priority GMAs could be defined for NT following the approach outlined for WA in Section 5.5 due to data limitations.

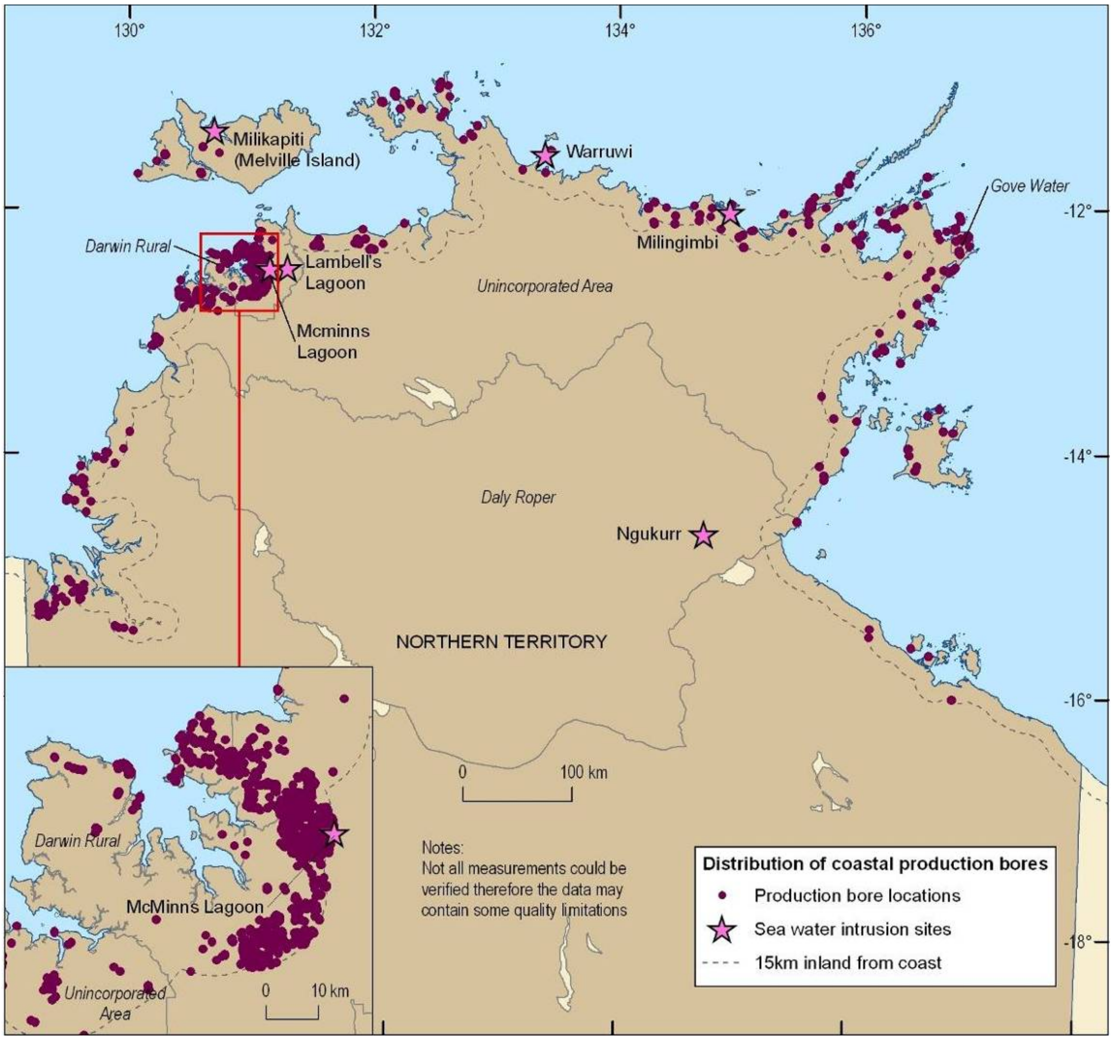


Figure 36 *Distribution of likely production bores, NT (note that stock and domestic bores may be included on this figure).*

Table 12 *Summary of VFA indicators by GMA for the Northern Territory*

GMA	SWI Sites	Groundwater Levels				Groundwater Salinity (TDS Concentration in mg/L)		
		Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS <3000 within 1 km >10,000		TDS concentration changes
		2000-2009	Pre 2000	Inter-decadal decline >2.5 m	Declining trend >0.5 m/yr	Pre 2000	2000-2009	Inter-decadal increase >1000
Daly Roper	Ngukurr	-	-	-	-	N	-	-
Darwin Rural	Lambell's Lagoon, Mcminns Lagoon	N	N	N	N	Y	N	N
Gove Water	-	-	-	-	-	N	-	-
Unincorporated Area	Warruwi, Milikapiti (Melville Island), Milingimbi	-	-	-	-	Y	N	N

7. Vulnerability Factor Analysis Results: Queensland

In Qld, surface water and groundwater management is undertaken on the basis of Water Resource Planning Boundaries (proclaimed areas). Catchments define the primary management boundaries, with managed groundwater subareas within termed Regulated Groundwater Areas (RGAs). The boundaries for these RGAs were provided by the then Department of Environment and Resource Management (DERM) for use in the VFA (see Figure 37). These regulatory units are referred to as GMAs below.

The total area of each GMA and the proportion of each GMA lying within 15 km of the coastline are provided in Table 13 which also indicates which of the Qld GMAs coincide with the GMUs defined in AWR (2006). There are 17 GMAs in Qld that are wholly or partially within 15 km of the coast and 16 contained data for consideration in this state assessment. A total of 8 GMAs had more than 90% of their total areas within 15 km of the coastline, suggesting that SWI vulnerability may be highly relevant to their overall management. The VFA results are discussed below and reported on the basis of GMAs in summary form in Section 7.5.

Table 14 provides details of the number of measurements collected and analysed for the VFA in Qld.

7.1. Groundwater Level Analysis

7.1.1. Minimum groundwater levels

Minimum groundwater levels measured in Qld within 15 km of the coast are presented on Figure 38 and Figure 39. Groundwater level data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data below.

7.1.1.1. Historical minimum groundwater levels

Minimum groundwater levels reported in monitoring wells prior to 2000 are summarised on Figure 38. Many areas along the Qld coast contained water level measurements for this period <0 m AHD, with particularly high densities of low water level readings in the northeast between Cooktown and the Pioneer Valley (including the Burdekin, Bowen and Pioneer Valley) and in the southeast near Bundaberg and Burnett Heads. Figure 38 should be consulted for the locations of all water level measurements <0 m AHD.

7.1.1.2. Minimum groundwater levels, 2000–2009

Minimum groundwater levels reported in monitoring wells for the period 2000-2009 are summarised on Figure 39. Although there are less measurement locations due to a shorter monitoring period, minimum water levels show a similar distribution to those measured historically. The distribution of these water levels relative to the coastline is discussed in Section 7.1.4 below.

7.1.2. Groundwater level changes

Changes in groundwater levels over time are plotted on Figure 40 (inter-decadal decline in minimum groundwater levels from 1990-1999 to 2000-2009) and Figure 41 (linear trends in groundwater levels) and discussed in the following text.

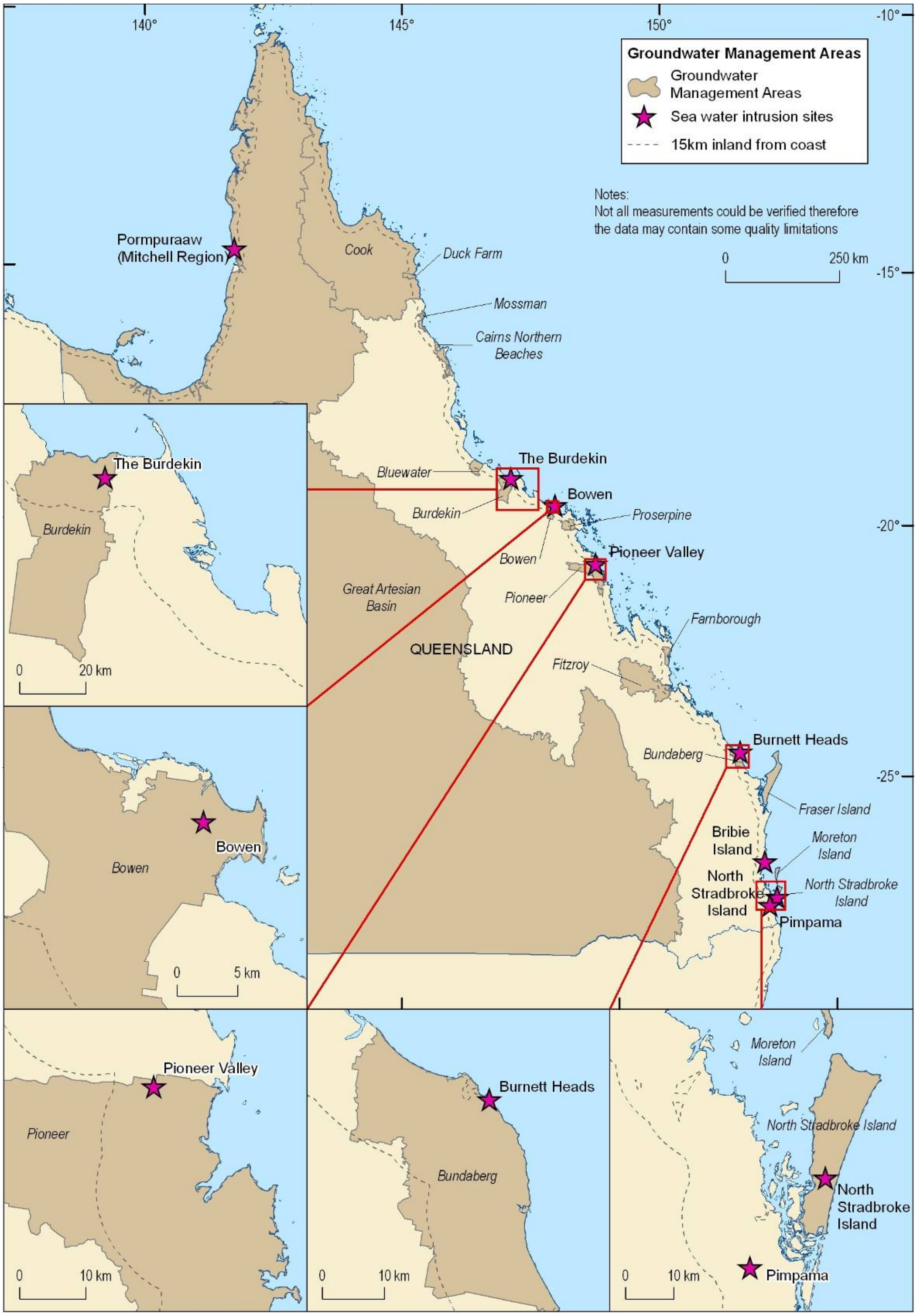


Figure 37 *GMAs in Qld that intersect the 15 km coastal buffer zone.*

Table 13 *Total Qld GMA areas that are wholly or partially within 15 km of the coast and percentage of total GMA areas within 15 km of the coast*

GMA Name	Total GMA Area (Hectares)**	Percentage of GMA Within 15 km of Coast
Cairns Northern Beaches*	11,375	100
Fraser Island*	162,296	100
Mossman*	30,792	100
Farnborough	43,826	97
North Stradbroke Island*	26,294	97
Moreton Island*	16,731	96
Bundaberg*	76,487	93
Cairns Coast	74,002	91
Bowen*	62,528	62
Duck Farm*	26,107	61
Bluewater*	62,312	59
Pioneer*	201,358	47
Proserpine*	55,628	40
Burdekin*	132,940	30
Cook*	5,447,735	17
Fitzroy*	571,549	8
Great Artesian Basin*	112,948,465	2

*Generally matches AWR 2006 GMU

**Areas calculated based on the GDA1994 datum using a Lambert Conformal Conic Projection

Table 14 *Groundwater data utilised in the VFA for Qld*

Data Type	Data Subset	No. of Measurements
Groundwater levels	All relative standing water levels	470,994
	Minimum RSWL (all years)	2,310
	Minimum RSWL Pre 2000	2,307
	Minimum RSWL 2000–2009	1,838
	Calculations of inter-decadal change in minimum RSWL from 1990-99 to 2000-09	1,561
	Groundwater linear trend analyses	126
Groundwater salinity	All salinity measurements	618,117
	Maximum TDS (all years)	8,518
	Maximum TDS Pre 2000	5,364
	Maximum TDS 2000–2009	3,823
	Calculations of inter-decadal change in maximum TDS from 1990-99 to 2000-09	1,351
Groundwater extraction	Bores with annual usage volumes in recent years used in analysis	1,279

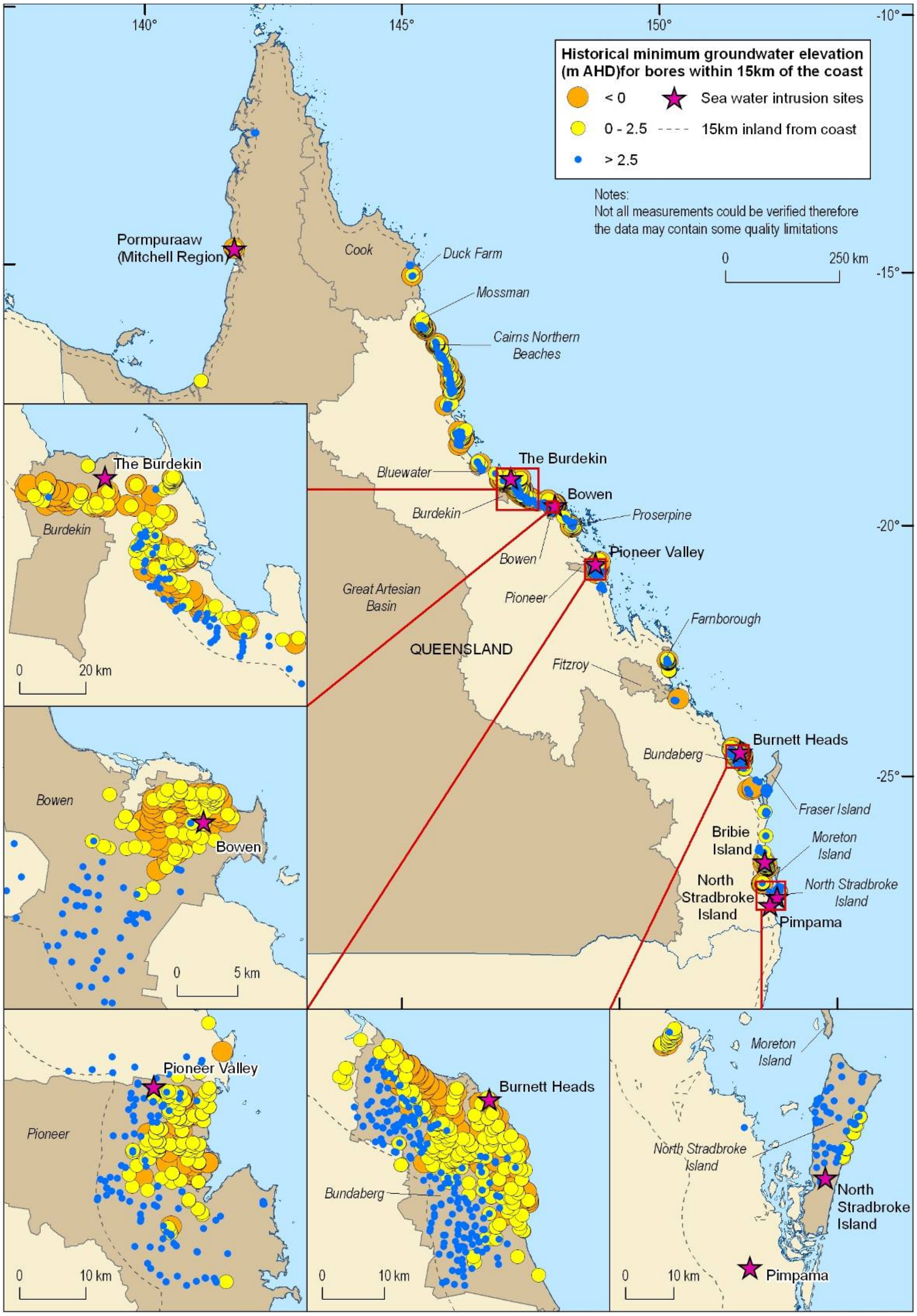


Figure 38 *Historical minimum groundwater levels measured prior to 2000, Qld.*

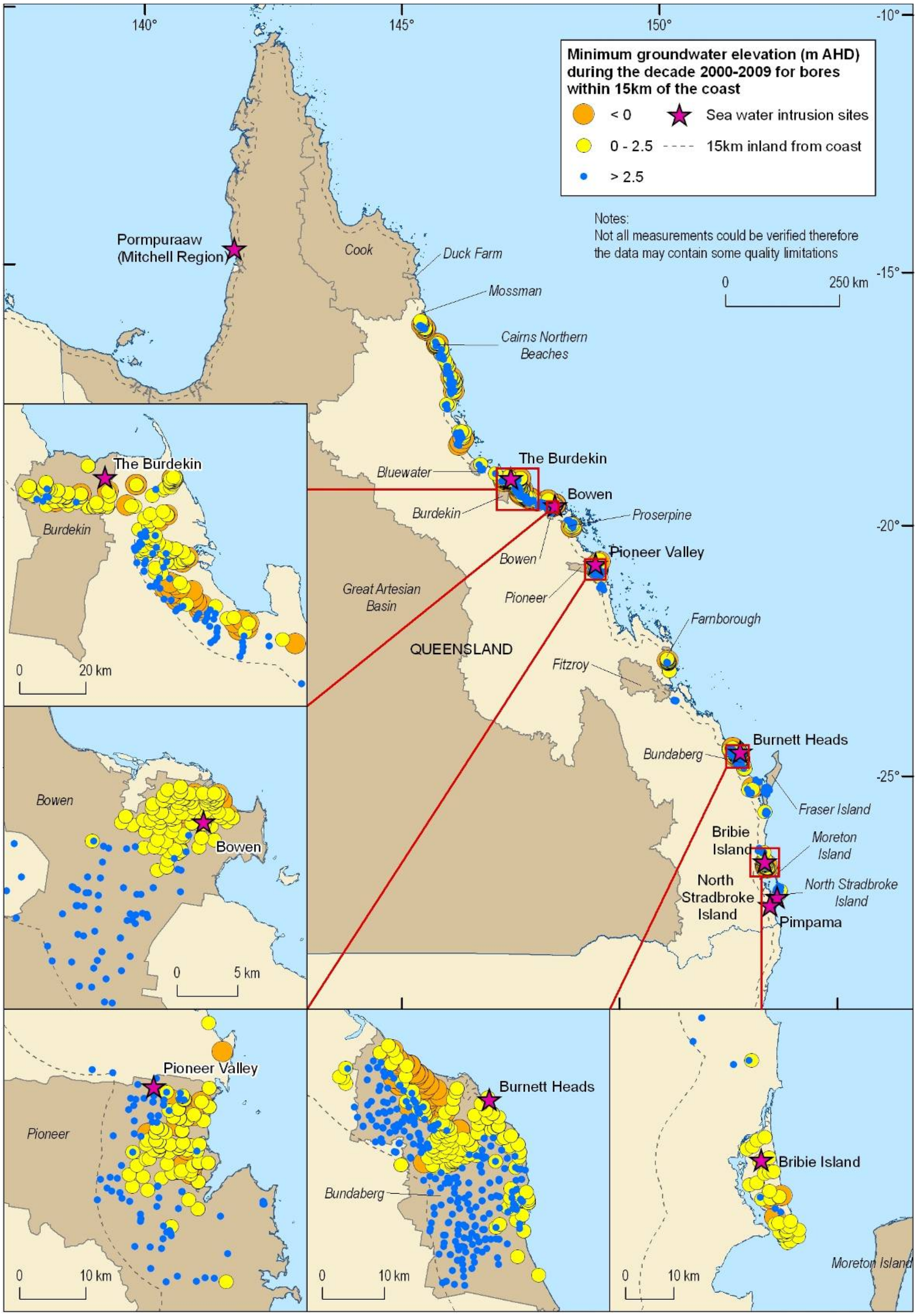


Figure 39 *Minimum groundwater levels measured in the period 2000-2009, Qld.*

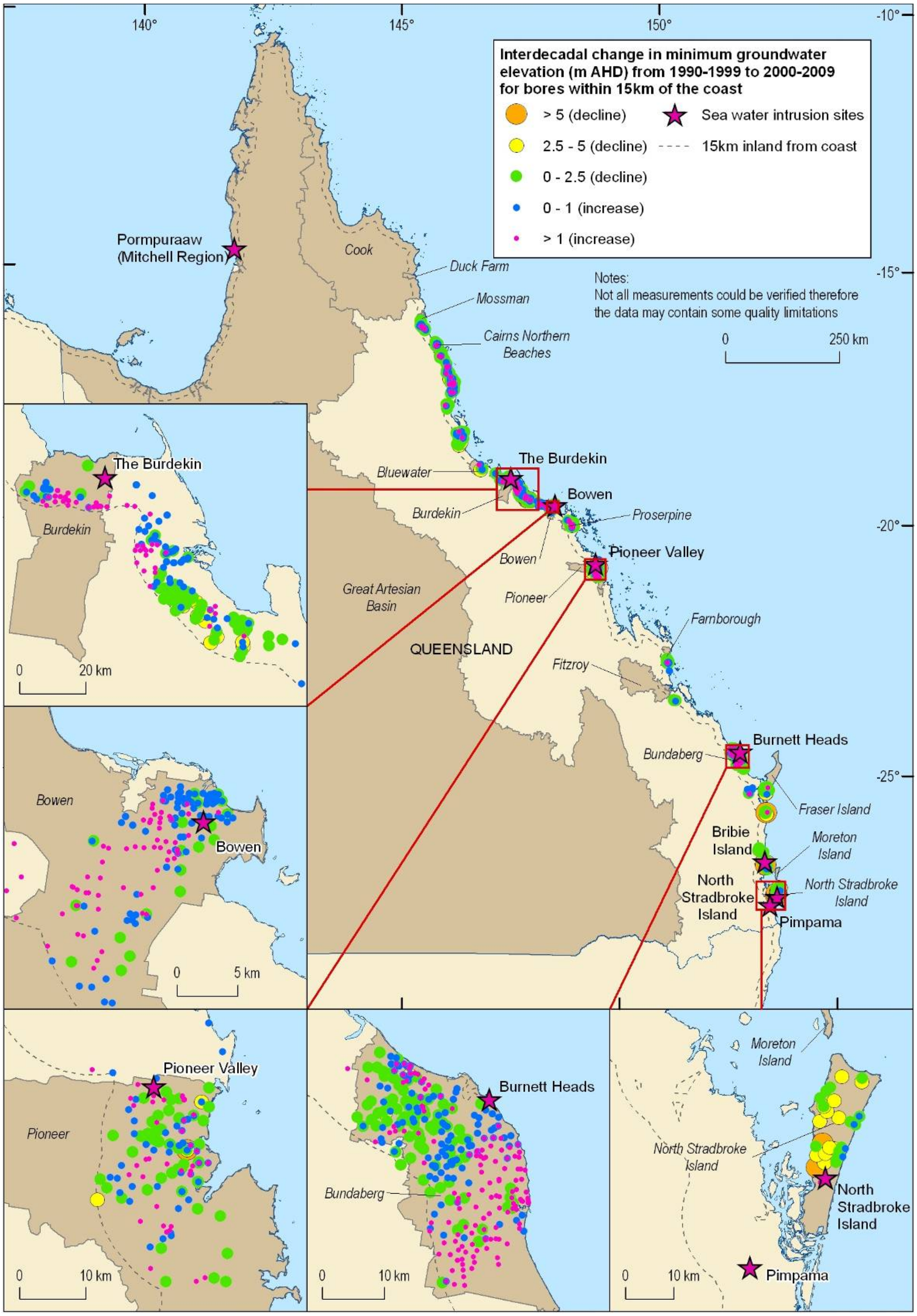


Figure 40 *Inter-decadal changes in minimum groundwater levels from 1990-1999 to 2000-2009, Qld.*

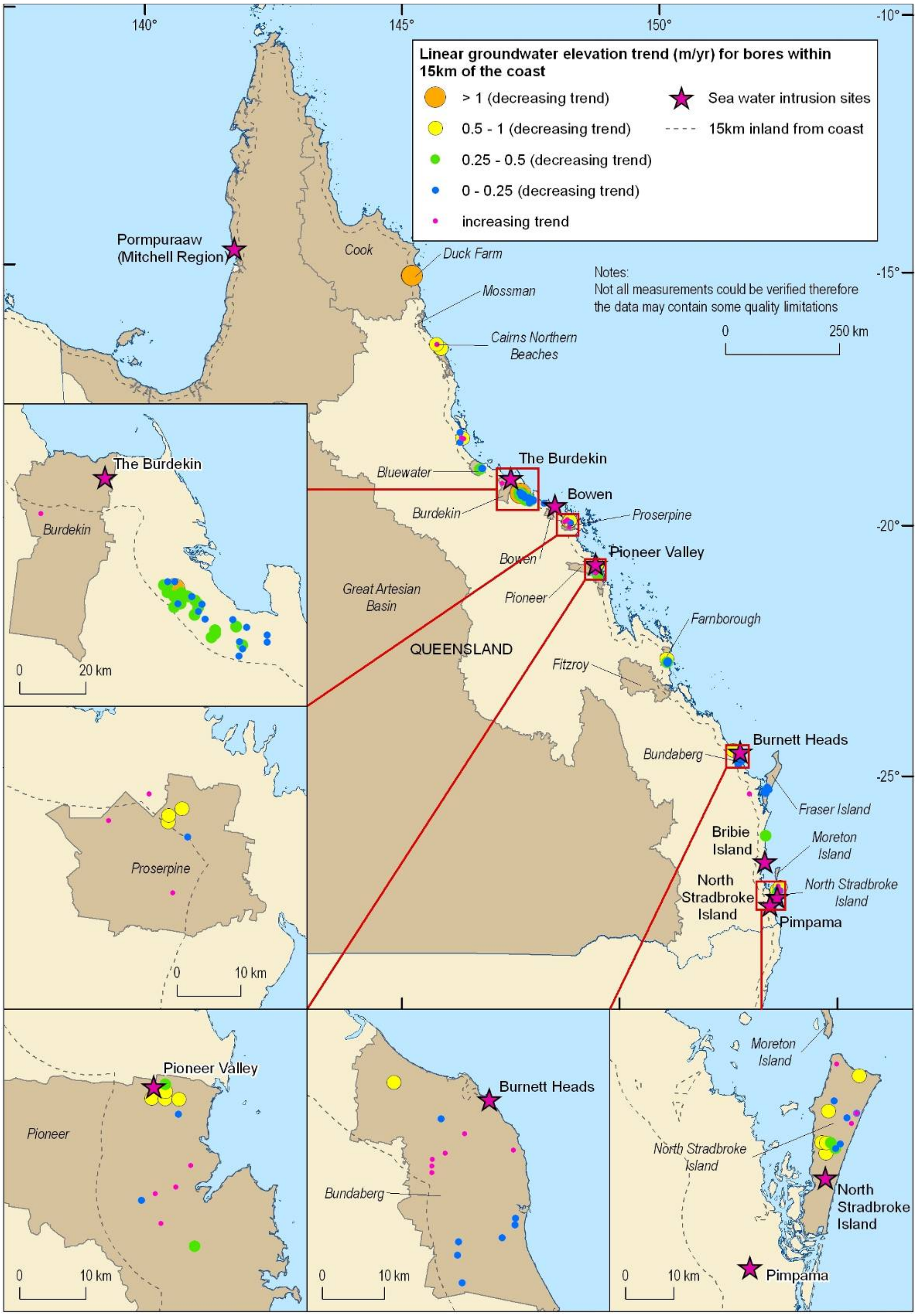


Figure 41 *Linear groundwater level trends in Qld.*

7.1.2.1. Inter-decadal changes in minimum groundwater levels

Figure 40 indicates that although inter-decadal declines of <2.5 m were common in the areas of low minimum groundwater levels outlined in Section 7.1, relatively few areas recorded declines in excess of 2.5 m. Areas showing declines > 5 m included the Pioneer Valley, Bribie Island, the area near Tin Can Bay and North Stradbroke Island. Other areas showing inter-decadal declines of between 2.5 m and 5 m included the Burdekin (and surrounds- i.e. the Burdekin covers a wider area than the Burdekin GMA marked on the figures), Pioneer Valley, and several locations between the Burdekin and Cairns (see Section 7.5 for affected GMAs).

7.1.2.2. Groundwater level trends

Figure 41 shows that decreasing groundwater level trend >1 m/year were identified near Cooktown and the Burdekin. Areas showing >0.5 m/year declining trends in groundwater levels included Cairns, Bowen, Pioneer Valley, Bundaberg and North Stradbroke Island.

7.1.3. Summary of groundwater level SWI vulnerability indicators

Figure 42 shows the high SWI vulnerability indicator categories for each of the groundwater level parameters presented in Section 7.1 above. It is apparent on the figure that several areas show low groundwater levels in conjunction with declining groundwater levels (inter-decadal declines or decreasing linear trends), including Cooktown, the Burdekin, Pioneer Valley and Bribie Island. Collectively these groundwater level parameters suggest that these areas may have high vulnerability to SWI and further detailed consideration is warranted. However, it is noted that the presence of fewer or no SWI vulnerability indicators in other areas may reflect a lack of data and they may still be highly vulnerable to SWI.

7.1.4. Spatial distribution of low groundwater level observations

The maximum distances that groundwater levels <0m AHD and <2.5 m AHD extend inland from the coast are presented for each GMA in Table 15. The data shown are based on minimum groundwater levels measured in boreholes over the decade 2000-2009. SWI may be anticipated to extend further inland in areas where low groundwater levels extend further from the coast. Minimum groundwater levels <0 m AHD were measured further inland than 10 km in the Bundaberg, Burdekin and Proserpine GMAs, and in the Pioneer GMA they extended inland >8 km. Although whether SWI occurs in these areas is dependent on many other factors in addition to groundwater levels, if SWI does occur in these areas groundwater level distributions may be such that SWI could extend a considerable distance inland if not appropriately managed.

The boundaries of some GMAs do not extend far inland from the coast thus Table 15 should be considered in conjunction with Figure 37 if assessing potential impacts to individual GMAs rather than total distance from the coast (e.g. North Stradbroke Island).

Minimum water levels for the entire monitoring period (historic and recent) in each monitoring bore are plotted against distance from the coast in Appendix 2 for each GMA. In some GMAs such as Bundaberg, many low water levels have been recorded extending relatively far inland from the coast suggesting that, if SWI were to occur here, groundwater levels may facilitate extensive impacts. In contrast, GMAs such as North Stradbroke Island show a more marked increase in groundwater levels with distance from the coast suggesting that impacts are more likely to be confined to more coastal areas if SWI was to occur there.

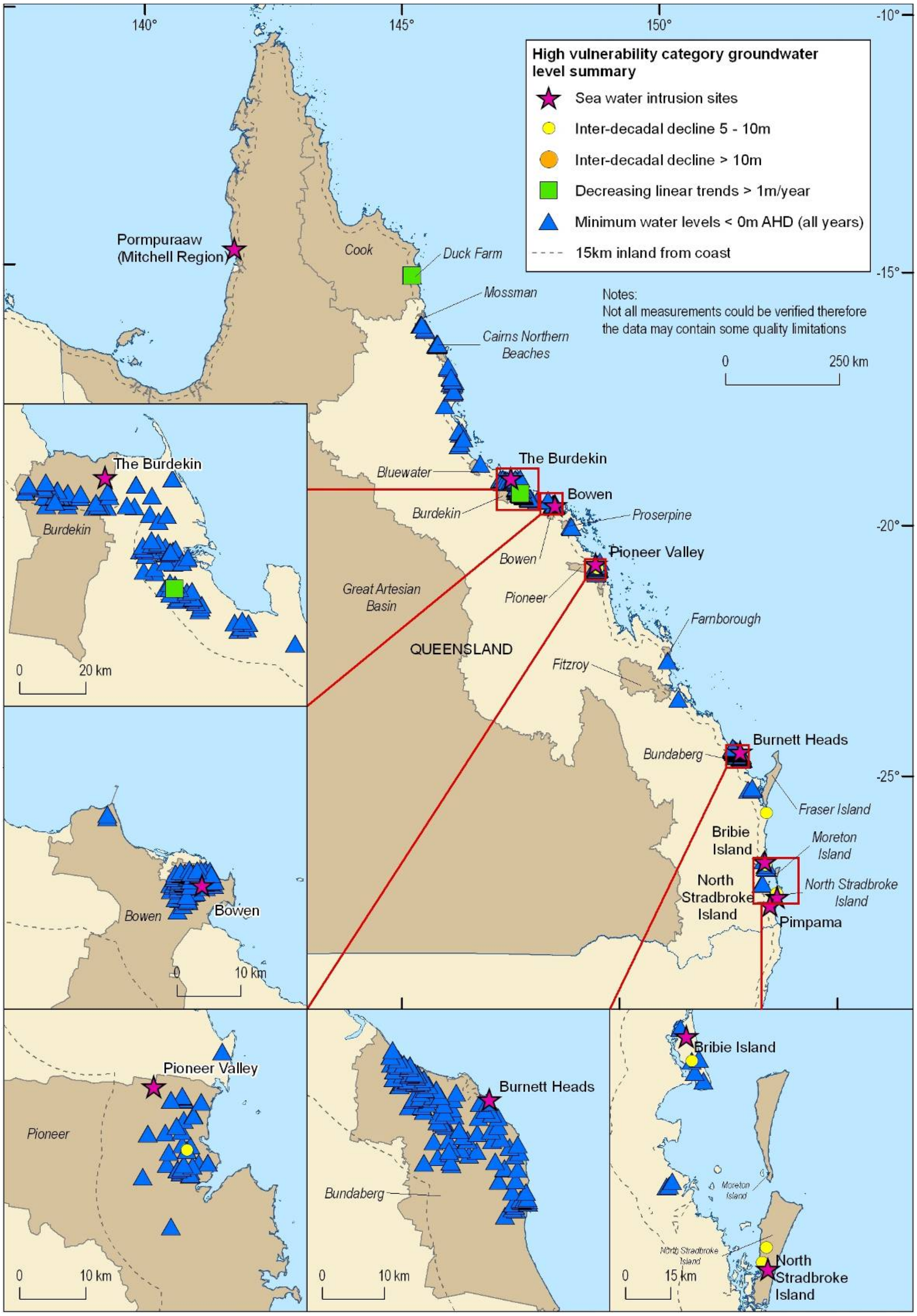


Figure 42 *Summary of groundwater level indicators of high SWI vulnerability, Qld.*

Table 15 *Maximum inland extent within 15 km of the coast of minimum groundwater levels <0 m AHD and <2.5 m AHD based on 2000-2009 monitoring data reported for Qld GMAs*

GMA	Maximum Inland Distance of <0 m AHD Groundwater Levels (km)	Maximum Inland Distance <2.5 m AHD Groundwater Levels (km)
Bluewater	All levels > 0m	3.92
Bowen	4.29	6.69
Bundaberg	12.29	12.29
Burdekin	13.73	14.98*
Cairns Coast	All levels > 0m AHD	10.33
Cairns Northern Beaches	1.89	6.00*
Cook	No elevation data	No elevation data
Duck Farm	No elevation data	No elevation data
Farnborough	3.30	4.58
Fitzroy	No elevation data	No elevation data
Fraser Island	All levels > 0m AHD	All levels > 2.5m AHD
Great Artesian Basin	No elevation data	No elevation data
Moreton Island	No elevation data	No elevation data
Mossman	1.17	3.65
North Stradbroke Island	All levels > 0m AHD	0.40
Pioneer	8.03	10.47
Proserpine	12.69	14.96*
OTHER (non GMA)	14.88	14.91

*Furthest inland water level measurement. Low water levels may extend further inland.

7.2. Rainfall Trend Analysis

Plots of cumulative deviation of monthly rainfall data from long term averages are included in Appendix 3 for locations near the SWI sites and summarised for Qld on Figure 43 for the period 2000-2009. Figure 43 shows that although rainfall generally remained stable or increased in places in the north (e.g. the Burdekin), much of Qld experienced declining rainfall trends over the period 2000-2009. Although additional groundwater pressures may be anticipated where rainfall has decreased, drought around the country has eased in 2010 and 2011 (visible on the plots in Appendix 3), and a reversal in rainfall trends is evident in some areas. The rainfall trends on Figure 43 may therefore not remain good indicators of vulnerability and should be updated in future assessments.

Figure 43 *Trends in cumulative deviation of monthly rainfall from long term averages for the period 2000-2009, Qld.*

7.3. Groundwater Salinity

7.3.1. Maximum salinity measurements

Groundwater salinity data for Qld are presented on Figure 44 and Figure 45. Data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data below to highlight areas that have recently shown groundwater salinity indicators of SWI vulnerability.

7.3.1.1. Historical maximum salinity measurements

Historical maximum TDS concentrations are shown on Figure 44. Groundwater with TDS concentrations <3000 mg/L has been identified in many places along the Qld coast suggesting that many coastal groundwater resources are suitable for a wide range of uses. Areas where groundwater with maximum TDS concentrations <3000 mg/L is located near groundwater with maximum TDS concentrations >10,000 mg/L are also common and may indicate higher potential for intrusion of high salinity water into freshwater resources.

7.3.1.2. Maximum salinity measurements, 2000-2009

Maximum TDS concentrations measured during the period 2000-2009 are shown on Figure 45. Although the data show a similar spatial distribution to the historic measurements, a smaller proportion of lower salinity groundwater measurements appear to have been recorded over the recent decade in places (e.g. Bowen). It is difficult to assess the significance of such changes since they are likely to be influenced by the number and location of monitoring points between the different time periods. Section 7.3.2 provides a more appropriate assessment of inter-decadal changes in salinity measurements.

7.3.2. Inter-decadal changes in maximum salinity measurements

Changes in maximum TDS concentrations between the decades 1990-1999 and 2000-2009 are shown on Figure 46. It is apparent that the majority of locations where data are available in Qld experienced a decrease or a slight increase (<1000 mg/L) in maximum TDS concentrations over this time. However, TDS concentration increases >1000 mg/L were relatively common and concentrations increases >3000 mg/L were identified in several places including the Burdekin, Bowen, Proserpine, Pioneer Valley, St Lawrence, Yeppoon and Bundaberg.

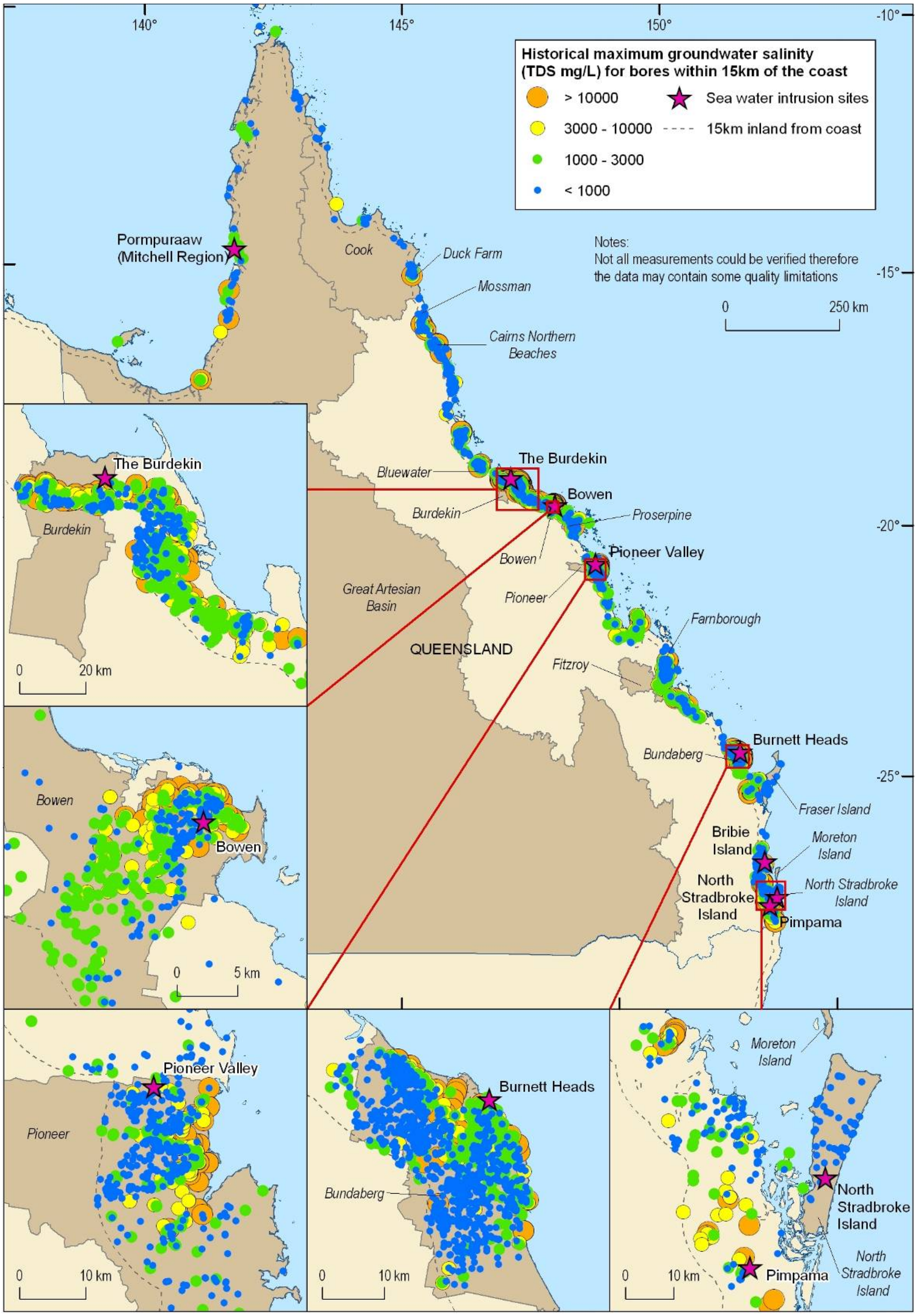


Figure 44 *Historical maximum TDS concentrations measured prior to 2000, Qld.*

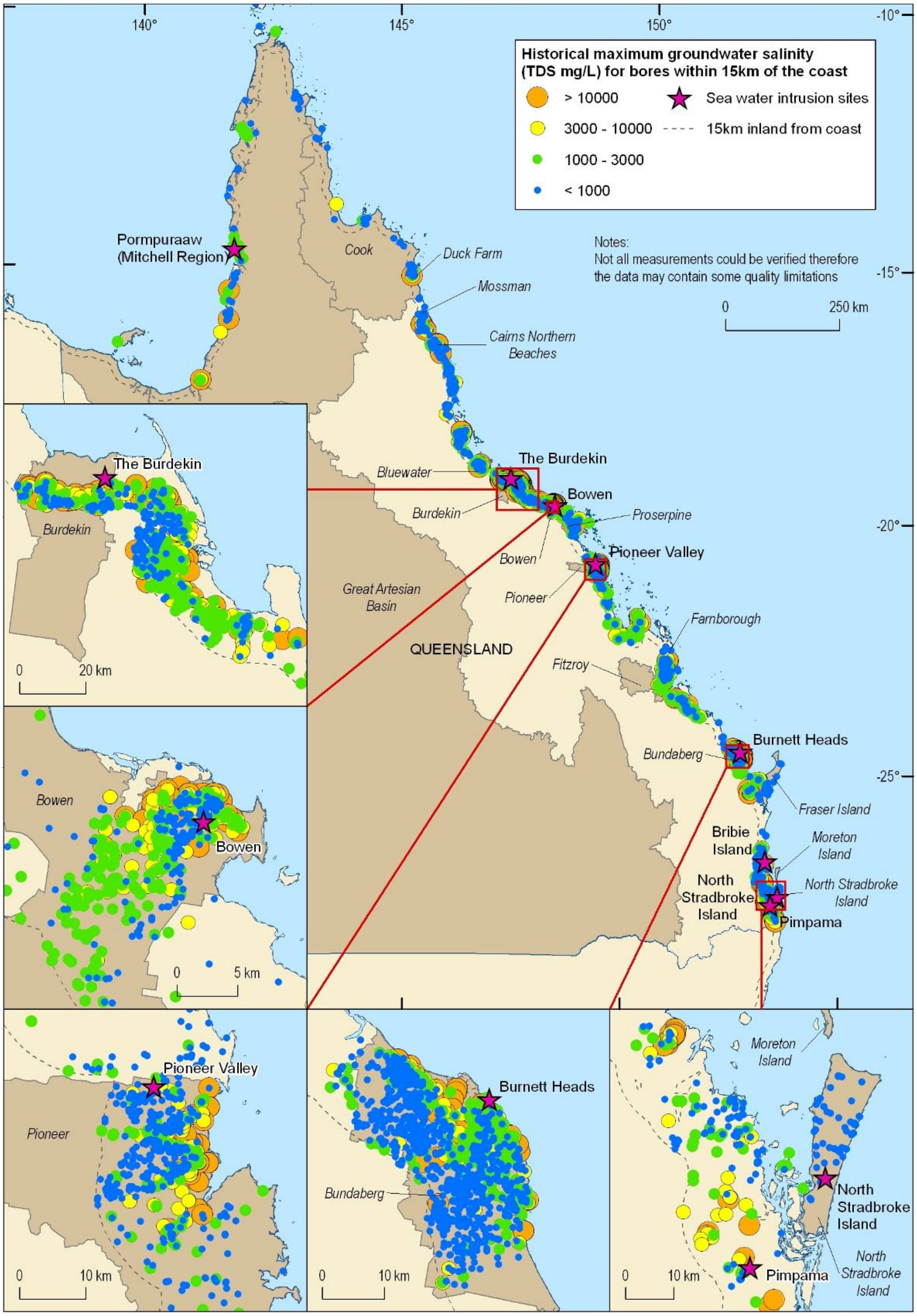


***Figure 45** Maximum TDS concentrations for the period 2000-2009, Qld.*

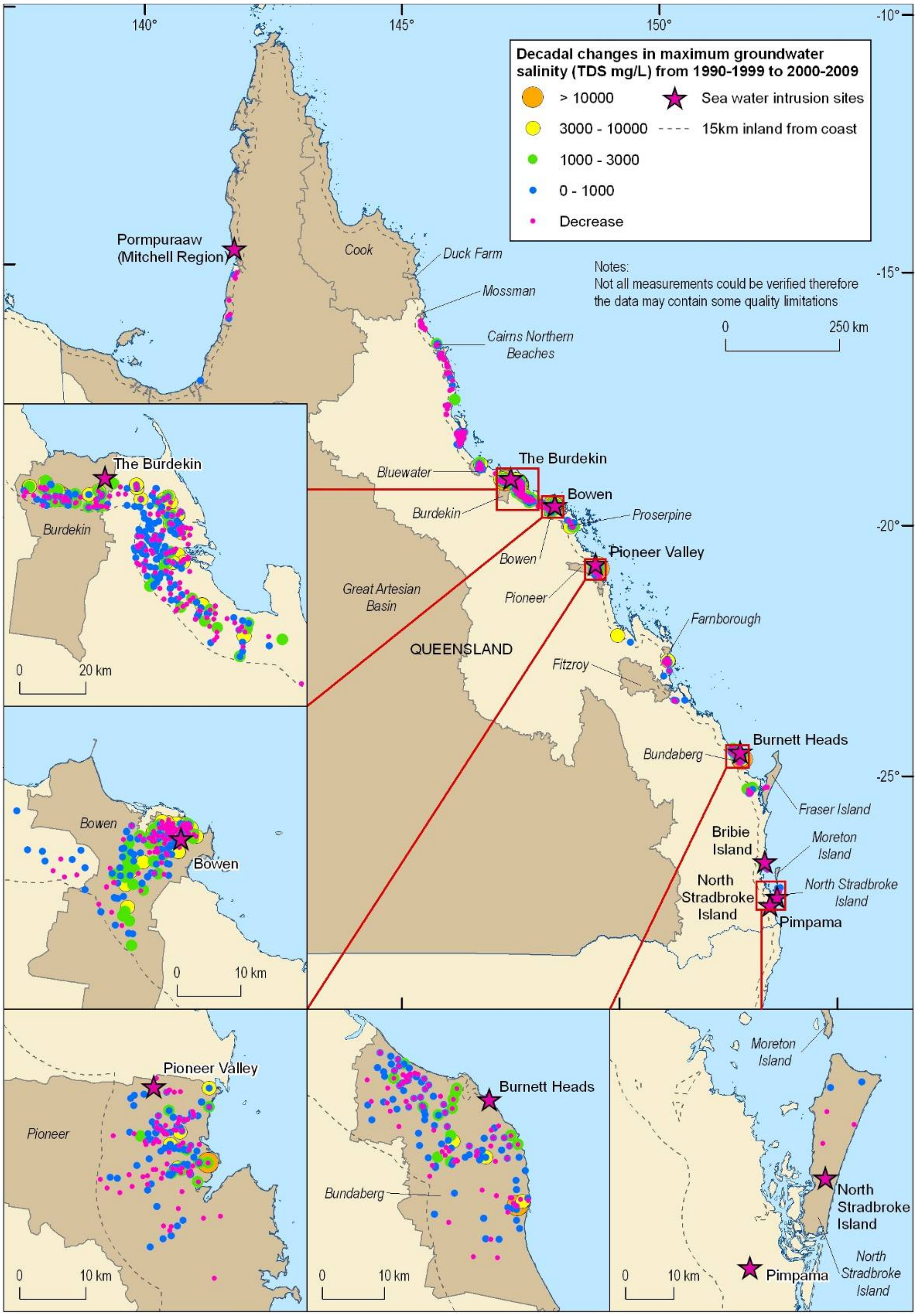


Figure 46 *Inter-decadal change in maximum TDS concentrations from 1990-1999 to 2000-2009, Qld.*

7.4. Groundwater Extraction

7.4.1. Distribution of production bores

The locations of recorded production bores provided by DERM are presented on Figure 47 (private stock and domestic supply bores are not included). Relatively high numbers and densities of production bores were recorded in Cairns, the Burdekin, Bowen, Pioneer Valley and Bundaberg.

7.4.2. Groundwater extraction rates

Figure 48 presents the recorded groundwater extraction rates in coastal Qld for the 2009-2010 financial year. As outlined in Section 3.4.3, in the context of SWI it is difficult to attach significance to extraction rates in the absence of recharge data. The information presented is best considered at a site specific level in conjunction with other available information. However, Figure 48 indicates that relatively high extraction rates >1000 ML/year are associated with individual production bores in the Burdekin and Bundaberg areas.

7.4.3. Cumulative groundwater extraction rates by area

Cumulative groundwater extraction rates in 5 x 5 km grid cells in coastal Qld are shown on Figure 49 based on Figure 48 data. The final category that each cell falls into is somewhat dependent on where the grid is positioned, but in general the information shows that in addition to those areas with high individual bore extraction rates listed above, the Pioneer Valley has relatively high cumulative extraction rates >1000 ML/year while cumulative extraction rates in Bowen exceeded 500 ML/year.

7.4.4. Groundwater extraction rates by GMA

Figure 50 summarises groundwater extraction rates within 15 km of the coast within GMAs from 1998-2010. Records indicate that groundwater extraction peaked in 2002-2003 (over 80 GL), declined to less than 40 GL in 2008-2009, and increased slightly to over 50GL in 2009-2010.

Extraction volumes for those portions of the GMAs within 15 km of the coast for the 2009-2010 financial year are presented in Table 16 where they are compared to the sustainable yield estimates for the GMUs in AWR (2006). The AWR (2006) GMUs do not directly correspond to the Qld GMAs in all instances thus care in interpretation is required (further details are included in Table 16).

Table 16 shows the percentage of AWR (2006) extraction for 2004-2005 relative to sustainable yield. Where extraction rates are high relative to sustainable yield, impacts on groundwater levels may occur resulting in SWI. Although this data is several years old, it provides an indication of which GMAs may be under extraction stress. Extraction at 50% of sustainable yield is taken to be a reasonable distinction between relatively low extraction rates and relatively high extraction rates. Of the GMAs for which data are available, Bluewater, Bowen and Bundaberg had a recorded extraction rate exceeding 50% of estimated sustainable yield for 2004-2005.

Table 16 includes the proportion of extraction in each GMA from 2009-2010 within 15 km of the coast relative to the AWR (2006) sustainable yield data. It indicates that the Bundaberg GMA has an extraction rate within 15 km of the coast that exceeds 50% of estimated sustainable yield. This suggests that it may be particularly susceptible to SWI (noting that those GMAs with a high proportion of their areas within 15 km of the coast are more likely to show higher values). However, groundwater levels near the coast depend on local extraction and recharge conditions that may be unrelated to sustainable yield for the entire GMA and therefore many of the other GMAs along the Qld coast may also be at risk on the basis of this analysis. Such detailed consideration is beyond the scope of the VFA which offers a broad scale assessment of available data. The requirement for further site specific investigation is emphasised.

7.5. VFA Summary: Queensland

The VFA results for Qld are summarised in Table 17 for each GMA. Following the approach outlined for WA in Section 5.5, the following state VFA priority GMAs were identified for Qld: Bowen, Bundaberg, Burdekin, Cairns Northern Beaches, Farnborough, Pioneer and Proserpine. These GMAs are considered to show a particularly high proportion and range of VFA indicators.

Notwithstanding the above discussion, a single VFA indicator of high vulnerability in an area may correspond to an area with high SWI vulnerability and some high SWI vulnerability areas may have no data or high category indicators at all. There are other areas in Qld showing indicators of high SWI vulnerability and a lack of data in many areas. Further, there were indicators of SWI vulnerability not captured in this summary since they were situated outside of the GMAs. Omission of locations from the list of state VFA priority GMAs should not be taken to imply that they are unlikely to be significantly vulnerable to SWI. The list simply highlights locations where considerable numbers of high SWI vulnerability indicators are present where data are available. Some of the GMAs cover large areas compared to others thus reporting at the GMA level is somewhat inconsistent. The data presented above should be considered on a case by case basis at a scale commensurate with the area of interest.

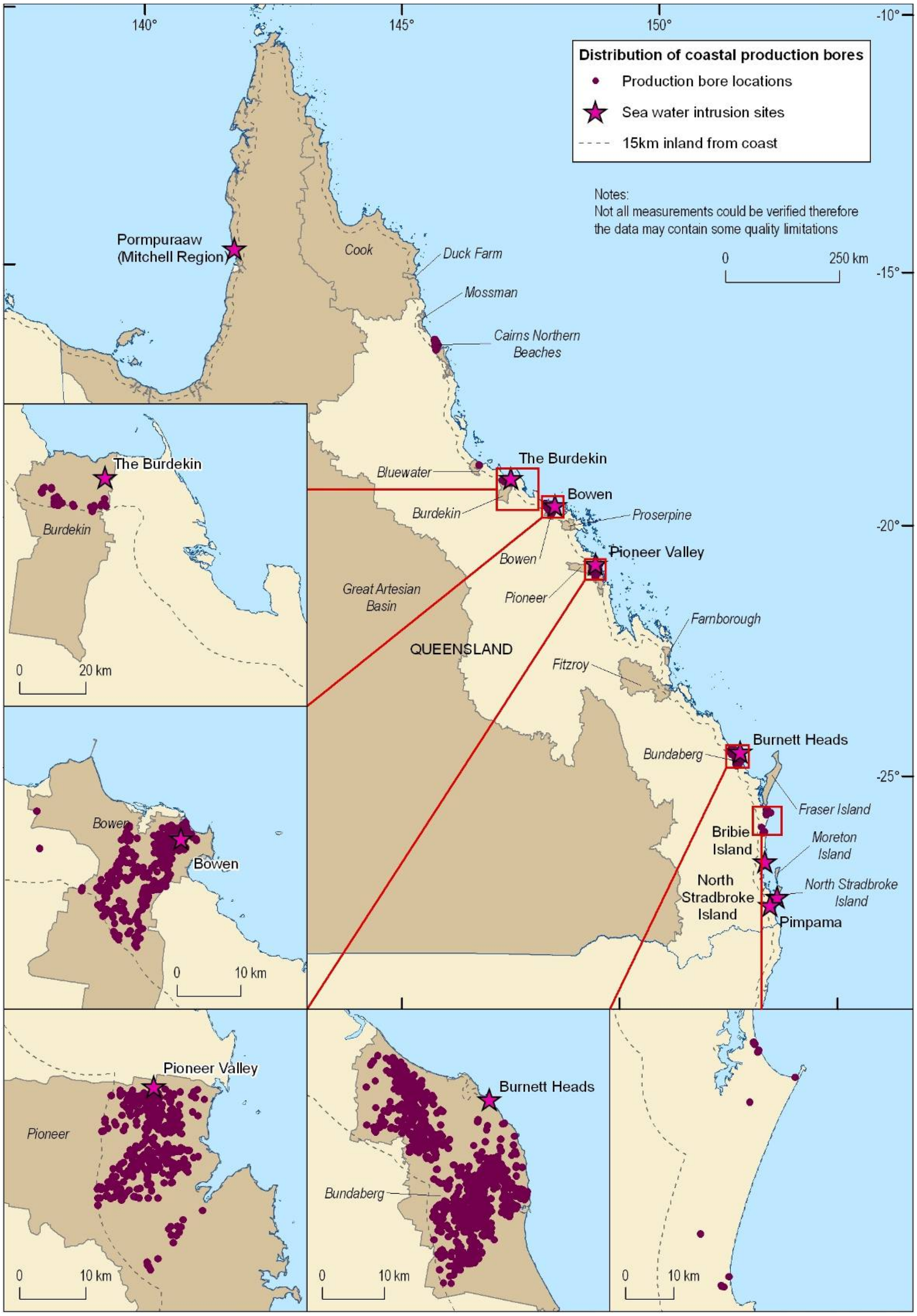


Figure 47 *Distribution of recorded production bores, Qld.*

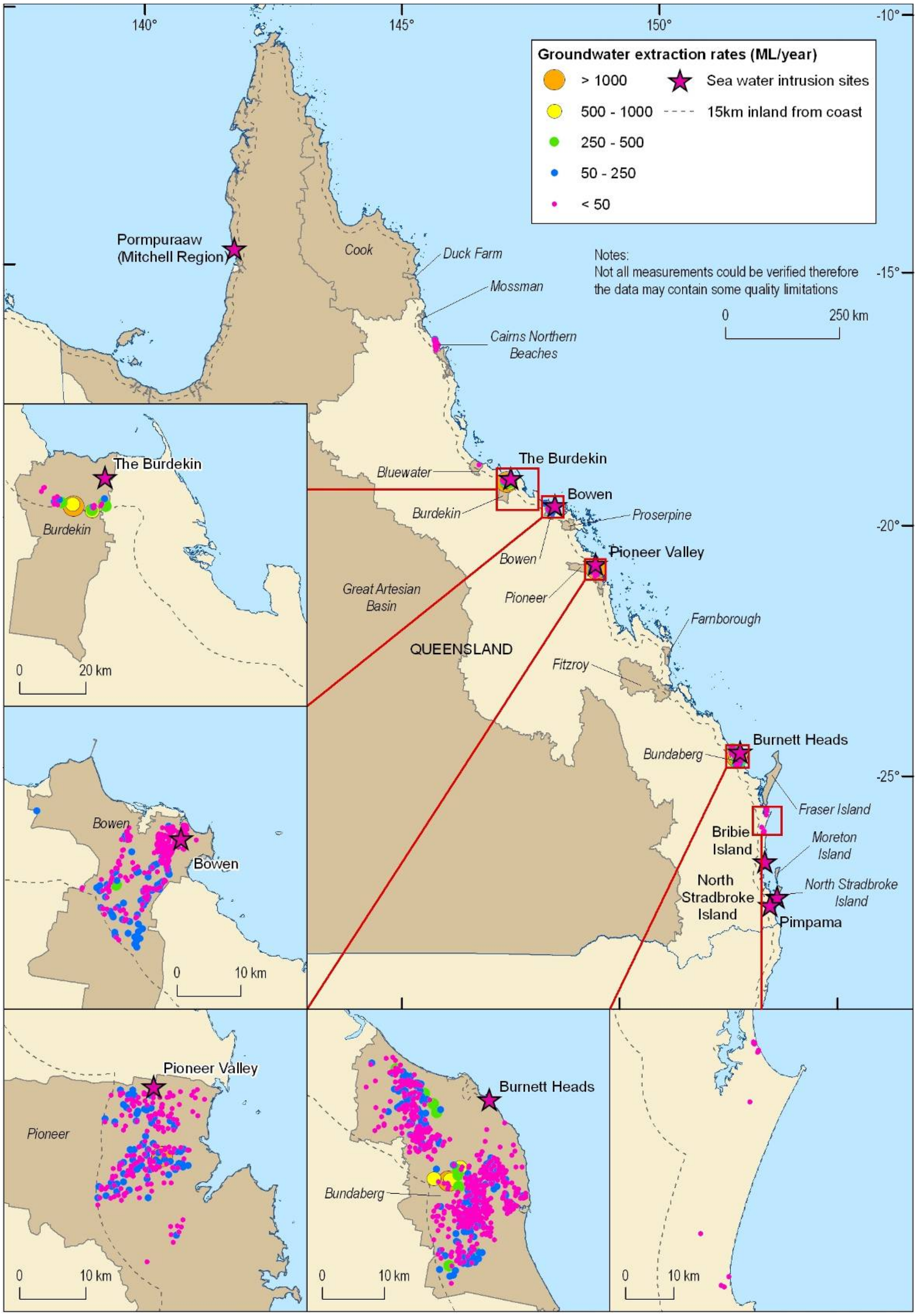


Figure 48 *Groundwater extraction rates for the 2009-2010 financial year, Qld (source: DERM).*

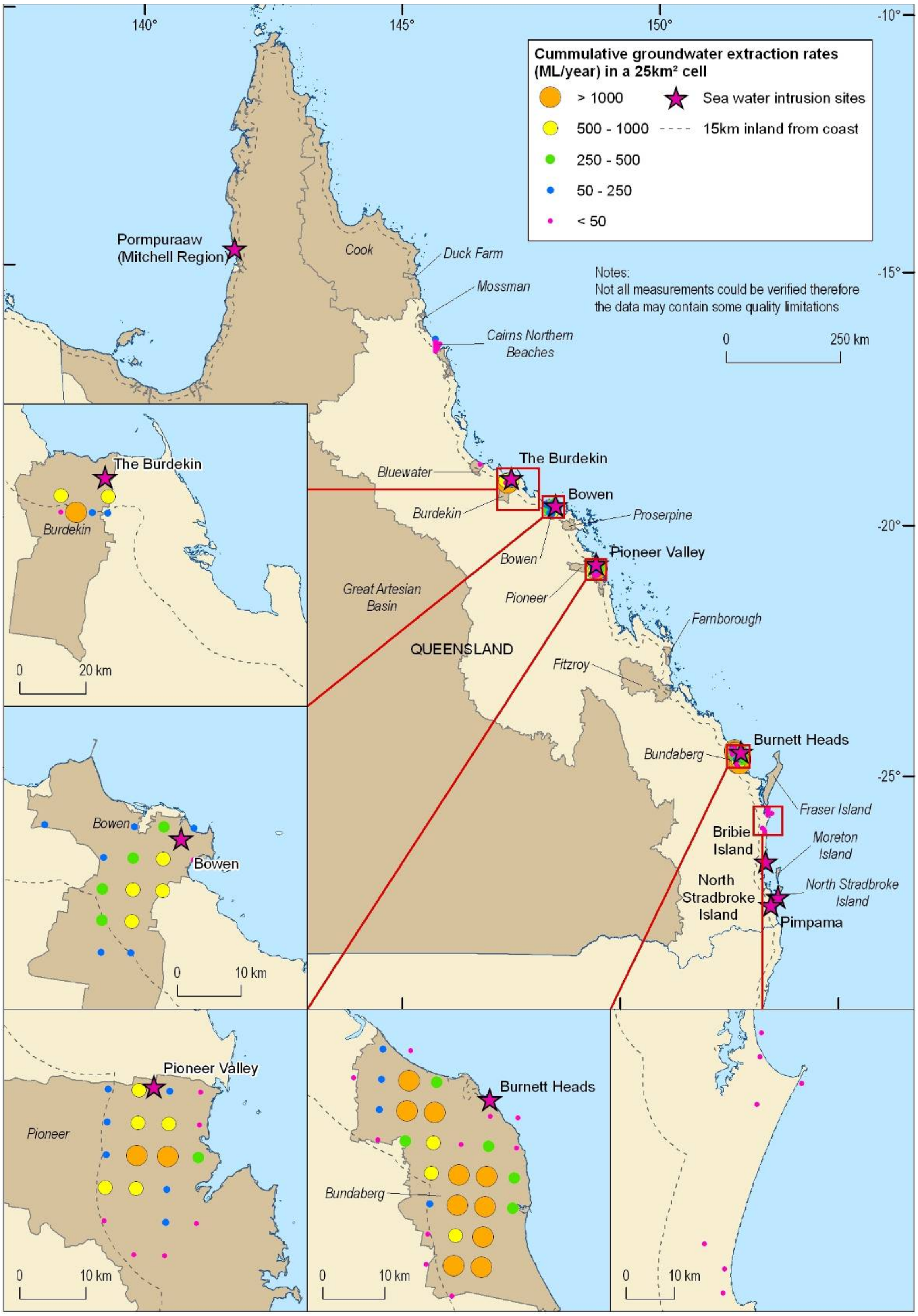


Figure 49 *Cumulative groundwater extraction rates within 5x5 km grid cells, Qld.*

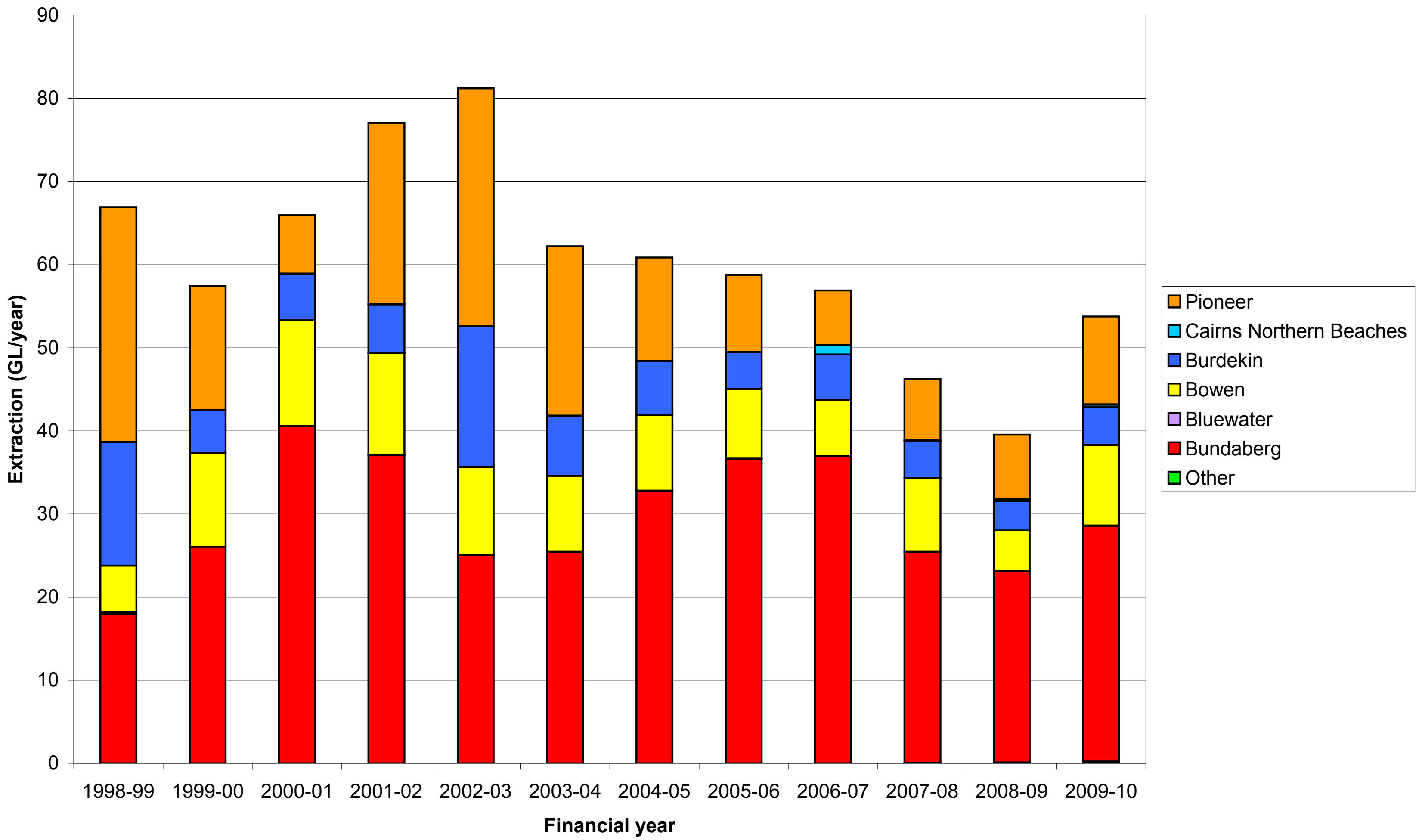


Figure 50 *Annual groundwater extraction (GL/year) within 15 km of the coast in each GMA for Qld (source: DERM)*

Table 16 *Summary of extraction and sustainable yield (SY) data, Qld*

GMA	AWR 2005 2004-2005 Extraction† (ML/yr)	AWR 2005 SY† (ML/yr)	2009-2010 Extraction within 15 km of coast* (ML/yr)	AWR 2005 Groundwater use relative to SY	2010-2011 Extraction within 15 km relative to SY
Bluewater	7000	6000	6.4	117%	0%
Bowen	16 322	20 000	9696.9	82%	48%
Bundaberg	29 023	40 000	28 390	73%	71%
Burdekin	108 303	-	4621.39	-	-
Cairns Coast**	7000	33 200	-	21%	-
Cairns Northern Beaches	7000	33 200	265.94	21%	1%
Cook	-	-	-	-	-
Duck Farm	-	-	-	-	-
Farnborough**	-	1000	-	-	-
Fitzroy	-	-	-	-	-
Fraser Island	-	-	-	-	-
Great Artesian Basin	-	-	-	-	-
Moreton Island	500	-	-	-	-
Mossman	-	-	-	-	-
North Stradbroke Island	11290	30000	-	38%	-
Pioneer	22008	60000	10558.7	37%	18%
Proserpine	-	19600	-	-	-

†Source: AWR (2006) for GMUs, noting that the GMU boundaries differ from GMA boundaries as indicated in the table.

*Source: available extraction data from DERM.

**GMA boundary supplied by DERM differs substantially from AWR (2006).

- = no data

*__Table 17__ Summary of VFA indicators by GMA for Queensland (State VFA Priority GMAs are indicated by *)*

GMA	SWI Sites	Groundwater Levels				Groundwater Salinity (TDS Concentration in mg/L)		
		Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS <3000 within 1 km >10,000		TDS conc. changes
		2000-2009	Pre 2000	Inter-decadal decline >2.5 m	Declining trend >0.5 m/yr	Pre 2000	2000-2009	Inter-decadal increase >1000
Bluewater		N	Y	N	-	Y	N	Y
*Bowen	Bowen	Y	Y	N	N	Y	Y	Y
*Bundaberg	Burnett Heads	Y	Y	Y	Y	Y	Y	Y
*Burdekin	Burdekin	Y	Y	N	Y	Y	Y	Y
Cairns Coast		N	Y	N	Y	N	Y	N
*Cairns Northern Beaches		Y	Y	N	N	Y	Y	Y
Cook		-	N	-	-	N	N	-
Duck Farm		-	Y	-	Y	Y	N	-
*Farnborough		Y	Y	N	Y	Y	Y	Y
Fitzroy				-	-	N	N	-
Fraser Island		N	N	Y	N	N	N	N
Great Artesian Basin	Pormpuraaw (Mitchell Region)		N	N	-	Y	N	N
Moreton Island				N	-	-	-	-
Mossman		Y	Y	N	-	Y	N	N
North Stradbroke Island	North Stradbroke Island	N	N	Y	Y	N	N	N
*Pioneer	Pioneer Valley	Y	Y	Y	Y	Y	Y	Y
*Proserpine		Y	Y	Y	Y	N	N	Y

8. Vulnerability Factor Analysis Results: New South Wales

Groundwater Management Areas (GMAs) are defined in NSW relating to Water Sharing Plans. The GMAs delineate aquifers approved under the *Water Management Act 2000*. The boundaries of these GMAs were provided by the NSW Office of Water and are shown on Figure 51 below.

The total area of each GMA and the proportion of each GMA lying within 15 km of the coastline are provided in Table 18 which also indicates which of the NSW GMAs coincide with the GMUs defined in AWR (2006). There are 13 GMAs in NSW that are wholly or partially within 15 km of the coast. A total of three GMAs had more than 90% of their total areas within 15 km of the coastline, suggesting that SWI vulnerability may be highly relevant to their overall management. The VFA results are discussed below and reported on the basis of GMAs in summary form in Section 8.5.

Table 19 provides details of the number of measurements collected and analysed for the VFA in NSW.

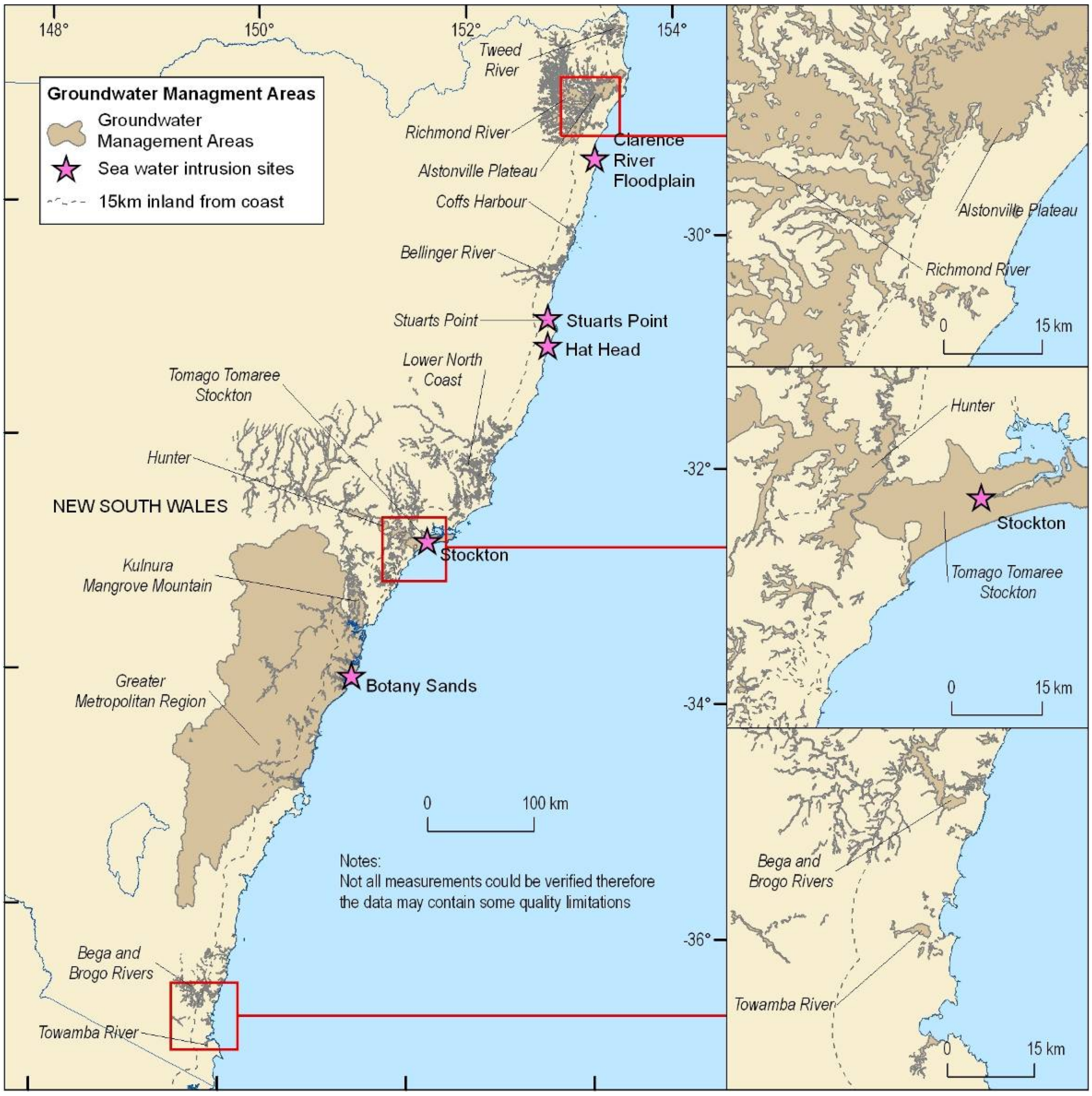


Figure 51 *GMAs in NSW that intersect the 15 km coastal buffer zone.*

Table 18 *Total NSW GMA areas that are wholly or partially within 15 km of the coast and percentage of total GMA areas within 15 km of the coast*

GMA Name	Total GMA Area (Hectares)**	Percentage of GMA Within 15 km of Coast
Coffs Harbour	6,405	100
Stuarts Point*	1,477	100
Tomago Tomaree Stockton*	37,496	99
Towamba River	2,405	73
Alstonville Plateau*	37,697	66
Bega and Brogo Rivers	12,573	59
Kulnura Mangrove Mountain*	48,179	59
Tweed River	14,602	51

GMA Name	Total GMA Area (Hectares)**	Percentage of GMA Within 15 km of Coast
Bellinger River	7,355	49
Lower North Coast	63,989	49
Greater Metropolitan Region	3,023,416	12
Hunter	158,213	12
Richmond River*	158,198	2

*Generally matches AWR 2006 GMU

**Areas calculated based on the GDA1994 datum using a Lambert Conformal Conic Projection

Table 19 *Groundwater data utilised in the VFA for NSW*

Data Type	Data Subset	No. of Measurements
Groundwater levels	All relative standing water levels	109,213
	Minimum RSWL (all years)	228
	Minimum RSWL Pre 2000	157
	Minimum RSWL 2000–2009	95
	Calculations of inter-decadal change in minimum RSWL from 1990-99 to 2000-09	31
	Groundwater linear trend analyses	15
Groundwater salinity	All salinity measurements	40,227
	Maximum TDS (all years)	1,192
	Maximum TDS Pre 2000	990
	Maximum TDS 2000–2009	184
	Calculations of inter-decadal change in maximum TDS from 1990-99 to 2000-09	11
Groundwater extraction	Bores with annual usage volumes in recent years used in analysis	0*

*Annual usage volumes not available at the time of analysis

8.1. Groundwater Level Analysis

8.1.1. Minimum groundwater levels

Minimum groundwater levels measured in NSW within 15 km of the coast are presented on Figure 52 and Figure 53. Groundwater level data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data below.

8.1.1.1. Historical minimum groundwater levels

Minimum groundwater levels reported in monitoring wells prior to 2000 are shown on Figure 52. Several areas along the NSW coast contained groundwater level measurements for this period <0 m AHD, including the area between Ballina and Evans Head, southwest of Port Macquarie, in the Taree area, southwest of Myall Lake, Botany, Bodalla and Bega.

8.1.1.2. Minimum groundwater levels, 2000–2009

Minimum groundwater levels reported in monitoring wells for the period 2000-2009 are presented on Figure 53. Areas showing minimum groundwater levels <0 m AHD include the area between Ballina and Evans Head, Stuarts Point, Taree, southwest of Myall Lake and Bega. The distribution of these water levels relative to the coastline is discussed in Section 8.1.4 below.

8.1.2. Groundwater level changes

Changes in groundwater levels over time are plotted on Figure 54 (inter-decadal decline in minimum groundwater levels from 1990-1999 to 2000-2009) and Figure 55 (linear trends in groundwater levels) and discussed below.

8.1.2.1. Inter-decadal changes in minimum groundwater levels

Available data limited the calculation of inter-decadal changes in minimum groundwater levels to relatively few areas in NSW as shown on Figure 54. Although some locations showed an increase in minimum groundwater level between decades, most areas showed decreases where data were available. Inter-decadal declines in minimum groundwater levels >2.5 m were measured in Botany while all other declines measured were <2.5 m in magnitude.

8.1.2.2. Groundwater level trends

Figure 55 shows that no decreasing groundwater level trends >0.5 m/year were identified in NSW. As per the inter-decadal groundwater level analysis above, data in this regard were limited. Some increasing trends were noted in Taree, Botany and Bodalla, while decreasing trends between 0 and 0.25 m/year were identified near Ballina and between 0.25 and 0.5 m/year in Bega.

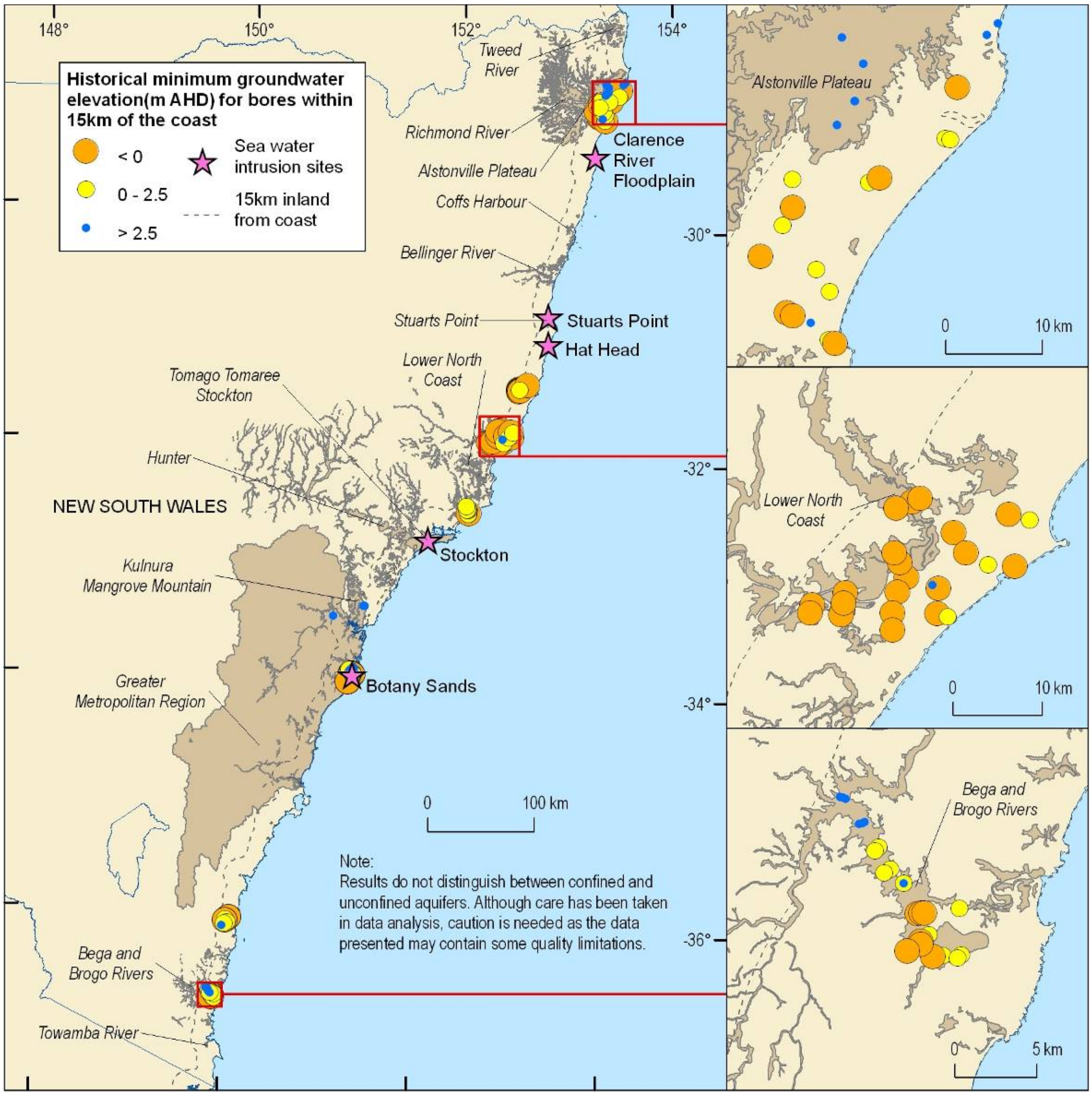


Figure 52 *Historical minimum groundwater levels measured prior to 2000, NSW.*

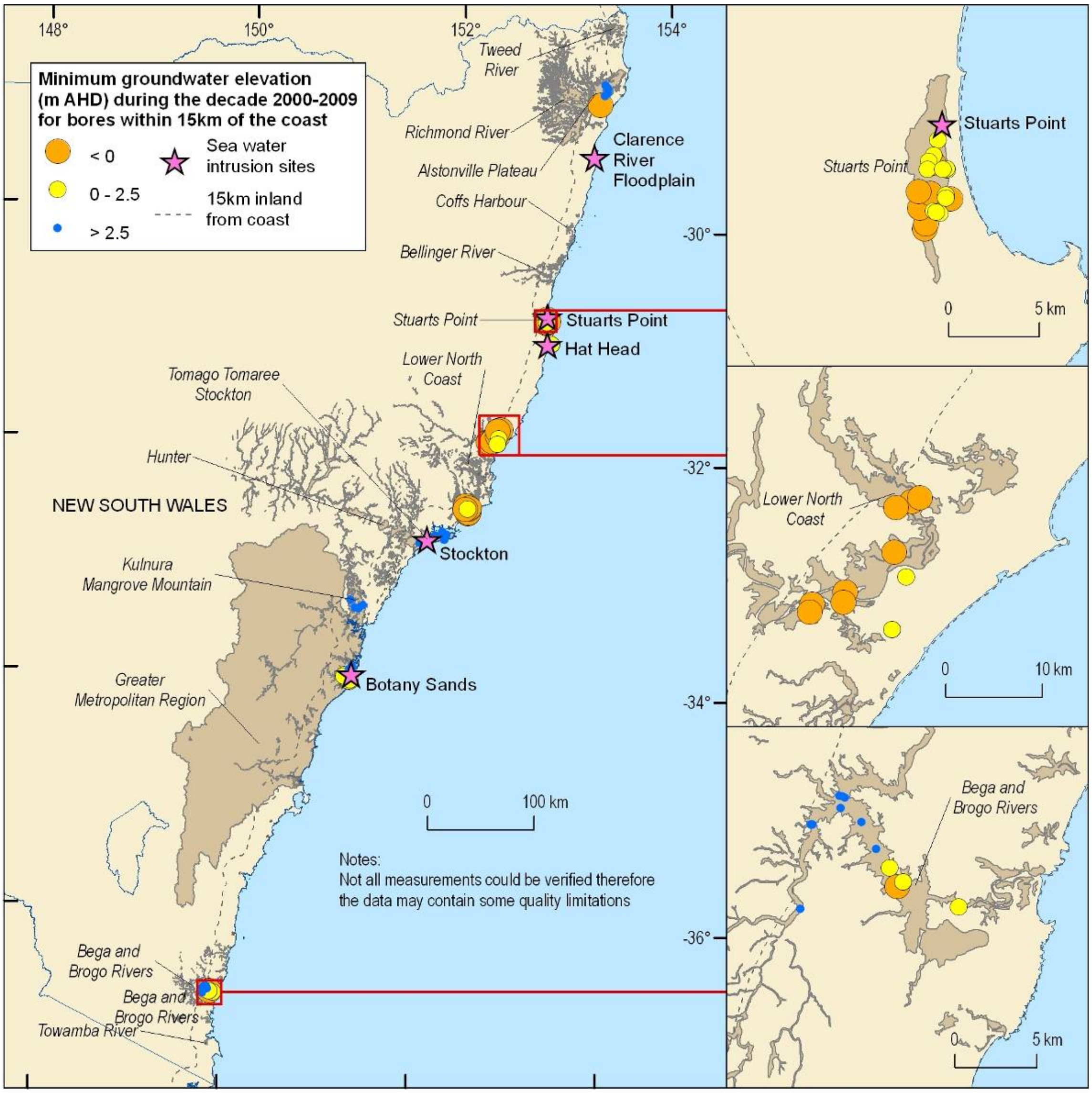


Figure 53 *Minimum groundwater levels measured in the period 2000-2009, NSW.*

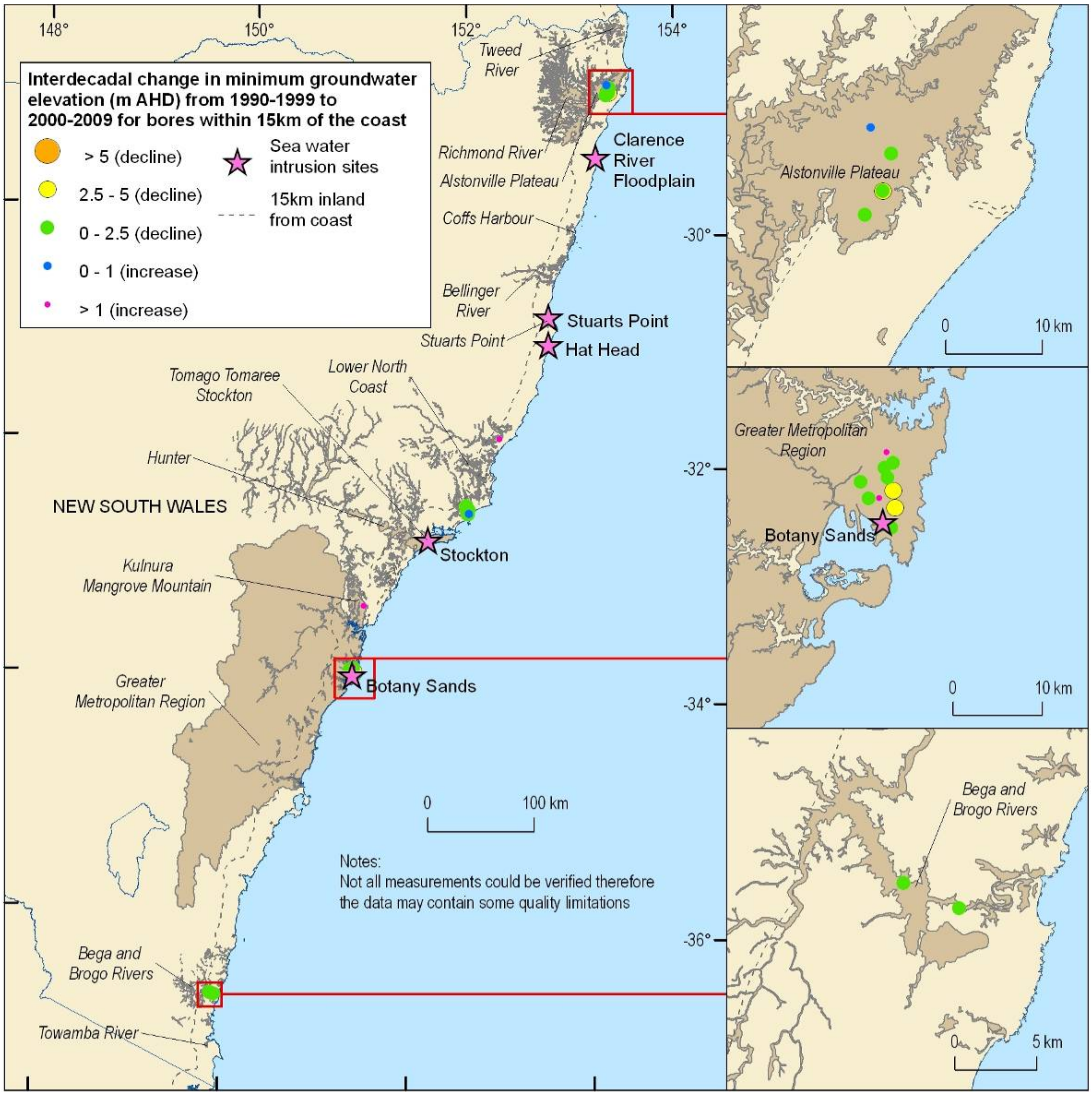


Figure 54 *Inter-decadal changes in minimum groundwater levels from 1990-1999 to 2000-2009, NSW.*

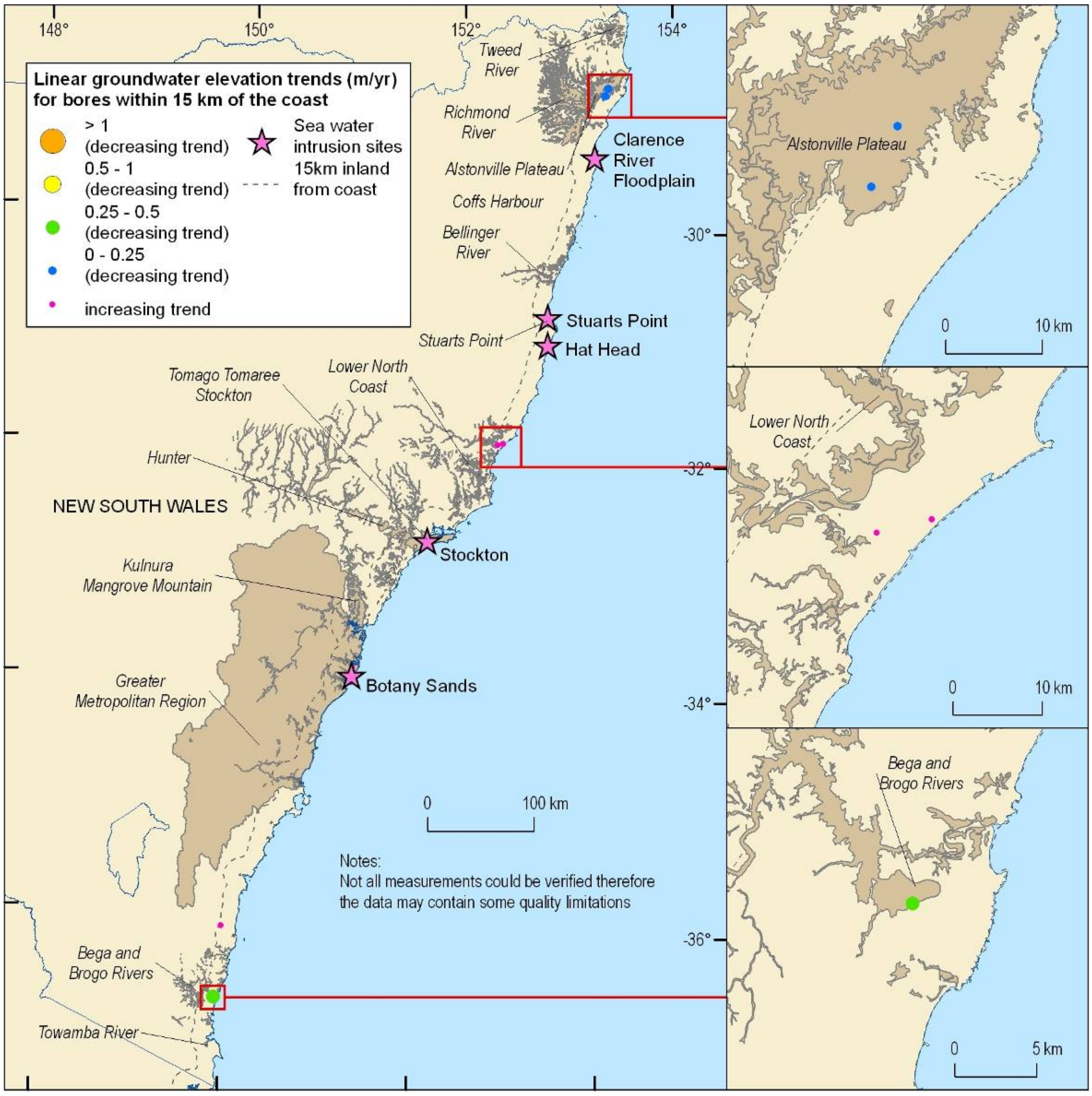


Figure 55 *Linear groundwater level trends in NSW.*

8.1.3. Summary of groundwater level SWI vulnerability indicators

Figure 56 shows the high SWI vulnerability indicator categories for each of the groundwater level parameters presented in above. Only low minimum groundwater levels were encountered in the highest vulnerability categories. Their distribution has been described previously in Sections 8.1.1.1 and 8.1.1.2.

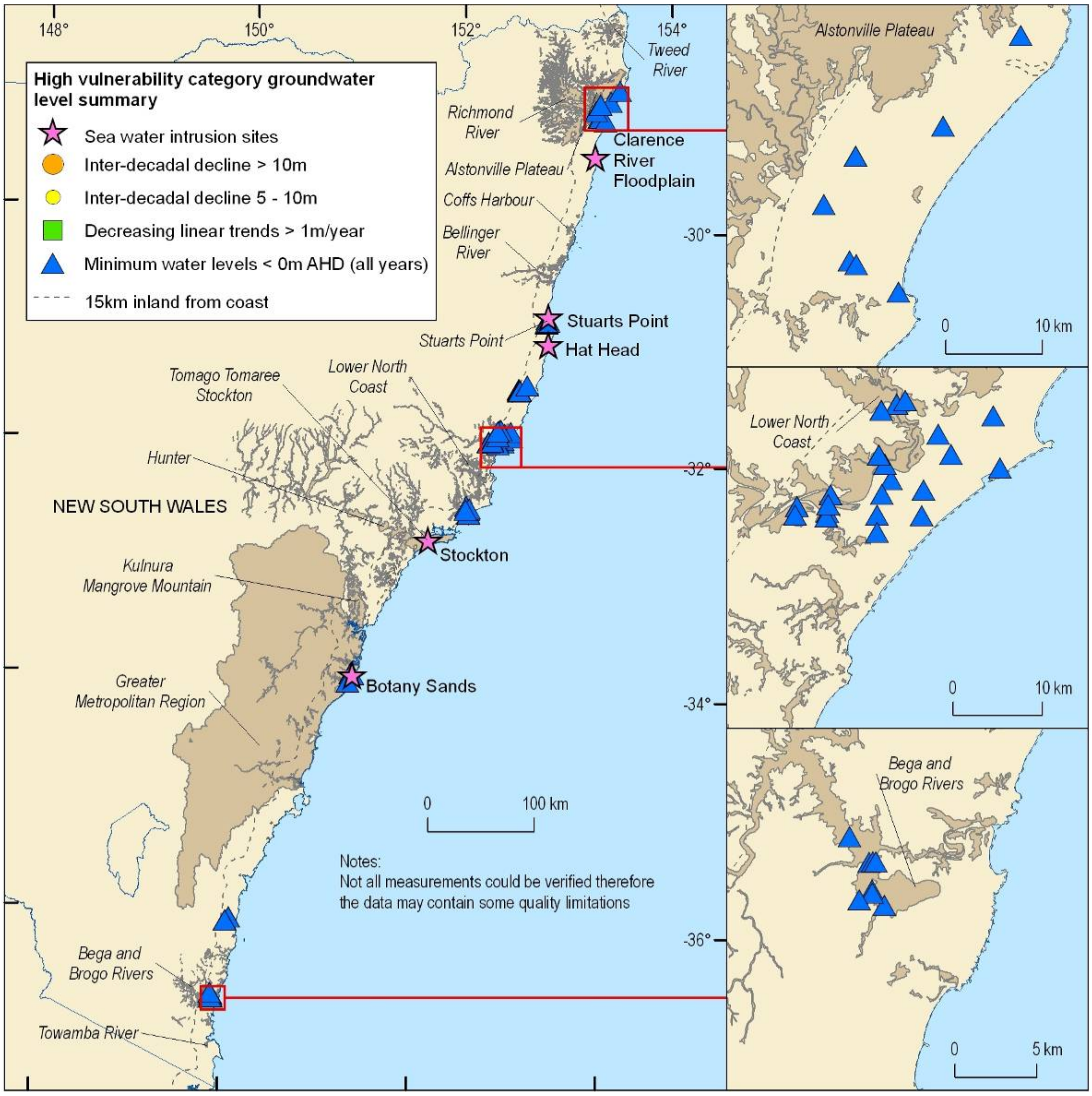


Figure 56 *Summary of groundwater level indicators of high SWI vulnerability, NSW.*

8.1.4. Spatial distribution of low groundwater level observations

The maximum distances that groundwater levels <0 m AHD and <2.5 m AHD extend inland from the coast are presented for each GMA in Table 20. SWI may be anticipated to extend further inland in areas where low groundwater levels extend further from the coast. Minimum groundwater levels below 0 m AHD were measured further inland than 10 km only in the Lower North Coast GMA. Although whether SWI occurs is dependent on many other factors in addition to groundwater levels, if SWI does occur in this area groundwater level distributions may be such that SWI could extend a considerable distance inland if not appropriately managed.

The boundaries of some GMAs do not extend far inland from the coast thus Table 20 should be considered in conjunction with Figure 51 if assessing potential impacts to individual GMAs rather than total distance from the coast.

Minimum water levels for the entire monitoring period (historic and recent) in each monitoring bore are plotted against distance from the coast in Appendix 2 for each GMA.

Table 20 *Maximum inland extent within 15 km of the coast of minimum groundwater levels <0 m AHD and <2.5 m AHD based on 2000-2009 monitoring data reported for NSW GMAs*

GMA	Maximum Inland Distance of <0 m AHD Groundwater Levels (km)	Maximum Inland Distance <2.5 m AHD Groundwater Levels (km)
Alstonville Plateau	All levels > 0m AHD	All levels > 2.5m AHD
Bega and Brogo Rivers	8.65	9.30
Bellinger River	No elevation data	No elevation data
Coffs Harbour	No elevation data	No elevation data
Greater Metropolitan Region	All levels > 0m AHD	1.46
Hunter	No elevation data	No elevation data
Kulnura Mangrove Mountain	All levels > 0m AHD	All levels > 2.5m AHD
Lower North Coast	12.40*	12.40*
Richmond River	No elevation data	No elevation data
Stuarts Point	3.09*	3.09*
Tomago Tomaree Stockton	All levels > 0m AHD	All levels > 2.5m AHD
Towamba River	No elevation data	No elevation data
Tweed River	No elevation data	No elevation data
OTHER (non GMA)	12.82*	12.82*

*Furthest inland water level measurement. Low water levels may extend further inland.

8.2. Rainfall Trend Analysis

Plots of cumulative deviation of monthly rainfall data from long term averages are included in Appendix 3 for locations near the SWI sites and summarised for NSW on Figure 57 for the period 2000-2009. Besides Stuarts Point where rainfall was relatively stable, all other locations where rainfall data have been assessed on Figure 57 have shown a decline in rainfall over this period. Although additional groundwater pressures may be anticipated where rainfall has decreased, drought around the country has eased in 2010 and 2011 (visible on the plots in Appendix 3), and a reversal in rainfall trends is evident in some areas. The rainfall trends on Figure 57 may therefore not remain good indicators of vulnerability and should be updated in future assessments.

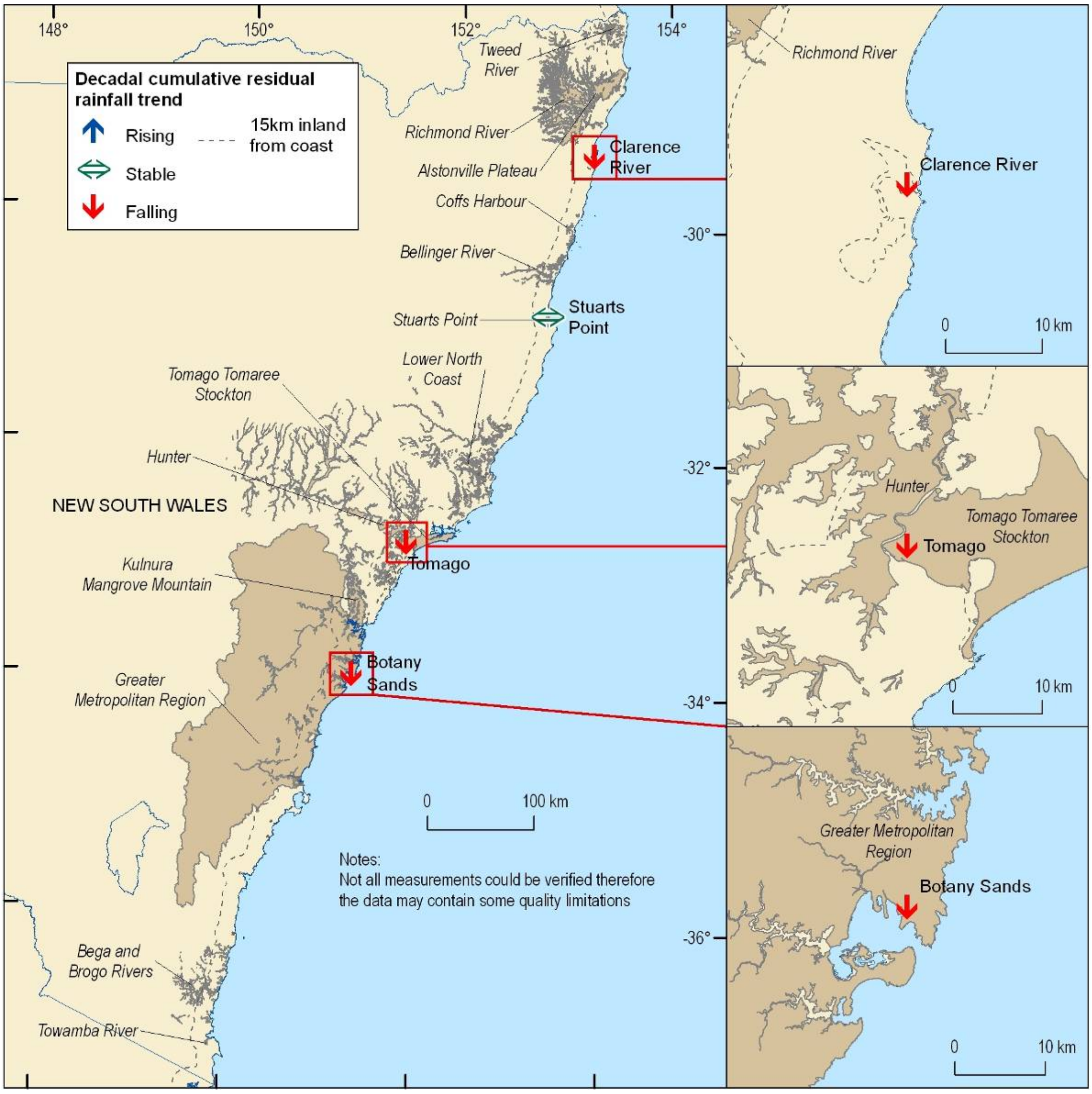


Figure 57 *Trends in cumulative deviation of monthly rainfall from long term averages for the period 2000-2009, NSW.*

8.3. Groundwater Salinity

8.3.1. Maximum salinity measurements

Groundwater salinity data for NSW are presented on Figure 58 and Figure 59. Data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data below to highlight areas that have recently shown groundwater salinity indicators of SWI vulnerability.

8.3.1.1. Historical maximum salinity measurements

Historical maximum TDS concentrations are shown on Figure 58. Groundwater with TDS concentrations <3000 mg/L has been identified in many places along the NSW coast suggesting that many coastal groundwater resources are suitable for a wide range of uses. Areas where groundwater with maximum TDS concentrations <3000 mg/L is located near groundwater with maximum TDS concentrations >10,000 mg/L are also common and may indicate higher potential for intrusion of high salinity water into freshwater resources. These are reported for each GMA in Section 8.5.

8.3.1.2. Maximum salinity measurements, 2000-2009

Maximum TDS concentrations measured during the period 2000-2009 are shown on Figure 45. Although the data show a similar spatial distribution to the historic measurements, a smaller proportion of lower salinity groundwater measurements appear to have been recorded over the recent decade in places. It is difficult to assess the significance of such changes since they are likely to be influenced by the number and location of monitoring points between the different time periods. Section 8.3.2 provides a more appropriate assessment of inter-decadal changes in salinity measurements.

8.3.2. Inter-decadal changes in maximum salinity measurements

Changes in maximum TDS concentrations between the decades 1990-1999 and 2000-2009 are shown on Figure 60. Inter-decadal changes could only be calculated in relatively few areas based on available data due to a lack of ongoing monitoring at the same locations between decades. Data were only available to the south of Stuarts Point (showing an increase in TDS concentration in the 0-1000 mg/L range) and in the Myall Lakes area (changes ranged from decreases in TDS concentrations to increases in the 1000-3000 mg/L category).

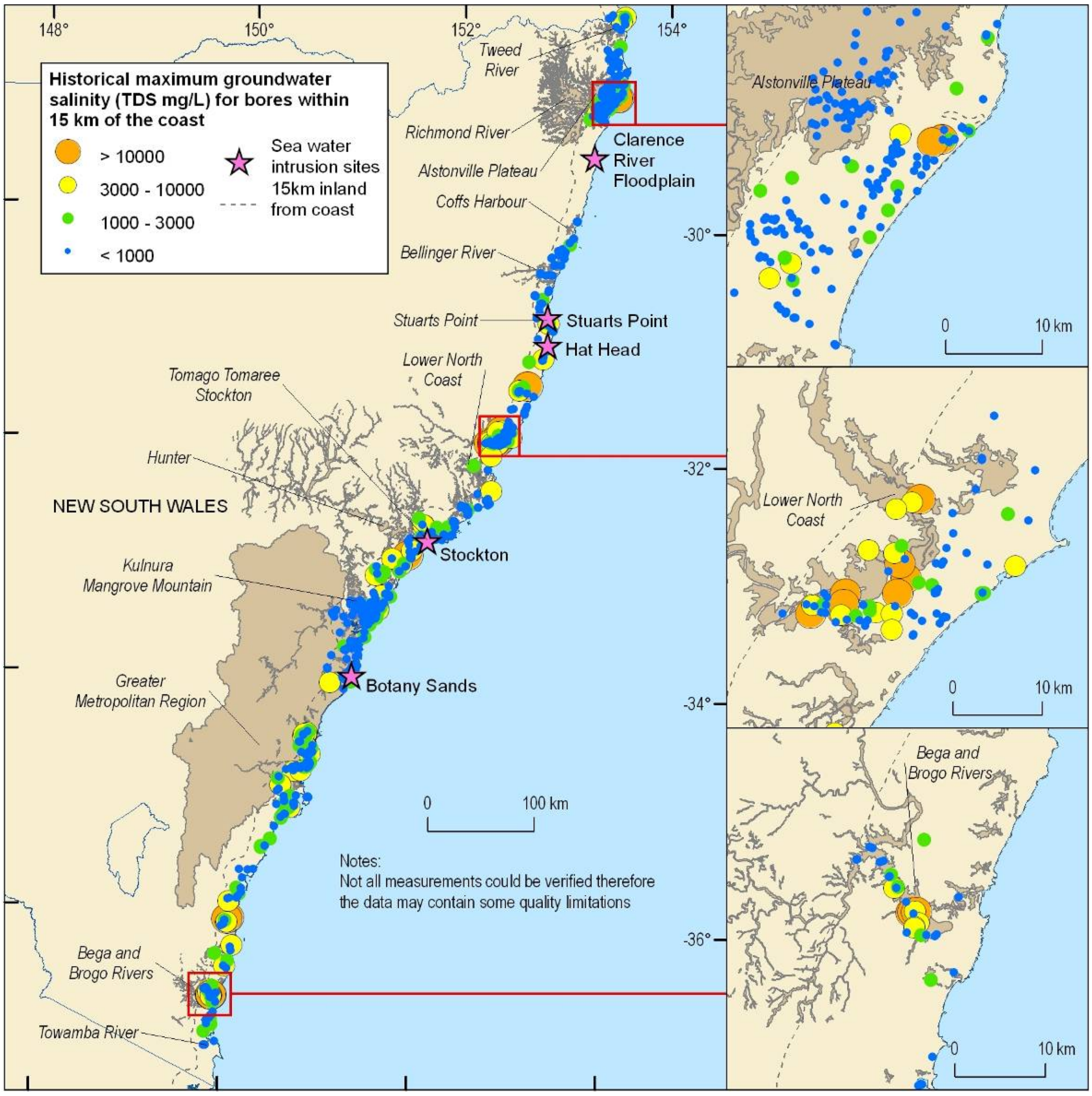


Figure 58 *Historical maximum TDS concentrations measured prior to 2000, NSW.*

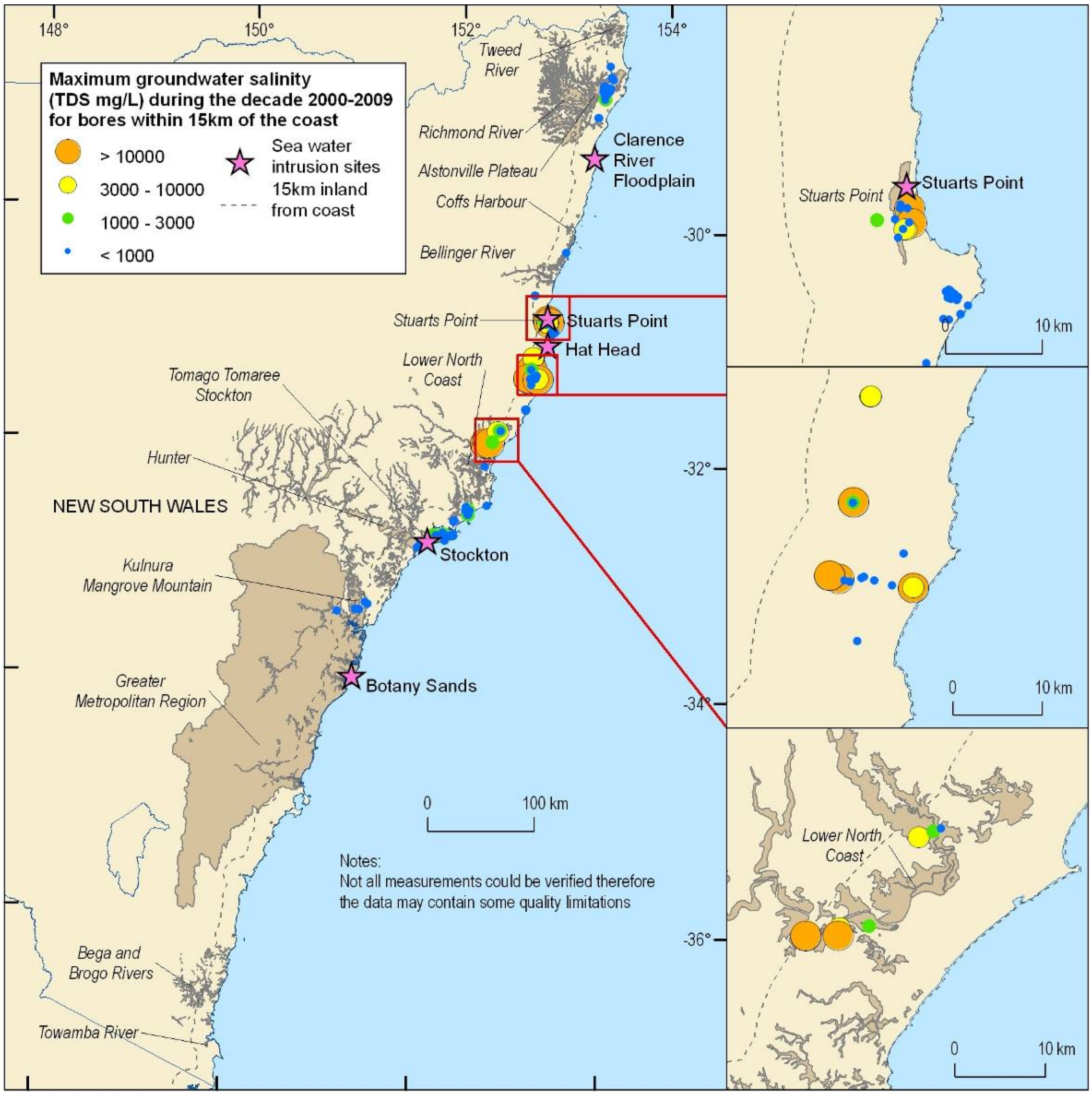


Figure 59 *Maximum TDS concentrations for the period 2000-2009, NSW.*

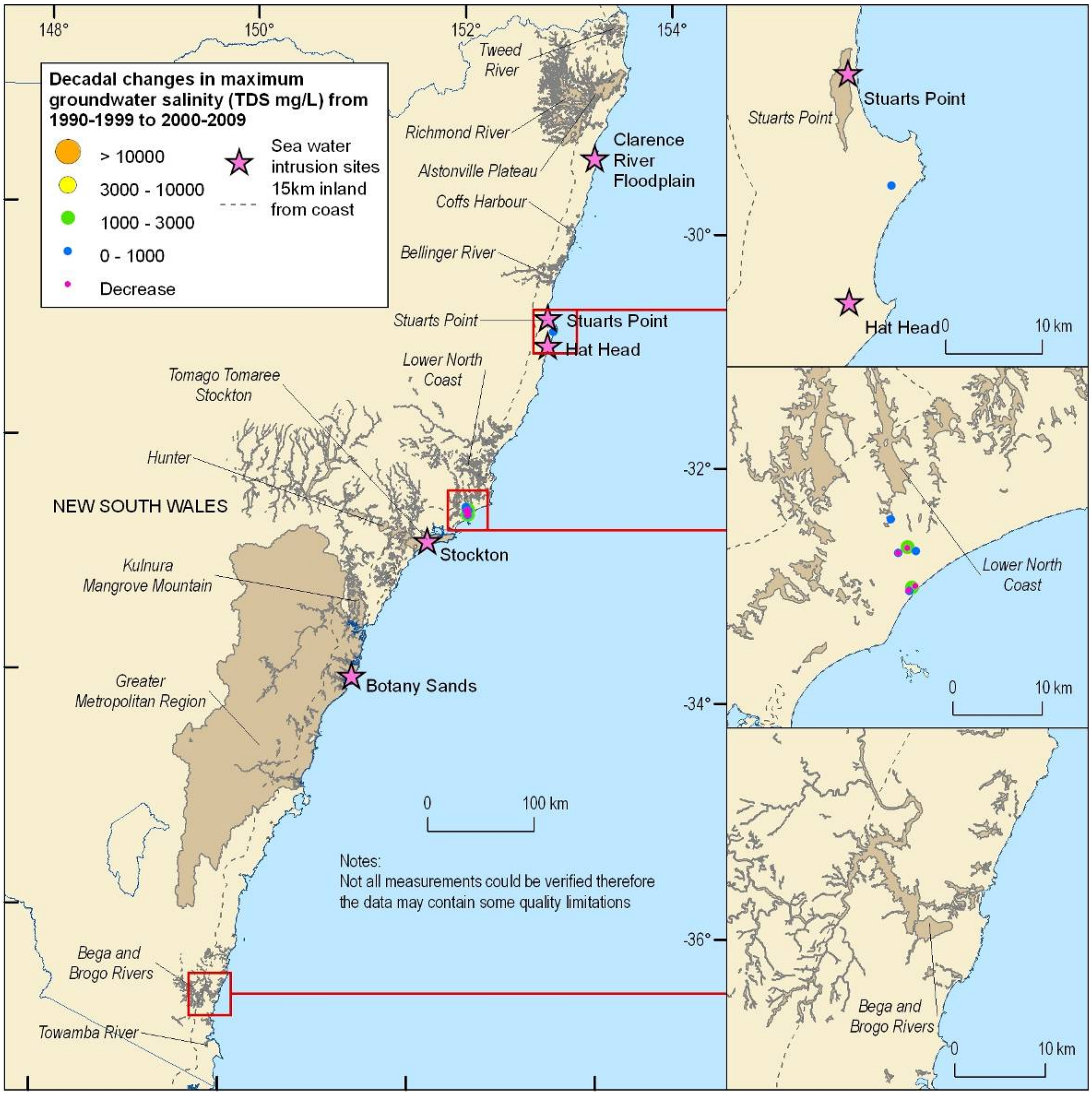


***Figure 60** Inter-decadal change in maximum TDS concentrations from 1990-1999 to 2000-2009, NSW.*

8.4. Groundwater Extraction

8.4.1. Distribution of production bores

The locations of recorded production bores were not made available for NSW during this project thus their distributions could not be assessed.

8.4.2. Groundwater extraction rates

No groundwater extraction volume data for NSW were made available at the time of preparing this report.

8.5. VFA Summary: New South Wales

The VFA findings for NSW are summarised in Table 21 for each GMA. Only limited groundwater data were available for NSW for consideration in the VFA and consequently it is difficult to draw conclusions on the likelihood of SWI along the NSW coast. As further data become available, their incorporation into the dataset and analysis following the methods presented above will provide useful indications of potential for high SWI vulnerability.

No state VFA priority GMAs could be defined for NSW following the approach outlined for WA in Section 5.5 due to these data limitations. It is noted that outside of the GMAs there are indicators of SWI vulnerability which are not captured in this summary.

Table 21 *Summary of VFA indicators by GMA for New South Wales*

GMA	SWI Sites	Groundwater Levels				Groundwater Salinity (TDS Concentration in mg/L)		
		Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS <3000 within 1 km >10,000		TDS conc. changes
		2000-2009	Pre 2000	Inter-decadal decline >2.5 m	Declining trend >0.5 m/yr	Pre 2000	2000-2009	Inter-decadal increase >1000
Alstonville Plateau		N	N	Y	N	N	N	N
Bega and Brogo Rivers		Y	Y	N	N	Y	-	-
Bellinger River		-	-	-	-	N	-	-
Coffs Harbour		-	-	-	-	N	-	-
Greater Metropolitan Region	Botany Sands	N	Y	Y	N	N	N	-
Hunter		-	-	-	-	N	-	-
Kulnura Mangrove Mountain		N	N	N	-	N	N	-
Lower North Coast		Y	Y	N	-	Y	N	-
Richmond River		-	-	-	-	N	N	-
Stuarts Point	Stuarts Point	Y	-	-	-	N	Y	-
Tomago Tomaree Stockton	Stockton	N	-	-	-	N	N	-
Towamba River		-	-	-	-	N	-	-
Tweed River		-	-	-	-	N	-	-

9. Vulnerability Factor Analysis Results: Victoria

In Vic, groundwater management is undertaken based on defined Groundwater Management Areas and Water Supply Protection Areas. Both types of regulatory units are collectively termed GMAs below. Data analysis in Vic is complicated since some GMAs refer to specific aquifer units and therefore overlap in places. When possible, bores and their associated measurements have been allocated to a GMA in the following analyses based on borehole depth. If an observation bore could not be associated with a particular GMA based on depth, its associated readings were allocated to all overlapping GMAs at its geographical location.

The GMA boundaries are shown on Figure 61. GMAs that overlap include Wy Yung with Stratford, Yarram with Giffard, Glenelg with SA/Vic Border, Stratford with Sale and Portland with Hawkesdale, Heywood, Yangery and Glenelg.

The total area of each GMA and the proportion of each GMA lying within 15 km of the coastline are provided in Table 22 which also indicates which of the Vic GMAs coincide with the GMUs defined in AWR (2006) . There are 26 GMAs in Vic partially or wholly within 15 km of the coast and 24 contained data for consideration in this state assessment. A total of 11 GMAs had more than 90% of their total areas within 15 km of the coastline, suggesting that SWI vulnerability may be highly relevant to their overall management. The VFA results for Vic are reported in the following sections and summarised on the basis of GMAs in Section 9.5.

Details of the number of measurements collected and analysed for the VFA in WA are provided in Table 23.

9.1. Groundwater Level Analysis

9.1.1. Minimum groundwater levels

Minimum groundwater levels measured in Vic within 15 km of the coast are presented on Figure 62 and Figure 63. Groundwater level data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data below.

9.1.1.1. Historical minimum groundwater levels

Minimum groundwater levels reported in monitoring wells prior to 2000 are summarised on Figure 62. Minimum water levels <0 m AHD were relatively common along the Vic coast during this period, with this being the most common minimum groundwater level category encountered. Due to the widespread occurrence of low water levels, individual occurrences are not listed here and Figure 62 should be referred to for their geographical locations. Minimum water level categories identified in each GMA are reported in Section 9.5.

9.1.1.2. Minimum groundwater levels, 2000–2009

Minimum groundwater levels reported in monitoring wells for the period 2000-2009 are summarised on Figure 63. They show a similar distribution to those measured historically and are reported for each GMA in Section 9.5.

9.1.2. Groundwater level changes

Changes in groundwater levels over time are plotted on Figure 64 (inter-decadal decline in minimum groundwater levels from 1990-1999 to 2000-2009) and Figure 65 (linear trends in groundwater levels) and discussed below.

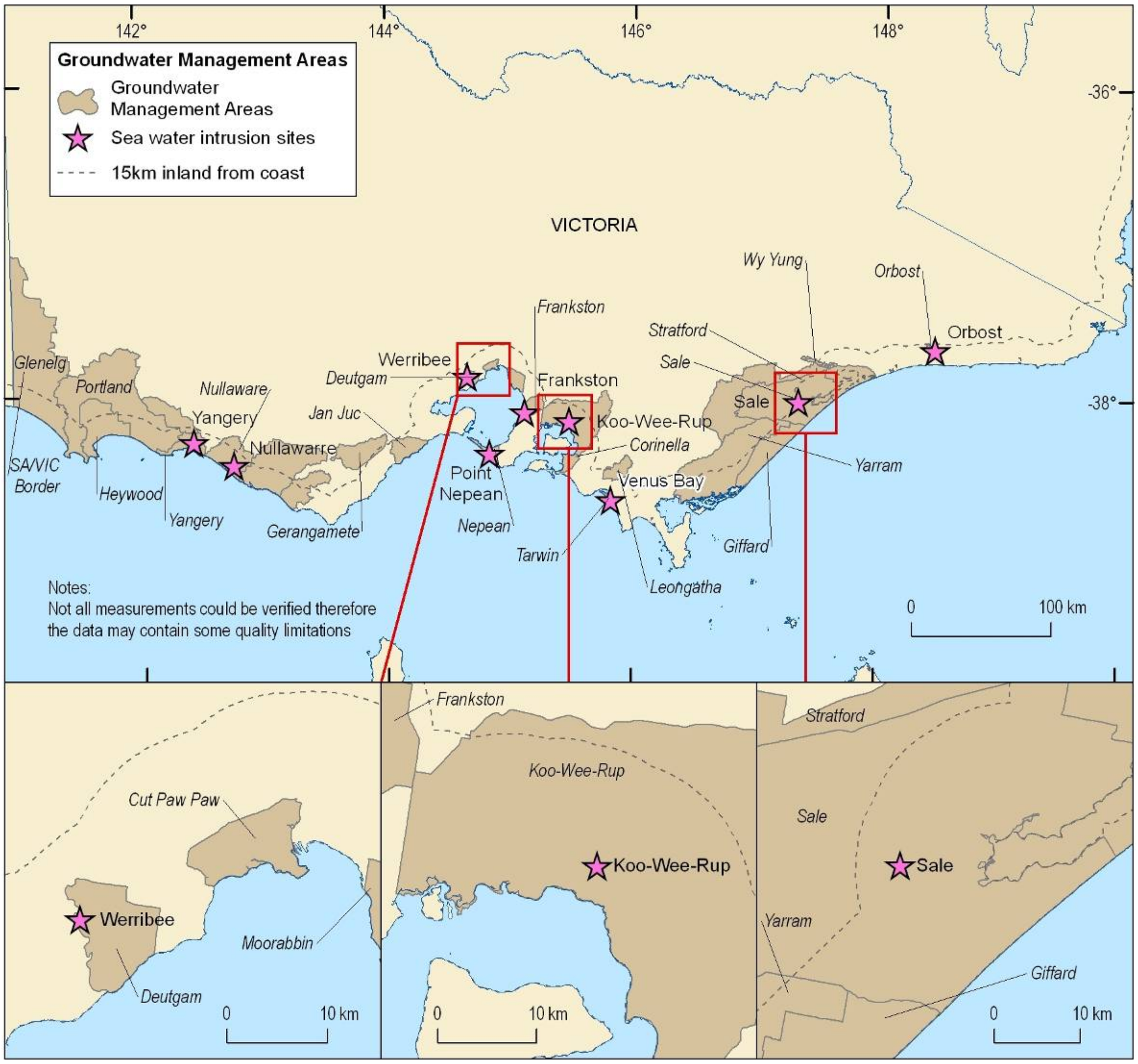


Figure 61 *GMAs in Vic that intersect the 15 km coastal buffer zone.*

Table 22 *Total Vic GMA areas that are wholly or partially within 15 km of the coast and percentage of total GMA areas within 15 km of the coast*

GMA Name	Total GMA Area (Hectares)***	Percentage of GMA Within 15 km of Coast
Corinella	11,195	100
Cut Paw Paw*	5,747	100
Deutgam*	6,588	100
Frankston*	14,431	100
Jan Juc*	29,407	100
Moorabbin*	13,823	100
Orbost*	3,661	100
Yangery*	29,825	100
Giffard*	68,586	99
Nepean*	10,515	99
Tarwin*	3,018	97
Nullawarre*	57,709	73
Heywood*	82,547	66
Koo Wee Rup*	112,951	64
Yarram*	263,514	59
Newlingrook*	45,500	57
Wy Yung*	5,509	46
Sale*	176,166	44
Hawkesdale**	143,335	43
Leongatha*	20,468	41
Portland*	402,684	39
Paaratte*	136,710	37
Stratford	471,234	23
Glenelg*	304,210	22
Sa/Vic Border**	898,246	4
Gerangamete*	49,143	4

*Generally matches AWR (2006) GMU

**GMA does not exist in AWR (2006)

***Areas calculated based on the GDA1994 datum using a Lambert Conformal Conic Projection

__Table 23__ Groundwater data utilised in the VFA for Vic

Data Type	Data Subset	No. of Measurements
Groundwater levels	All relative standing water levels	69,551
	Minimum RSWL (all years)	639
	Minimum RSWL Pre 2000	567
	Minimum RSWL 2000–2009	456
	Calculations of inter-decadal change in minimum RSWL from 1990-99 to 2000-09	383
	Groundwater linear trend analyses	156
Groundwater salinity	All salinity measurements	4,793
	Maximum TDS (all years)	325
	Maximum TDS Pre 2000	189
	Maximum TDS 2000–2009	175
	Calculations of inter-decadal change in maximum TDS from 1990-99 to 2000-09	48
Groundwater extraction	Bores with annual usage volumes in recent years used in analysis	1,099

9.1.2.1. Inter-decadal changes in minimum groundwater levels

It is evident from Figure 64 that many places on the Vic coast experienced inter-decadal declines in minimum groundwater levels with relatively few increases recorded. Large declines >5 m were identified in several places including the areas near Portland, Port Fairy, Torquay, Koo Wee Rup, French Island, Yarram, Sale and Bairnsdale. Declines between 2.5 m and 5 m were also measured in many of these areas and near Werribee. Declines in the 0 – 2.5 m category were common.

9.1.2.2. Groundwater level trends

Figure 65 shows that decreasing groundwater level trends were measured in many areas along the Vic coast with relatively few increasing trends recorded. Trends >1 m/year were identified near Brooklyn, Yarram and Sale, while declining trends in the 0.5-1 m/year category were identified in several other localities including Torquay, east of Brooklyn and west of Yarram.

9.1.3. Summary of groundwater level SWI vulnerability indicators

Figure 66 shows the high SWI vulnerability indicator categories for each of the groundwater level parameters presented in Section 9.1 above. Combinations of boreholes showing low groundwater levels, large inter-decadal declines in groundwater levels and high decreasing trends in groundwater levels were identified in Yarram and Sale.

9.1.4. Spatial distribution of low groundwater level observations

The maximum distances that groundwater levels <0 m AHD and <2.5 m AHD extend inland from the coast are presented for each GMA in Table 24. The data shown are based on minimum groundwater levels measured in boreholes over the decade 2000-2009. SWI may be anticipated to extend further inland in areas where low groundwater levels extend further from the coast. Minimum groundwater levels <0 m AHD were measured further inland than 10 km in the Koo Wee Rup, Orbost, Sale and Yarram GMAs. Although whether SWI occurs is dependent on many other factors in addition to groundwater levels, if SWI does occur in these areas groundwater level distributions may be such that SWI could extend a considerable distance inland if not appropriately managed.

The boundaries of some GMAs do not extend far inland from the coast thus Table 24 should be considered in conjunction with Figure 61 if assessing potential impacts to individual GMAs rather than total distance from the coast.

Minimum water levels for the entire monitoring period (historic and recent) in each monitoring bore are plotted against distance from the coast in Appendix 2 for each GMA. In some GMAs such as Koo Wee Rup, many low water levels have been recorded extending relatively far inland from the coast suggesting that, if SWI were to occur here, groundwater levels may facilitate extensive impacts. In contrast, GMAs such as Moorabbin show a more marked increase in groundwater levels with distance from the coast suggesting that impacts are more likely to be confined to more coastal areas if SWI was to occur there.

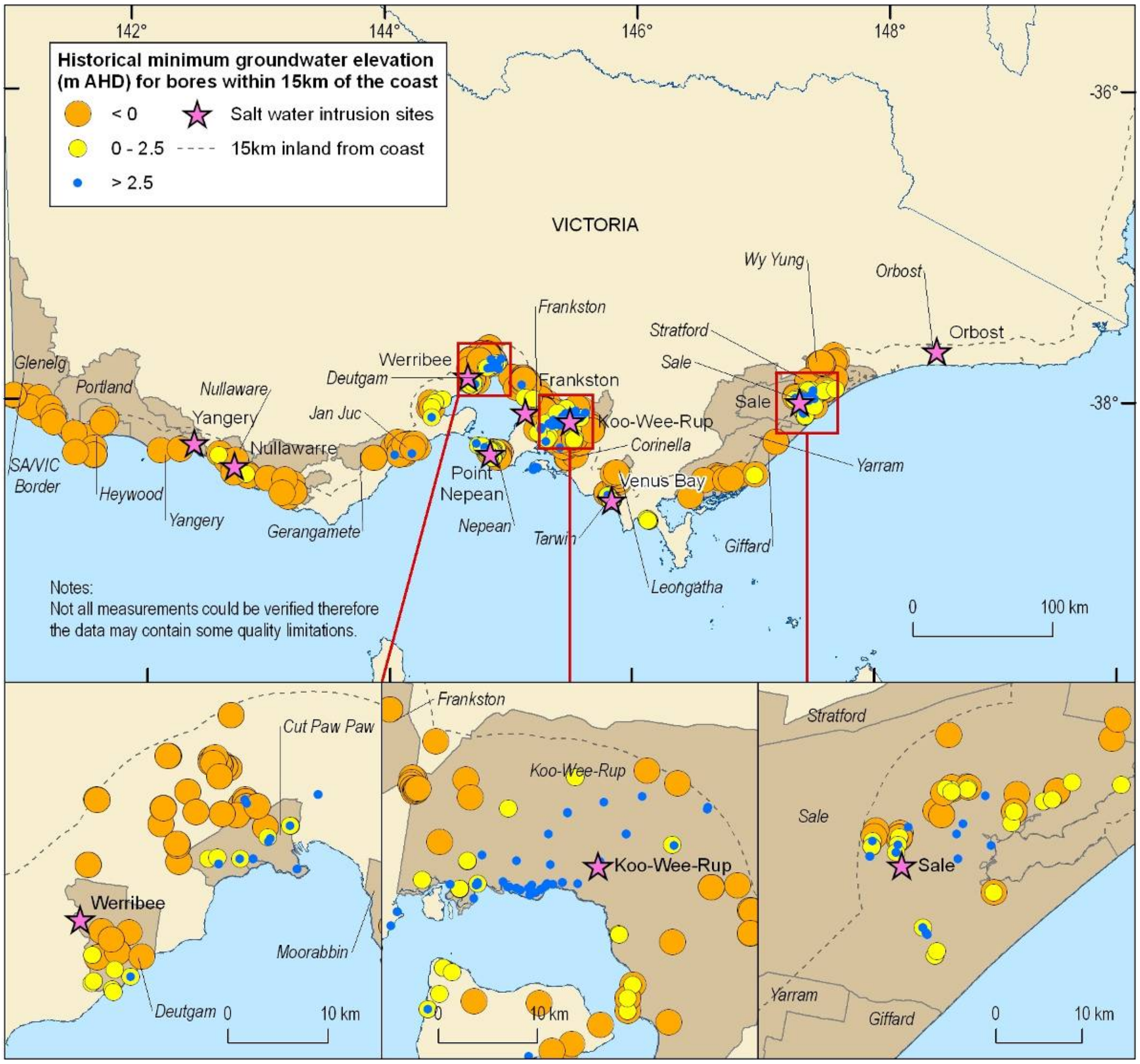


Figure 62 Historical minimum groundwater levels measured prior to 2000, Vic.

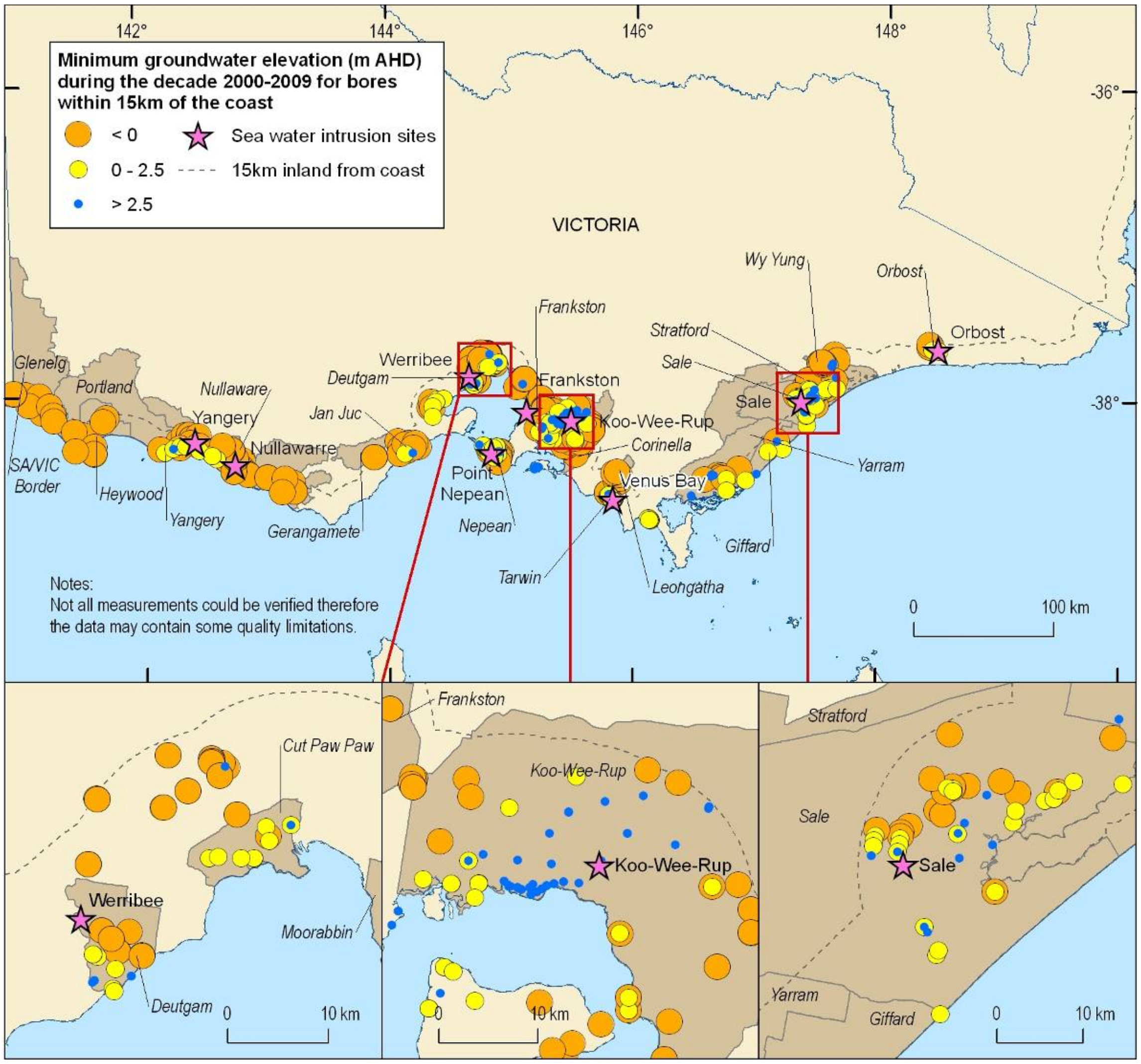


Figure 63 *Minimum groundwater levels measured in the period 2000-2009, Vic.*

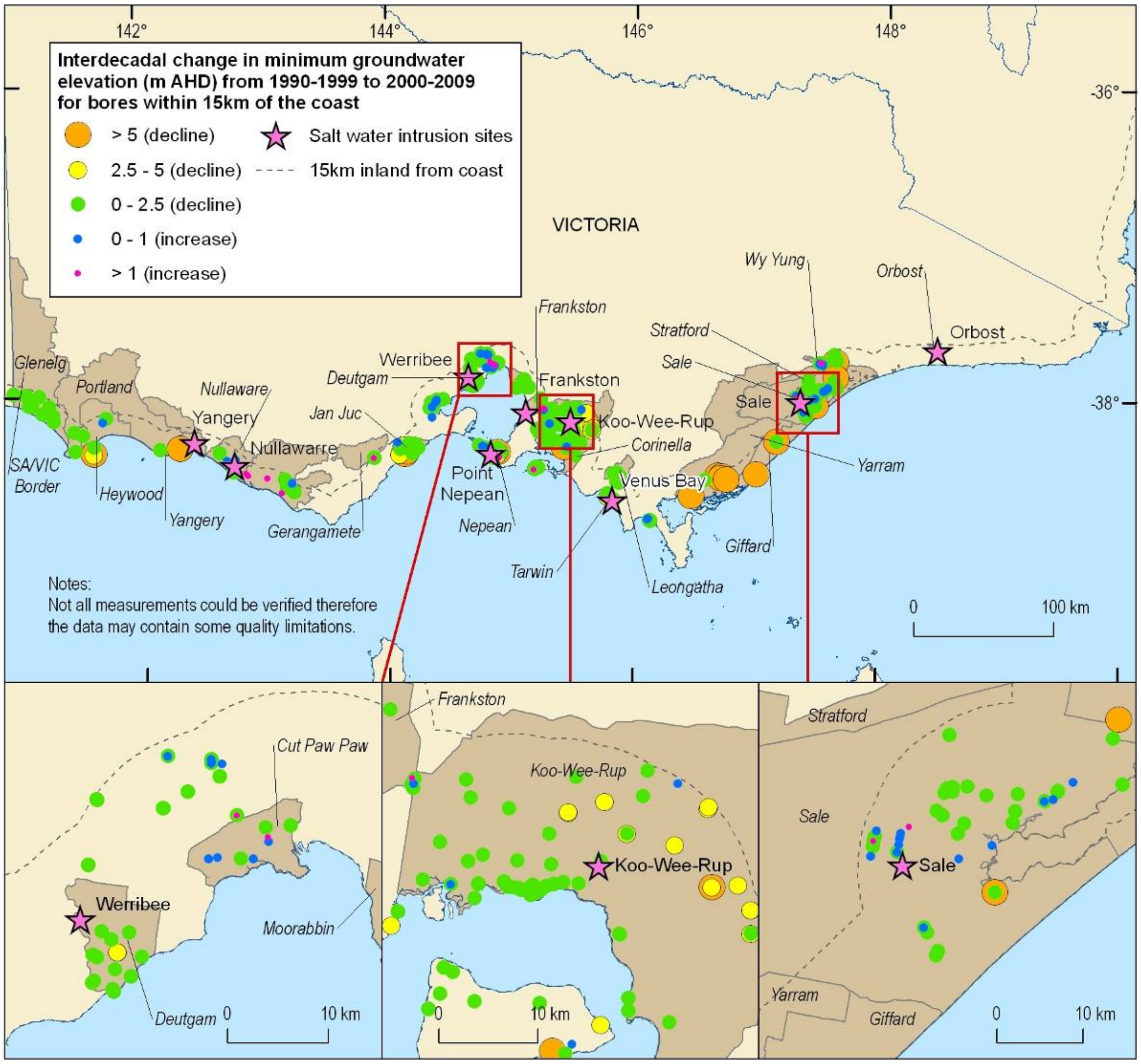


Figure 64 *Inter-decadal changes in minimum groundwater levels from 1990-1999 to 2000-2009, Vic.*

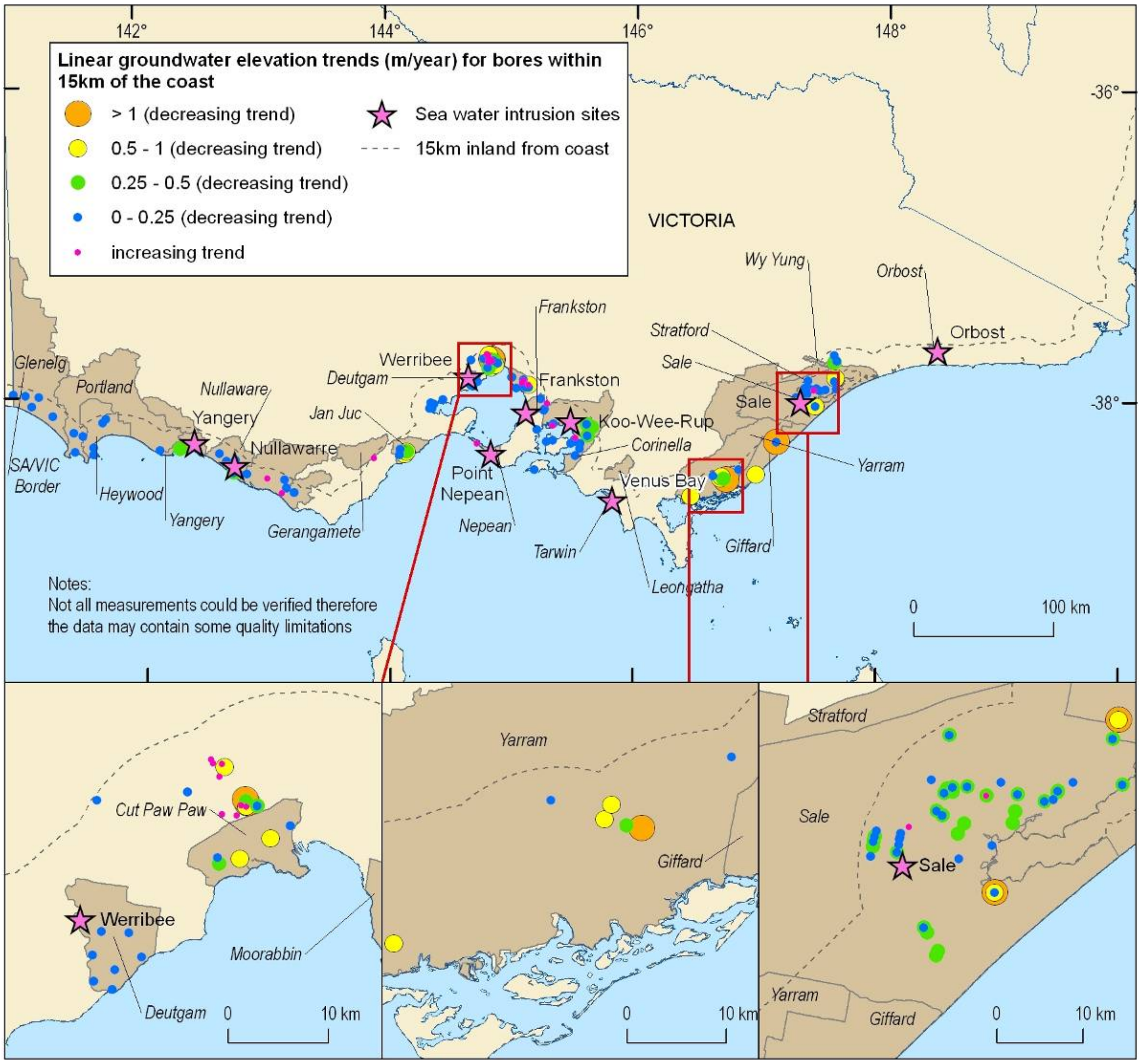


Figure 65 *Linear groundwater level trends in Vic.*

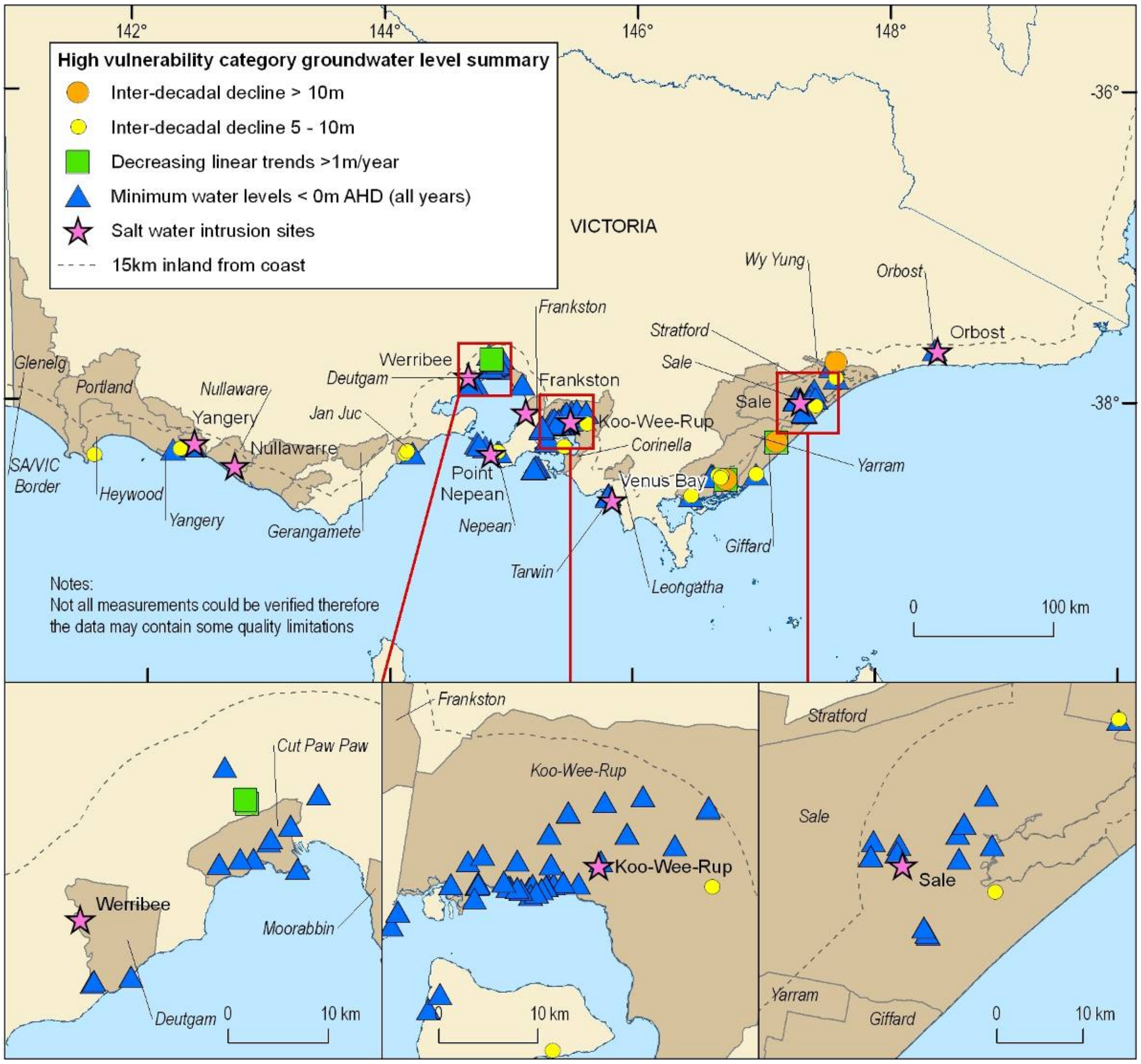


Figure 66 *Summary of groundwater level indicators of high SWI vulnerability, Vic.*

Table 24 *Maximum inland extent within 15 km of the coast of minimum groundwater levels <0 m AHD and <2.5 m AHD based on 2000-2009 monitoring data reported for Vic GMAs*

GMA	Maximum Inland Distance of <0 m AHD Groundwater Levels (km)	Maximum Inland Distance <2.5 m AHD Groundwater Levels (km)
Corinella	All levels > 0m AHD	All levels > 2.5m AHD
Cut Paw Paw	1.74	3.12*
Deutgam	1.67	3.92
Frankston	All levels > 0m AHD	All levels > 2.5m AHD
Gerangamete	No elevation data	No elevation data
Giffard	All levels > 0m AHD	6.21
Glenelg	All levels > 0m AHD	All levels > 2.5m AHD
Hawkesdale	No elevation data	No elevation data
Heywood	All levels > 0m AHD	All levels > 2.5m AHD

GMA	Maximum Inland Distance of <0 m AHD Groundwater Levels (km)	Maximum Inland Distance <2.5 m AHD Groundwater Levels (km)
Jan Juc	0.20	2.55
Koo Wee Rup	14.46*	14.46*
Leongatha	All levels > 0m AHD	All levels > 2.5m AHD
Moorabbin	3.89	3.89
Nepean	4.33	4.57*
Newlingrook	All levels > 0m AHD	All levels > 2.5m AHD
Nullawarre	All levels > 0m AHD	1.54
Orbost	10.55	10.55
Paaratte	All levels > 0m AHD	All levels > 2.5m AHD
Portland	All levels > 0m AHD	All levels > 2.5m AHD
Sa/Vic Border	All levels > 0m AHD	All levels > 2.5m AHD
Sale	13.52*	13.52*
Stratford	4.48	8.55
Tarwin	0.55	1.20*
Wy Yung	6.64	6.64
Yangery	2.99	2.99
Yarram	12.04*	12.04*
OTHER	10.15	10.15

*Furthest inland water level measurement. Low water levels may extend further inland.

9.2. Rainfall Trend Analysis

Plots of cumulative deviation of monthly rainfall data from long term averages are included in Appendix 3 for locations near the SWI sites and summarised for Vic on Figure 67 for the period 2000-2009. Of the locations assessed, all showed decreasing rainfall trends over the 2000-2009 period. Although additional groundwater pressures may be anticipated where rainfall has decreased, drought around the country has eased in 2010 and 2011 (visible on the plots in Appendix 3), and a reversal in rainfall trends is evident in some areas. The rainfall trends on Figure 67 may therefore not remain good indicators of vulnerability and should be updated in future assessments.

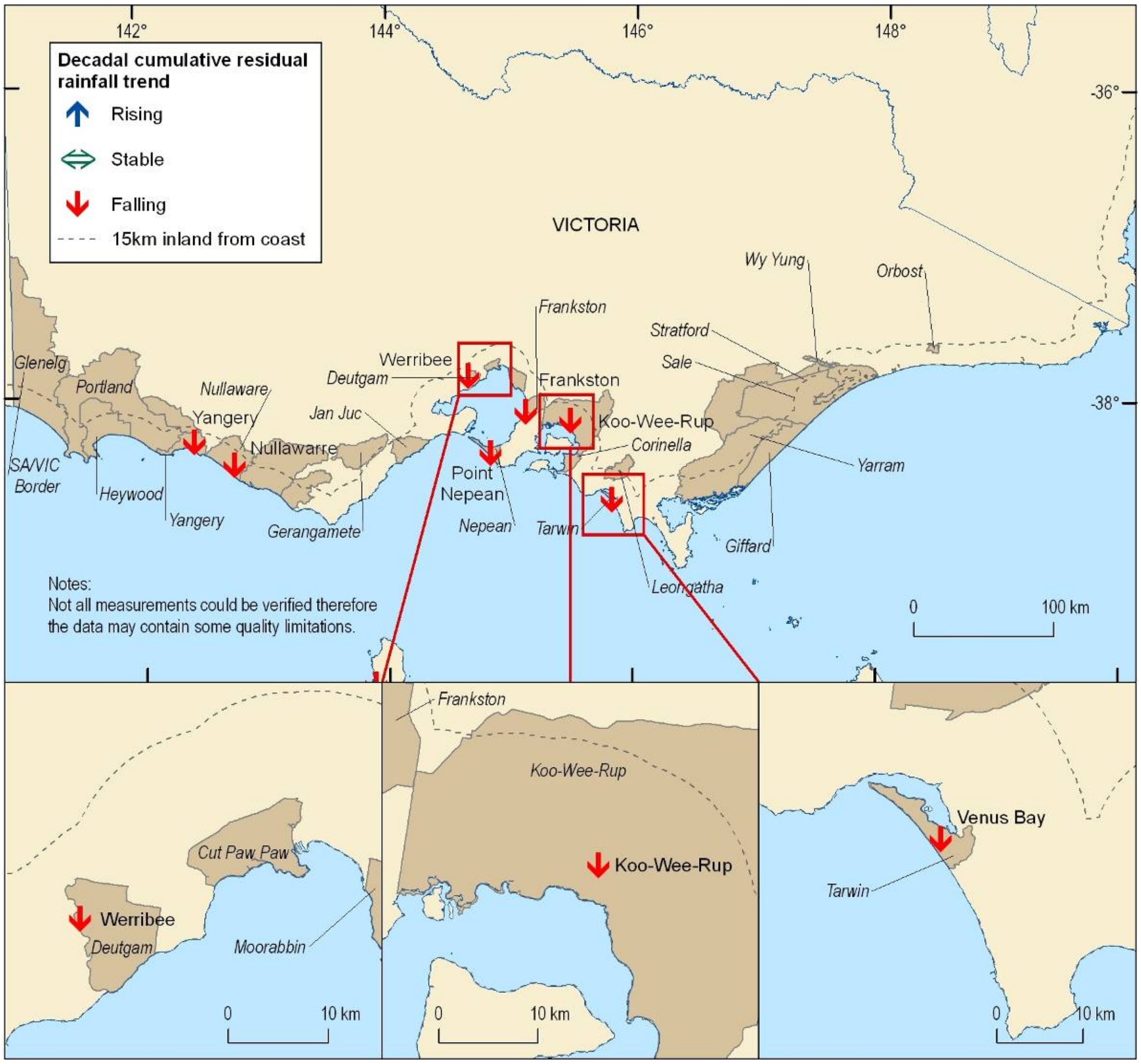


Figure 67 *Trends in cumulative deviation of monthly rainfall from long term averages for the period 2000-2009, Vic.*

9.3. Groundwater Salinity

9.3.1. Maximum salinity measurements

Groundwater salinity data for Vic are presented on Figure 68 and Figure 69. Data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data below to highlight areas that have recently shown groundwater salinity indicators of SWI vulnerability.

9.3.1.1. Historical maximum salinity measurements

Historical maximum TDS concentrations are shown on Figure 68. Locations where groundwater has TDS concentrations <3000 mg/L are of interest since it is suitable for a wide range of uses and constitutes an important resource. Areas where groundwater with maximum TDS concentrations <3000 mg/L is located near groundwater with maximum TDS concentrations >10,000 mg/L are also of interest since they may indicate higher potential for intrusion of high salinity water into freshwater resources. There were relatively few locations where TDS data were available for analysis in Vic.

Where data were available they suggested maximum TDS concentrations were commonly high in the 3000-10,000 mg/L and >10,000 mg/L ranges.

9.3.1.2. Maximum salinity measurements, 2000-2009

Maximum TDS concentrations measured during the period 2000-2009 are shown on Figure 69. Data were available for this period in a number of locations where historical data was lacking. A greater proportion of maximum TDS concentrations in the <3000 mg/L range were measured in this period.

9.3.2. Inter-decadal changes in maximum salinity measurements

Changes in maximum TDS concentrations between the decades 1990-1999 and 2000-2009 are shown on Figure 70. It is apparent that the majority of locations where data are available in Vic experienced an increase in salinity between decades. Most increases in TDS concentrations were in the 0-1000 mg/L and 1000-3000 mg/L ranges, although increases in the 3000-10,000 mg/L range were identified in Koo Wee Rup.

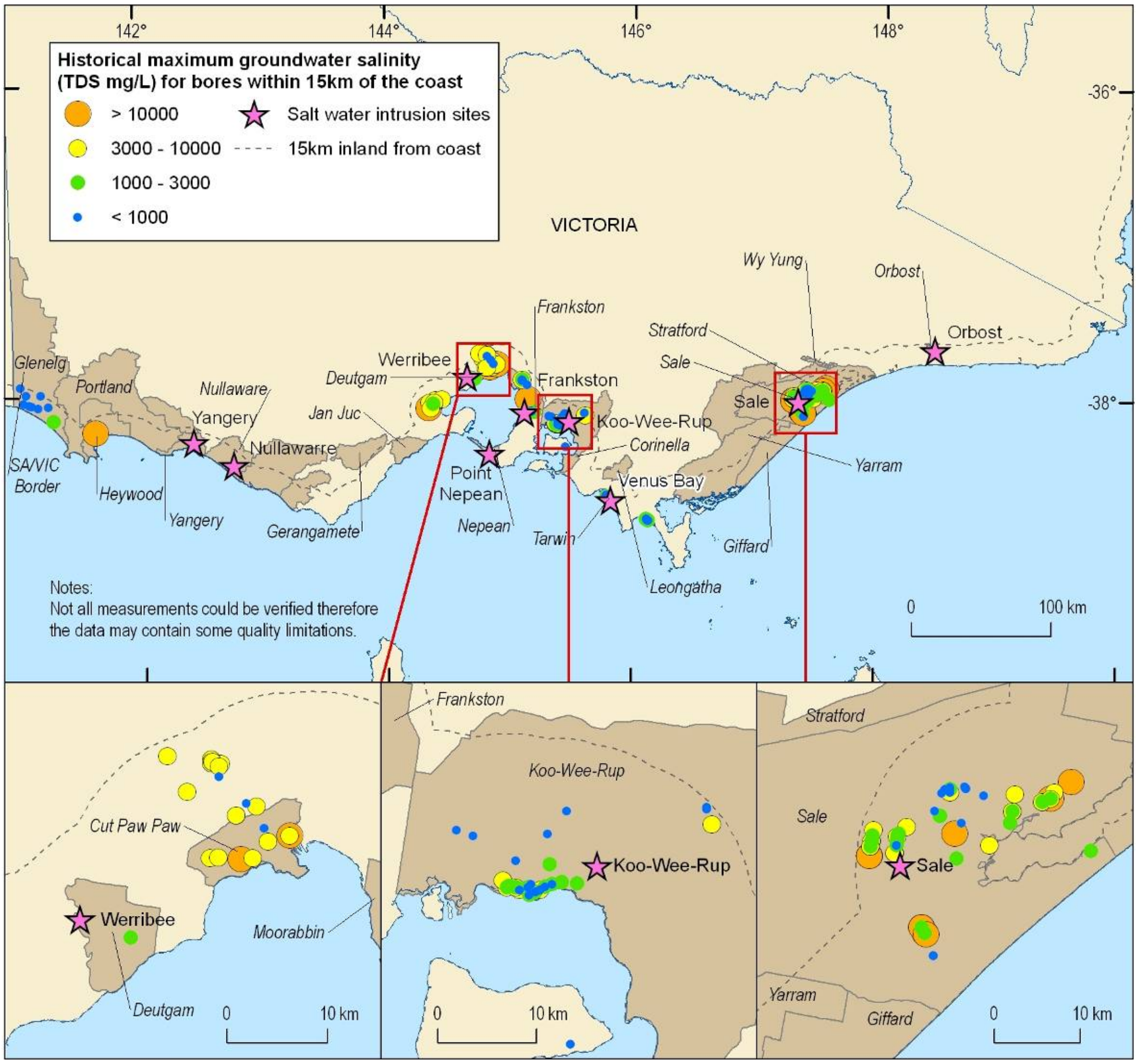


Figure 68 *Historical maximum TDS concentrations measured prior to 2000, Vic.*

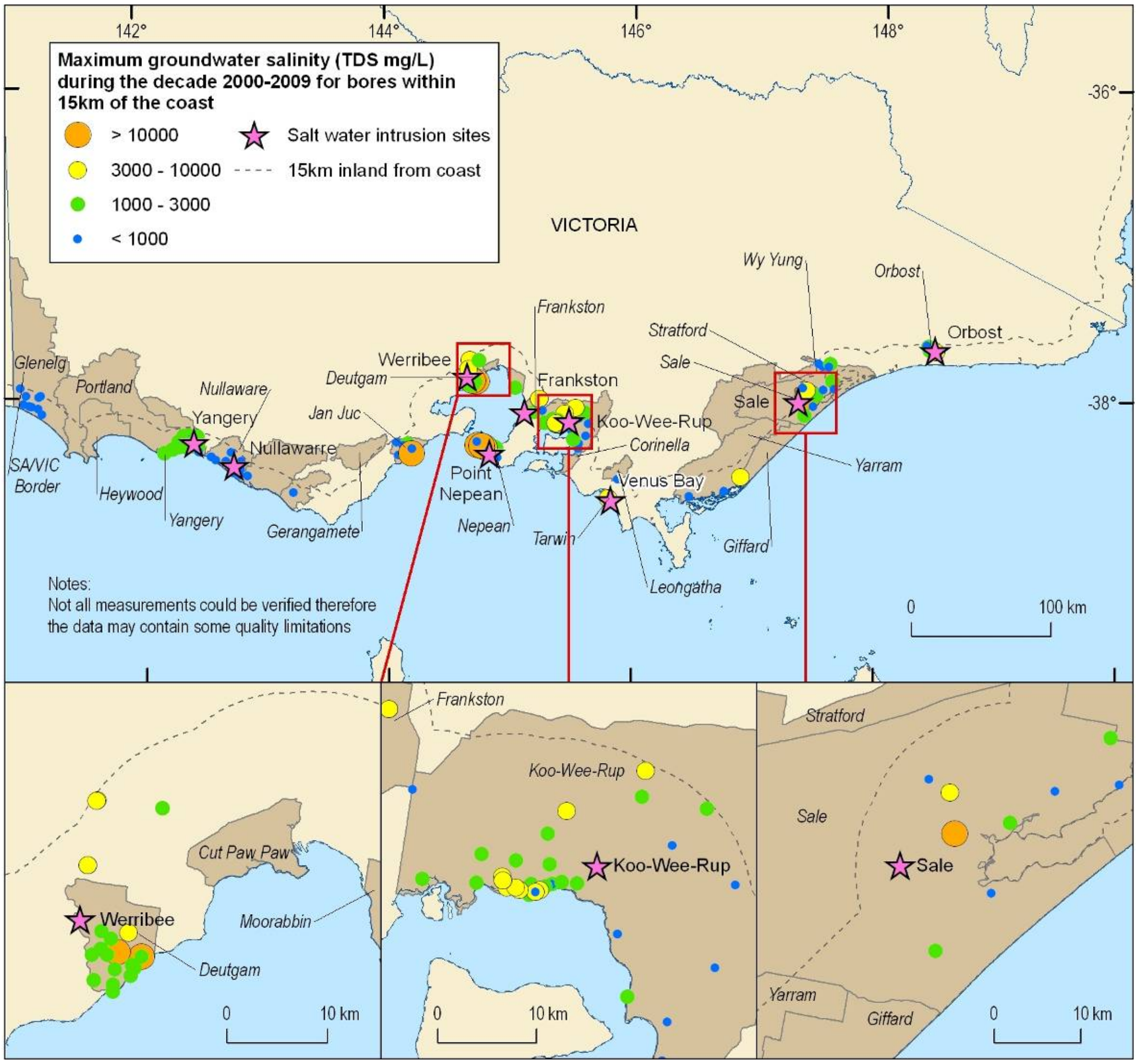


Figure 69 *Maximum TDS concentrations for the period 2000-2009, Vic.*

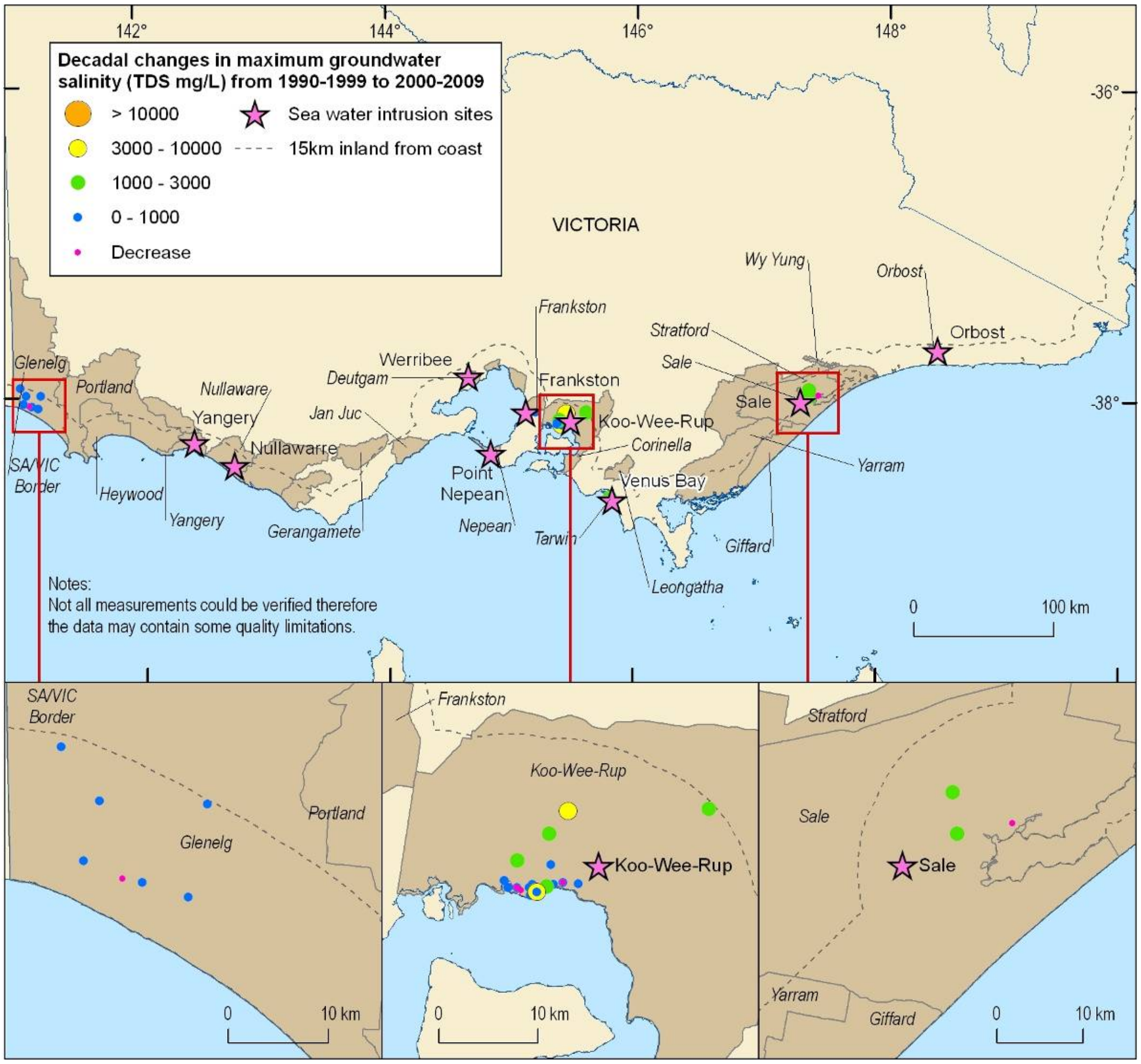


Figure 70 *Inter-decadal change in maximum TDS concentrations from 1990-1999 to 2000-2009, Vic.*

9.4. Groundwater Extraction

9.4.1. Distribution of production bores

The locations of recorded production bores provided by Southern Rural Water (SRW) are presented on Figure 71 (SRW indicated that the error associated with these locations is unknown). A large number of production bores are present within 15 km of the Vic coast. Particularly high numbers and densities of production bores were recorded near Port Fairy and Nulllaware, Werribee, Koo Wee Rup, and Bairnsdale.

9.4.2. Groundwater extraction rates

Figure 72 presents the recorded groundwater extraction rates in coastal Vic for the 2009-2010 financial year. As outlined in Section 3.4.3, in the context of SWI it is difficult to attach significance to extraction rates in the absence of recharge data. The information presented is best considered at a site specific level in conjunction with other available information. Figure 72 indicates that relatively high extraction rates >1000 ML/year are associated with individual production bores near Portland, Torquay, Yarram and Sale.

9.4.3. Cumulative groundwater extraction rates by area

Cumulative groundwater extraction rates in 5 x 5 km grid cells in coastal Vic are shown on Figure 73 based on Figure 72 data. The final category that each cell falls into is somewhat dependent on where the grid is positioned, but in general the information shows that in addition to those areas with high individual bore extraction rates listed above, Point Nepean had a cumulative extraction rate >1000 ML/year in a 5 x 5 km area.

9.4.4. Groundwater extraction rates by GMA

Figure 74 summarises groundwater extraction rates within 15 km of the coast within GMAs from 2006-2010. Records indicate that groundwater extraction volumes were similar in all financial years over this period with the exception of 2007-2008 when extraction fell from around 60 GL to around 30 GL.

Extraction volumes for those portions of the GMAs within 15 km of the coast for the 2009-2010 financial year are presented in Table 25 where they are compared to the sustainable yield estimates for the GMUs in AWR (2006). Extraction data supplied by the Department of Sustainability and Environment (DSE) in the annual Victorian water accounts are also presented for whole GMAs for comparison to AWR (2006) data. The AWR (2006) GMUs do not directly correspond to the Vic GMAs in all instances thus care in interpretation is required (further details are included in Table 16).

Table 25 shows the percentage of AWR (2006) extraction for 2004-2005 relative to sustainable yield. Where extraction rates are high relative to sustainable yield, impacts on groundwater levels may occur resulting in SWI. Although this data is several years old, it provides an indication of which GMAs may have been under extraction stress in the past. Extraction at 50% of sustainable yield is taken to be a reasonable distinction between relatively low extraction rates and relatively high extraction rates. Of the GMAs for which data are available, Giffard, Sale and Yangery had recorded extraction rates exceeding 50% of estimated sustainable yield for 2004-2005. Extraction for the entire GMA in 2009-2010 is also included in the table. Relative to AWR (2006) sustainable yield estimates, Jan Juc, Nepean, and Sale had reported extraction rates exceeding 50% of sustainable yield for 2009-2010.

Table 25 presents the proportion of extraction in each GMA from 2009-2010 within 15 km of the coast relative to the AWR (2006) sustainable yield data. Caution in interpretation is required since where GMAs overlap, extraction associated with individual bores has been assigned to all overlapping GMAs (see the introduction to Section 9 above) thus the table will overestimate extraction in some instances. In addition, some of the extraction estimates for the 15 km coastal zone (based on individual extraction bore data supplied by SRW) exceed the total GMA extraction volume reported by DSE. While this may be explained in most instances by double counting extraction where GMAs overlap, no GMAs overlap with Deutgam. This GMA is situated entirely within 15 km of the coast and yet the DSE reported extraction value of 15 ML is only a fraction of that calculated from individual bores in this area (120 ML).

Table 25 indicates that the Giffard, Jan Juc and Nepean GMAs have an extraction rate within 15 km of the coast that exceeds 50% of estimated sustainable yield for the entire GMA. This suggests that they may be particularly susceptible to SWI (noting that those GMAs with a high proportion of their areas within 15 km of the coast are more likely to show higher values). However, groundwater levels near the coast depend on local extraction and recharge conditions that may be unrelated to sustainable yield for the entire GMA and therefore many of the other GMAs along the Vic coast may also be at risk on the basis of this analysis. Such detailed consideration is beyond the scope of the VFA which offers a broad scale assessment of available data. The requirement for further site specific investigation is emphasised.

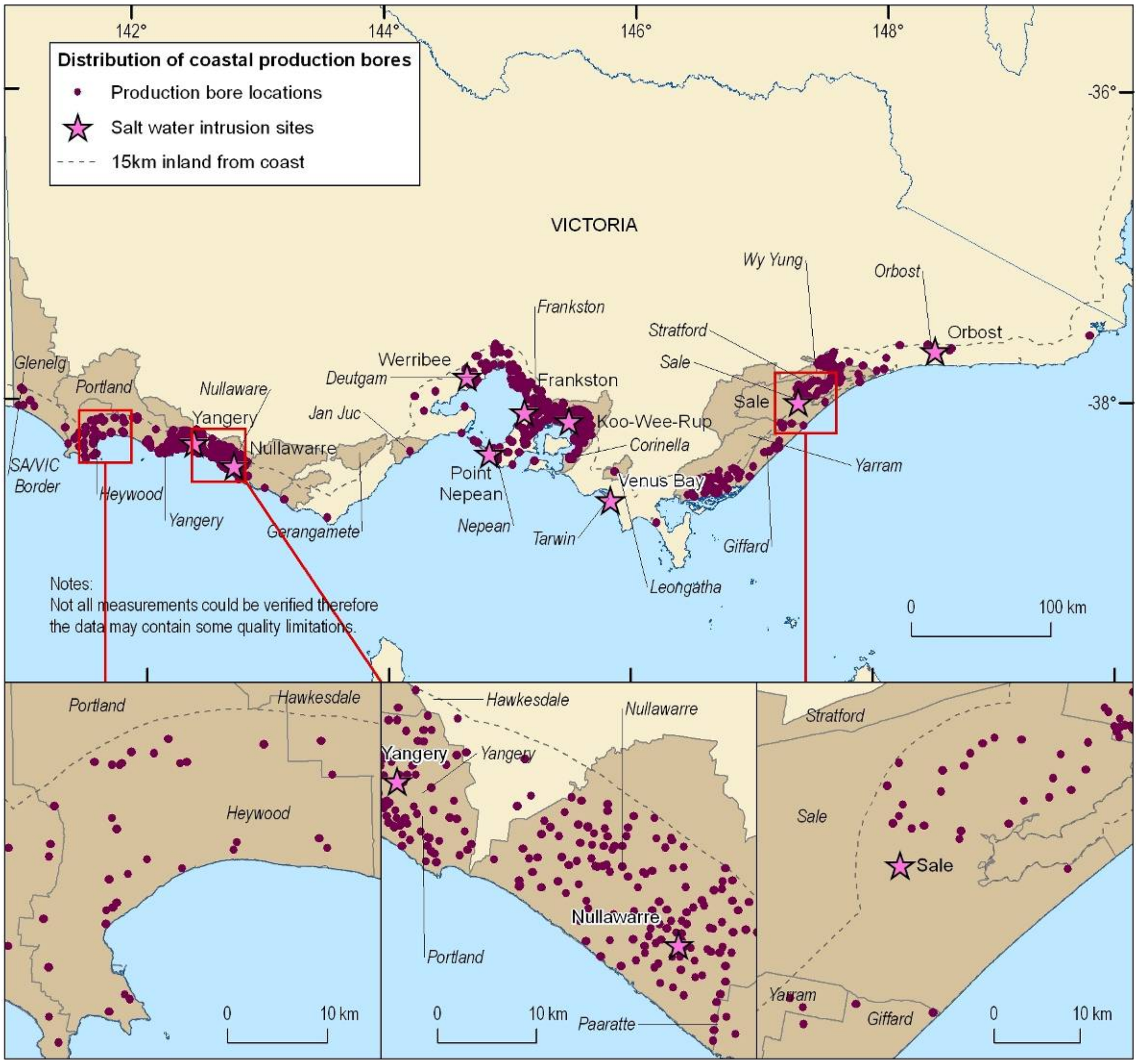


Figure 71 Distribution of recorded production bores, Vic.

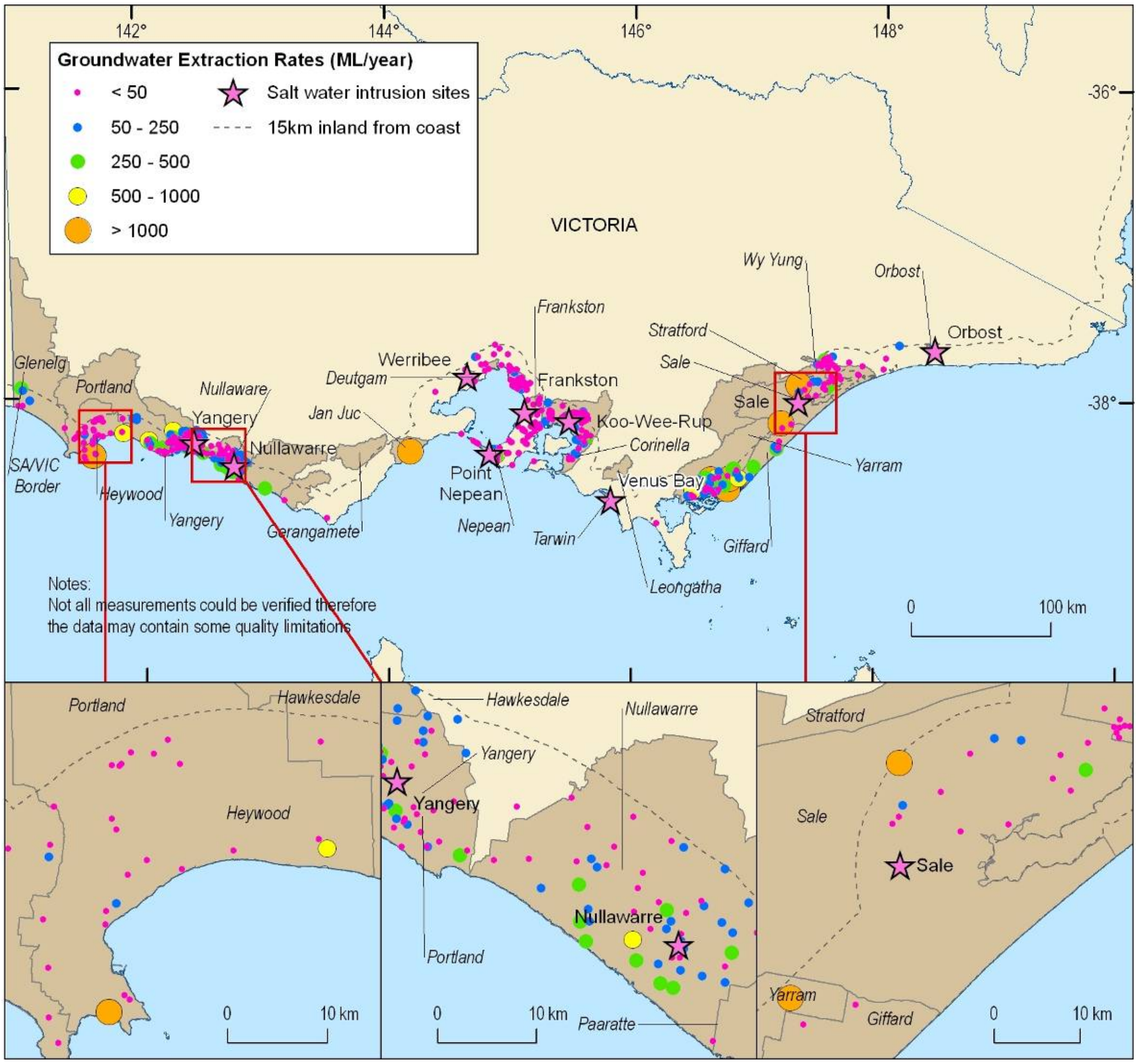


Figure 72 *Groundwater extraction rates for the 2009-2010 financial year, Vic (source: SRW).*

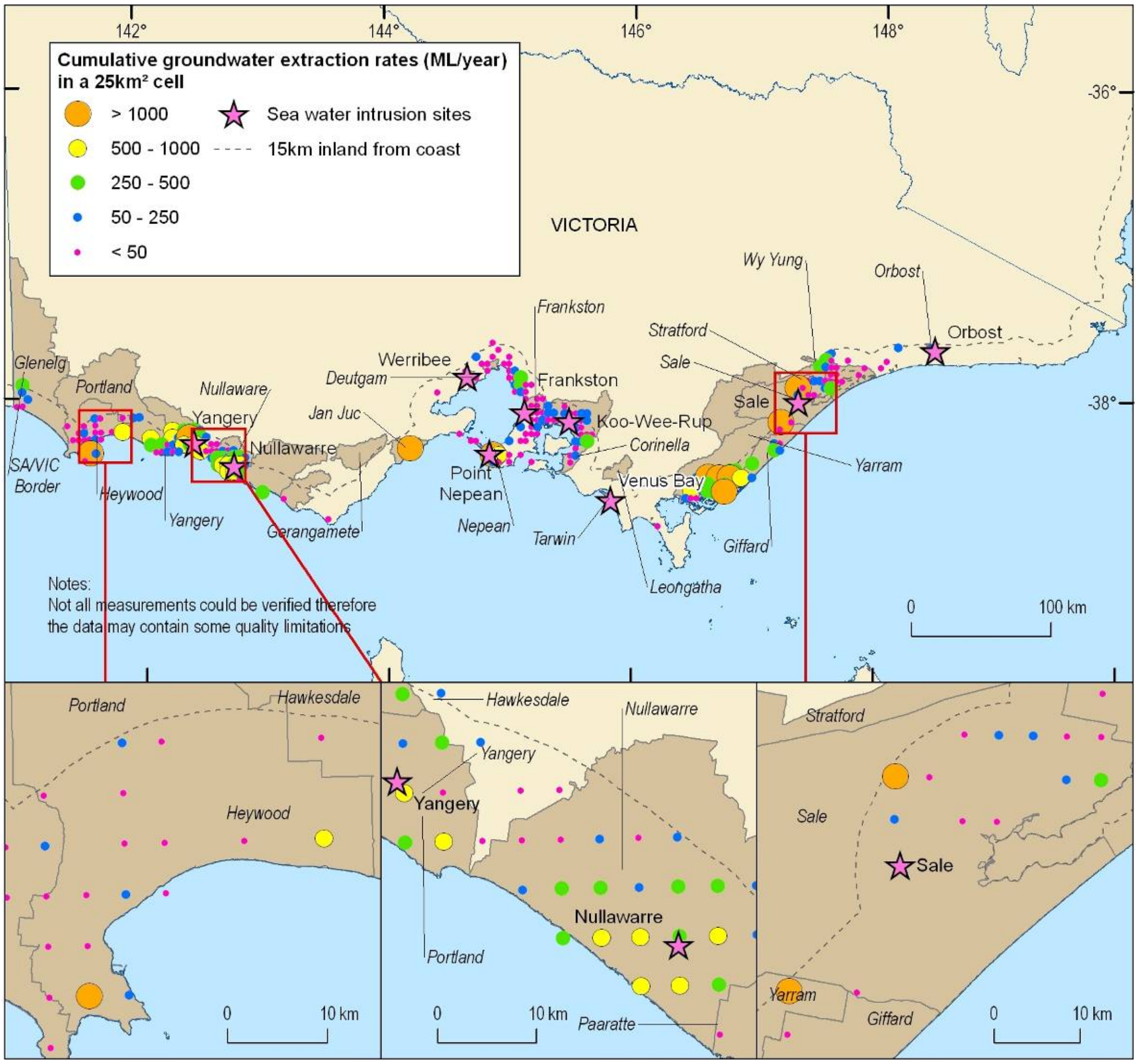
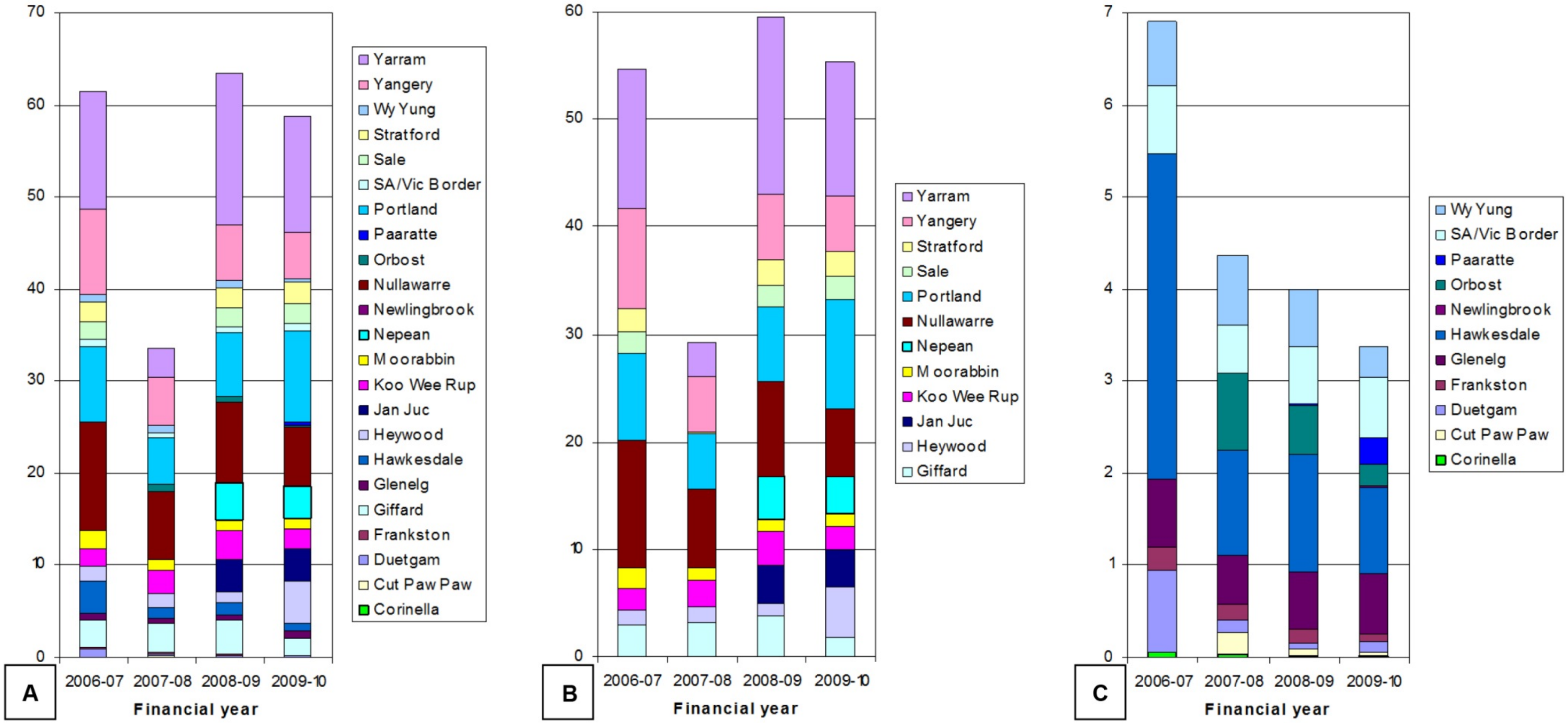


Figure 73 *Cumulative groundwater extraction rates within 5x5 km grid cells, Vic*



Note: Extraction rates will be overestimated where GMAs overlap. Bore extraction volumes were assigned to all overlapping GMAs in the overlap areas since no data were

Figure 74 *Annual groundwater extraction (GL/year) within 15 km of the coast in each GMA for Vic [data source: SRW (2011)].*
A: All GMAs; B: GMAs with 12 greatest extractions; C: GMAs with 11 lowest extractions.

Table 25 *Summary of extraction and sustainable yield (SY) data, Vic*

GMA	AWR 2005 2004-2005 Extraction† (ML/yr)	AWR 2005 SY† (ML/yr)	2009/10 GMA extraction *(ML/yr)	2009/10 Extraction within 15 km of coast^(ML/yr)	AWR 2005 Extraction relative to SY	2009/10 GMA Extraction relative to SY	2009/10 Extraction within 15 km relative to SY
Corinella**	371	2550	129	26.5	15%	5%	1%
Cut Paw Paw	190	3650	25	22.4	5%	1%	1%
Deutgam	1217	-	15	120.4	-	-	-
Frankston	782	3200	126	82.7	24%	4%	3%
Gerangamete	10	-	12692	-	-	-	-
Giffard	2862	3000	1717	1909.6	95%	57%	64%
Glenelg	19950	-	7759	653.9	-	-	-
Hawkesdale***	-	-	5214	4606.9	-	-	-
Heywood	5725	21763	1578	4590.2	26%	7%	21%
Jan Juc	1400	6804	3457	3456.6	21%	51%	51%
Koo Wee Rup	3670	-	3378	2158.1	-	-	-
Leongatha	743	6500	158	-	11%	2%	-
Moorabbin	1201	4305	1203	1188.7	28%	28%	28%
Nepean	2466	5000	3521	3513.7	49%	70%	70%
Newlingrook	689	74970	95	6.4	1%	0%	0%
Nullawarre	10687	25100	9859	6368.2	43%	39%	25%
Orbost	270	1200	333	237.3	23%	28%	20%
Paaratte	1125	4606	291	291.3	24%	6%	6%
Portland	702	20683	2726	10012.1	3%	13%	48%
Sa/Vic Border***	-	-	-	653.9	-	-	-
Sale	8599	13000	11094	2188	66%	85%	17%
Stratford**	18050§	-	27796*	2286.9	-	-	-
Tarwin	256	1300	6		20%	0%	0%
Wy Yung	906	9070	798	342	10%	9%	4%
Yangery	5952	11500	4026	5153	52%	35%	45%
Yarram	9070	26625	11778	12560.6	34%	44%	47%

†Source: AWR (2006) for GMUs, noting that the GMU boundaries differ from GMA boundaries as indicated in the table.

*Source: Total GMA extraction data from DSE.

**GMA boundary supplied by Vic differs substantially from AWR (2006).

***GMA does not exist in AWR (2006).

^ Source: Production bore extraction data available from SRW.

- = no data.

Extraction data do not include stock and domestic use

9.5. VFA Summary: Victoria

The VFA findings for Vic are summarised in Table 26 for each GMA. Following the approach outlined for WA in Section 5.5, the following state VFA priority GMAs were identified for Vic: Deutgam, Koo Wee Rup, Sale, Stratford and Tarwin. These GMAs are considered to show a particularly high proportion and range of VFA indicators. It is noted that many other GMAs showed a range of high category groundwater level indicators of SWI vulnerability but a lack of salinity data precluded their classification as state VFA priority GMAs.

It is important to note that a single VFA indicator of high vulnerability in an area may correspond to an area with high SWI vulnerability and some high SWI vulnerability areas may have no data or high category indicators at all. There are other areas in Vic showing indicators of high SWI vulnerability and a lack of data in many areas. Further, there were indicators of SWI vulnerability not captured in this summary since they were situated outside of the GMAs. Omission of locations from the list of state VFA priority GMAs should not be taken to imply that they are unlikely to be significantly vulnerable to SWI. The list simply highlights locations where considerable numbers of high SWI vulnerability indicators are present where data are available. Some of the GMAs cover large areas compared to others thus reporting at the GMA level is somewhat inconsistent. The data presented above should be considered on a case by case basis at a scale commensurate with the area of interest.

Table 26 *Summary of VFA indicators for Victoria (State VFA Priority GMAs are indicated by *)*

GMA	SWI Sites	Groundwater Levels				Groundwater Salinity (TDS Concentration in mg/L)		
		Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS <3000 within 1 km >10,000		TDS conc. changes
		2000-2009	Pre 2000	Inter-decadal decline >2.5 m	Declining trend >0.5 m/yr	Pre 2000	2000-2009	Inter-decadal increase >1000
Corinella	-	N	N	N	N	-	-	-
Cut Paw Paw	-	Y	Y	N	Y	N	-	-
*Deutgam	Werribee	Y	Y	Y	N	N	Y	-
Frankston	Frankston	N	N	N	N	N	N	N
Gerangamete	-	-	-	-	-	-	-	-
Giffard	-	N	N	N	N	-	N	-
Glenelg	-	N	N	Y	N	N	N	-
Hawkesdale	-	-	-	-	-	-	-	-
Heywood	-	N	N	N	N	N	-	-
Jan Juc	-	Y	Y	Y	Y	-	N	-
*Koo Wee Rup	Koo Wee Rup	Y	Y	Y	N	N	N	Y
Leongatha	-	N	N	N	N	-	N	-
Moorabbin	-	Y	Y	Y	N	N	N	-
Nepean	Point Nepean	Y	Y	Y	N	-	N	-
Newlingrook	-	N	N	N	N	-	N	-
Nullawarre	Nullawarre	N	N	N	N	-	N	-
Orbost	Orbost	Y	-	-	-	-	N	-
Paaratte	-	N	N	N	N	-	N	-

GMA	SWI Sites	Groundwater Levels				Groundwater Salinity (TDS Concentration in mg/L)		
		Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS <3000 within 1 km >10,000		TDS conc. changes
		2000-2009	Pre 2000	Inter-decadal decline >2.5 m	Declining trend >0.5 m/yr	Pre 2000	2000-2009	Inter-decadal increase >1000
Portland	-	N	N	Y	N	-	-	-
SA/Vic Border	-	N	N	N	N	N	N	N
*Sale	Sale	Y	Y	N	N	Y	N	Y
*Stratford	-	Y	Y	Y	Y	Y	N	Y
*Tarwin	Venus Bay	Y	Y	Y	-	N	N	Y
Wy Yung	-	Y	N	N	-	-	N	-
Yangery	Yangery	Y	N	Y	N	-	N	-
Yarram	-	Y	N	Y	Y	-	N	-

10. Vulnerability Factor Analysis Results: Tasmania

It is understood that legislation in Tas allows for the declaration of Groundwater Areas for management of groundwater resources and licensing of extraction. However, at the time of publication of this document, there were no declared Groundwater Areas in Tas. For the purposes of the VFA, Managed Groundwater Areas for Tas were obtained from BoM which were indicated to have been defined by the state agencies responsible for groundwater management and current as of September 2009. They are referred to as GMAs below and shown in Figure 75.

The total area of each GMA and the proportion of each GMA lying within 15 km of the coastline are provided in Table 27 which also indicates which of the Tas GMAs coincide with the GMUs defined in AWR (2006) . There are 14 GMAs in Tas partially or wholly within 15 km of the coast and 24 contained data for consideration in this state assessment. A total of 7 GMAs had more than 90% of their total areas within 15 km of the coastline, suggesting that SWI vulnerability may be highly relevant to their overall management. The VFA results are reported on the basis of GMAs in summary form in Section 10.5.

Table 27 summarises the number of measurements collected and analysed for the VFA in Tas. Data were not available for many of the categories analysed in preceding sections and the assessment below is correspondingly limited.

10.1. Groundwater Level Analysis

10.1.1. Minimum groundwater levels

Minimum groundwater levels measured in monitoring bores in Tas are shown on Figure 76 and Figure 77. Groundwater level data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data to highlight areas that have recently shown groundwater level indicators of vulnerability.

10.1.1.1. Historical minimum groundwater levels

Minimum groundwater levels reported in monitoring wells prior to 2000 are shown on Figure 76. Data are only available near Port Arthur and inland from Bridport. Both locations historically showed minimum groundwater levels >2.5 m AHD.

10.1.1.2. Minimum groundwater levels, 2000–2009

Minimum groundwater levels measured between 2000 and 2009 are shown on Figure 77. Data were available at a greater number of locations for this decade than historically. Most groundwater levels were in the > 2.5 m AHD category but groundwater levels <0 m AHD were identified in the Smithton and King Bay areas.

10.1.2. Groundwater level changes

10.1.2.1. Inter-decadal changes in minimum groundwater levels

Inter-decadal changes in minimum groundwater levels are shown on Figure 78. Data are only available near Port Arthur and inland from Bridport. Both locations showed a decrease in minimum groundwater levels over between decades in the range 0 – 2.5 m.

10.1.2.2. Groundwater level trends

Due to a lack of suitable time series water level measurements, no linear trends in groundwater levels are presented for Tas.

10.1.3. Spatial distribution of low groundwater level observations

The maximum distances that groundwater levels <0m AHD and <2.5 m AHD extend inland from the coast are presented for each GMA in Table 29. The data shown are based on minimum groundwater levels measured in boreholes over the decade 2000-2009. SWI may be anticipated to extend further inland in areas where low groundwater levels extend further from the coast. Minimum groundwater levels <0 m AHD were not measured further inland than 2.2 km in any of the Tas GMAs. However, this may reflect a lack of data rather than be representative of Tas GMAs. The analysis should be further developed as more data become available.

Minimum water levels for the entire monitoring period (historic and recent) in each monitoring bore are plotted against distance from the coast in Appendix 2 for each GMA. The limited data precludes meaningful analysis of the results but the plots are included for reference purposes.

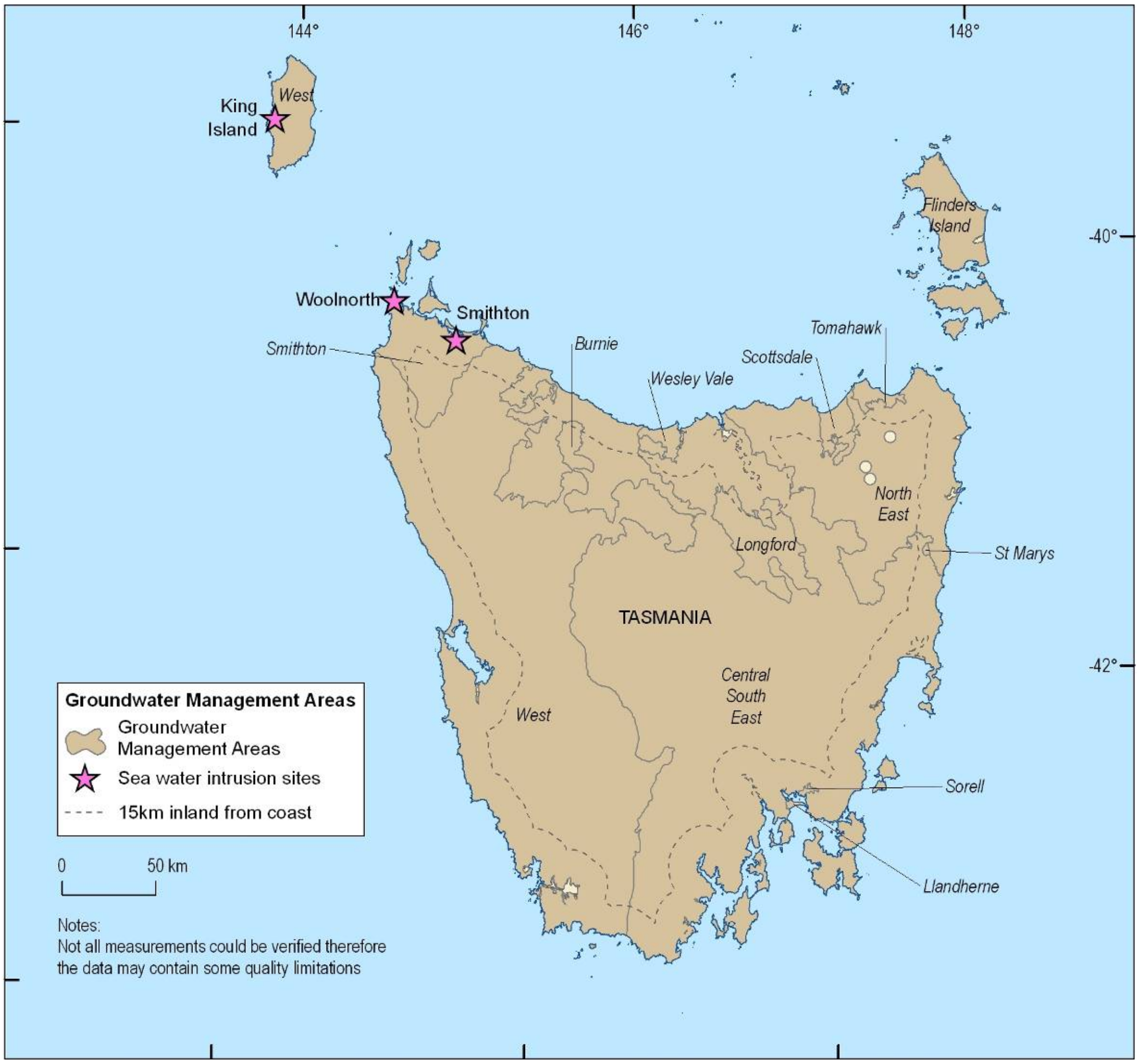


Figure 75 *GMAs in Tas that intersect the 15 km coastal buffer zone.*

Table 27 *Total Tas GMA areas that are wholly or partially within 15 km of the coast and percentage of total GMA areas within 15 km of the coast*

GMA Name	Total GMA Area (Hectares)**	Percentage of GMA Within 15 km of Coast
Flinders Island	138,145	100
Llandherne*	2,617	100
Sorell*	2,995	100
Spreyton*	9,939	100
St Marys*	1,773	100
Tomahawk*	21,493	100
Wesley Vale*	21,713	100
Scottsdale*	41,590	66
Smithton*	190,019	60

GMA Name	Total GMA Area (Hectares)**	Percentage of GMA Within 15 km of Coast
North East	784,135	47
West*	2,488,957	35
Central South East*	2,924,963	34
Burnie*	352,280	29
Longford*	157,753	8

*Generally matches AWR (2006) GMU

**Areas calculated based on the GDA1994 datum using a Lambert Conformal Conic Projection

Table 28 *Groundwater data utilised in the VFA for Tas*

Data Type	Data Subset	No. of Measurements
Groundwater levels	All relative standing water levels	526,333
	Minimum RSWL (all years)	19
	Minimum RSWL Pre 2000	2
	Minimum RSWL 2000–2009	19
	Calculations of inter-decadal change in minimum RSWL from 1990-99 to 2000-09	2
	Groundwater linear trend analyses	0
Groundwater salinity	All salinity measurements	0
	Maximum TDS (all years)	0
	Maximum TDS Pre 2000	0
	Maximum TDS 2000–2009	0
	Calculations of inter-decadal change in maximum TDS from 1990-99 to 2000-09	0
Groundwater extraction	Bores with annual usage volumes in recent years used in analysis	0*

*Annual usage volumes not available at the time of analysis

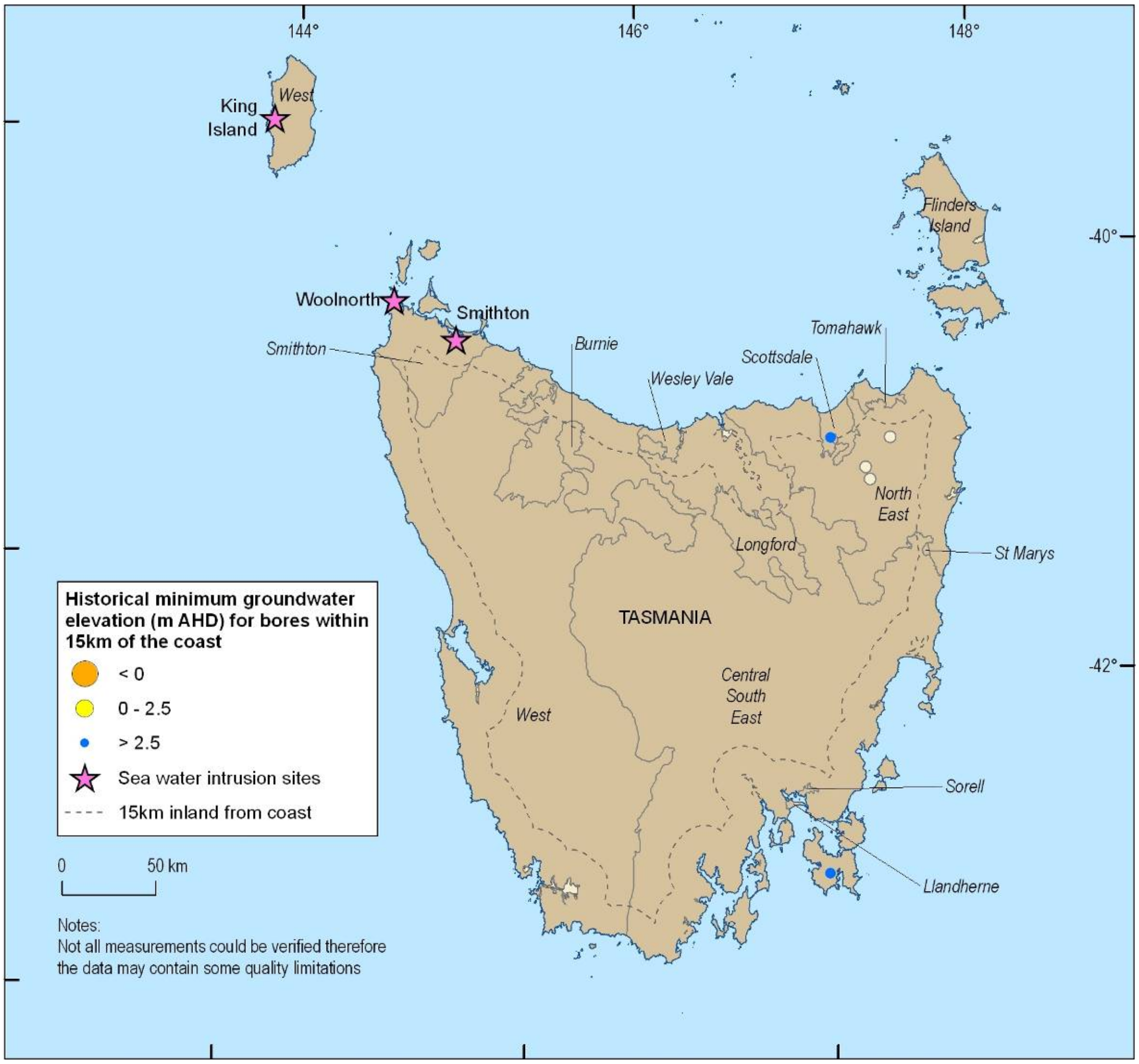


Figure 76 *Historical minimum groundwater levels measured prior to 2000, Tas.*

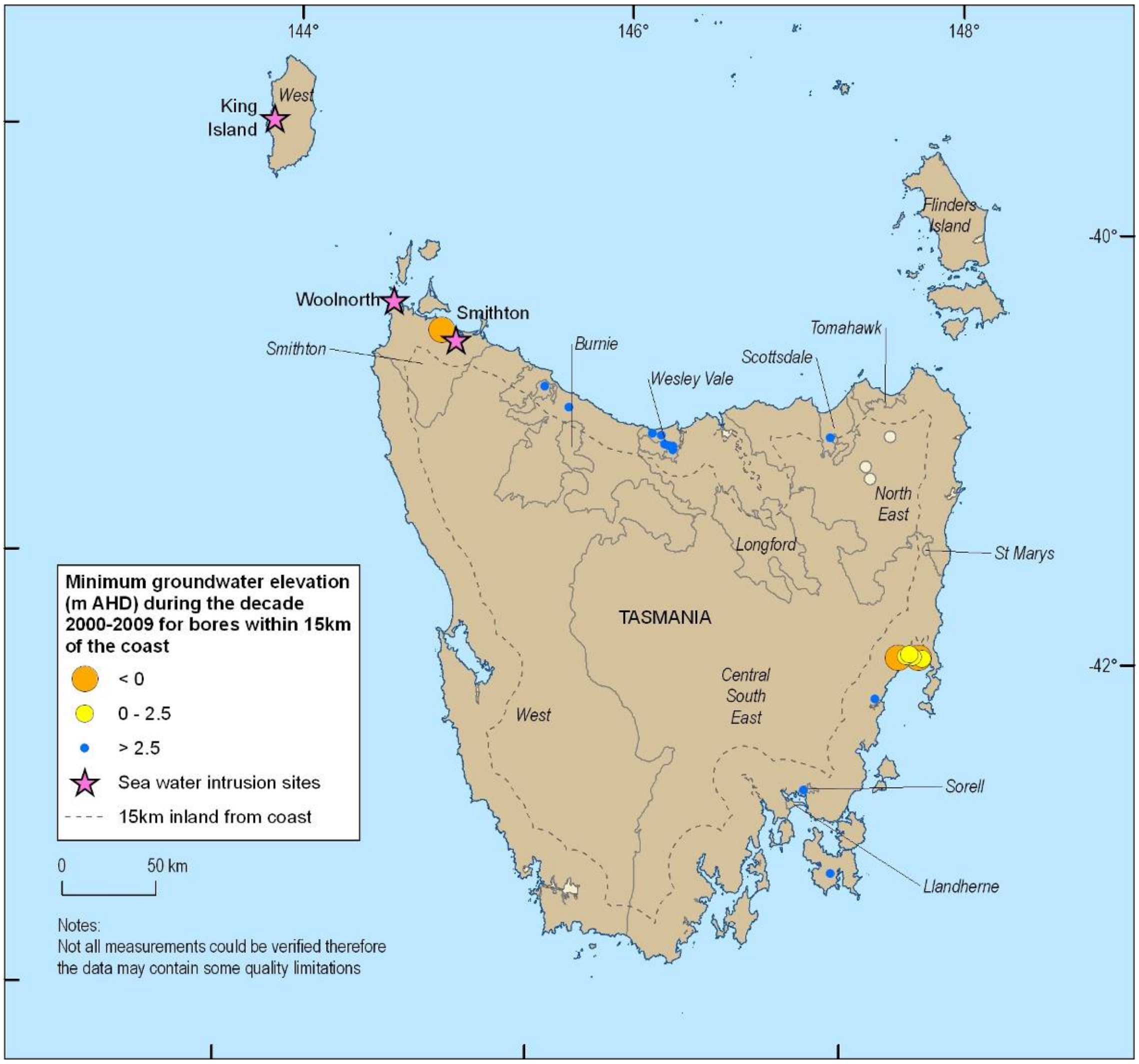


Figure 77 *Minimum groundwater levels measured in the period 2000-2009, Tas.*

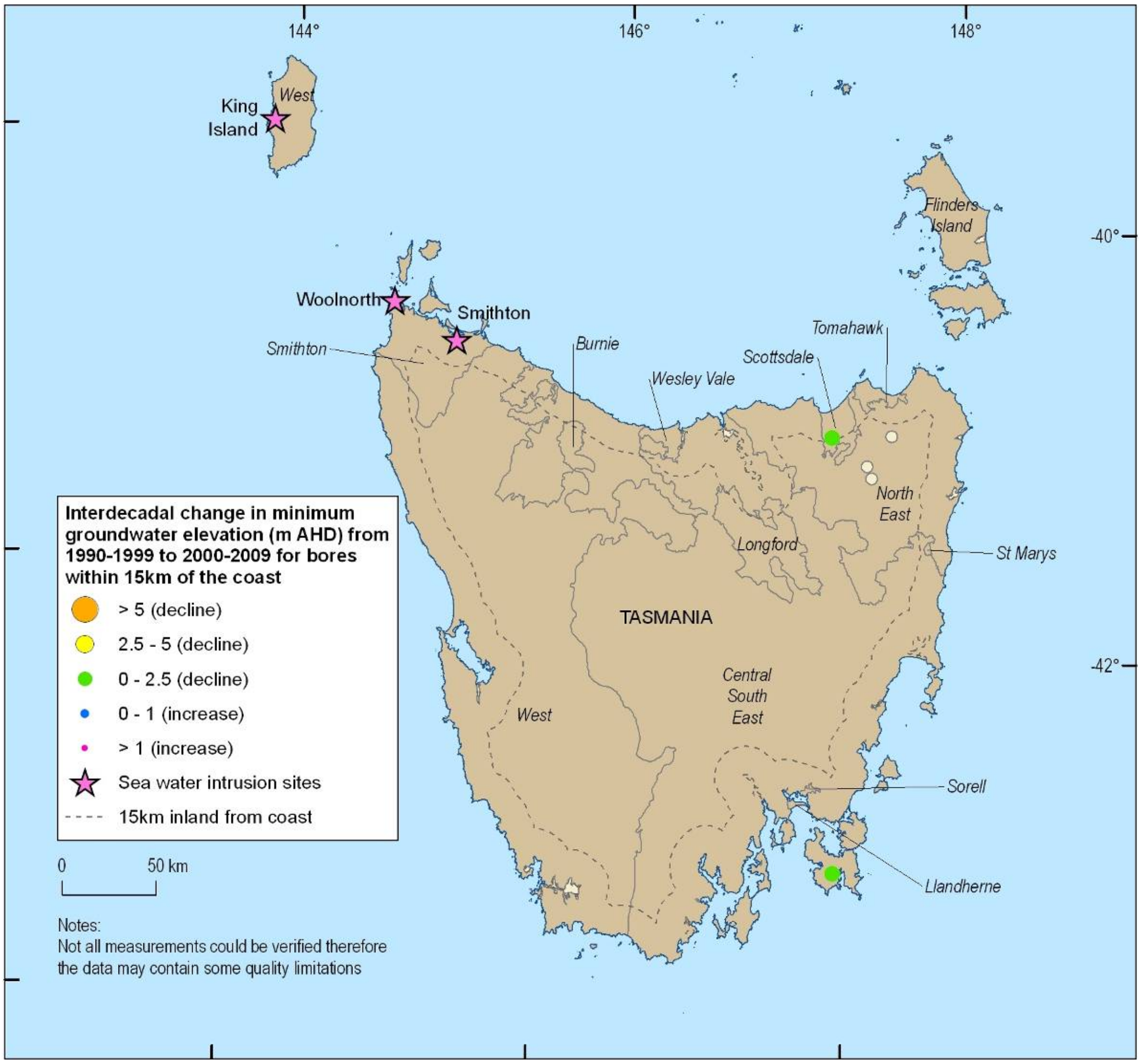


Figure 78 *Inter-decadal changes in minimum groundwater levels from 1990-1999 to 2000-2009, Tas.*

Table 29 *Maximum inland extent within 15 km of the coast of minimum groundwater levels <0 m AHD and <2.5 m AHD based on 2000-2009 monitoring data reported for Tas GMAs*

GMA	Maximum Inland Distance of <0 m AHD Groundwater Levels (km)	Maximum Inland Distance of <2.5 m AHD Groundwater Levels (km)
Burnie	All levels > 0m AHD	All levels > 2.5m AHD
Central South East	0.76	0.76
Flinders Island	No elevation data	No elevation data
Llandherne	No elevation data	No elevation data
Longford	No elevation data	No elevation data
North East	No elevation data	No elevation data
Scottsdale	All levels > 0m AHD	All levels > 2.5m AHD
Smithton	2.23*	2.23*
Sorell	All levels > 0m AHD	All levels > 2.5m AHD
Spreyton	No elevation data	No elevation data
St Marys	No elevation data	No elevation data
Tomahawk	No elevation data	No elevation data
Wesley Vale	All levels > 0m AHD	All levels > 2.5m AHD
West	All levels > 0m AHD	All levels > 2.5m AHD

10.2. Rainfall Trend Analysis

Plots of cumulative deviation of monthly rainfall data from long term averages are included in Appendix 3 for locations near the SWI sites and summarised for Tas on Figure 79 for the period 2000-2009. Rainfall generally increased in Smithton and decreased in Woolnorth in the northwest of Tas over the period 2000-2009 and decreased on King Island to the northwest. Although additional groundwater pressures may be anticipated where rainfall has decreased, drought around the country has eased in 2010 and 2011 (visible on the plots in Appendix 3), and a reversal in rainfall trends is evident in some areas. Rainfall trends presented may therefore not remain good indicators of vulnerability and should be updated in future assessments.

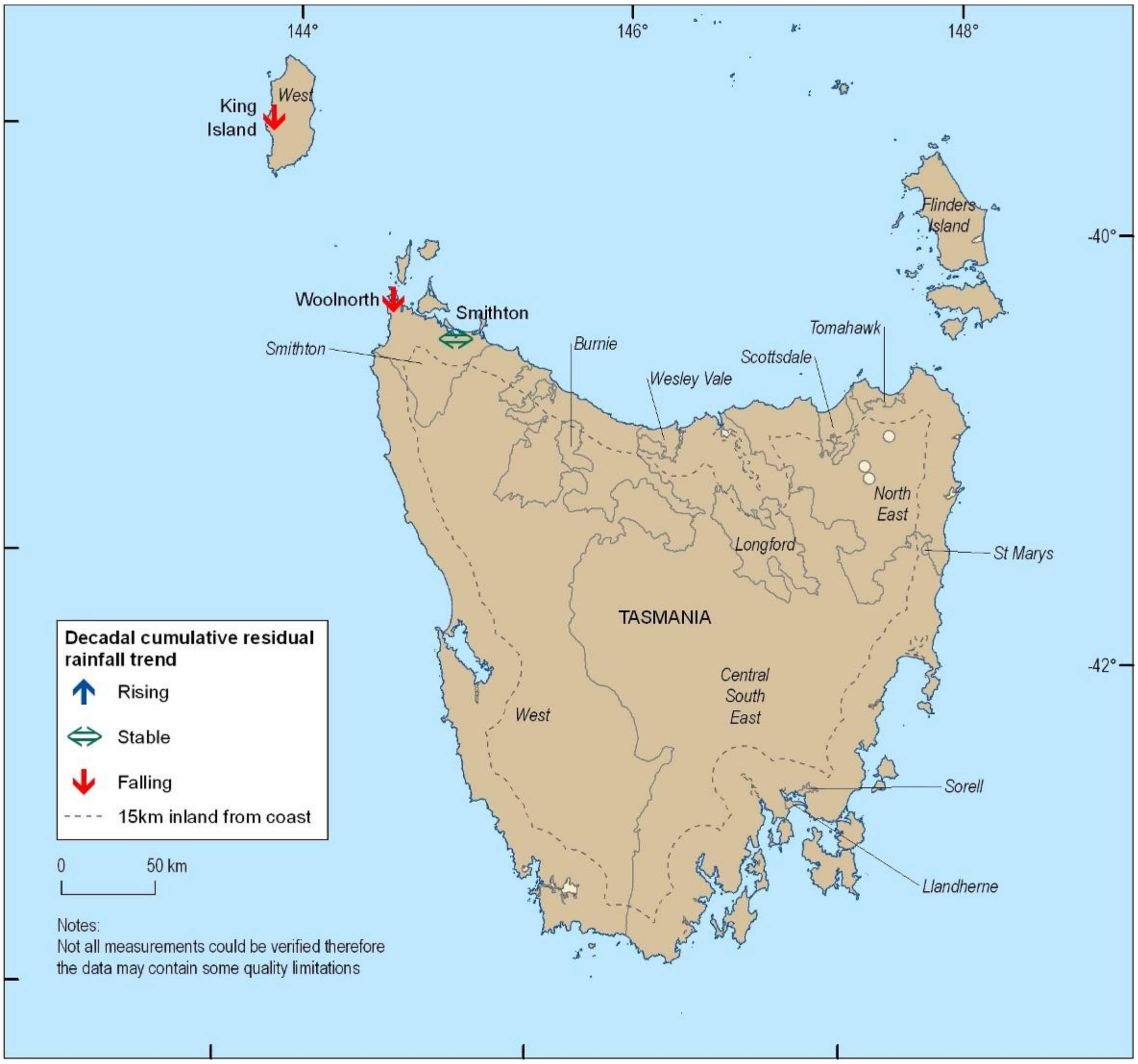


Figure 79 *Trends in cumulative deviation of monthly rainfall from long term averages for the period 2000-2009, Tas.*

10.3. Groundwater Salinity

Although some limited groundwater salinity data as single measurements in boreholes were available for Tas, the dates of measurement were not available and there was a high degree of uncertainty over data quality so no salinity data are presented here.

10.4. Groundwater Extraction

No data were available on the locations and volumes of groundwater extraction in Tas at the time of publication.

10.5. Summary of VFA analysis: Tasmania

Only limited groundwater data were available for Tas for consideration in the VFA. Consequently, it is difficult to draw conclusions on the likelihood of SWI around the coast. As further data become available, their incorporation into the dataset and analysis following the methods presented above will provide useful indications of potential for high SWI vulnerability.

The VFA parameter categories identified in Tas GMAs are summarised in Table 12. No state VFA priority GMAs could be defined for Tas following the approach outlined for WA in Section 5.5 due to data limitations.

__Table 30__ Summary of VFA indicators by GMA for Tasmania

GMA	SWI Sites	Groundwater Levels				Groundwater Salinity (TDS Concentration in mg/L)		
		Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS <3000 within 1 km >10,000		TDS conc. changes
		2000-2009	Pre 2000	Inter-decadal decline >2.5 m	Declining trend >0.5 m/yr	Pre 2000	2000-2009	Inter-decadal increase >1000
Burnie	-	N	-	-	-	-	-	-
Central South East	-	Y	N	N	-	-	-	-
Flinders Island	-	-	-	-	-	-	-	-
Llandherne	-	-	-	-	-	-	-	-
Longford	-	-	-	-	-	-	-	-
North East	-	-	-	-	-	-	-	-
Scottsdale	-	N	N	N	-	-	-	-
Smithton	Smithton, Woolnorth	Y	-	-	-	-	-	-
Sorell	-	N	-	-	-	-	-	-
Spreyton	-	-	-	-	-	-	-	-
St Marys	-	-	-	-	-	-	-	-
Tomahawk	-	-	-	-	-	-	-	-
Wesley Vale	-	N	-	-	-	-	-	-
West	King Island	N	-	-	-	-	-	-

11. Vulnerability Factor Analysis Results: South Australia

In SA, groundwater management is undertaken based on Prescribed Well Areas (PWAs, which define groundwater management units), and Prescribed Water Resource Areas (PWRAs, which define combined groundwater and surface water management units). Both types of regulatory units are collectively termed GMAs below. The GMA boundaries are shown on Figure 80.

The McLaren Vale PWA forms part of the Western Mount Lofty Ranges PWRA and is entirely contained within its boundaries. The results for the Western Mount Lofty Ranges reported below only relate to those areas not covered by the McLaren Vale PWA to avoid double counting of data. However, since McLaren Vale is part of the Western Mount Loft Ranges, any discussion surrounding it must relate to both areas.

The total area of each GMA and the proportion of each GMA lying within 15 km of the coastline are provided in Table 31 which also indicates which of the SA GMAs coincide with the GMUs defined in AWR (2006). There are 9 GMAs in SA partially or wholly within 15 km of the coast and all contained data for consideration in this state assessment. Two of the GMAs (Baroota and Southern Basins) had more than 90% of their total areas within 15 km of the coastline, suggesting that SWI vulnerability may be highly relevant to their overall management. The VFA results are reported below and summarised on the basis of GMAs in Section 11.5.

Details of the number of measurements collected and analysed for the VFA in SA are provided in Table 32.

11.1. Groundwater Level Analysis

11.1.1. Minimum groundwater levels

Minimum groundwater levels measured in SA within 15 km of the coast are presented on Figure 81 and Figure 82. Groundwater level data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data below.

11.1.1.1. Historical minimum groundwater levels

Minimum groundwater levels reported in monitoring wells prior to 2000 are summarised on Figure 81. Minimum water levels <0 m AHD were relatively common along the SA coast during this period. Due to the widespread occurrence of low water levels, individual locations are not listed in detail here and Figure 81 should be referred to for their geographical locations. However, relative to the rest of the SA coast, higher numbers and densities of <0 m AHD minimum groundwater level measurements were identified near Streaky Bay, on the Eyre Peninsula (near Lincoln National Park), in the Northern Adelaide Plains – Central Adelaide area and near Goolwa (noting that this is not a definitive list). Minimum water level categories identified in each GMA are reported in Section 11.5.

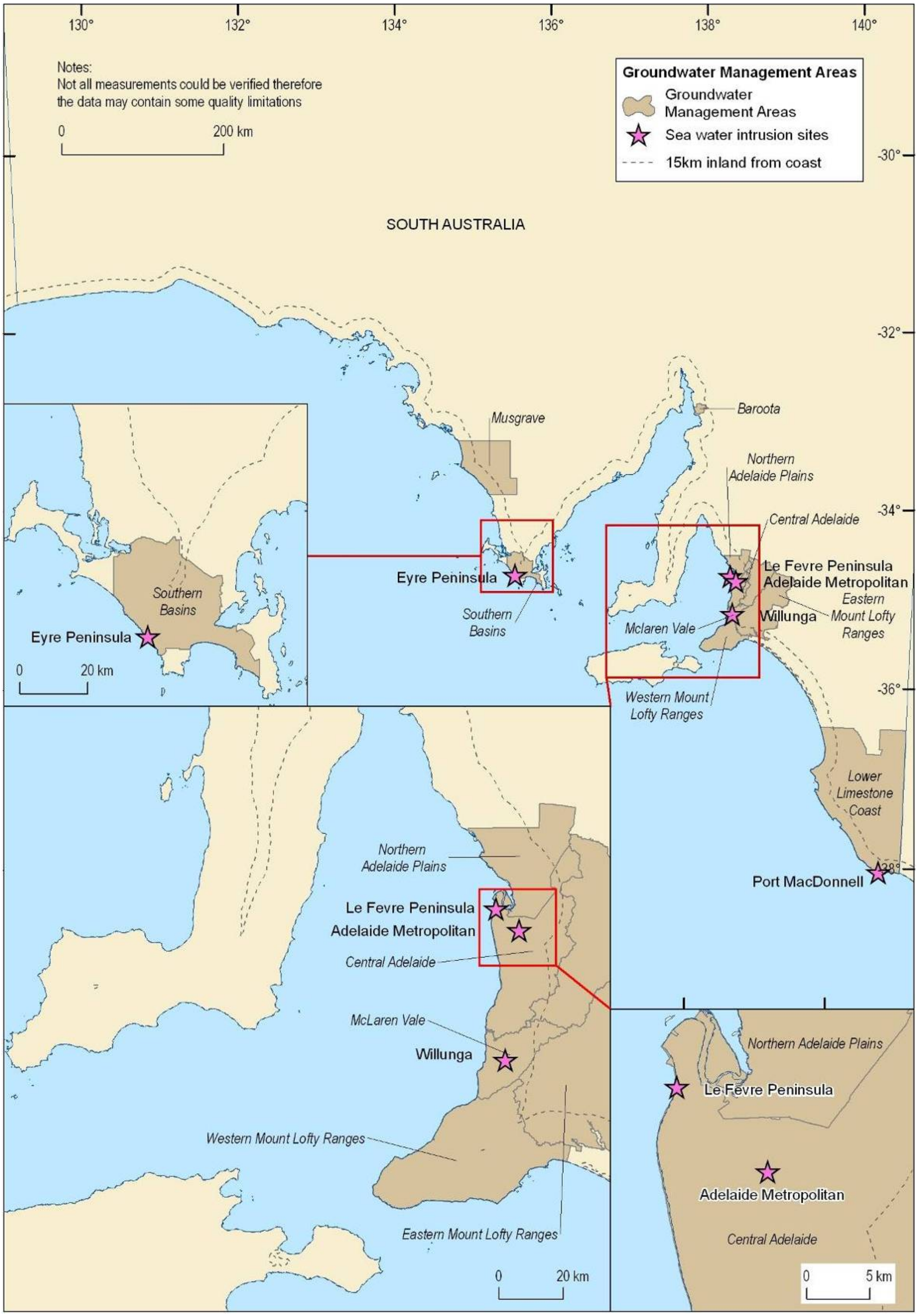


Figure 80 *GMAs in SA that intersect the 15 km coastal buffer zone.*

Table 31 *Total SA GMA areas that are wholly or partially within 15 km of the coast and percentage of total GMA areas within 15 km of the coast*

GMA Name	Total GMA Area (Hectares)^	Percentage of GMA Within 15 km of Coast
Baroota	13,057	99
Southern Basins*	86,446	97
McLaren Vale*	31,685	84
Central Adelaide***	84,594	77
Northern Adelaide Plains	60,420	71
Western Mount Lofty Ranges**	273,670	55
Musgrave*	355,679	35
Lower Limestone Coast	1,465,344	24
Eastern Mount Lofty Ranges**	283,189	12

*Generally matches AWR (2006) GMU

**GMA does not exist in AWR (2006)

***GMA consists of Lower Torrens, Patawalonga, Yatla and Adelaide GMUs in AWR (2006).

^Areas calculated based on the GDA1994 datum using a Lambert Conformal Conic Projection

Table 32 *Groundwater data utilised in the VFA for SA*

Data Type	Data Subset	No. of Measurements
Groundwater levels	All relative standing water levels	235,345
	Minimum RSWL (all years)	16,258
	Minimum RSWL Pre 2000	12,594
	Minimum RSWL 2000–2009	4,486
	Calculations of inter-decadal change in minimum RSWL from 1990-99 to 2000-09	1004
	Groundwater linear trend analyses	441
Groundwater salinity	All salinity measurements (e.g. lab/field EC, TDS; 6/1903–8/2010)	290,211
	Maximum TDS (all years)	50,549
	Maximum TDS Pre 2000	24,632
	Maximum TDS 2000–2009	4,306
	Calculations of inter-decadal change in maximum TDS from 1990-99 to 2000-09	1,253
Groundwater extraction	Bores with annual usage volumes in recent years used in analysis	719

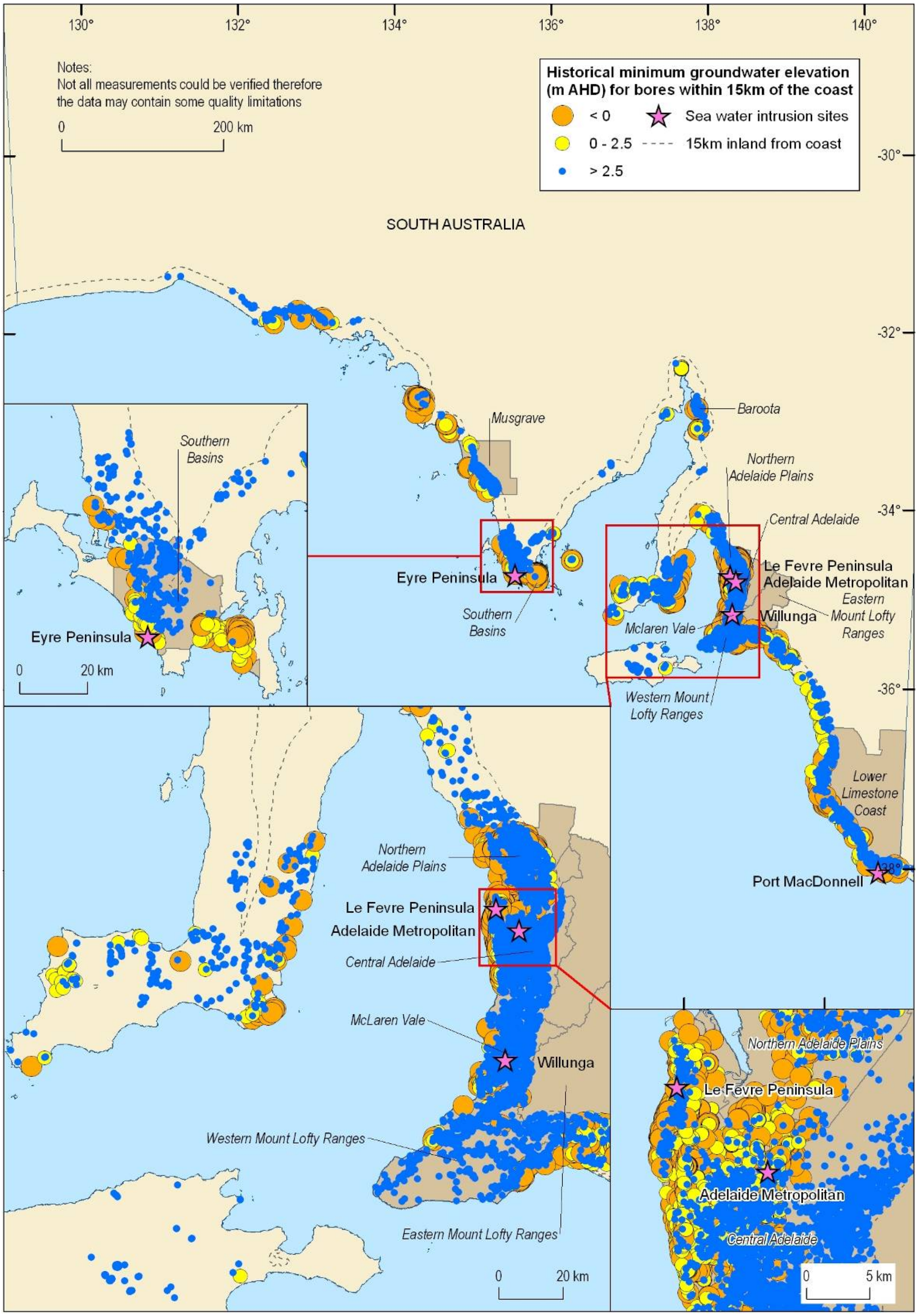


Figure 81 *Historical minimum groundwater levels measured prior to 2000, SA.*

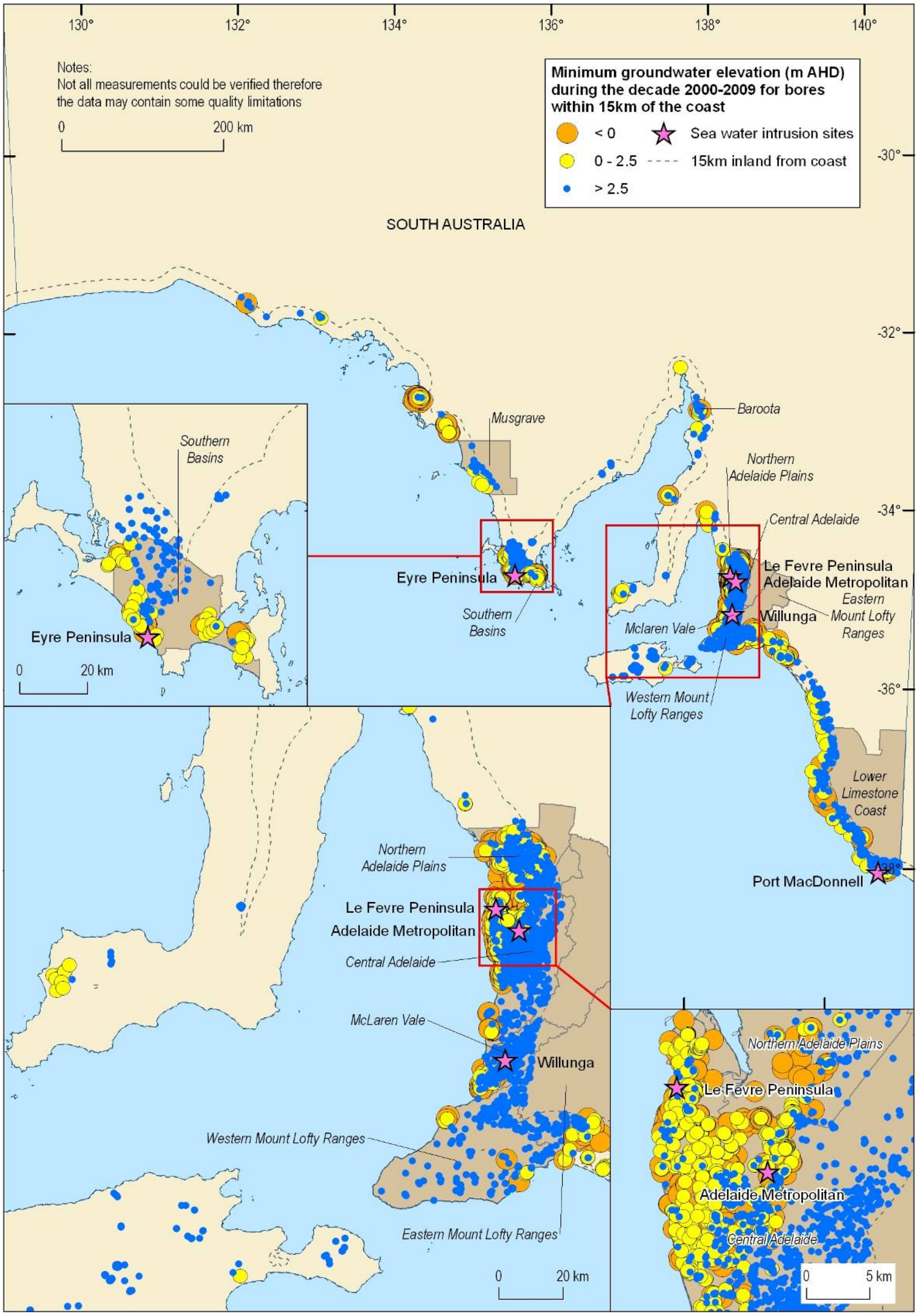


Figure 82 *Minimum groundwater levels measured in the period 2000-2009, SA.*

11.1.1.2. Minimum groundwater levels, 2000–2009

Minimum groundwater levels reported in monitoring wells for the period 2000-2009 are summarised on Figure 82. Although there are fewer measurements due to a shorter monitoring period, they show a similar distribution to those measured historically. Relative to the rest of the SA coast, higher numbers and densities of <0 m AHD minimum groundwater level measurements were recorded at Streaky Bay, in the Northern Adelaide Plains – Central Adelaide area and near Goolwa (noting that this is not a definitive list). They are reported for each GMA in Section 11.5.

11.1.2. Groundwater level changes

Changes in groundwater levels over time are plotted on Figure 83 (inter-decadal decline in minimum groundwater levels from 1990-1999 to 2000-2009) and Figure 84 (linear trends in groundwater levels) and discussed below.

11.1.2.1. Inter-decadal changes in minimum groundwater levels

Figure 83 shows that although boreholes recording an increase in groundwater levels between 1990-99 and 2000-09 were common, a greater proportion showed inter-decadal declines in minimum groundwater levels. A notable exception was the Northern Adelaide Plains area where relatively few increases in minimum water levels were recorded. Large declines >5 m were identified in several places including the areas of Uley South, Northern Adelaide Plains, Adelaide and surrounds, McLaren Vale, and Goolwa. Declines between 2.5 m and 5 m were also measured in many of these areas and near Streaky Bay, Port Kenny, Aldinga Beach, Carpenter Rocks and Millicent. Declines in the 0 – 2.5 m category were common along much of the SA coast.

11.1.2.2. Groundwater level trends

Figure 84 shows that decreasing groundwater level trends were measured in many areas along the SA coast with relatively few increasing trends recorded. Declining trends >1 m/year were identified in the areas of Northern Adelaide Plains, Adelaide and surrounds, McLaren Vale, and southeast of Millicent while declining trends in the 0.5-1 m/year category were identified in several other areas including Uley South, Port Germein, Kangaroo Island, and Goolwa.

11.1.3. Summary of groundwater level SWI vulnerability indicators

Figure 85 shows the high SWI vulnerability indicator categories for each of the groundwater level parameters presented in Section 11.1 above. Combinations of boreholes showing low groundwater levels, large inter-decadal declines in groundwater levels and high decreasing trends in groundwater levels were identified in the Adelaide area and surrounds and McLaren Vale.

11.1.4. Spatial distribution of low groundwater level observations

The maximum distances that groundwater levels <0m AHD and <2.5 m AHD extend inland within 15 km of the coast are presented for each GMA in Table 33. The data shown are based on minimum groundwater levels measured in boreholes over the decade 2000-2009. SWI may be anticipated to extend further inland in areas where low groundwater levels extend further from the coast. Minimum groundwater levels <0 m AHD were measured further inland than 10 km in the Northern Adelaide Plains, Lower Limestone Coast and Eastern Mount Lofty Ranges. Minimum water levels <0 m AHD also extended to >10 km from the coast in areas outside of the GMAs (summarised as “other” in the table). Although whether SWI occurs is dependent on many other factors in addition to groundwater levels, if SWI does occur in these areas groundwater level distributions may be such that SWI could extend a considerable distance inland if not appropriately managed.

Minimum water levels for the entire monitoring period (historic and recent) in each monitoring bore are plotted against distance from the coast in Appendix 2 for each GMA. In some GMAs such as the Northern Adelaide Plains, many low water levels have been recorded extending relatively far inland from the coast suggesting that, if SWI were to occur here, groundwater levels may facilitate extensive impacts. In contrast, GMAs such as Baroota show a more marked increase in groundwater levels with distance from the coast suggesting that impacts are more likely to be confined to more coastal areas if SWI was to occur there. Some of the plots show strong indications that minimum water levels are from two or more separate aquifers e.g. in Central Adelaide, where a distinct separation occurs on the plot between a group of bores with higher minimum water levels and a group with lower minimum water levels. Such features emphasise the limitations of the broad scale approach of the VFA (which does not distinguish between different aquifers) and the requirement for detailed site specific information when assessing SWI vulnerability.

Table 33 *Maximum inland extent within 15 km of the coast of minimum groundwater levels <0 m AHD and <2.5 m AHD based on 2000-2009 monitoring data reported for SA GMAs*

GMA	Maximum Inland Distance of <0 m AHD Groundwater Levels (km)	Maximum Inland Distance <2.5 m AHD Groundwater Levels (km)
Baroota	8.22	8.22
Central Adelaide	8.45	8.47
Eastern Mount Lofty Ranges	13.85	13.85
Lower Limestone Coast	14.88	14.88
McLaren Vale	5.46	5.46
Musgrave	All levels > 0m AHD	6.82
Northern Adelaide Plains	14.46	14.48
Southern Basins	4.17	6.49
Western Mount Lofty Ranges*	7.50	7.50
OTHER	14.55	14.55

*Excludes McLaren Vale which forms part of the Western Mount Lofty Ranges.

11.2. Rainfall Trend Analysis

Plots of cumulative deviation of monthly rainfall data from long term averages are included in Appendix 3 for locations near the SWI sites and summarised for SA on Figure 86 for the period 2000-2009. Of the locations assessed, most showed decreasing rainfall trends over the 2000-2009 period. The only exception was Port MacDonnell where rainfall was steady over this period. Although additional groundwater pressures may be anticipated where rainfall has decreased, drought around the country has eased in 2010 and 2011 (visible on the plots in Appendix 3), and a reversal in rainfall trends is evident in some areas. The rainfall trends on Figure 86 may therefore not remain good indicators of vulnerability and should be updated in future assessments.

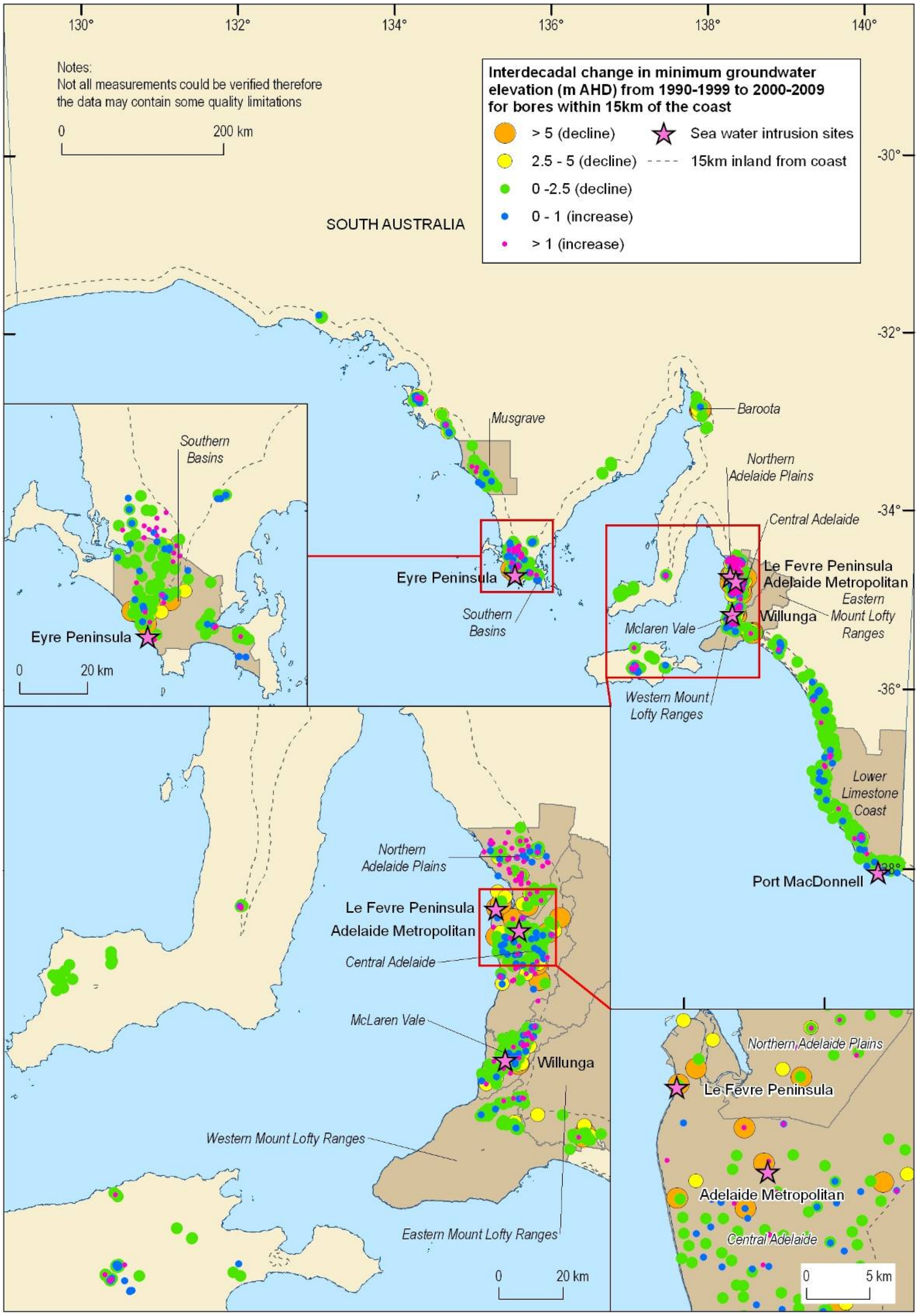


Figure 83 Inter-decadal changes in minimum groundwater levels from 1990-1999 to 2000-2009, SA.

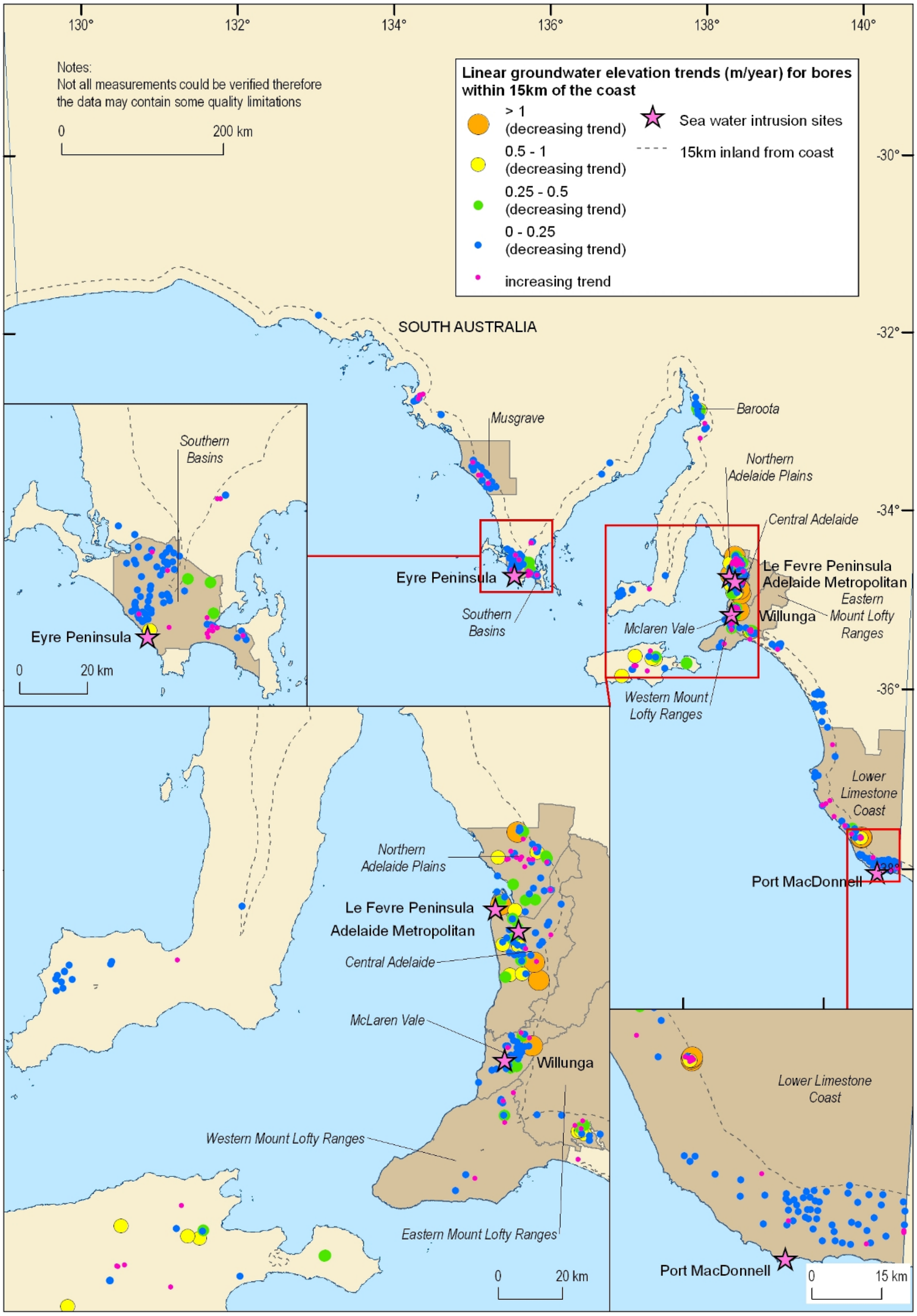


Figure 84 *Linear groundwater level trends in SA.*

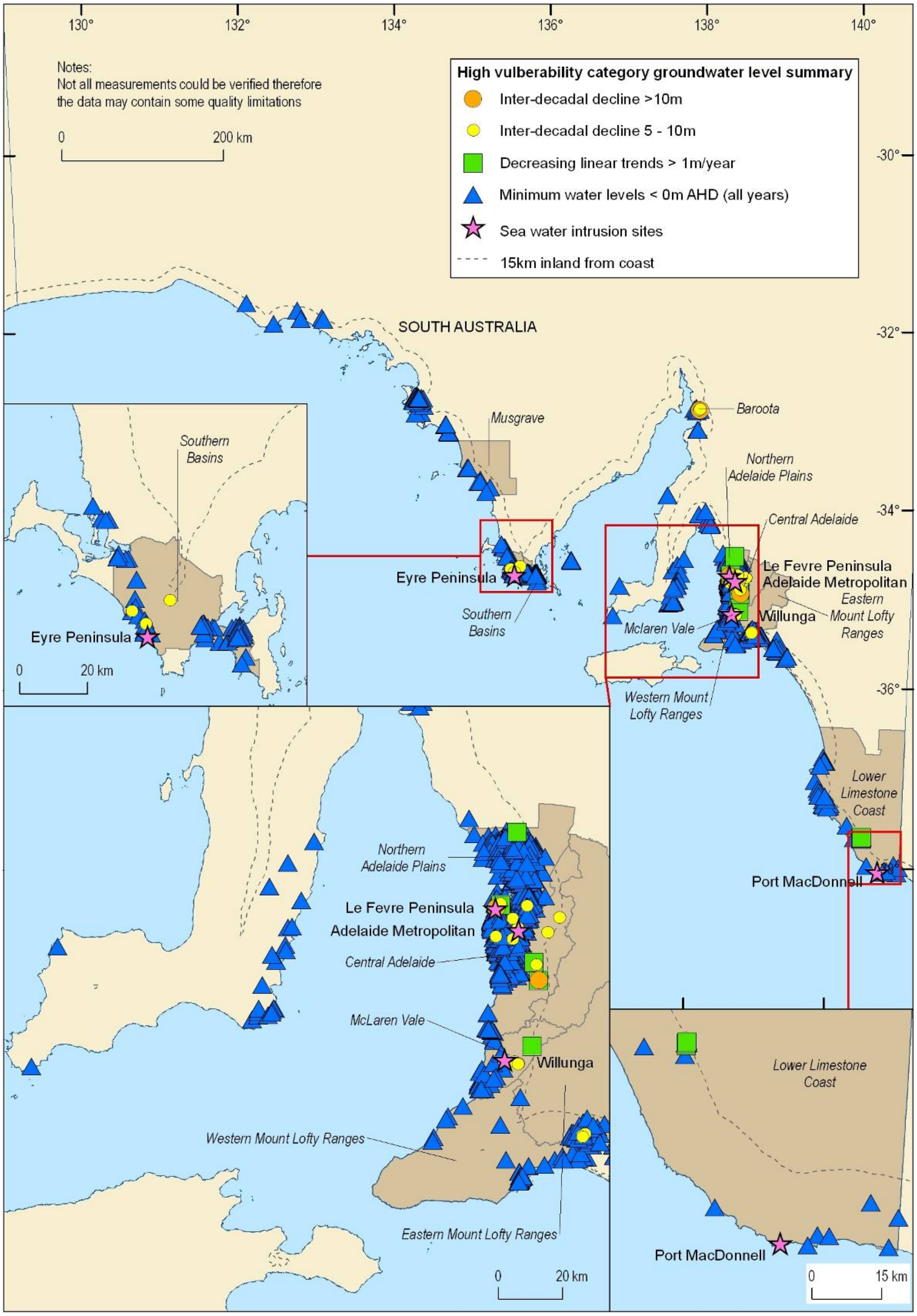


Figure 85 *Summary of groundwater level indicators of high SWI vulnerability, SA.*

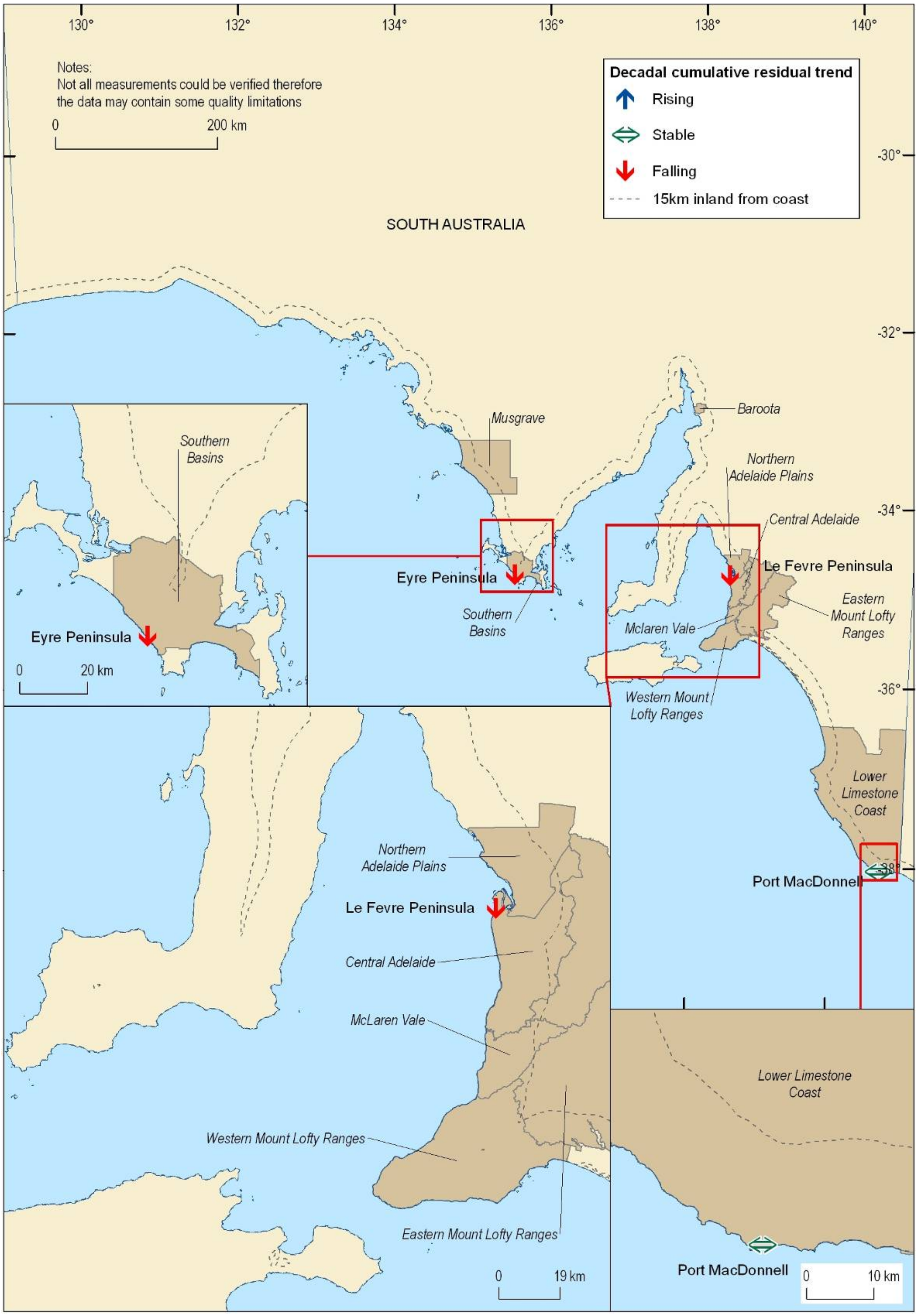


Figure 86 *Trends in cumulative deviation of monthly rainfall from long term averages for the period 2000-2009, SA.*

11.3. Groundwater Salinity

11.3.1. Maximum salinity measurements

Groundwater salinity data for SA are presented on Figure 87 and Figure 88. Data for the most recent decade (2000 to 2009) are considered separately from pre-2000 data below to highlight areas that have recently shown groundwater salinity indicators of SWI vulnerability.

11.3.1.1. Historical maximum salinity measurements

Historical maximum TDS concentrations are shown on Figure 87. Locations where groundwater has TDS concentrations <3000 mg/L is of interest since it is suitable for a wide range of uses and constitutes an important resource. Areas where groundwater with maximum TDS concentrations <3000 mg/L is located near groundwater with maximum TDS concentrations >10,000 mg/L are also of interest since they may indicate higher potential for intrusion of high salinity water into freshwater resources.

It is apparent from Figure 87 that relatively few maximum measurements <3000 mg/L were identified in the west of the state where groundwater appears relatively saline. In contrast, maximum TDS concentrations <3000 mg/L were more common in the central parts of the coastline from Elliston around the Eyre Peninsula to Tumby Bay, Port Germein, and from Port Rickaby to Stansbury and very common along the eastern parts of the coastline south and eastwards from the Northern Adelaide Plains to Goolwa and on the Lower Limestone Coast.

11.3.1.2. Maximum salinity measurements, 2000-2009

Maximum TDS concentrations measured during the period 2000-2009 are shown on Figure 88. Although there are fewer data, they show a similar distribution to the historic maximum TDS concentrations on Figure 87.

11.3.2. Inter-decadal changes in maximum salinity measurements

Changes in maximum TDS concentrations between the decades 1990-1999 and 2000-2009 are shown on Figure 89. It is apparent that although decreases in maximum TDS concentrations were common in places, the majority of locations where data are available in SA experienced an increase in TDS concentrations between decades in the range 0-1000 mg/L. Increases >10,000 mg/L were identified in Streaky Bay and Port Kenny, while increases in the range 3,000-10,000 mg/L were present at Uley South, Northern Adelaide Plains and Aldinga Beach.

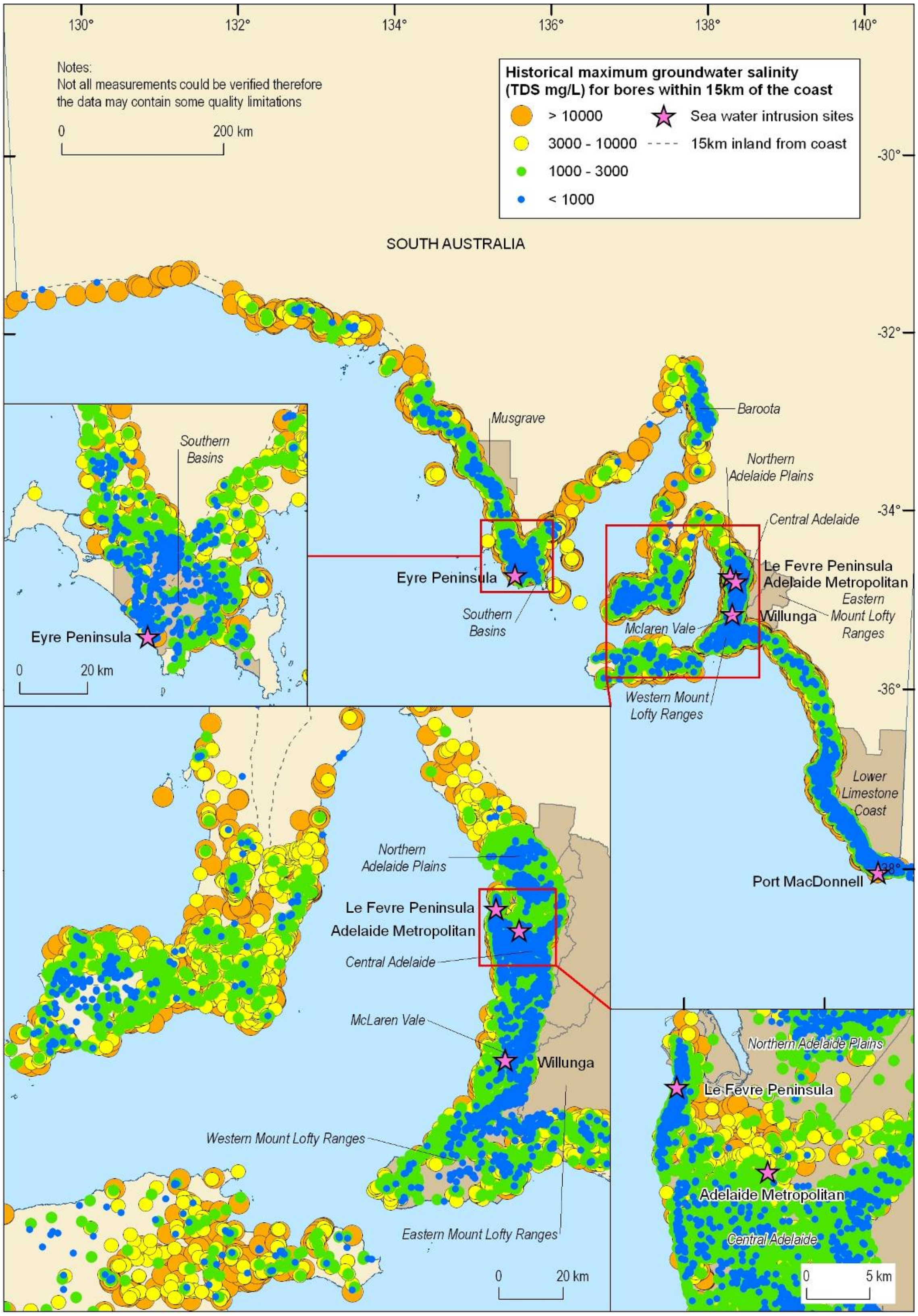


Figure 87 *Historical maximum TDS concentrations measured prior to 2000, SA.*

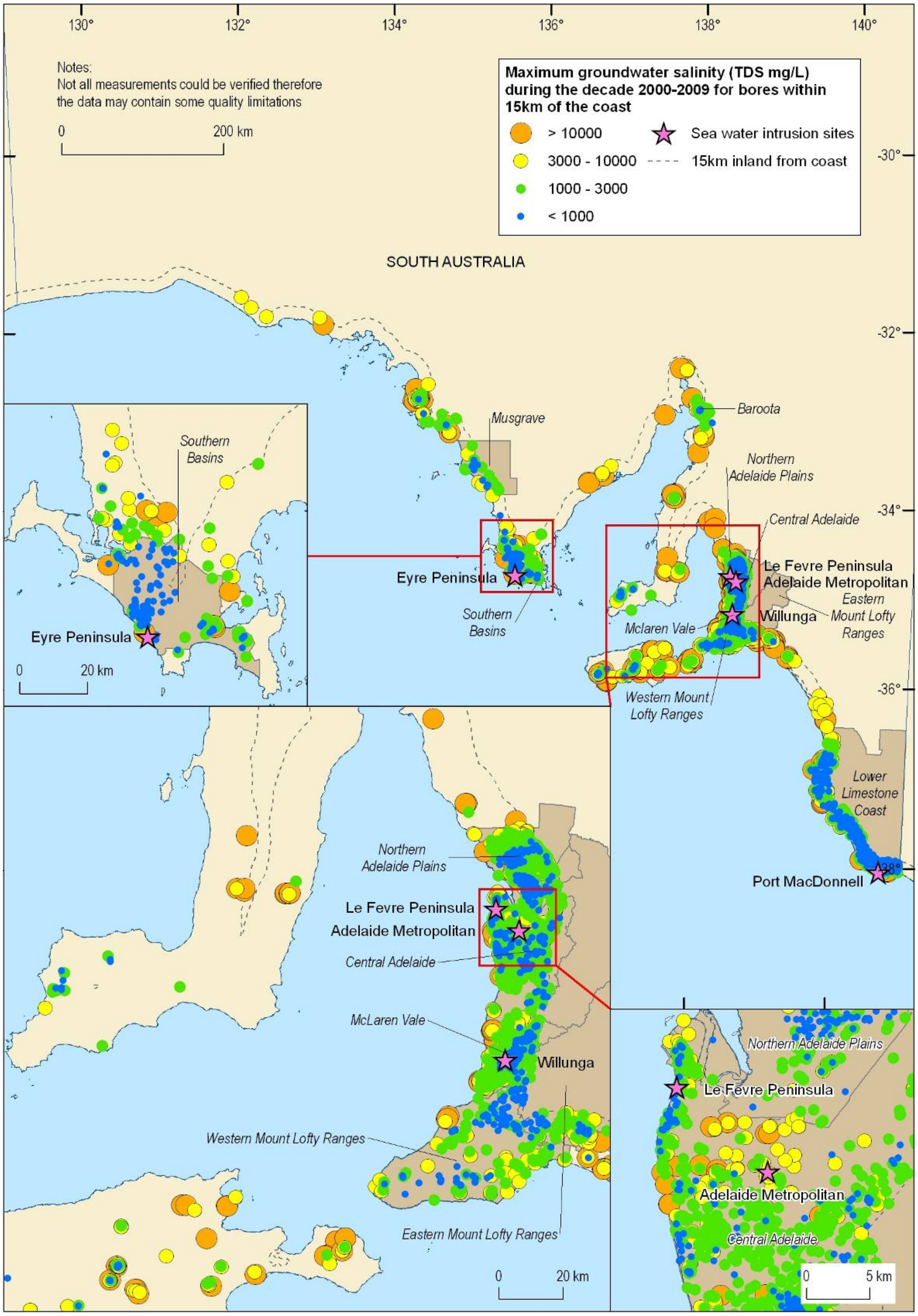


Figure 88 *Maximum TDS concentrations for the period 2000-2009, SA.*

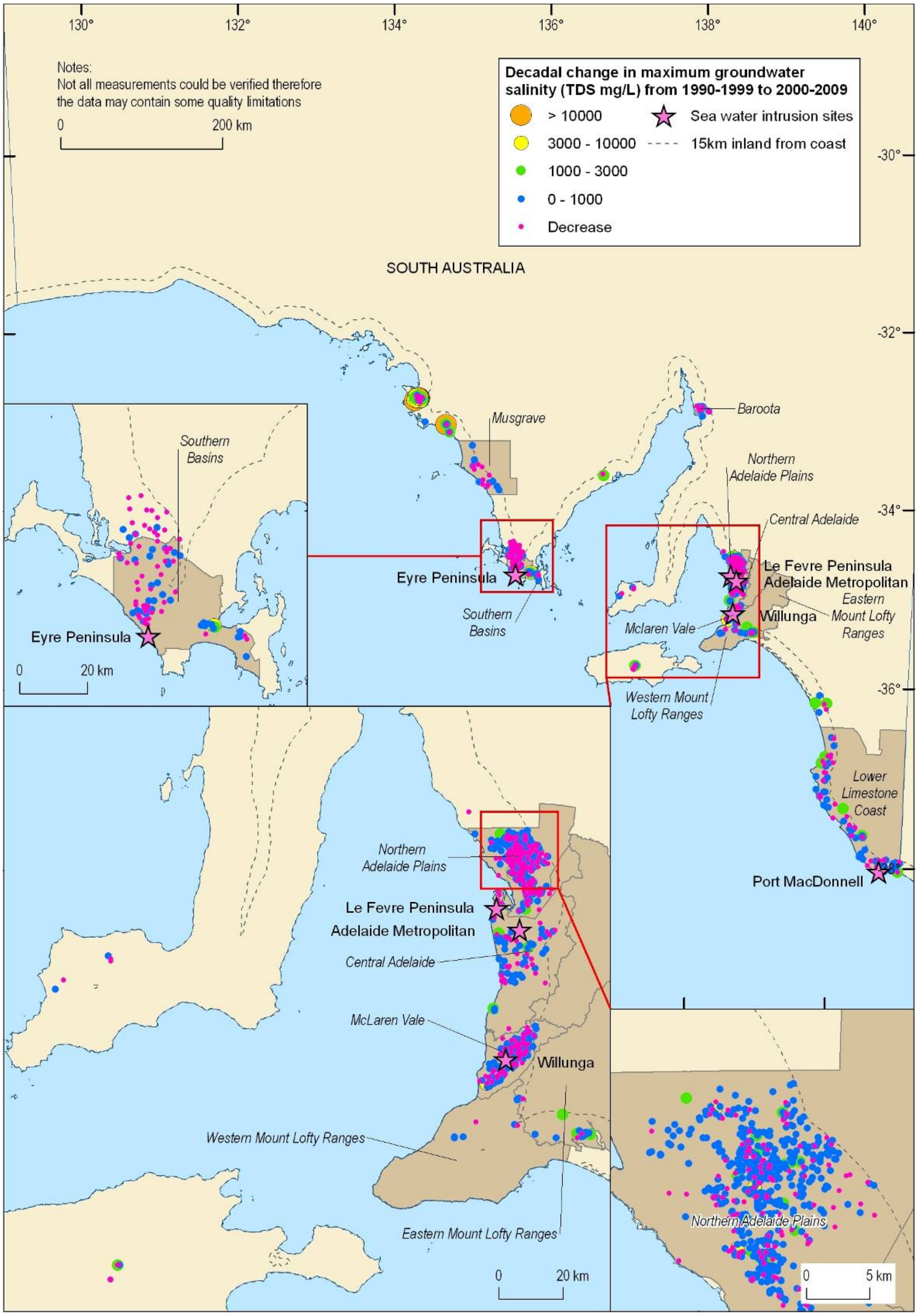


__Figure 89__ Inter-decadal change in maximum TDS concentrations from 1990-1999 to 2000-2009, SA.

11.4. Groundwater Extraction

Where available, historical groundwater usage data were provided by the Department for Water (DfW) for production bores located in the coastal GMAs. The type of bore extraction data was variable between GMAs: actual usage data for individual bores were available for Southern Basins, Musgrave and McLaren Vale; estimates rather than actual metering were available for production bores in Northern Adelaide Plains and Central Adelaide; and usage data for licenses were provided for Baroota. Complete usage information for all GMAs was not available for any one financial year. Consequently, the discussion below focuses on a mix of the 2007/08 and 2008/09 financial year data which provided the most complete coastal coverage.

11.4.1. Distribution of production bores

The locations of recorded production bores provided by DfW are presented on Figure 90. The highest numbers and densities of production bores were recorded in the Northern Adelaide Plains, Central Adelaide, McLaren Vale and Lower Limestone Coast GMAs.

11.4.2. Groundwater extraction rates

Figure 91 presents the recorded groundwater extraction rates in coastal SA for the 2007-2008 (Lower Limestone Coast) and 2008-2009 (elsewhere) financial years. As outlined in Section 3.4.3, in the context of SWI it is difficult to attach significance to extraction rates in the absence of recharge data. The information presented is best considered at a site specific level in conjunction with other available information. Figure 91 indicates that extraction rates in the >1000 ML/year were only associated with a single bore in the Southern Basins GMA, while individual bores in the Baroota and Lower Limestone Coast GMAs recorded extraction rates in the 500-1000 ML/year category.

11.4.3. Cumulative groundwater extraction rates

Cumulative groundwater extraction rates in 5 x 5 km grid cells in coastal SA are shown Figure 92 based on Figure 91 data. The final category that each cell falls into is somewhat dependent on where the grid is positioned, but in general the information shows that in addition to those GMAs with high individual bore extraction rates listed above, Northern Adelaide Plains, Central Adelaide and the Lower Limestone Coast had cumulative extraction rates >1000 ML/year in 5 x 5 km areas, while McLaren Vale recorded cumulative extraction rates in the 500-1000 ML/year range.

11.4.4. Groundwater extraction rates by GMA

Extraction volumes for those portions of the GMAs within 15 km of the coast in recent financial years are presented in Table 34 where they are compared to the sustainable yield estimates for the GMUs in AWR (2006). The AWR (2006) GMUs do not directly correspond to the SA GMAs in all instances thus care in interpretation is required (further details are included in Table 16).

Table 34 shows the percentage of AWR (2006) extraction for 2004-2005 relative to sustainable yield. Where extraction rates are high relative to sustainable yield, impacts on groundwater levels may occur resulting in SWI. Although this data is several years old, it provides an indication of which GMAs may have been under extraction stress in the past. Extraction at 50% of sustainable yield is taken to be a reasonable distinction between relatively low extraction rates and relatively high extraction rates. Of the GMAs for which data are available, Baroota, McLaren Vale, Northern Adelaide Plains and Southern Basins had recorded extraction rates exceeding 50% of estimated sustainable yield for 2004-2005.

Table 34 presents the proportion of extraction in each GMA in recent financial years within 15 km of the coast relative to the AWR (2006) sustainable yield data. The Baroota, McLaren Vale and Southern Basins GMAs have extraction rates within 15 km of the coast that exceed 50% of estimated sustainable yield for the entire GMA (noting that the Baroota sustainable yield value in AWR (2006) may not be representative of the current GMA since it suggests recent extraction >16 times sustainable yield). This suggests that they may be particularly susceptible to SWI (noting that those GMAs with a high proportion of their areas within 15 km of the coast are more likely to show higher values). However, groundwater levels near the coast depend on local extraction and recharge conditions that may be unrelated to sustainable yield for the entire GMA and therefore many of the other GMAs along the SA coast may also be at risk on the basis of this analysis. Such detailed consideration is beyond the scope of the VFA which offers a broad scale assessment of available data. The requirement for further site specific investigation is emphasised.

11.5. VFA Summary: South Australia

The VFA results for SA are summarised in Table 35 for each GMA. Following the approach outlined for WA in Section 5.5, the following state VFA priority GMAs were identified for SA: Baroota, Central Adelaide, Eastern Mount Lofty Ranges, Lower Limestone Coast, McLaren Vale, Northern Adelaide Plains, Southern Basins and Western Mount Lofty Ranges. These GMAs are considered to show a particularly high proportion and range of VFA indicators.

It is important to note that a single VFA indicator of high vulnerability in an area may correspond to an area with high SWI vulnerability and some high SWI vulnerability areas may have no data or high category indicators at all. There are other areas in SA showing indicators of high SWI vulnerability and a lack of data in many areas. Further, there were indicators of SWI vulnerability not captured in this summary since they were situated outside of the GMAs. Omission of locations from the list of state VFA priority GMAs should not be taken to imply that they are unlikely to be significantly vulnerable to SWI. The list simply highlights locations where considerable numbers of high SWI vulnerability indicators are present where data are available. Some of the GMAs cover large areas compared to others thus reporting at the GMA level is somewhat inconsistent. The data presented above should be considered on a case by case basis at a scale commensurate with the area of interest.

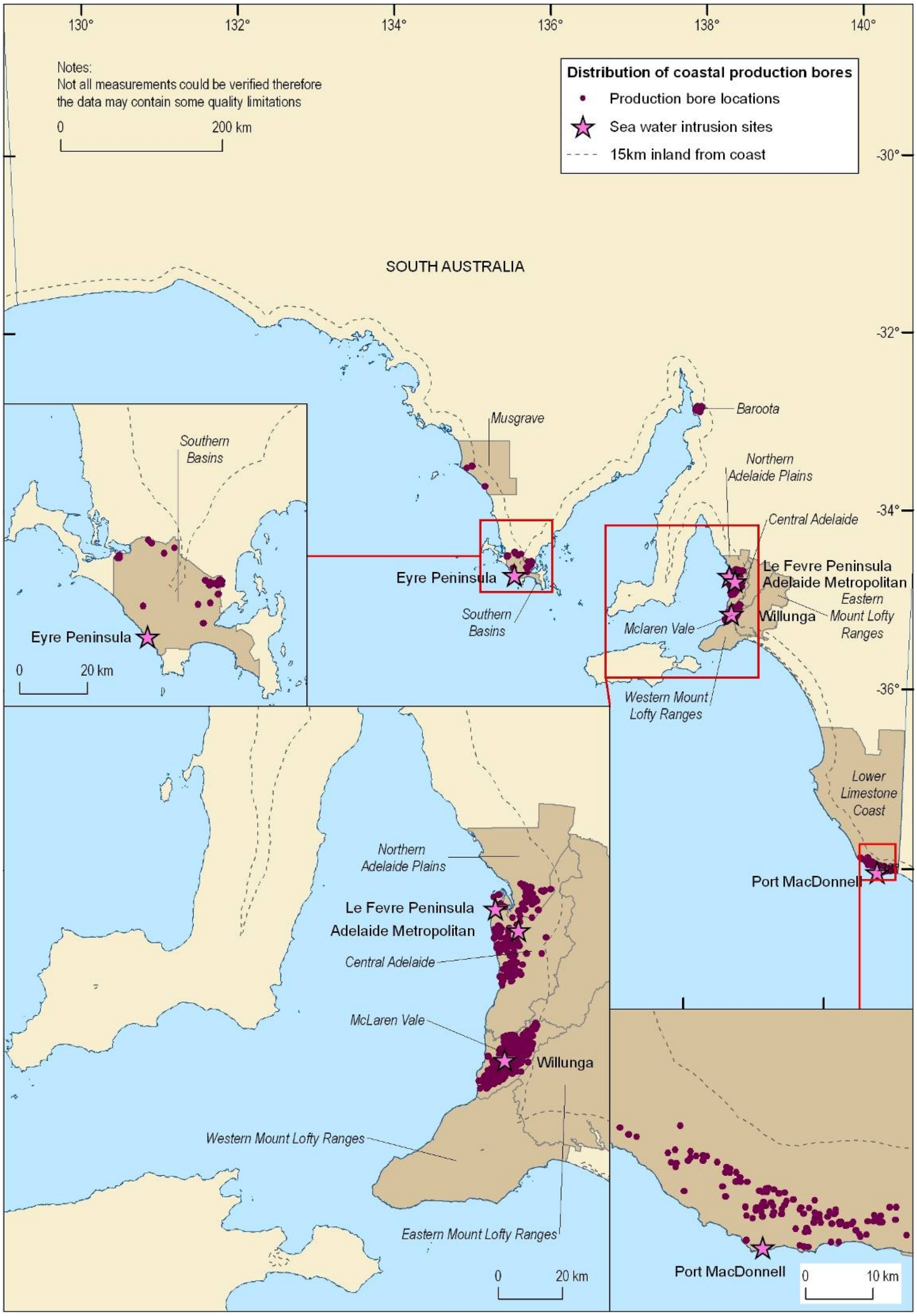


Figure 90 *Distribution of recorded production bores, SA.*

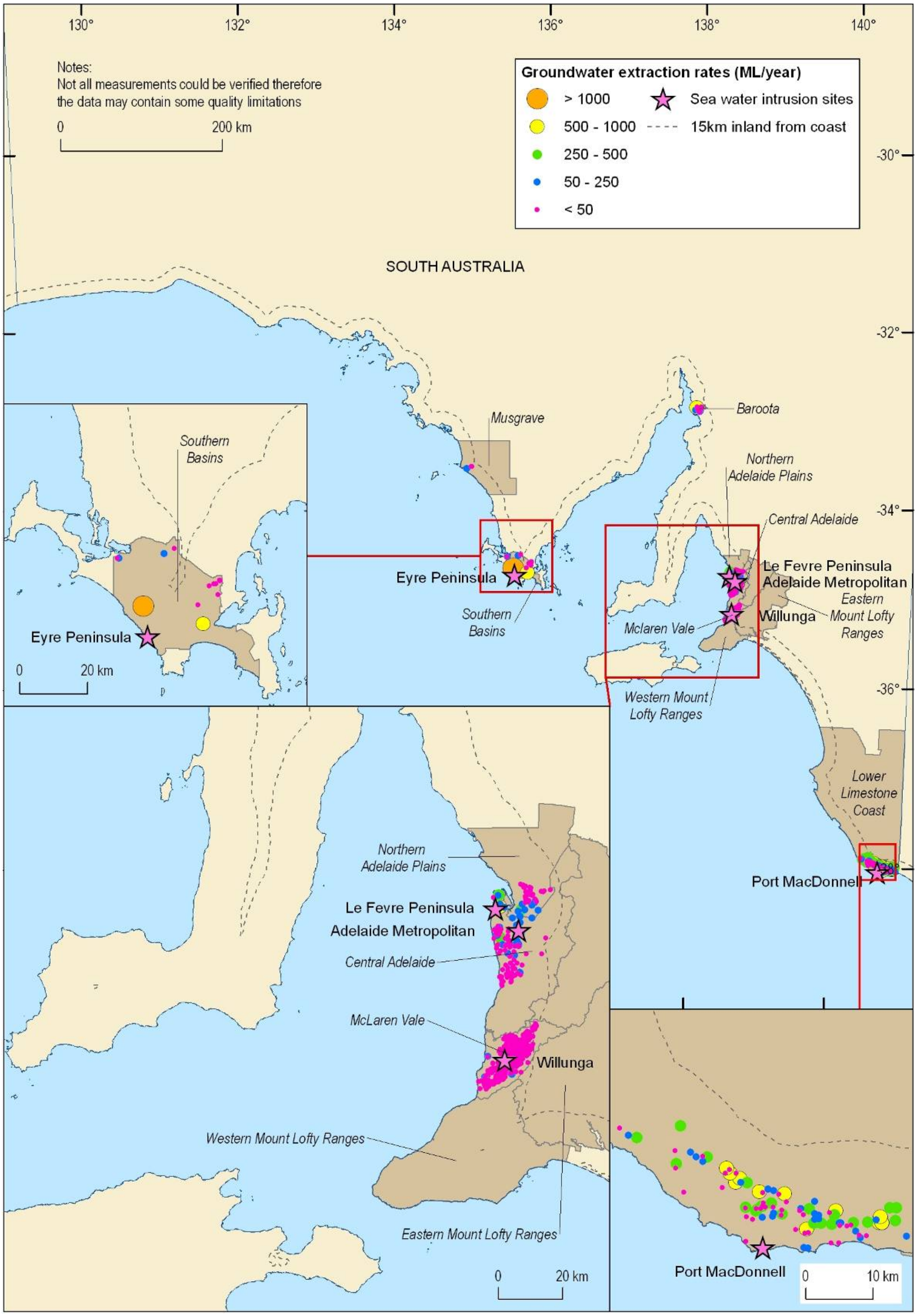


***Figure 91** Groundwater extraction rates for the 2007-2008 (Lower Limestone Coast) and 2008-2009 (elsewhere) financial years, SA (source: DfW).*

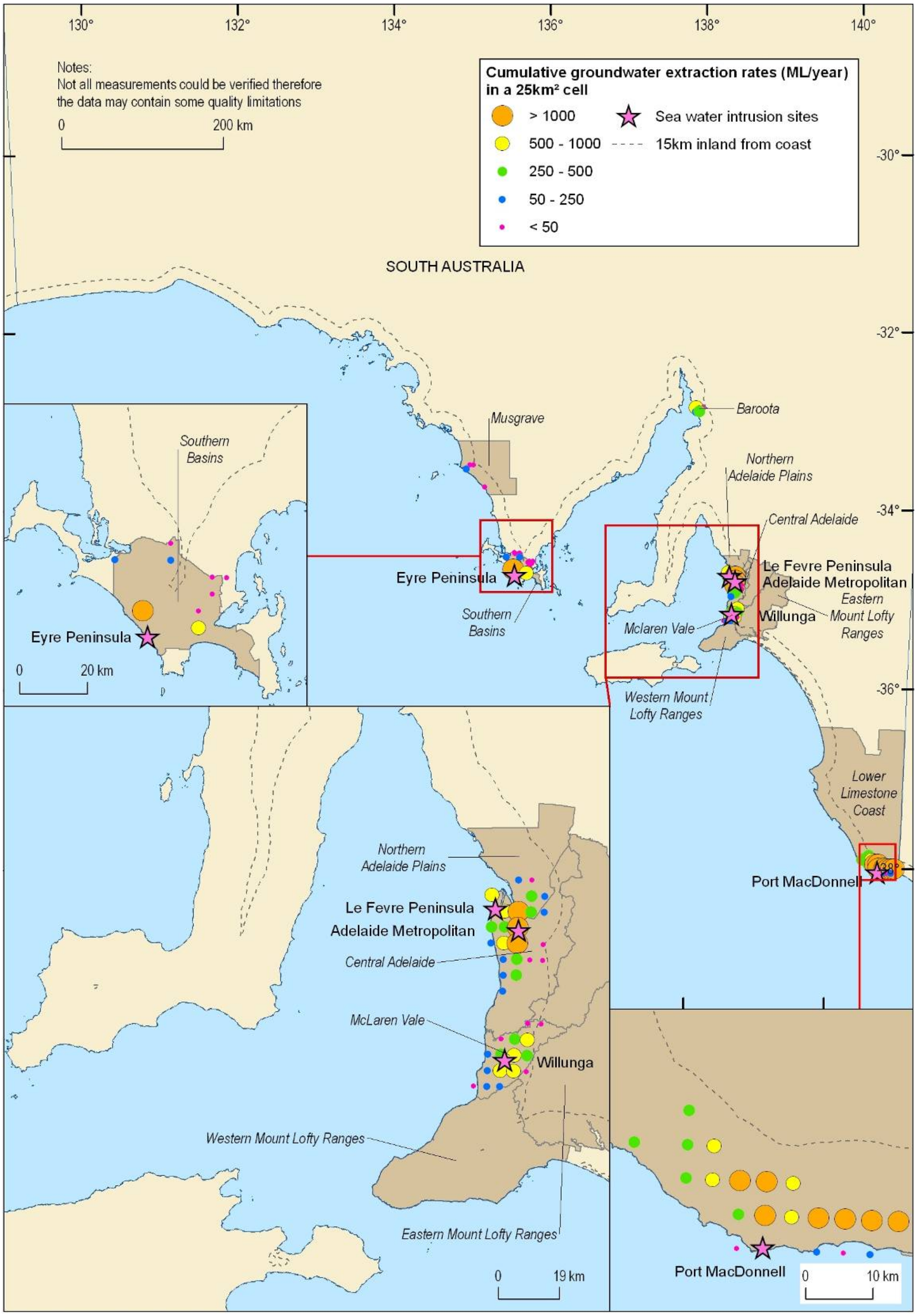


***Figure 92** Cumulative groundwater extraction rates within 5x5 km grid cells, SA.*

Table 34 *Summary of extraction and sustainable yield (SY) data, SA*

GMA	AWR 2005 2004-2005 Extraction† (ML/yr)	AWR 2005 SY† (ML/yr)	Extraction within 15 km of coast^ (ML/yr)	AWR 2005 Extraction relative to SY	Extraction within 15 km relative to SY
Baroota**	200	70	1170	286%	1671%
Central Adelaide#	-	-	6743	-	-
Eastern Mount Lofty Ranges***	-	-	-	-	-
Lower Limestone Coast**	188393	756250	18885	25%	2%
McLaren Vale	3800	6600	4756	58%	72%
Musgrave	330	19860	81	2%	0%
Northern Adelaide Plains**	14500	15000	1991	97%	13%
Southern Basins	5000-9999	9000	7287	56-111%	81%
Western Mount Lofty Ranges***	-	-	-	-	-

†Source: AWR (2006) for GMUs, noting that the GMU boundaries differ from GMA boundaries as indicated in the table.

*Source: Total GMA extraction data from the Department of Sustainability and Environment (DSE).

**GMA boundary supplied by SA differs substantially from AWR (2006).

***GMA does not exist in AWR (2006).

#GMA consists of Lower Torrens, Patawalonga, Yatla and Adelaide GMUs in AWR (2006). AWR data were not available for most of these GMUs so no values are presented.

^ Source: Extraction data available from Department for Water (DfW) for 2007-08 (Lower Limestone Coast) and 2008-09 (elsewhere).

- = no data.

Extraction data do not include stock and domestic use

Table 35 *Summary of VFA indicators by GMA for South Australia (VFA priority GMAs are indicated by *)*

GMA	SWI Sites	Groundwater Levels				Groundwater Salinity (TDS Concentration in mg/L)		
		Min. groundwater levels <0 m AHD		Groundwater level changes		Max. TDS <3000 within 1 km >10,000		TDS conc. changes
		2000-2009	Pre 2000	Inter-decadal decline >2.5 m	Declining trend >0.5 m/yr	Pre 2000	2000-2009	Inter-decadal increase >1000
*Baroota	-	Y	Y	Y	Y	Y	N	N
*Central Adelaide	Le Fevre Peninsula, Adelaide Metropolitan	Y	Y	Y	Y	Y	Y	Y
*Eastern Mount Lofty Ranges	-	Y	Y	Y	Y	Y	Y	Y
*Lower Limestone Coast	Port MacDonnell	Y	Y	Y	Y	Y	Y	Y
*McLaren Vale	Willunga	Y	Y	Y	Y	Y	Y	Y
Musgrave	-	N	Y	N	N	Y	N	N
*Northern Adelaide Plains	-	Y	Y	N	Y	Y	Y	Y
*Southern Basins	Eyre Peninsula	Y	Y	-	Y	Y	Y	Y
*Western Mount Lofty Ranges	-	Y	Y	Y	Y	Y	N	N

12. Limitations

Only general limitations are discussed in this section and reference should be made to preceding sections for further limitations specific to each VFA parameter considered.

The VFA is limited spatially and temporally by the availability of relevant groundwater datasets, which are described in the preceding sections. Much of Australia's coastline is data poor, and the lack of SWI vulnerability indicators in these areas should not be taken to mean that they are unlikely to be vulnerable to SWI. The figures presented in this report record where data were available for analysis, and no attempt was made to infer conditions outside these areas. However, it is noted that data-rich regions may coincide with areas of relatively high groundwater use and therefore areas where SWI may be of greater concern.

Data filtering was undertaken to remove obvious outliers and many measurements in the higher vulnerability categories have been verified by state/territory hydrogeologists. However, not all data could be verified due the high number and nature of measurements. Although the national assessment methodology of removing data where less than three data points within a 5 km radius fall into the same category will help to remove anomalous readings, caution is required when making assessments based on the data presented since some quality limitations may remain.

The VFA should not be considered in isolation from the other assessments of vulnerability in the national-scale vulnerability assessment of seawater intrusion project. The vulnerability factors presented in the VFA serve only as indicators of an area's SWI vulnerability level. To fully assess an area's vulnerability to SWI, additional information must be incorporated into the analysis as undertaken in the summary report for this project (Ivkovic et. al, 2012a). It was not possible at the VFA scale to include information on several important parameters affecting SWI vulnerability, including aquifer geometry, aquifer hydraulic properties, sea–aquifer connectivity and recharge rates. As an example, an aquifer with low water levels that is hydraulically isolated from the sea would not be vulnerable to SWI, but the VFA might identify it as an area containing vulnerability indicators since low groundwater levels suggest that SWI may occur. No distinction has been made between confined and unconfined systems, which may respond differently to stress.

In summary, the VFA identifies areas where there are indicators of high SWI vulnerability within 15 km of Australia's coast for use in the holistic SWI vulnerability assessment in Ivkovic et. al, (2012a). There may be many other locations around the coast where data are limited that are highly vulnerable to SWI and other areas where factors other than those considered in the VFA make locations highly vulnerable to SWI. Data must be considered on a site specific basis in the context of local hydrogeological factors for a full assessment of SWI vulnerability which is beyond the scope of the VFA.

13. Summary and Future Directions

13.1. VFA Project Summary

This VFA technical report forms part of a project that aims to identify Australian coastal groundwater resources currently vulnerable to seawater intrusion (SWI), and potentially at risk in the future as a consequence of over-extraction, sea-level rise and/or recharge-discharge variations associated with climate change. A summary of the overall project findings is presented in the project summary report by Ivkovic et al. (2012a).

The VFA was undertaken to provide a first-pass, regional assessment of SWI vulnerability indicators in Australia's coastal areas based on state and territory datasets. Due to the scale of the VFA assessment and limits on data availability, it was not possible to include information on several important, site-specific parameters affecting SWI vulnerability including aquifer geometry, aquifer hydraulic properties, sea-aquifer connectivity and recharge rates. Consequently, the VFA cannot provide a definitive assessment of an area's vulnerability to SWI. Instead, the VFA indicators were used to identify priority areas of concern for further, site-specific analysis of SWI vulnerability and inform the national vulnerability assessment in Ivkovic et al. (2012a).

The VFA is subject to the limitations outlined in Section 12 of this document.

13.1.1. VFA Project Methodology

The VFA was based on a series of groundwater datasets provided by the various state and territory water agencies for individual groundwater bores. In total, more than 1.7 million groundwater levels and more than 1.1 million salinity measurements were compiled and evaluated as part of this project. This large dataset allowed analysis of a greater portion of Australia's coastline than has been assessed in previous studies.

Although additional factors are relevant when assessing vulnerability of groundwater systems to SWI, the VFA was restricted to a consideration of the following parameters due to constraints on data availability and the limitations of undertaking a national-scale analysis:

- groundwater levels in monitoring bores (minimum groundwater level, inter-decadal changes in groundwater level and groundwater level trends);
- rainfall trends measured at BoM weather stations;
- groundwater salinity in monitoring bores (maximum salinity and inter-decadal changes in salinity); and
- groundwater extraction from production bores (locations and rates).

Values for each of the above parameters were separated into SWI vulnerability level indicator categories and plotted on a series of maps to facilitate spatial and temporal data analysis. Data were analysed following different methods at the state and national-scales as outlined in the results summary section below.

Following a general presentation and discussion of the distribution of vulnerability indicators, areas where a relatively wide range of high SWI vulnerability category VFA indicators are present were identified in the VFA as priority areas for future, detailed assessment. Due to limitations to the usefulness of available rainfall and groundwater extraction data, only groundwater level and salinity data were considered in the prioritisation assessment. The following seven categories of VFA parameters were taken to indicate that high SWI vulnerability was likely in an area:

1. Historic minimum groundwater levels <0 m AHD (pre 2000);
2. Recent minimum groundwater levels <0 m AHD (2000-2009);
3. Inter-decadal decline in groundwater levels between 1990-1999 and 2000-2009 >2.5 m;
4. Declining groundwater level trends >0.5 m/year;
5. Historic maximum TDS concentrations >10,000 mg/L located within 1 km of maximum TDS concentrations <3000 mg/L (pre 2000);
6. Recent maximum TDS concentrations >10,000 mg/L located within 1 km of maximum TDS concentrations <3000 mg/L (2000-2009); and
7. Inter-decadal increase in maximum TDS concentrations >1000 mg/L between 1990-1999 and 2000-2009.

Justification of the above categories is provided in the methodology section of this report. Locations showing greater than 50 % (4 or more) of the above category indicators and including at least one indicator from both groundwater level (any of the indicators listed in points 1 to 4 above) and salinity (any of the indicators listed in points 5 to 7 above) categories were classified as priority VFA areas containing a significant proportion and range of VFA indicators.

13.1.2. VFA Project Findings

The VFA priority areas identified under the national and state level VFA analyses are listed below where summaries of the national and state VFA approaches are included. However, there are many other areas around Australia showing indicators of high SWI vulnerability and a lack of data in many areas (e.g. a lack of data in NT, NSW and Tas precluded identification of priority VFA areas in these states). Omission of locations from the lists of VFA priority areas below should not be taken to imply that they are not highly vulnerable to SWI. The discussion simply highlights locations where relatively large numbers of high SWI vulnerability indicators are present where data are available around Australia's coast.

13.1.2.1. National VFA Summary

The national-scale assessment highlights geographical areas where groups of three or more data points (boreholes) within a 5 km radius fall within the same vulnerability indicator category for groundwater level and salinity data. This approach is useful for assessing the general vulnerability of large scale areas and reducing the likelihood of classifications based on single anomalous measurements.

The distributions of individual VFA indicators are discussed in detail within the national assessment section of this technical report (Section 4).

The following localities (names refer to the general location and surrounding areas) were categorised as "national VFA priority areas" where a wide range (>50% of the seven key indicators- see

Section 4.5) of high SWI vulnerability indicators have been identified (noting that indicators of high SWI vulnerability were also identified in many other areas):

- WA: Carnarvon and the Swan Coastal Plain (including the following locations and surrounds: Mindarie, Perth, Munster, Peron, Peel Inlet, Harvey Estuary, Lake Preston and Abbey);
- Qld: The area north of Cairns (around Holloways Beach), The Burdekin, Bowen, Pioneer Valley and Mackay, Bundaberg and Burnett Heads;
- Vic: Koo Wee Rup; and
- SA: Streaky Bay, Uley South, Northern Adelaide Plains, Adelaide, McLaren Vale, Aldinga Beach and Goolwa.

13.1.2.2. State VFA Summary

In contrast to the national assessment, all data are presented in the VFA for individual boreholes in the state and territory analyses which provide a finer scale assessment than the national approach.

The distributions of individual VFA indicators are discussed in detail within the various state and territory sections of this technical report (Sections 5 to 11).

At a state level, summary results were reported on the basis of GMAs (defined areas where groundwater use is regulated by state authorities). “State VFA priority GMAs” where a wide range (>50% of the seven key indicators- see Section 5.5) of high SWI vulnerability indicators have been identified included (noting that indicators of high SWI vulnerability were also identified in many other areas):

- WA: Arrowsmith, Bunbury, Busselton-Capel, Carnarvon, Cockburn, Gascoyne, Gingin, Murray, Perth, Stakehill, Southwest Coastal and Yanchep;
- Qld: Bowen, Bundaberg, Burdekin, Cairns Northern Beaches, Farnborough, Pioneer and Proserpine;
- Vic: Deutgam, Koo Wee Rup, Sale, Stratford and Tarwin; and
- SA: Baroota, Central Adelaide, Eastern Mount Lofty Ranges, Lower Limestone Coast, McLaren Vale, Northern Adelaide Plains, Southern Basins and Western Mount Lofty Ranges.

The national VFA priority areas and state VFA priority GMAs are shown in Figure 93 below. It is reiterated that omission of locations from Figure 93 or the lists in Sections 13.1.2.1 and 13.1.2.2 should not be taken to imply that they are not highly vulnerable to SWI. Figure 93 simply highlights locations where a relatively wide range of high SWI vulnerability indicators are present where data are available around Australia’s coast.

13.2. Future Directions

The VFA results are incorporated into the holistic SWI vulnerability assessment in Ivkovic et al. (2012a). While it was developed with the specific intention of informing the national-scale vulnerability assessment of seawater intrusion project, the VFA outlines a methodology suitable for evaluating groundwater data at both national and state scales to provide an indication of SWI vulnerability levels and prioritise areas for further investigation and research should groundwater resources be developed or continue to be used. As evident on the figures throughout this report, the VFA identified large areas around Australia’s coast where there are insufficient data to provide an indication of likely SWI vulnerability level and further investigation is recommended in these areas.

SWI vulnerability is dependent on a range of factors that vary over time (e.g. groundwater levels relative to sea level, climate, groundwater extraction relative to recharge etc), and consequently the VFA assessment is time-dependent and requires revision as further data become available. While the VFA may serve as a useful model for future analysis, its methodology was developed to suit available data and should also be reconsidered as further information becomes available. One of the main drivers of SWI is extraction relative to recharge, and an incorporation of some measure of this ratio into any future assessment would be valuable. However, it must be kept in mind that the VFA is a broad-scale approach to analysis and if such estimates require detailed, site-specific data, the VFA approach presented here is unlikely to remain relevant.

Figure 93 *National VFA priority areas and state VFA priority GMAs*

(Note that due to a lack of sufficient data for priority area classification along the majority of the Australian coast, many other areas not classified on this figure may also have high SWI vulnerability as outlined in the preceding text).

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Appendix 1: Plots of TDS concentration measurements over time in selected monitoring bores

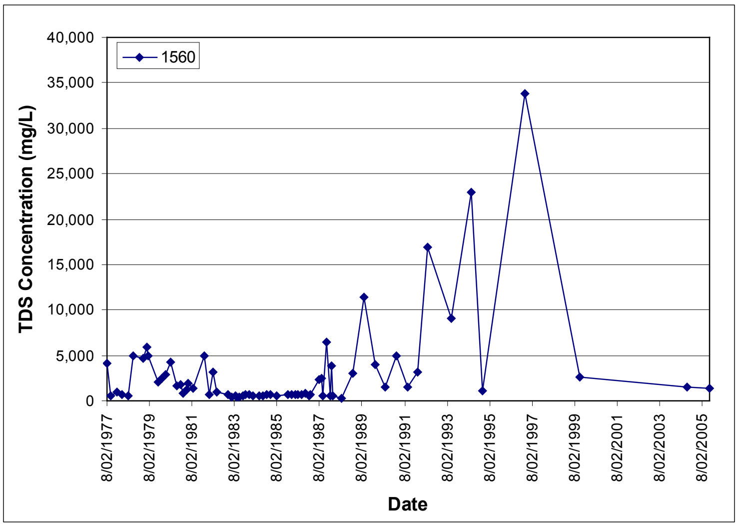
As outlined in Section 3.3.2, part of the data filtering process for salinity measurements entailed plotting TDS concentrations over time to facilitate identification of anomalous readings. Only borehole salinity time series with an RDM (see Section 3.3.2) value >0.5 were examined. During this process, a number of boreholes were identified that showed strong indications of possible SWI in their measurements (locations are shown on the figure below).

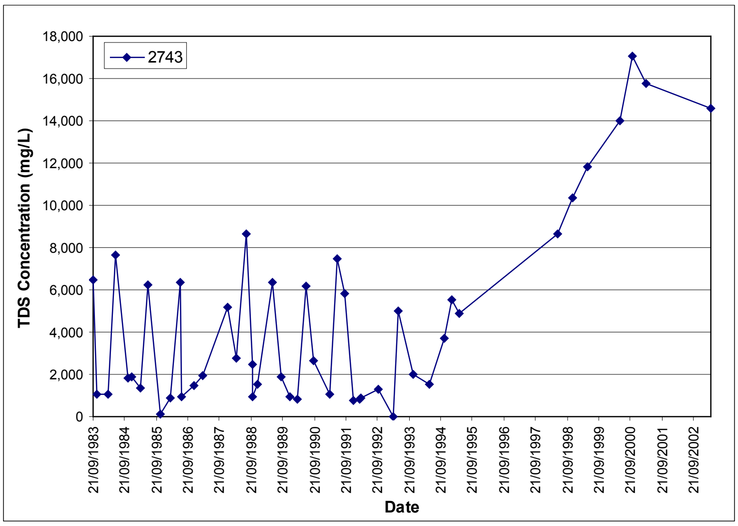
Since such analyses were only undertaken on a small subset of the salinity data and the total number of TDS time series precluded analysis of all measurement points, it was not considered appropriate to present the data within the main report body. Presentation of the data would place unjustifiable emphasis on the locations where time series TDS analysis was undertaken. However, time series TDS plots for boreholes showing indications of SWI are included for reference purposes here (borehole numbers provided by the various state agencies are included on the plots). It is noted that the plots are not definitive indications of SWI since such an assessment would require interpretation in the context of site specific information.

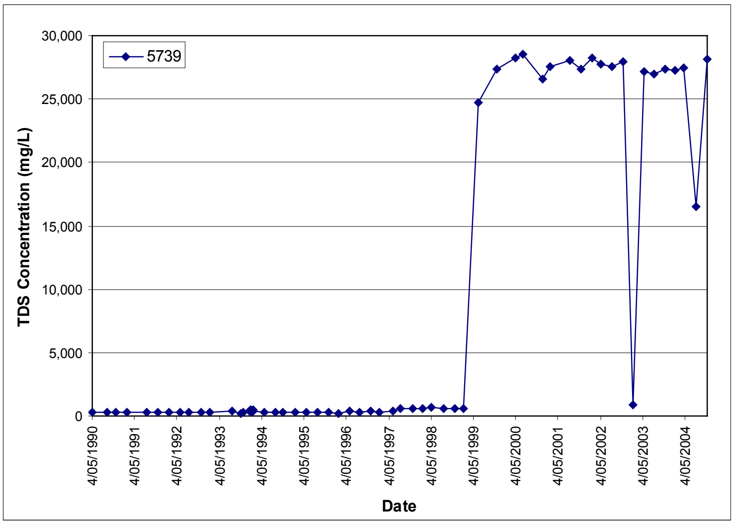
Figure 94 *Locations of bores where a strong indication of SWI was identified in TDS concentration time series data*

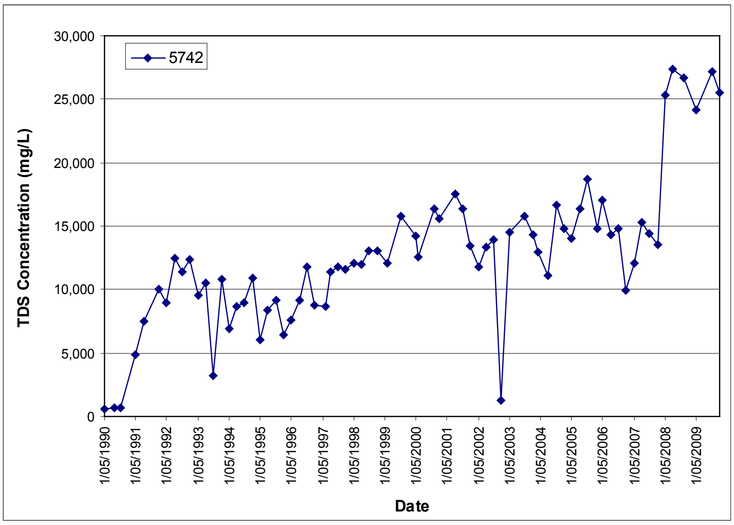
(NB: see preceding text for limitations).

Western Australia









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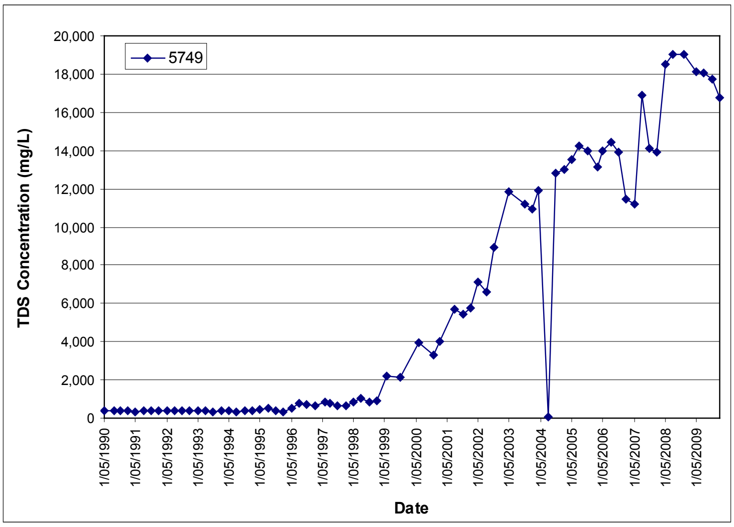

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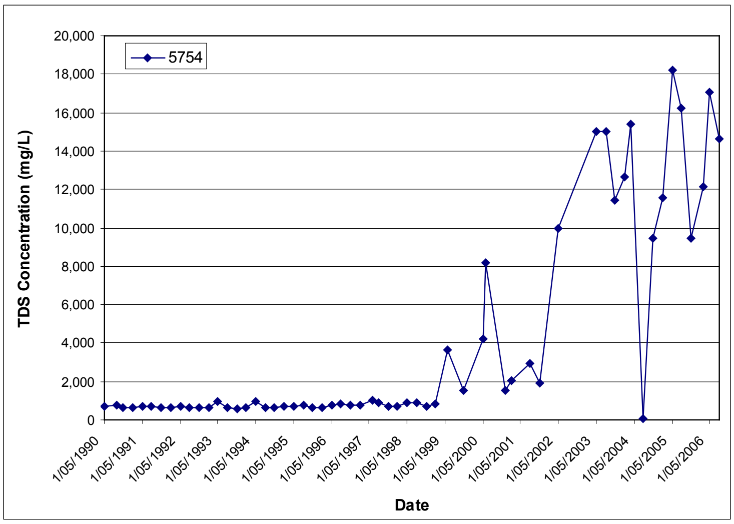

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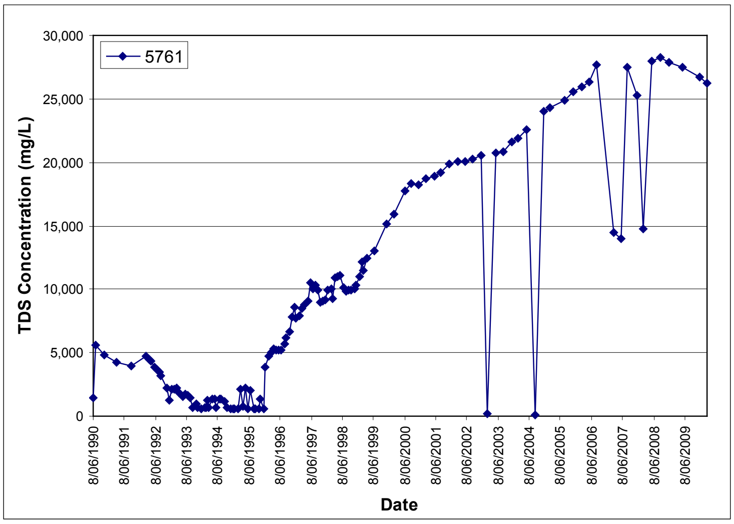
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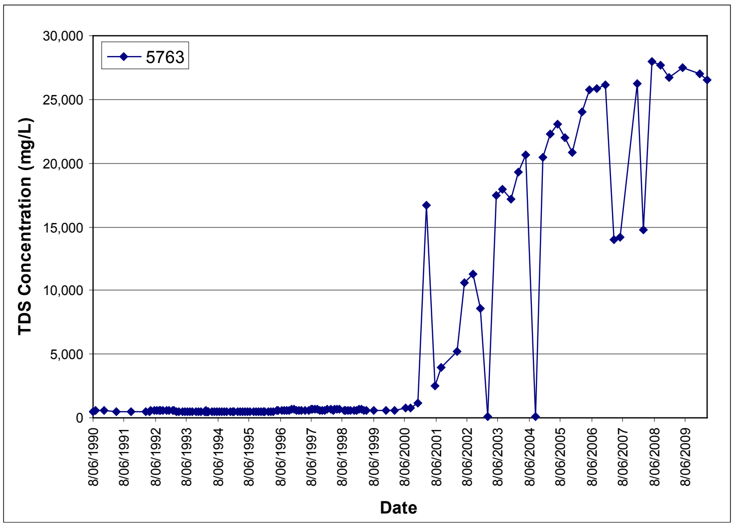
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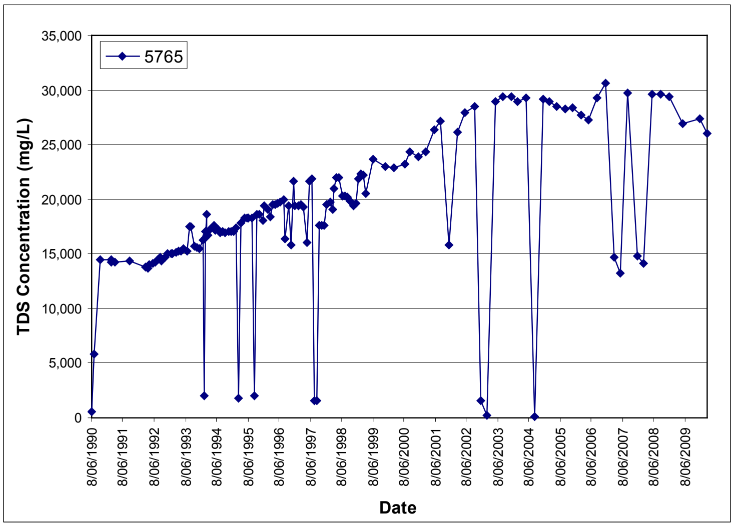
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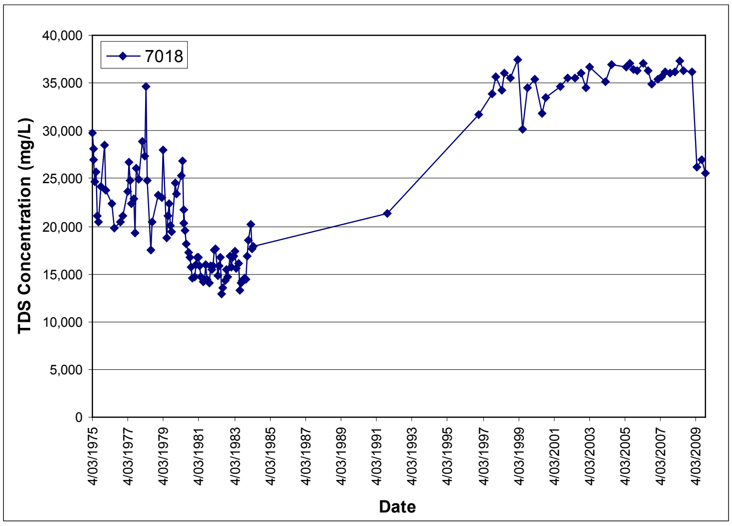
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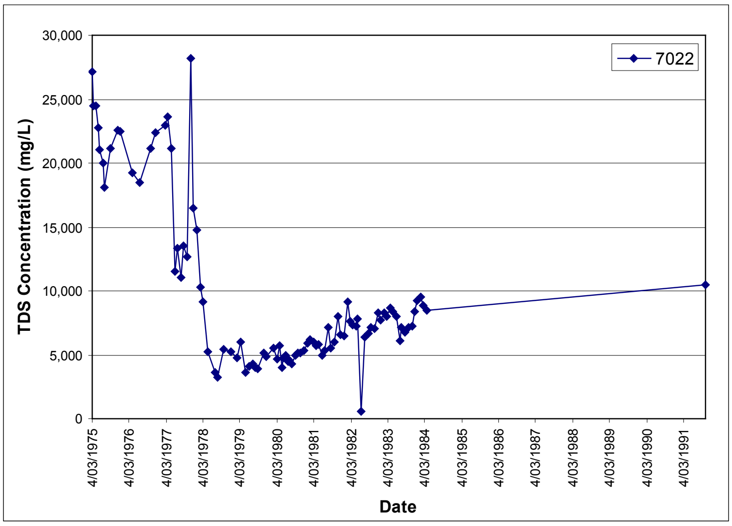
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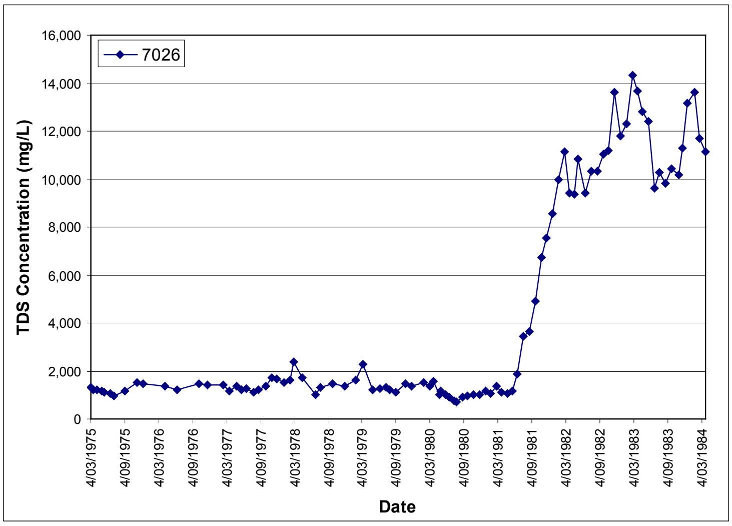
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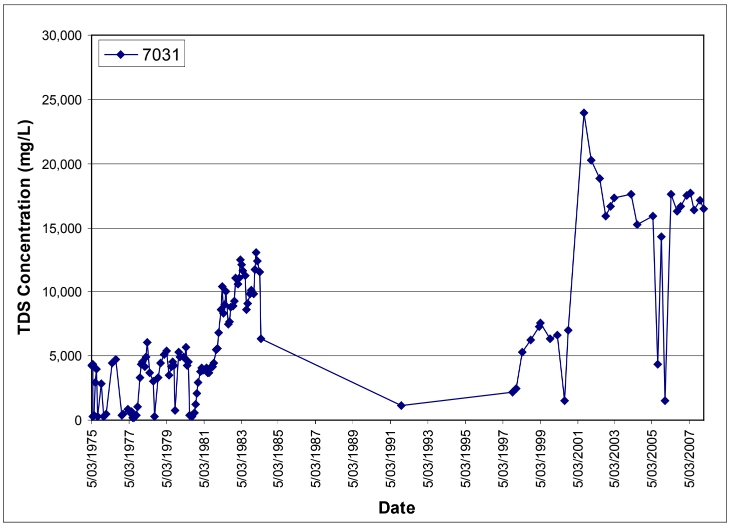
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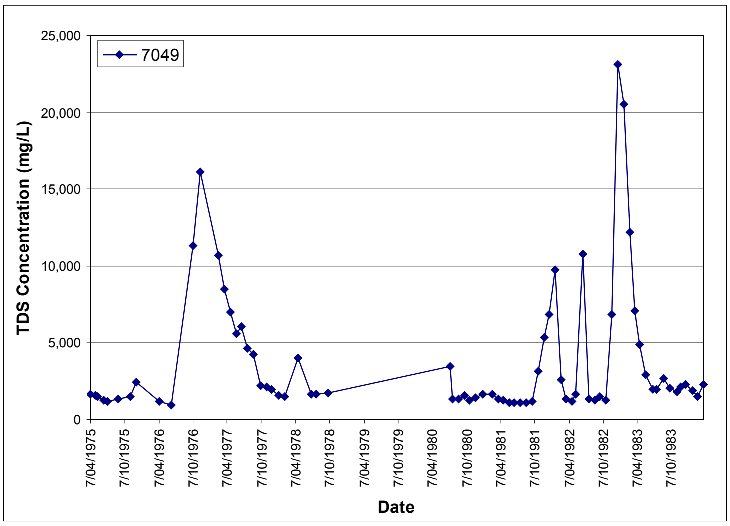
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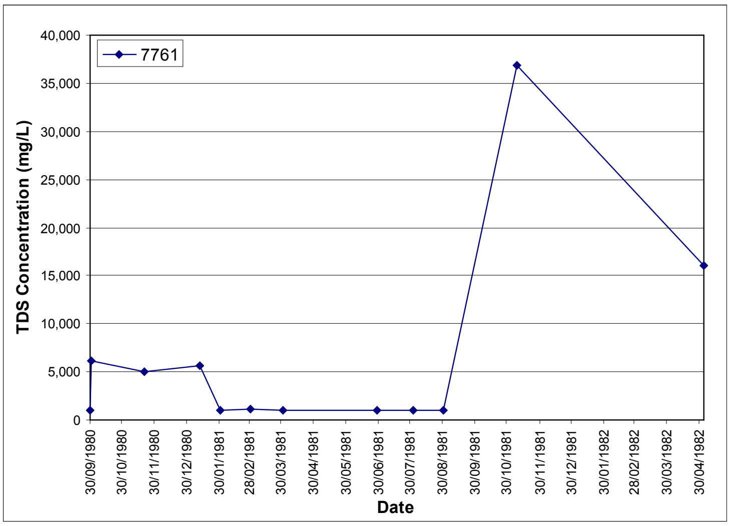
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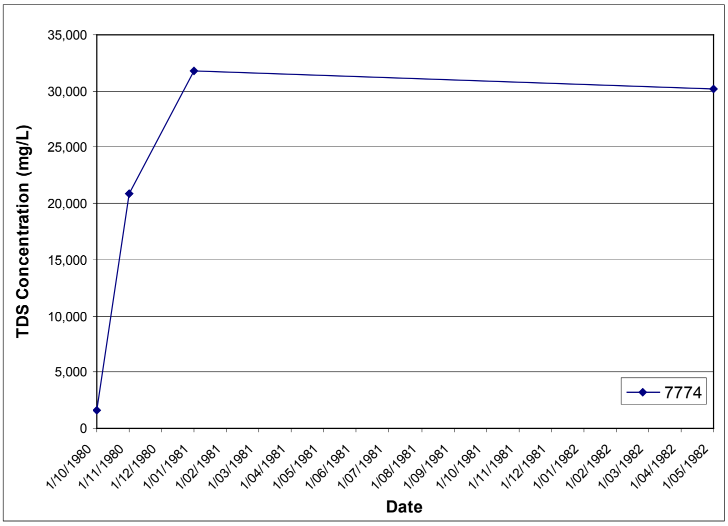
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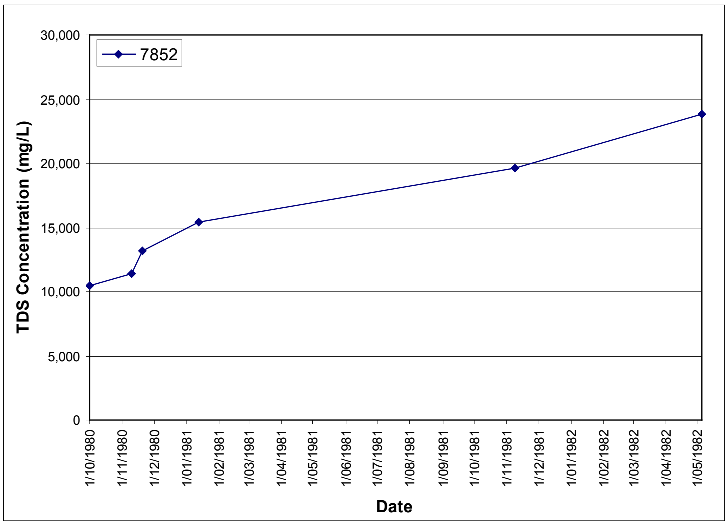
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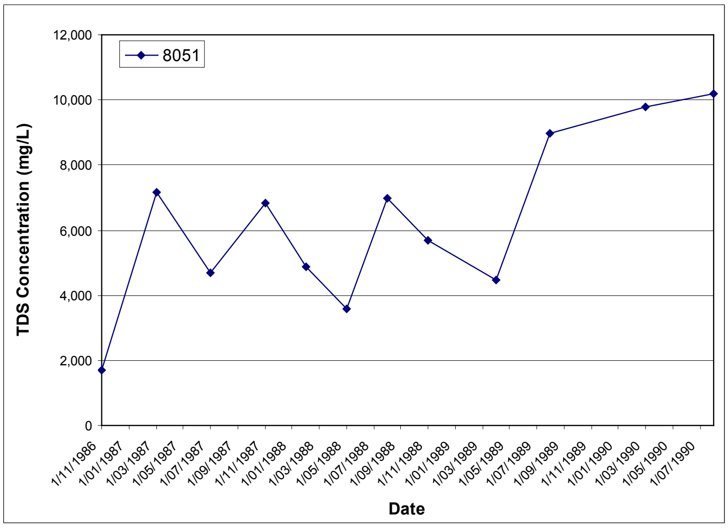
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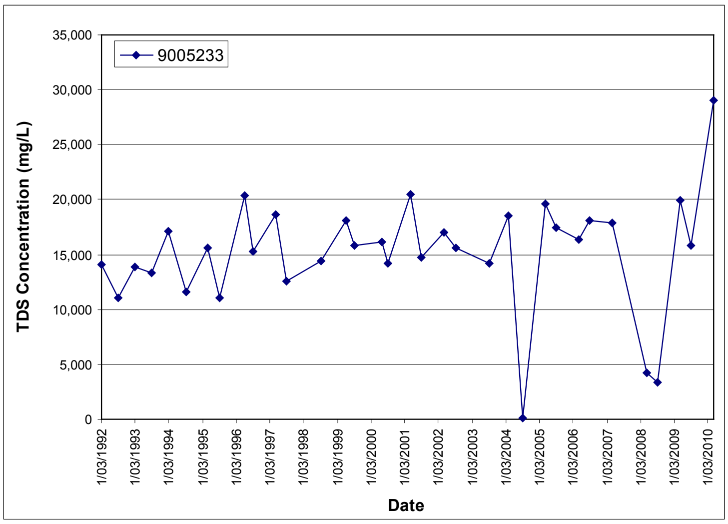
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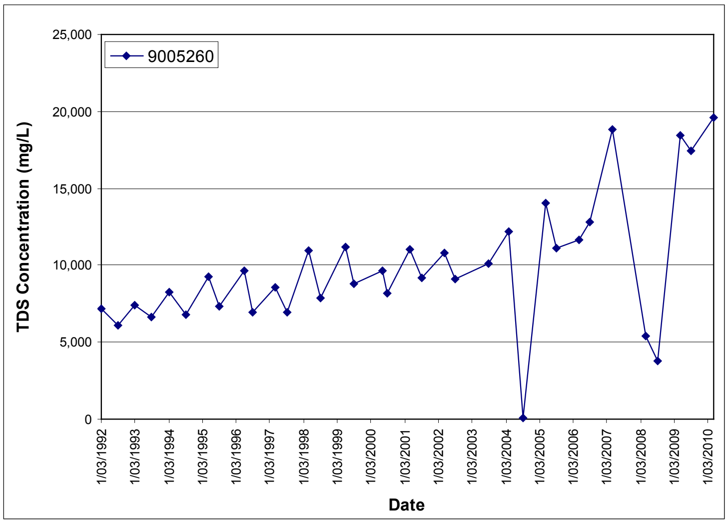
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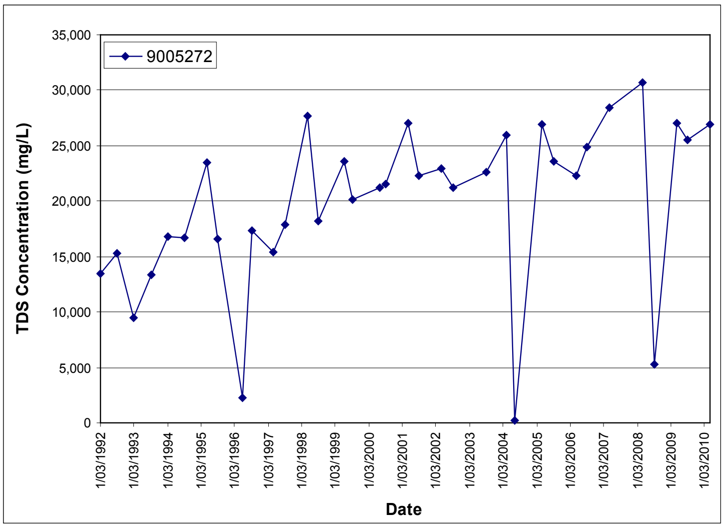
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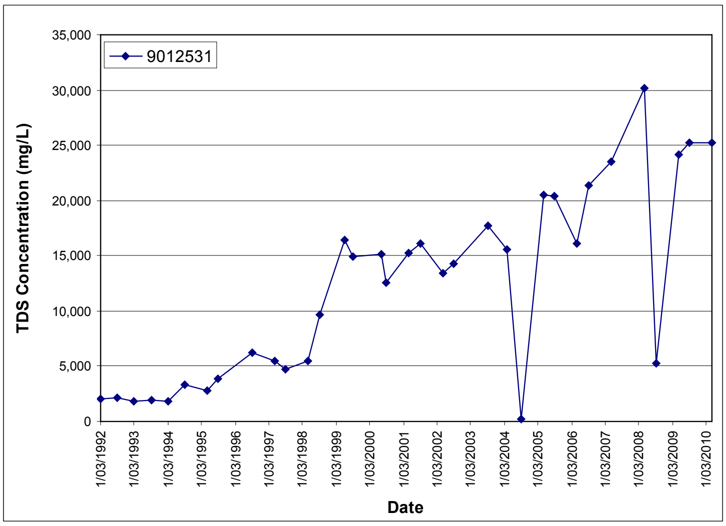

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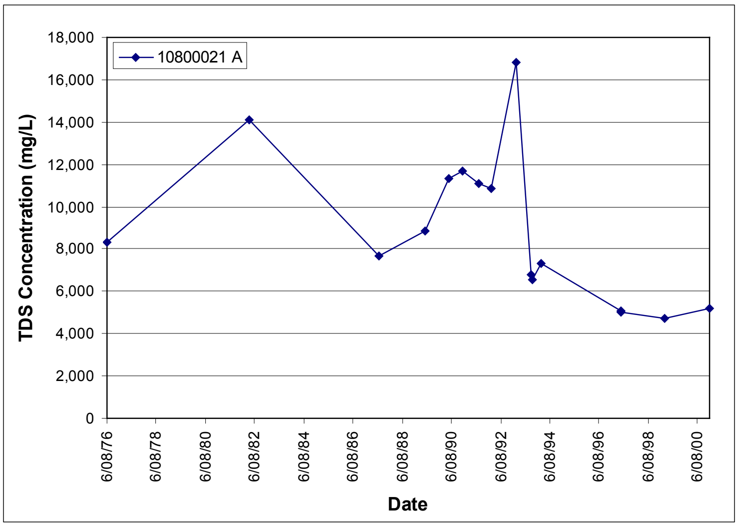
Queensland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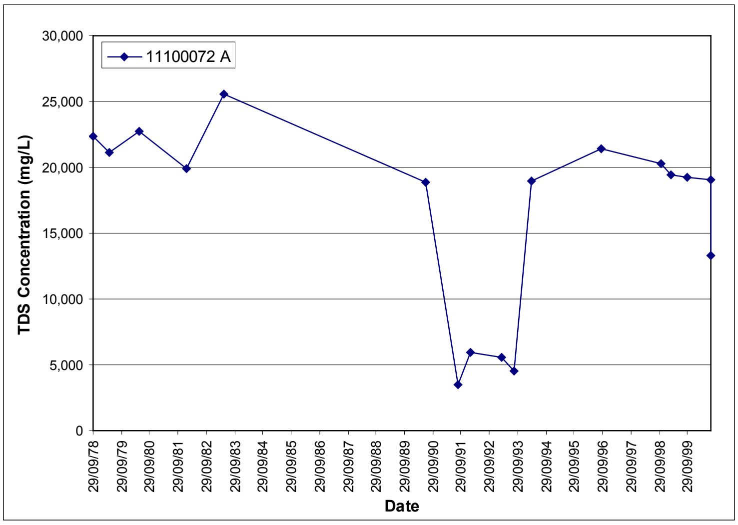
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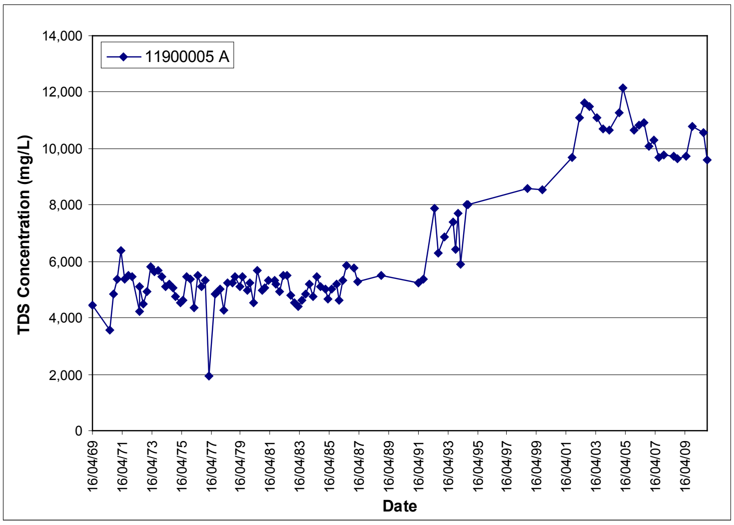
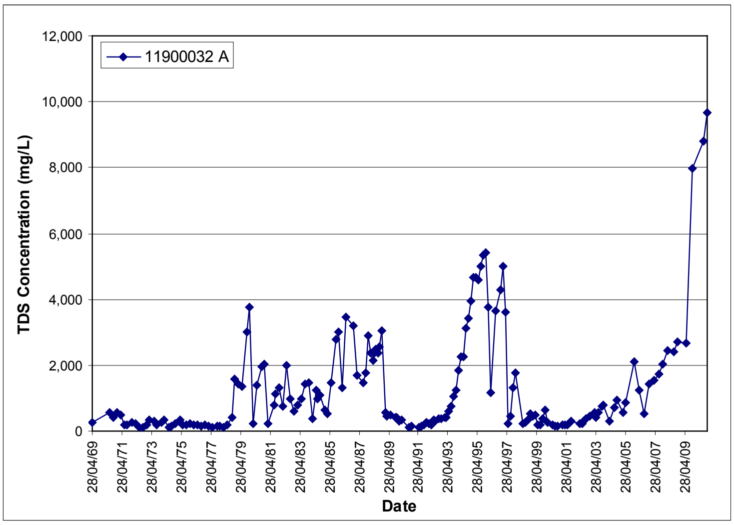
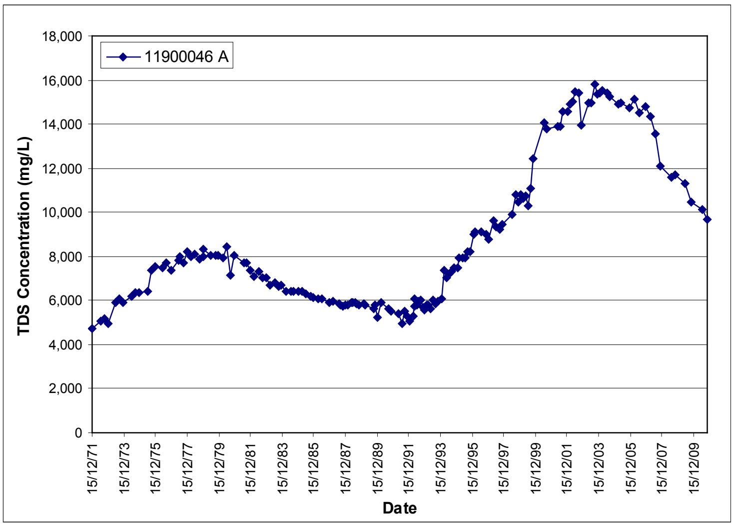
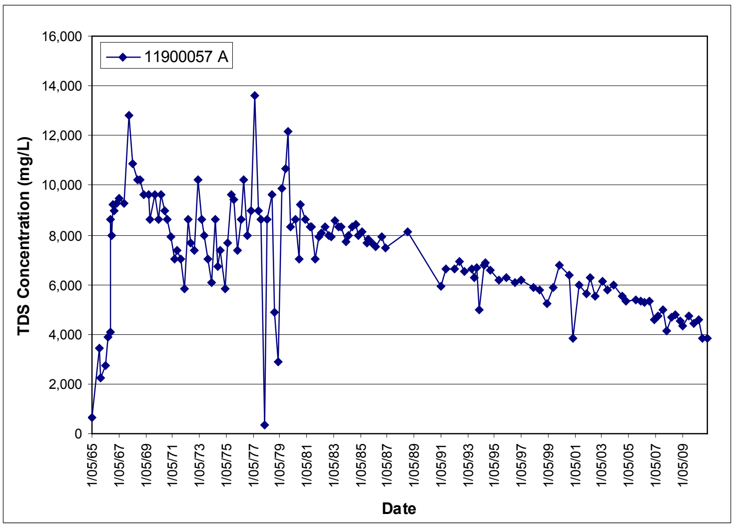
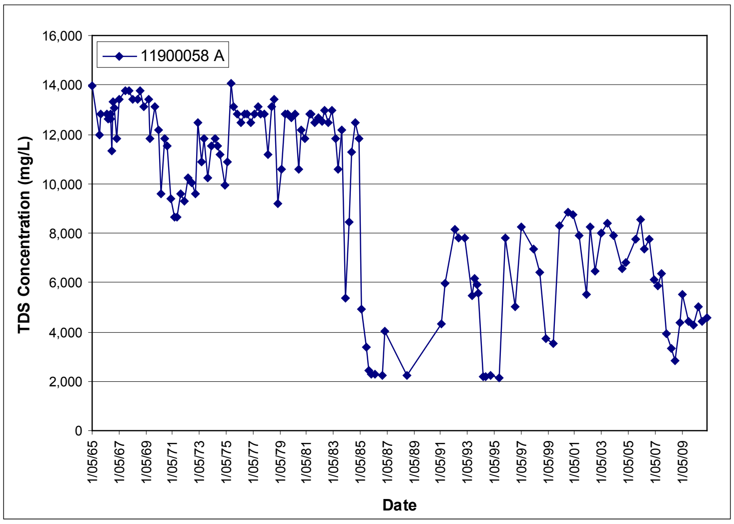
29/09/80
29/09/81
29/09/82
29/09/83
29/09/84
29/09/85
29/09/86
29/09/87
29/09/88
29/09/89
29/09/90
29/09/91
29/09/92
29/09/93
29/09/94
29/09/95
29/09/96
29/09/97
29/09/98
29/09/99
Date


11900005 A
TDS Concentration (mg/L)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
16/04/69
16/04/71
16/04/73
16/04/75
16/04/77
16/04/79
16/04/81
16/04/83
16/04/85
16/04/87
16/04/89
16/04/91
16/04/93
16/04/95
16/04/97
16/04/99
16/04/01
16/04/03
16/04/05
16/04/07
16/04/09
Date

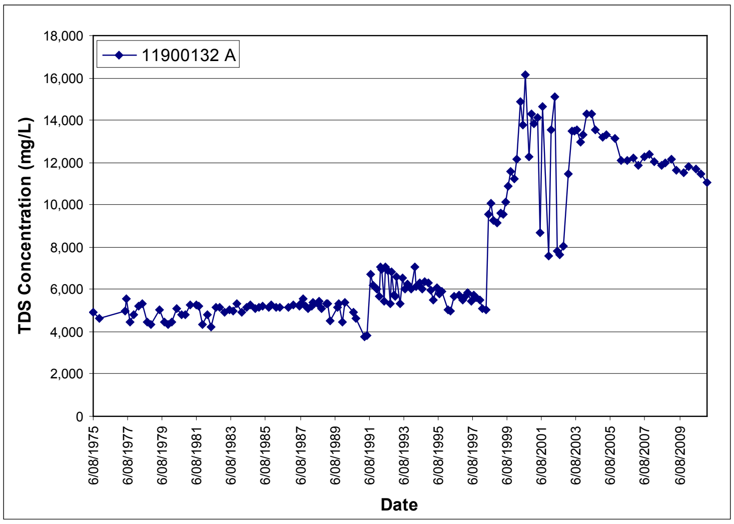

11900032 A
TDS Concentration (mg/L)
Date
12,000
10,000
8,000
6,000
4,000
2,000
0
28/04/69
28/04/71
28/04/73
28/04/75
28/04/77
28/04/79
28/04/81
28/04/83
28/04/85
28/04/87
28/04/89
28/04/91
28/04/93
28/04/95
28/04/97
28/04/99
28/04/01
28/04/03
28/04/05
28/04/07
28/04/09


11900046 A
TDS Concentration (mg/L)
Date
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
15/12/71
15/12/73
15/12/75
15/12/77
15/12/79
15/12/81
15/12/83
15/12/85
15/12/87
15/12/89
15/12/91
15/12/93
15/12/95
15/12/97
15/12/99
15/12/01
15/12/03
15/12/05
15/12/07
15/12/09

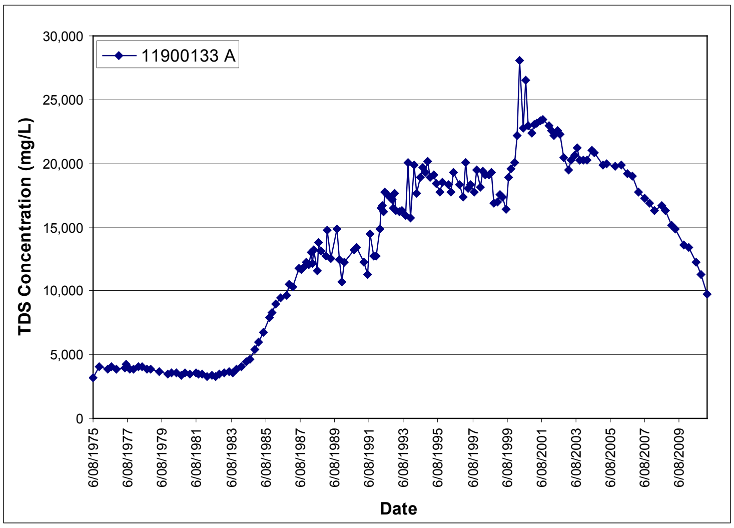

11900057 A
TDS Concentration (mg/L)
Date
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1/05/65
1/05/67
1/05/69
1/05/71
1/05/73
1/05/75
1/05/77
1/05/79
1/05/81
1/05/83
1/05/85
1/05/87
1/05/89
1/05/91
1/05/93
1/05/95
1/05/97
1/05/99
1/05/01
1/05/03
1/05/05
1/05/07
1/05/09



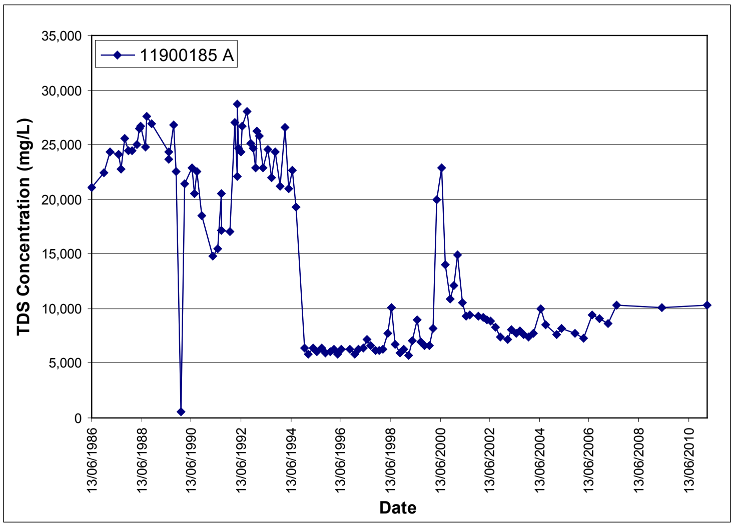
11900058 A
TDS Concentration (mg/L)
Date
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1/05/65
1/05/67
1/05/69
1/05/71
1/05/73
1/05/75
1/05/77
1/05/79
1/05/81
1/05/83
1/05/85
1/05/87
1/05/89
1/05/91
1/05/93
1/05/95
1/05/97
1/05/99
1/05/01
1/05/03
1/05/05
1/05/07
1/05/09

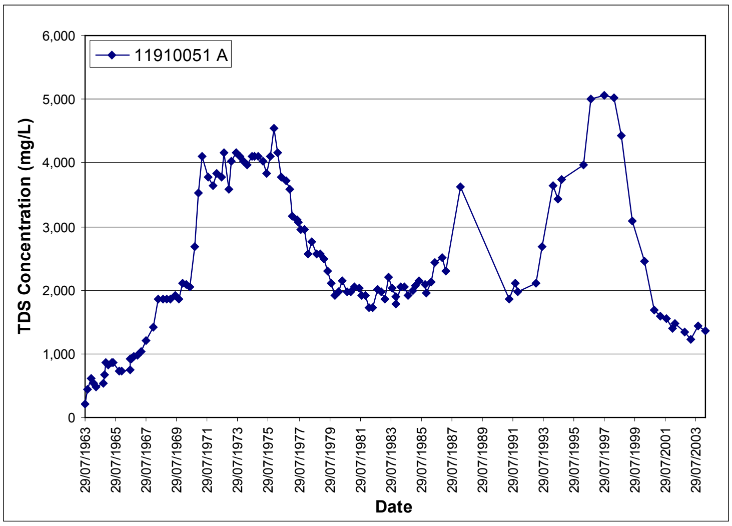


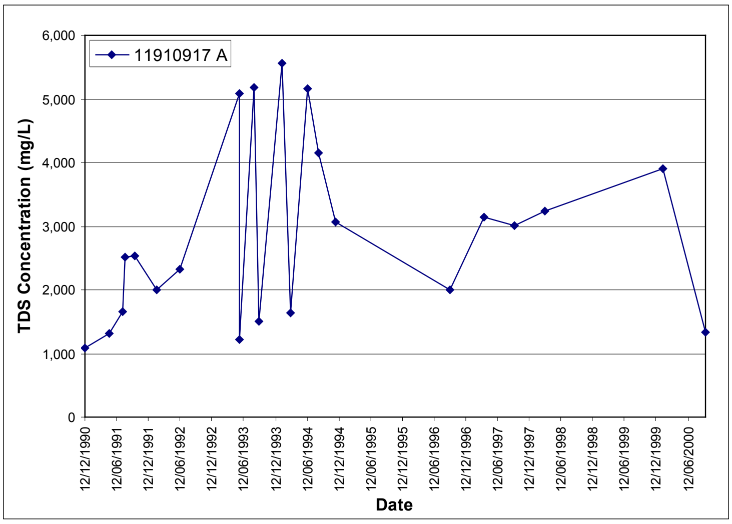
11900132 A
TDS Concentration (mg/L)
Date
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
6/08/1975
6/08/1977
6/08/1979
6/08/1981
6/08/1983
6/08/1985
6/08/1987
6/08/1989
6/08/1991
6/08/1993
6/08/1995
6/08/1997
6/08/1999
6/08/2001
6/08/2003
6/08/2005
6/08/2007
6/08/2009

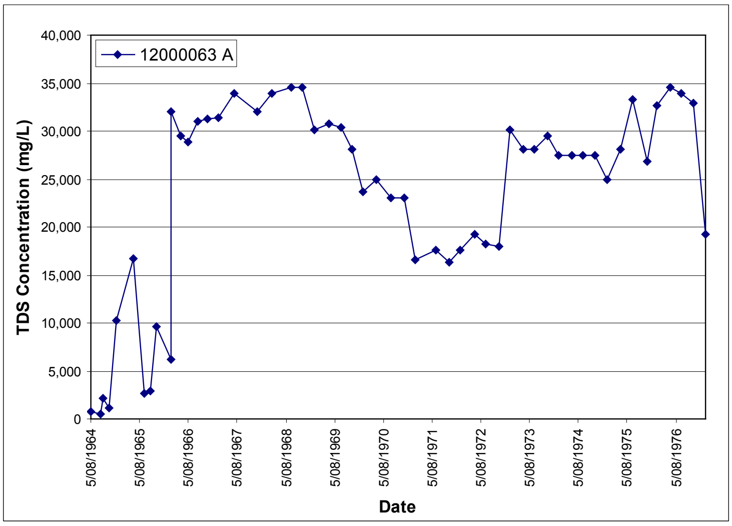


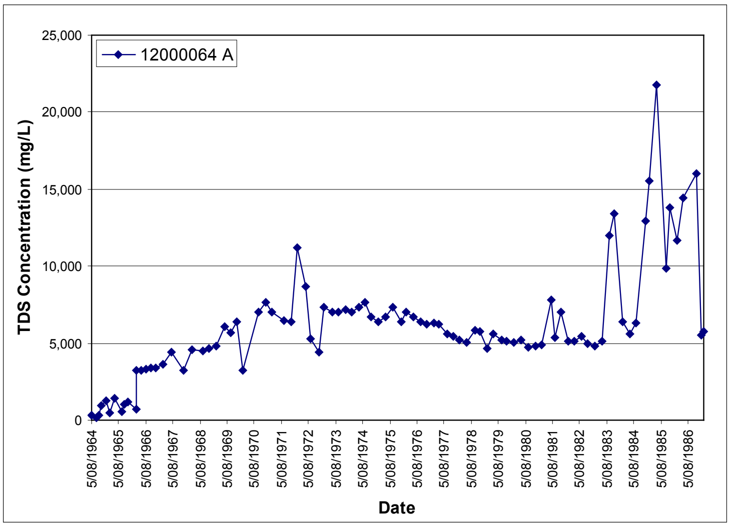
11900133 A
TDS Concentration (mg/L)
Date
30,000
25,000
20,000
15,000
10,000
5,000
0
6/08/1975
6/08/1977
6/08/1979
6/08/1981
6/08/1983
6/08/1985
6/08/1987
6/08/1989
6/08/1991
6/08/1993
6/08/1995
6/08/1997
6/08/1999
6/08/2001
6/08/2003
6/08/2005
6/08/2007
6/08/2009

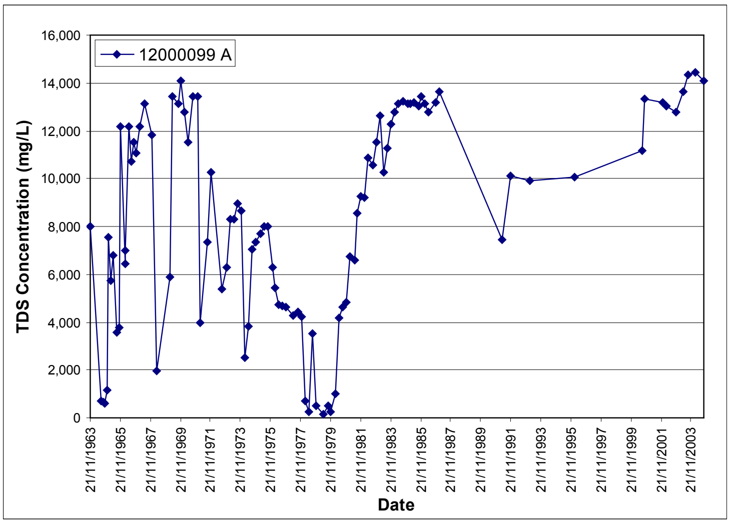

11900185 A
TDS Concentration (mg/L)
Date
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
13/06/1986
13/06/1988
13/06/1990
13/06/1992
13/06/1994
13/06/1996
13/06/1998
13/06/2000
13/06/2002
13/06/2004
13/06/2006
13/06/2008
13/06/2010

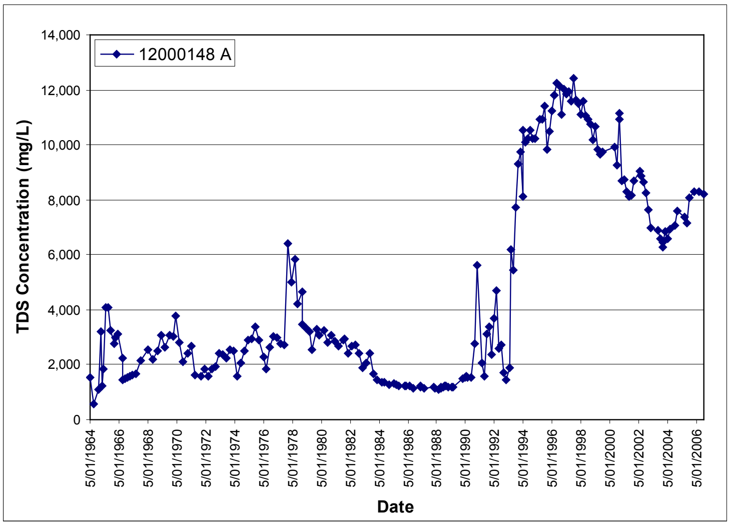

11910051 A
TDS Concentration (mg/L)
Date
6,000
5,000
4,000
3,000
2,000
1,000
0
29/07/1963
29/07/1965
29/07/1967
29/07/1969
29/07/1971
29/07/1973
29/07/1975
29/07/1977
29/07/1979
29/07/1981
29/07/1983
29/07/1985
29/07/1987
29/07/1989
29/07/1991
29/07/1993
29/07/1995
29/07/1997
29/07/1999
29/07/2001
29/07/2003

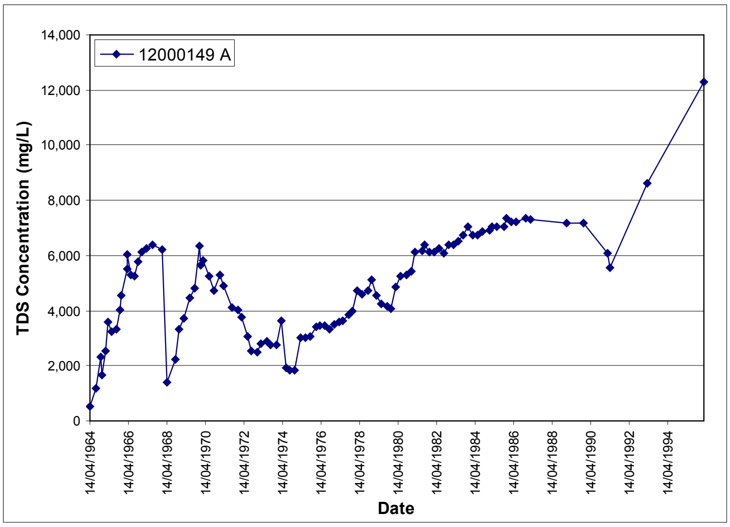

11910917 A
TDS Concentration (mg/L)
Date
6,000
5,000
4,000
3,000
2,000
1,000
0
12/12/1990
12/06/1991
12/12/1991
12/06/1992
12/12/1992
12/06/1993
12/12/1993
12/06/1994
12/12/1994
12/06/1995
12/12/1995
12/06/1996
12/12/1996
12/06/1997
12/12/1997
12/06/1998
12/12/1998
12/06/1999
12/12/1999
12/06/2000

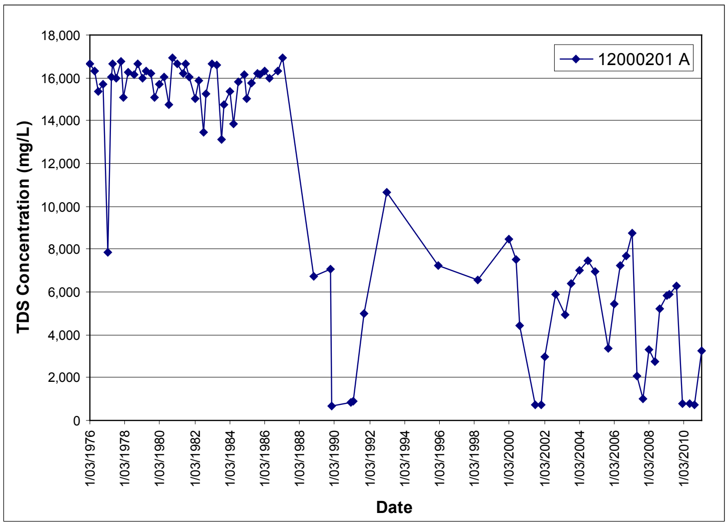

12000063 A
TDS Concentration (mg/L)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
5/08/1964
5/08/1965
5/08/1966
5/08/1967
5/08/1968
5/08/1969
5/08/1970
5/08/1971
5/08/1972
5/08/1973
5/08/1974
5/08/1975
5/08/1976
Date

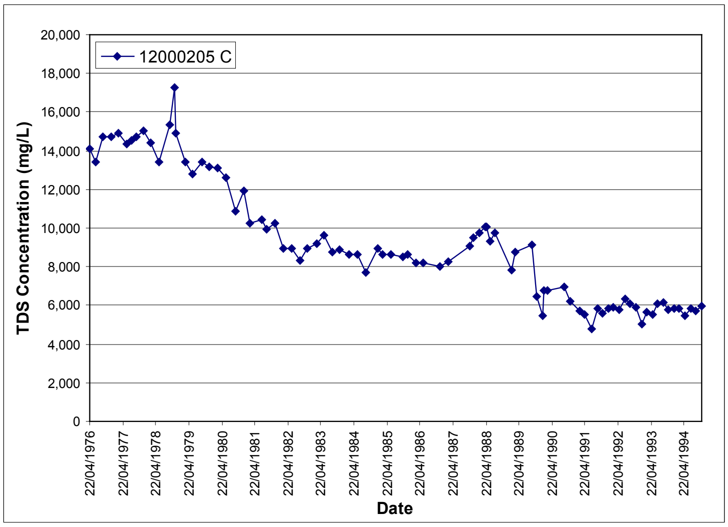

12000064 A
TDS Concentration (mg/L)
25,000
20,000
15,000
10,000
5,000
0
5/08/1964
5/08/1965
5/08/1966
5/08/1967
5/08/1968
5/08/1969
5/08/1970
5/08/1971
5/08/1972
5/08/1973
5/08/1974
5/08/1975
5/08/1976
5/08/1977
5/08/1978
5/08/1979
5/08/1980
5/08/1981
5/08/1982
5/08/1983
5/08/1984
5/08/1985
5/08/1986
Date

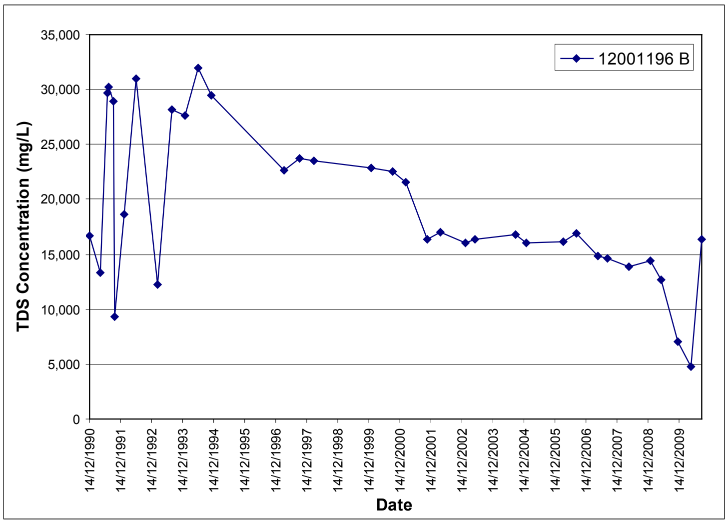

12000099 A
TDS Concentration (mg/L)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
21/11/1963
21/11/1965
21/11/1967
21/11/1969
21/11/1971
21/11/1973
21/11/1975
21/11/1977
21/11/1979
21/11/1981
21/11/1983
21/11/1985
21/11/1987
21/11/1989
21/11/1991
21/11/1993
21/11/1995
21/11/1997
21/11/1999
21/11/2001
21/11/2003
Date

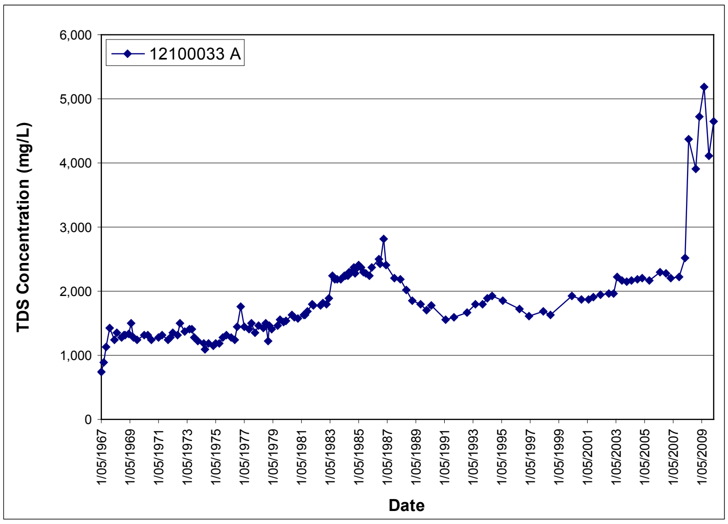

12000148 A
TDS Concentration (mg/L)
Date

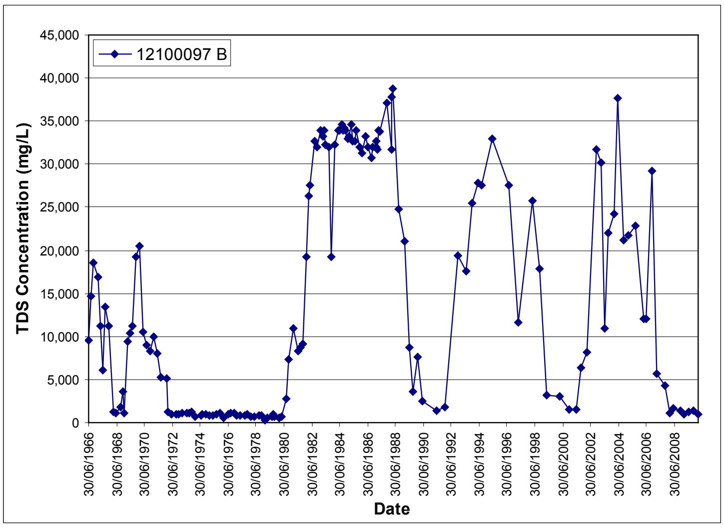

12000149 A
TDS Concentration (mg/L)
Date


12000201 A
TDS Concentration (mg/L)
Date

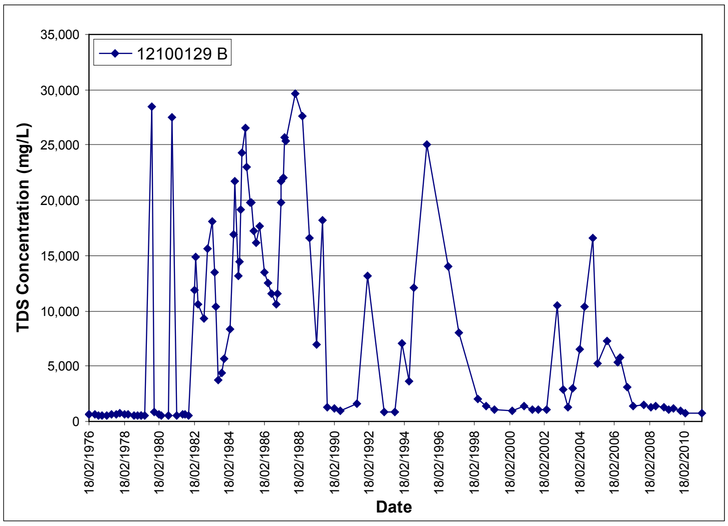

12000205 C
TDS Concentration (mg/L)
Date
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
22/04/1976
22/04/1977
22/04/1978
22/04/1979
22/04/1980
22/04/1981
22/04/1982
22/04/1983
22/04/1984
22/04/1985
22/04/1986
22/04/1987
22/04/1988
22/04/1989
22/04/1990
22/04/1991
22/04/1992
22/04/1993
22/04/1994


12001196 B
TDS Concentration (mg/L)
Date
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
14/12/1990
14/12/1991
14/12/1992
14/12/1993
14/12/1994
14/12/1995
14/12/1996
14/12/1997
14/12/1998
14/12/1999
14/12/2000
14/12/2001
14/12/2002
14/12/2003
14/12/2004
14/12/2005
14/12/2006
14/12/2007
14/12/2008
14/12/2009

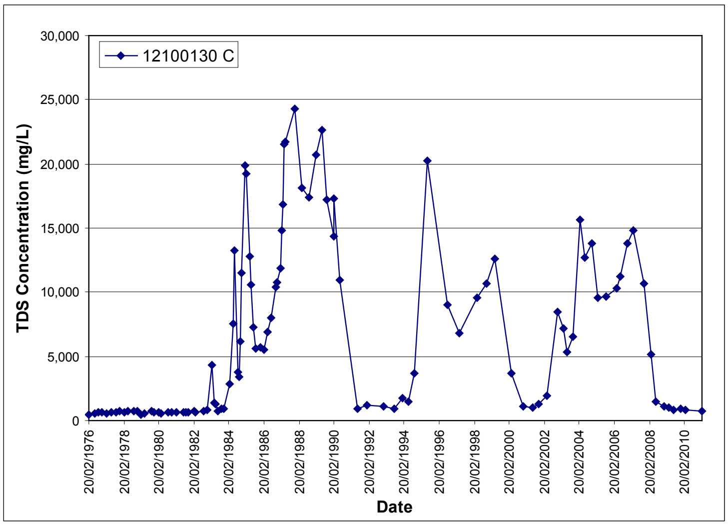

12100033 A
TDS Concentration (mg/L)
Date
6,000
5,000
4,000
3,000
2,000
1,000
0
1/05/1967
1/05/1969
1/05/1971
1/05/1973
1/05/1975
1/05/1977
1/05/1979
1/05/1981
1/05/1983
1/05/1985
1/05/1987
1/05/1989
1/05/1991
1/05/1993
1/05/1995
1/05/1997
1/05/1999
1/05/2001
1/05/2003
1/05/2005
1/05/2007
1/05/2009



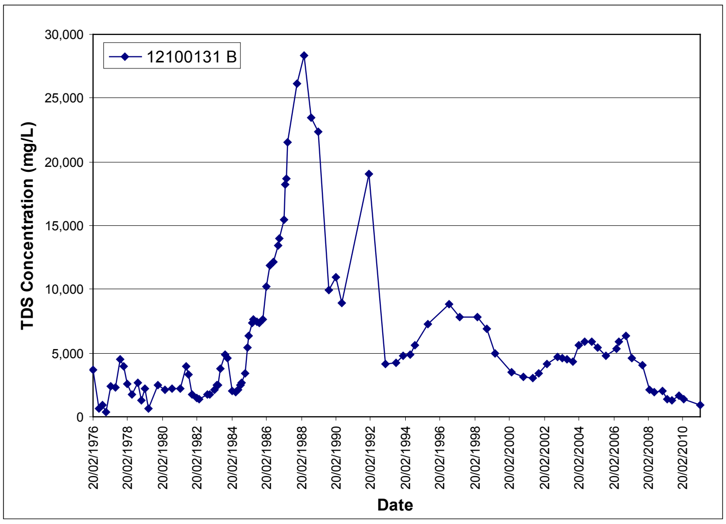
12100097 B
TDS Concentration (mg/L)
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
30/06/1966
30/06/1968
30/06/1970
30/06/1972
30/06/1974
30/06/1976
30/06/1978
30/06/1980
30/06/1982
30/06/1984
30/06/1986
30/06/1988
30/06/1990
30/06/1992
30/06/1994
30/06/1996
30/06/1998
30/06/2000
30/06/2002
30/06/2004
30/06/2006
30/06/2008
Date



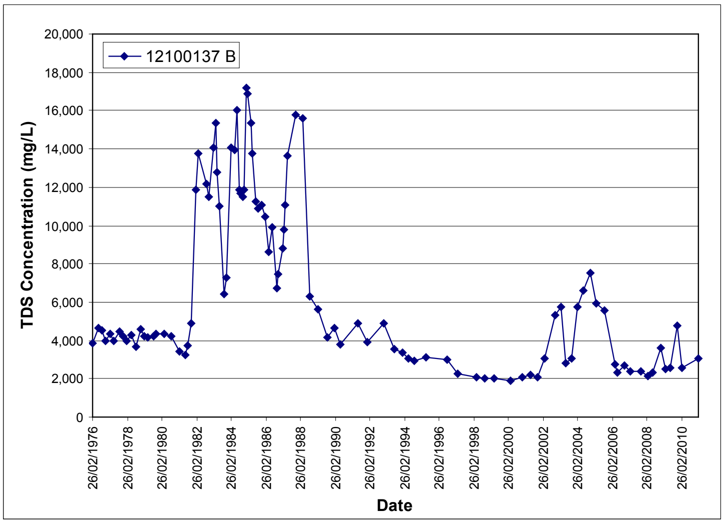
12100129 B
TDS Concentration (mg/L)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
18/02/1976
18/02/1978
18/02/1980
18/02/1982
18/02/1984
18/02/1986
18/02/1988
18/02/1990
18/02/1992
18/02/1994
18/02/1996
18/02/1998
18/02/2000
18/02/2002
18/02/2004
18/02/2006
18/02/2008
18/02/2010
Date



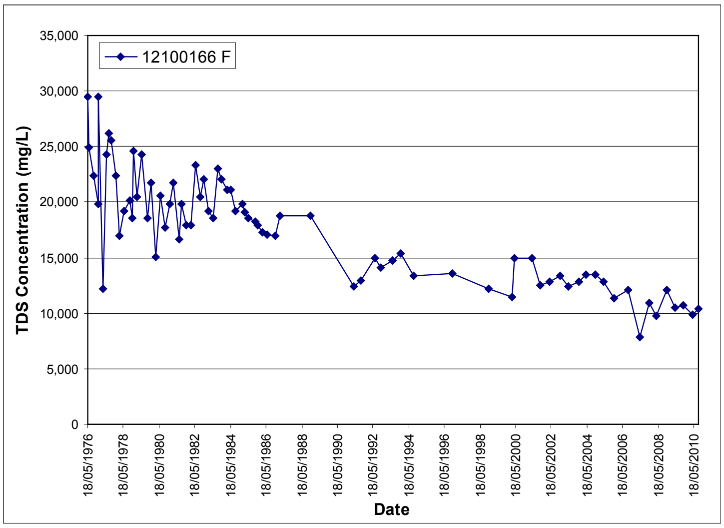
12100130 C
TDS Concentration (mg/L)
30,000
25,000
20,000
15,000
10,000
5,000
0
20/02/1976
20/02/1978
20/02/1980
20/02/1982
20/02/1984
20/02/1986
20/02/1988
20/02/1990
20/02/1992
20/02/1994
20/02/1996
20/02/1998
20/02/2000
20/02/2002
20/02/2004
20/02/2006
20/02/2008
20/02/2010
Date



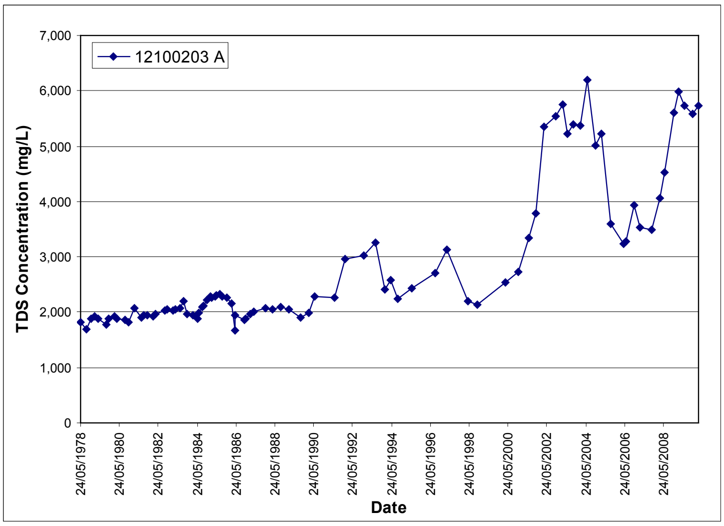
12100131 B
TDS Concentration (mg/L)
Date
30,000
25,000
20,000
15,000
10,000
5,000
0
20/02/1976
20/02/1978
20/02/1980
20/02/1982
20/02/1984
20/02/1986
20/02/1988
20/02/1990
20/02/1992
20/02/1994
20/02/1996
20/02/1998
20/02/2000
20/02/2002
20/02/2004
20/02/2006
20/02/2008
20/02/2010

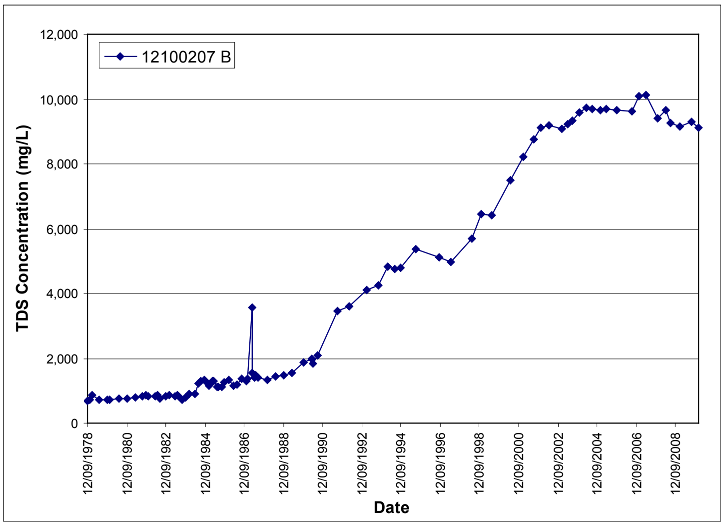


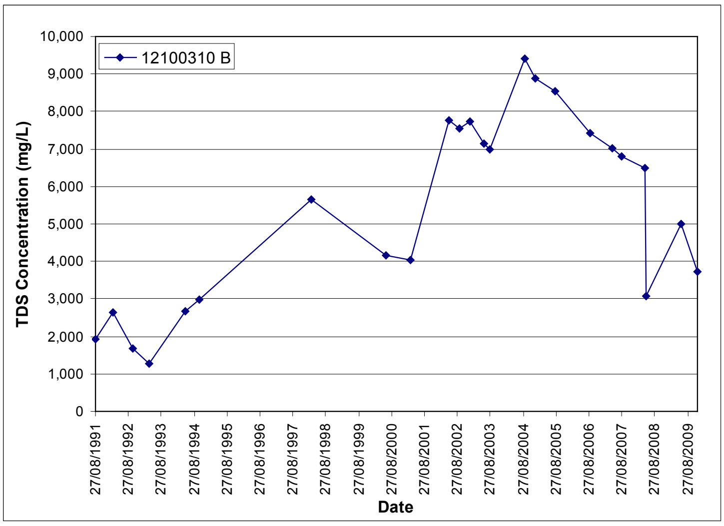
12100137 B
TDS Concentration (mg/L)
Date
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
26/02/1976
26/02/1978
26/02/1980
26/02/1982
26/02/1984
26/02/1986
26/02/1988
26/02/1990
26/02/1992
26/02/1994
26/02/1996
26/02/1998
26/02/2000
26/02/2002
26/02/2004
26/02/2006
26/02/2008
26/02/2010

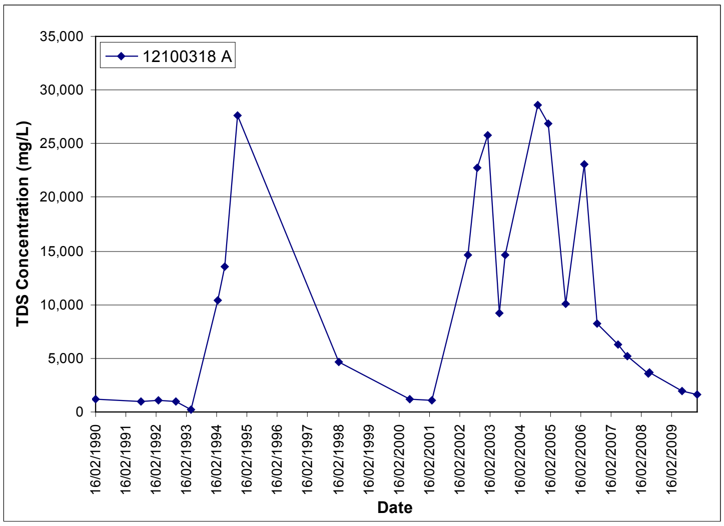


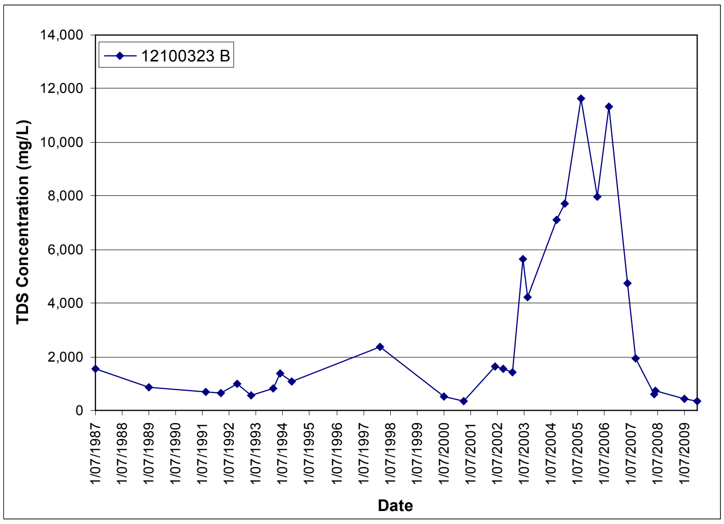
12100166 F
TDS Concentration (mg/L)
Date
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
18/05/1976
18/05/1978
18/05/1980
18/05/1982
18/05/1984
18/05/1986
18/05/1988
18/05/1990
18/05/1992
18/05/1994
18/05/1996
18/05/1998
18/05/2000
18/05/2002
18/05/2004
18/05/2006
18/05/2008
18/05/2010

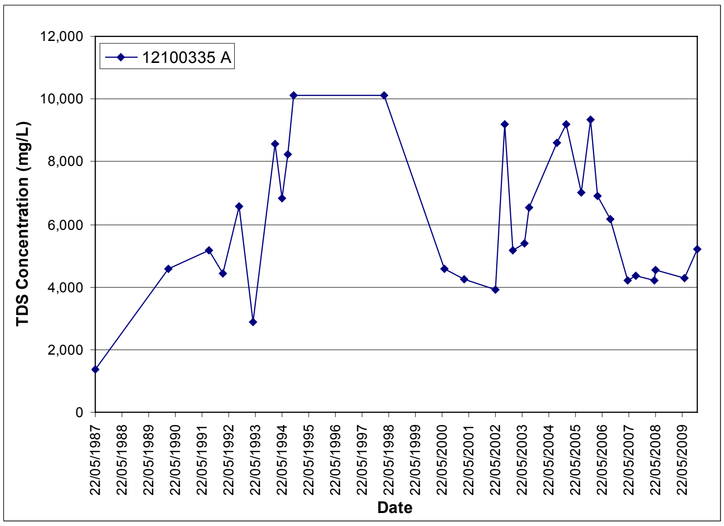

12100203 A
TDS Concentration (mg/L)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
24/05/1978
24/05/1980
24/05/1982
24/05/1984
24/05/1986
24/05/1988
24/05/1990
24/05/1992
24/05/1994
24/05/1996
24/05/1998
24/05/2000
24/05/2002
24/05/2004
24/05/2006
24/05/2008
Date

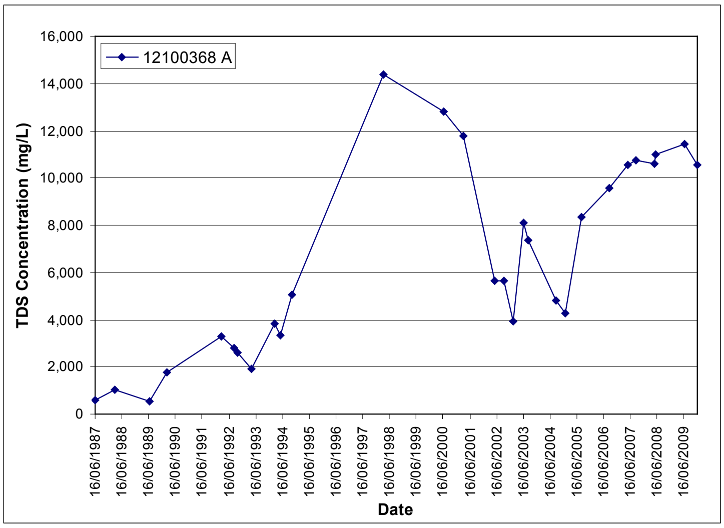

12100207 B
TDS Concentration (mg/L)
12,000
10,000
8,000
6,000
4,000
2,000
0
12/09/1978
12/09/1980
12/09/1982
12/09/1984
12/09/1986
12/09/1988
12/09/1990
12/09/1992
12/09/1994
12/09/1996
12/09/1998
12/09/2000
12/09/2002
12/09/2004
12/09/2006
12/09/2008
Date

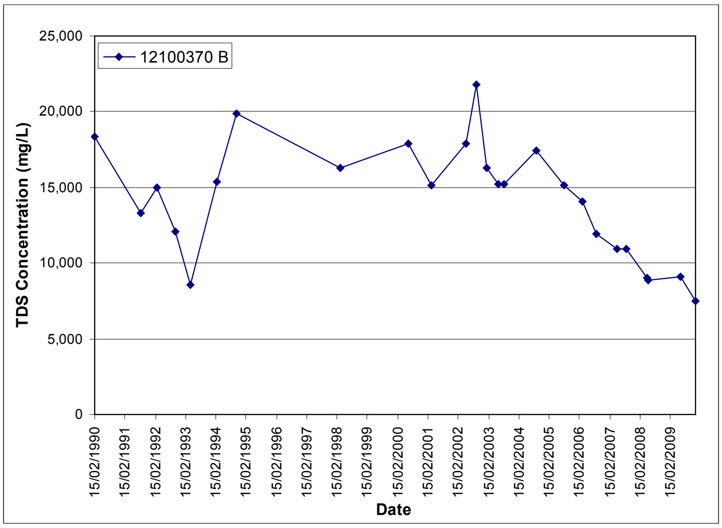

12100310 B
TDS Concentration (mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
27/08/1991
27/08/1992
27/08/1993
27/08/1994
27/08/1995
27/08/1996
27/08/1997
27/08/1998
27/08/1999
27/08/2000
27/08/2001
27/08/2002
27/08/2003
27/08/2004
27/08/2005
27/08/2006
27/08/2007
27/08/2008
27/08/2009
Date

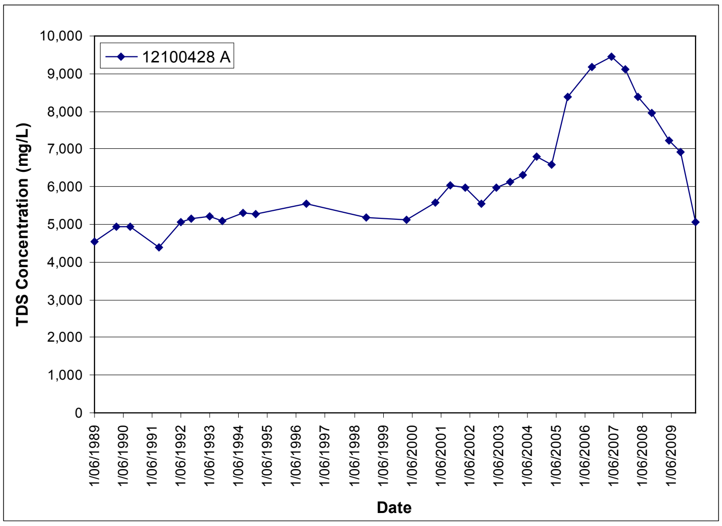

12100318 A
TDS Concentration (mg/L)
Date
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
16/02/1990
16/02/1991
16/02/1992
16/02/1993
16/02/1994
16/02/1995
16/02/1996
16/02/1997
16/02/1998
16/02/1999
16/02/2000
16/02/2001
16/02/2002
16/02/2003
16/02/2004
16/02/2005
16/02/2006
16/02/2007
16/02/2008
16/02/2009

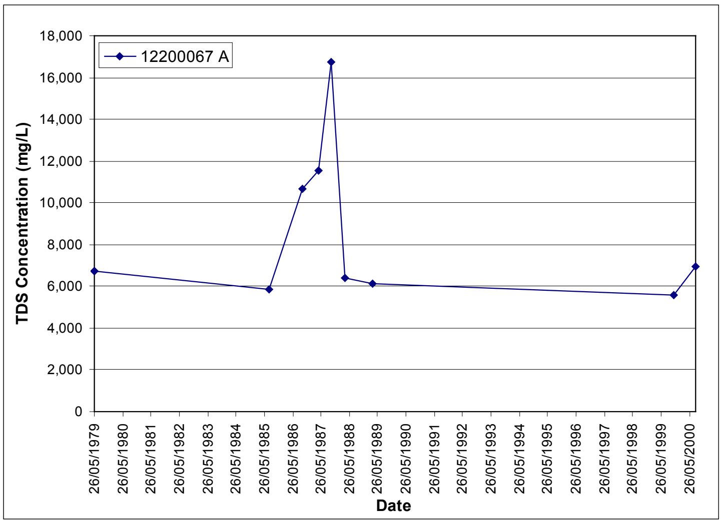

12100323 B
TDS Concentration (mg/L)
Date
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1/07/1987
1/07/1988
1/07/1989
1/07/1990
1/07/1991
1/07/1992
1/07/1993
1/07/1994
1/07/1995
1/07/1996
1/07/1997
1/07/1998
1/07/1999
1/07/2000
1/07/2001
1/07/2002
1/07/2003
1/07/2004
1/07/2005
1/07/2006
1/07/2007
1/07/2008
1/07/2009

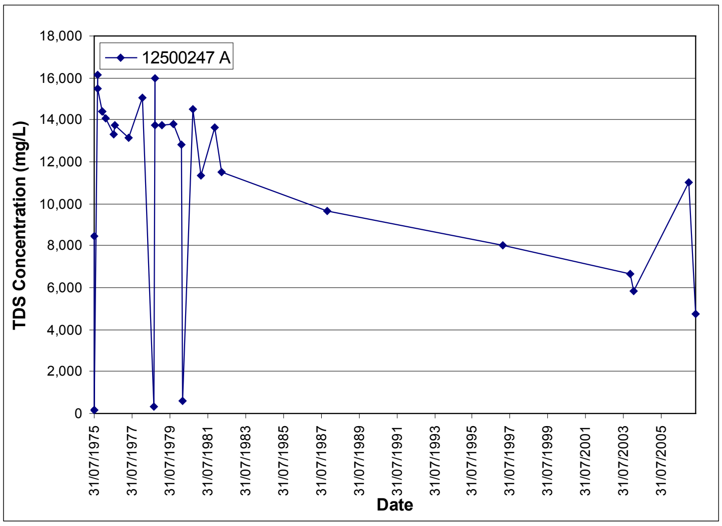

12100335 A
TDS Concentration (mg/L)
Date
12,000
10,000
8,000
6,000
4,000
2,000
0
22/05/1987
22/05/1988
22/05/1989
22/05/1990
22/05/1991
22/05/1992
22/05/1993
22/05/1994
22/05/1995
22/05/1996
22/05/1997
22/05/1998
22/05/1999
22/05/2000
22/05/2001
22/05/2002
22/05/2003
22/05/2004
22/05/2005
22/05/2006
22/05/2007
22/05/2008
22/05/2009

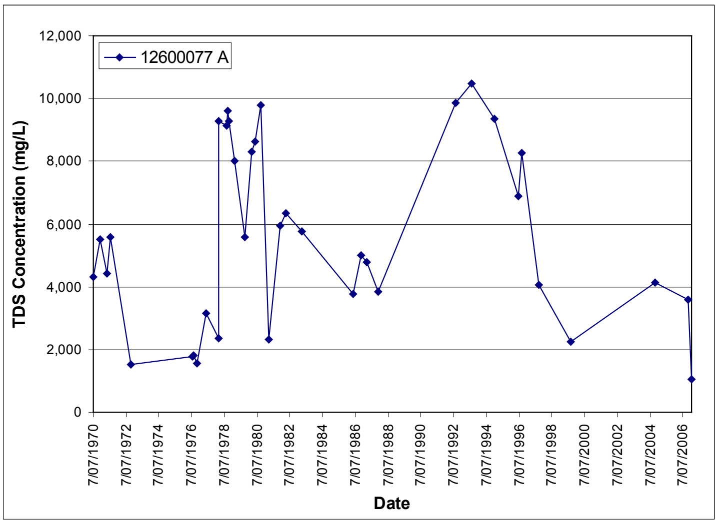

12100368 A
TDS Concentration (mg/L)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
16/06/1987
16/06/1988
16/06/1989
16/06/1990
16/06/1991
16/06/1992
16/06/1993
16/06/1994
16/06/1995
16/06/1996
16/06/1997
16/06/1998
16/06/1999
16/06/2000
16/06/2001
16/06/2002
16/06/2003
16/06/2004
16/06/2005
16/06/2006
16/06/2007
16/06/2008
16/06/2009
Date

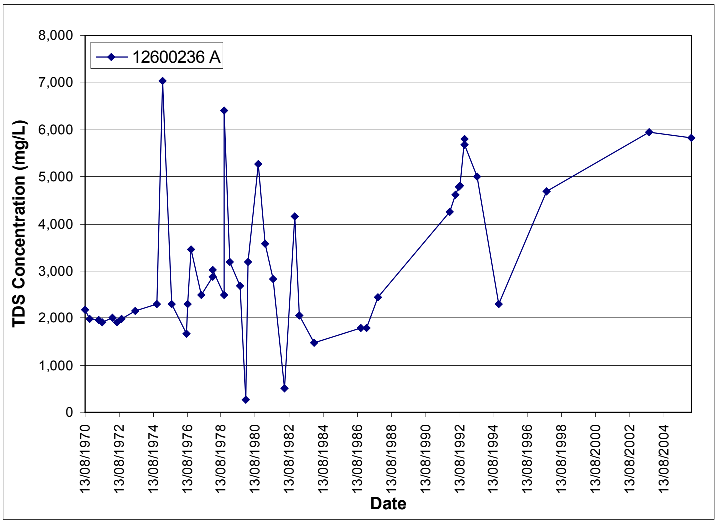

12100370 B
TDS Concentration (mg/L)
25,000
20,000
15,000
10,000
5,000
0
15/02/1990
15/02/1991
15/02/1992
15/02/1993
15/02/1994
15/02/1995
15/02/1996
15/02/1997
15/02/1998
15/02/1999
15/02/2000
15/02/2001
15/02/2002
15/02/2003
15/02/2004
15/02/2005
15/02/2006
15/02/2007
15/02/2008
15/02/2009
Date


12100428 A
TDS Concentration (mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1/06/1989
1/06/1990
1/06/1991
1/06/1992
1/06/1993
1/06/1994
1/06/1995
1/06/1996
1/06/1997
1/06/1998
1/06/1999
1/06/2000
1/06/2001
1/06/2002
1/06/2003
1/06/2004
1/06/2005
1/06/2006
1/06/2007
1/06/2008
1/06/2009
Date

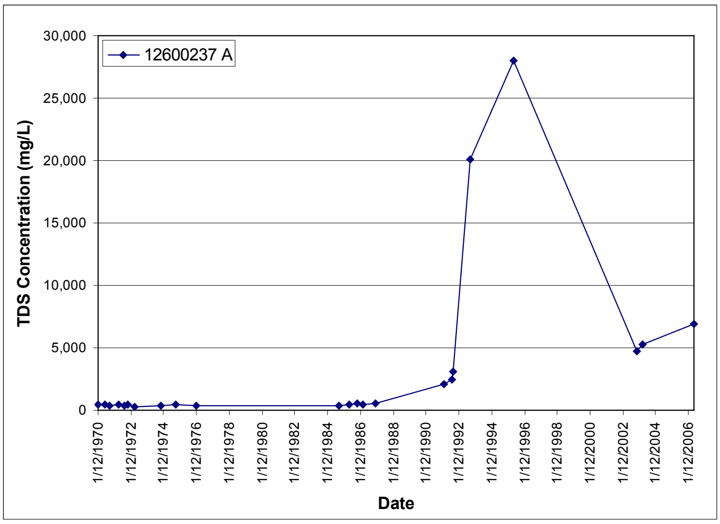

12200067 A
TDS Concentration (mg/L)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
26/05/1979
26/05/1980
26/05/1981
26/05/1982
26/05/1983
26/05/1984
26/05/1985
26/05/1986
26/05/1987
26/05/1988
26/05/1989
26/05/1990
26/05/1991
26/05/1992
26/05/1993
26/05/1994
26/05/1995
26/05/1996
26/05/1997
26/05/1998
26/05/1999
26/05/2000
Date


12500247 A
TDS Concentration (mg/L)
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
31/07/1975
31/07/1977
31/07/1979
31/07/1981
31/07/1983
31/07/1985
31/07/1987
31/07/1989
31/07/1991
31/07/1993
31/07/1995
31/07/1997
31/07/1999
31/07/2001
31/07/2003
31/07/2005
Date

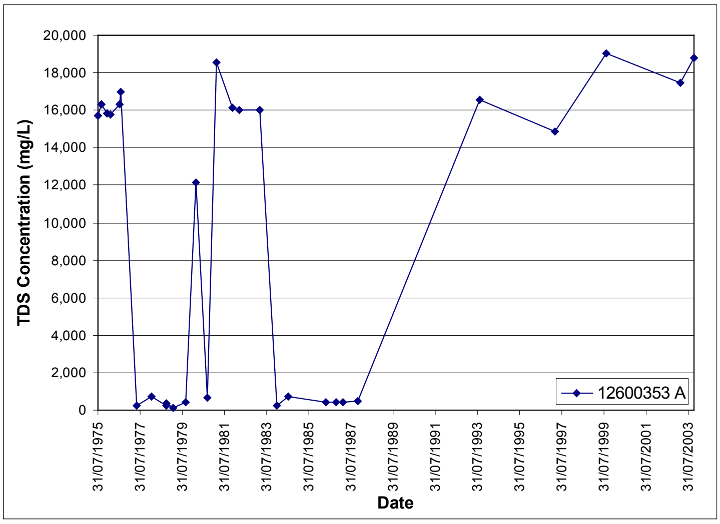

12600077 A
TDS Concentration (mg/L)
12,000
10,000
8,000
6,000
4,000
2,000
0
7/07/1970
7/07/1972
7/07/1974
7/07/1976
7/07/1978
7/07/1980
7/07/1982
7/07/1984
7/07/1986
7/07/1988
7/07/1990
7/07/1992
7/07/1994
7/07/1996
7/07/1998
7/07/2000
7/07/2002
7/07/2004
7/07/2006
Date



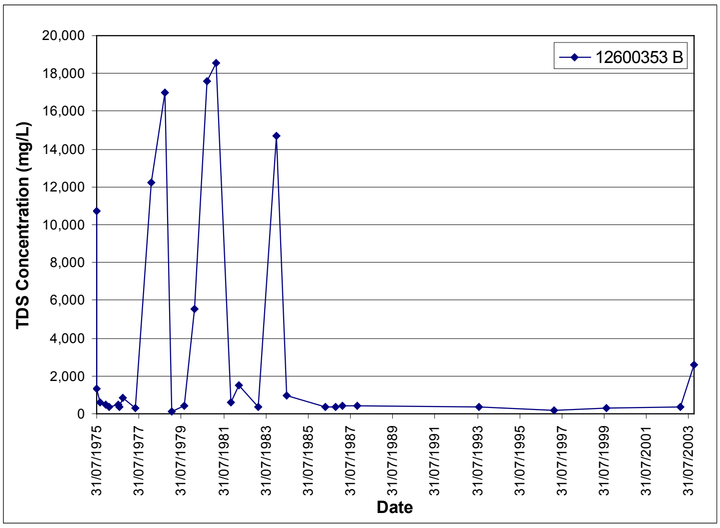
12600236 A
TDS Concentration (mg/L)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
13/08/1970
13/08/1972
13/08/1974
13/08/1976
13/08/1978
13/08/1980
13/08/1982
13/08/1984
13/08/1986
13/08/1988
13/08/1990
13/08/1992
13/08/1994
13/08/1996
13/08/1998
13/08/2000
13/08/2002
13/08/2004
Date



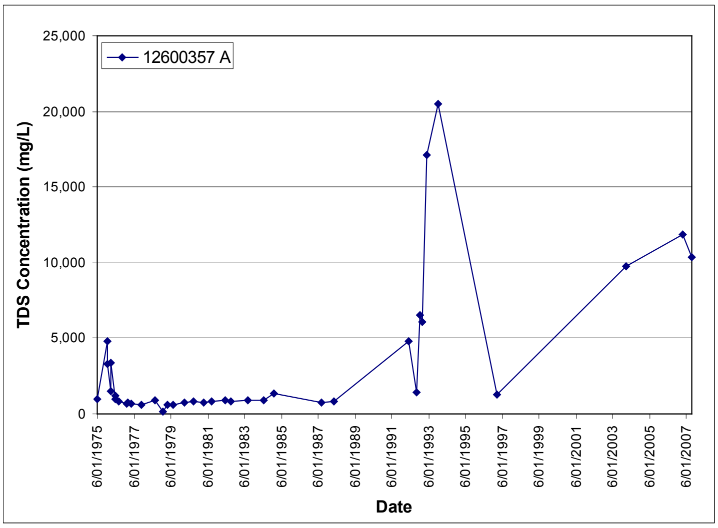
12600237 A
TDS Concentration (mg/L)
30,000
25,000
20,000
15,000
10,000
5,000
0
1/12/1970
1/12/1972
1/12/1974
1/12/1976
1/12/1978
1/12/1980
1/12/1982
1/12/1984
1/12/1986
1/12/1988
1/12/1990
1/12/1992
1/12/1994
1/12/1996
1/12/1998
1/12/2000
1/12/2002
1/12/2004
1/12/2006
Date



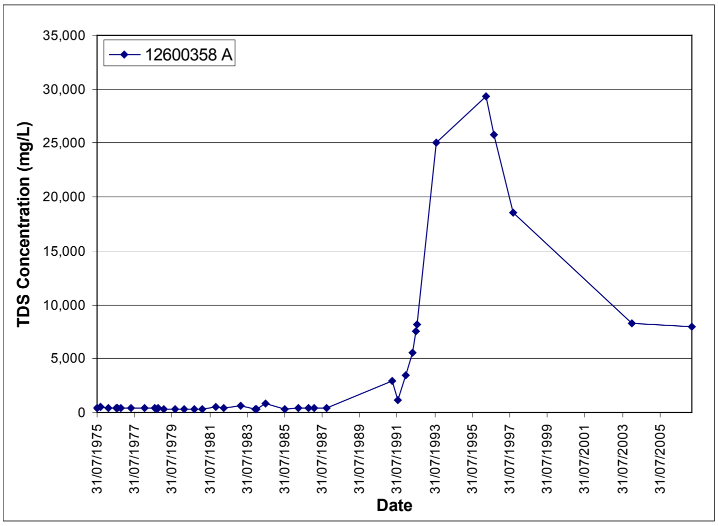
12600353 A
TDS Concentration (mg/L)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
31/07/1975
31/07/1977
31/07/1979
31/07/1981
31/07/1983
31/07/1985
31/07/1987
31/07/1989
31/07/1991
31/07/1993
31/07/1995
31/07/1997
31/07/1999
31/07/2001
31/07/2003
Date



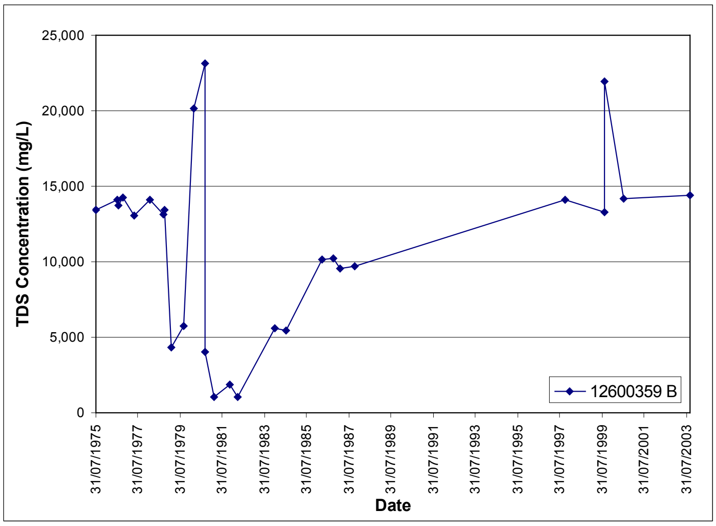
12600353 B
TDS Concentration (mg/L)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
31/07/1975
31/07/1977
31/07/1979
31/07/1981
31/07/1983
31/07/1985
31/07/1987
31/07/1989
31/07/1991
31/07/1993
31/07/1995
31/07/1997
31/07/1999
31/07/2001
31/07/2003
Date

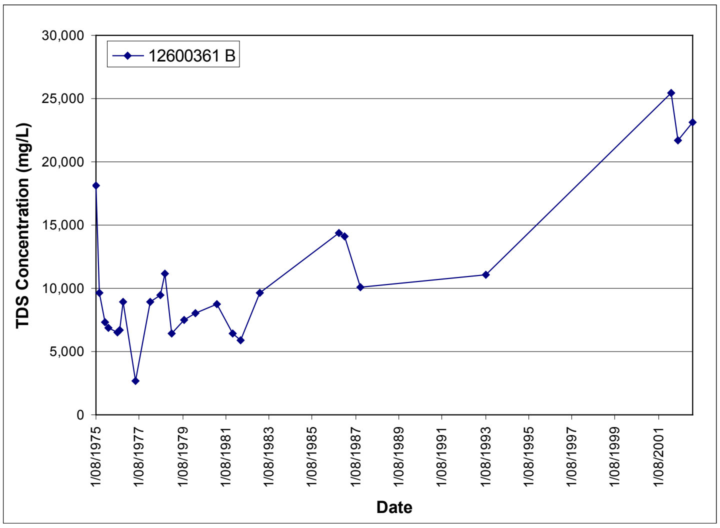


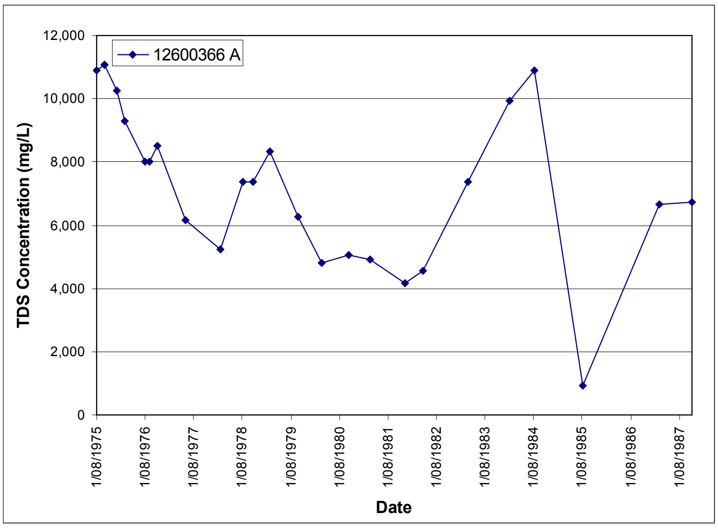
12600357 A
TDS Concentration (mg/L)
25,000
20,000
15,000
10,000
5,000
0
6/01/1975
6/01/1977
6/01/1979
6/01/1981
6/01/1983
6/01/1985
6/01/1987
6/01/1989
6/01/1991
6/01/1993
6/01/1995
6/01/1997
6/01/1999
6/01/2001
6/01/2003
6/01/2005
6/01/2007
Date

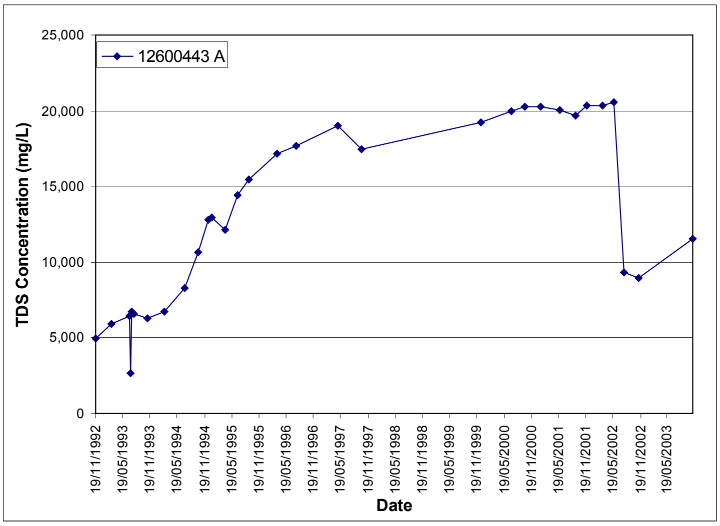


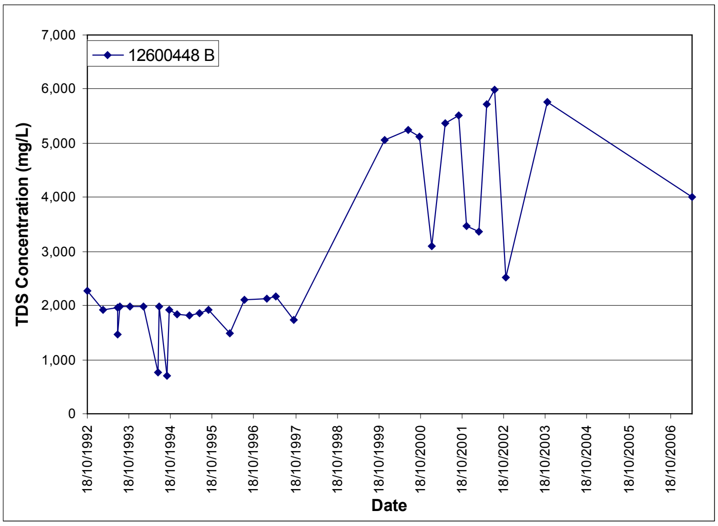
12600358 A
TDS Concentration (mg/L)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
31/07/1975
31/07/1977
31/07/1979
31/07/1981
31/07/1983
31/07/1985
31/07/1987
31/07/1989
31/07/1991
31/07/1993
31/07/1995
31/07/1997
31/07/1999
31/07/2001
31/07/2003
31/07/2005
Date

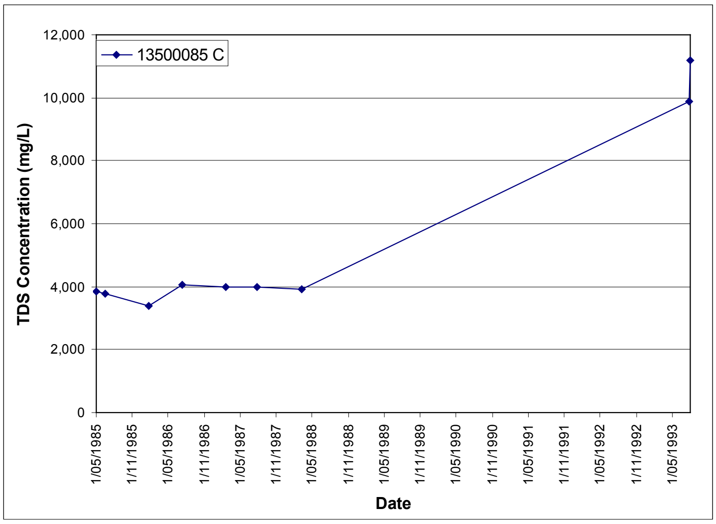

TDS Concentration (mg/L)
25,000
20,000
15,000
10,000
5,000
0
12600359 B
31/07/1975
31/07/1977
31/07/1979
31/07/1981
31/07/1983
31/07/1985
31/07/1987
31/07/1989
31/07/1991
31/07/1993
31/07/1995
31/07/1997
31/07/1999
31/07/2001
31/07/2003
Date

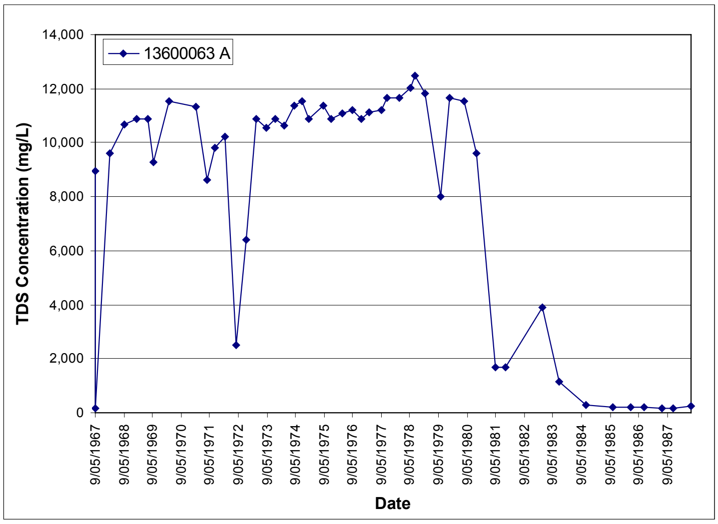

TDS Concentration (mg/L)
30,000
25,000
20,000
15,000
10,000
5,000
0
12600361 B
1/08/1975
1/08/1977
1/08/1979
1/08/1981
1/08/1983
1/08/1985
1/08/1987
1/08/1989
1/08/1991
1/08/1993
1/08/1995
1/08/1997
1/08/1999
1/08/2001
Date

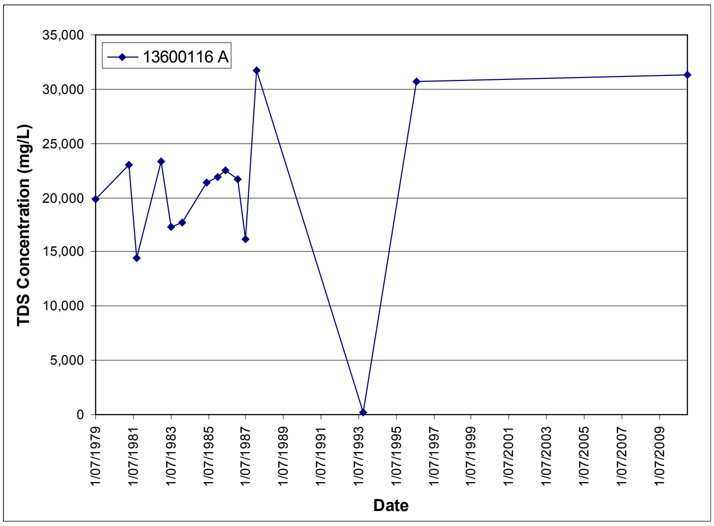

TDS Concentration (mg/L)
12,000
10,000
8,000
6,000
4,000
2,000
0
12600366 A
1/08/1975
1/08/1976
1/08/1977
1/08/1978
1/08/1979
1/08/1980
1/08/1981
1/08/1982
1/08/1983
1/08/1984
1/08/1985
1/08/1986
1/08/1987
Date

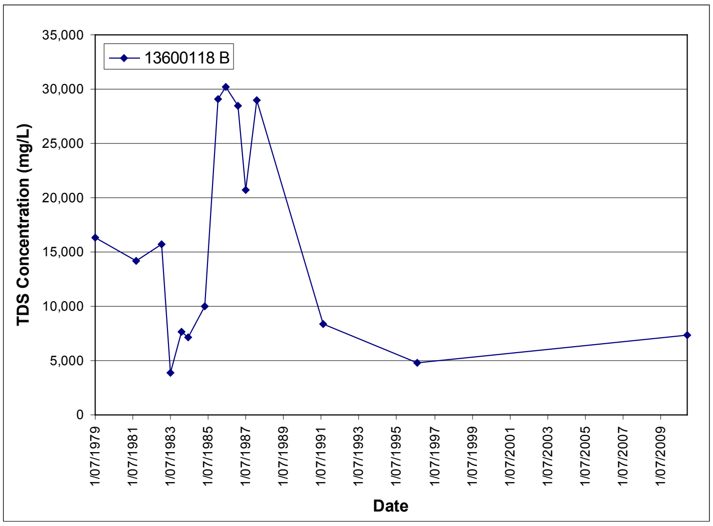

12600443 A
TDS Concentration (mg/L)
Date
0
5,000
10,000
15,000
20,000
25,000
19/11/1992
19/05/1993
19/11/1993
19/05/1994
19/11/1994
19/05/1995
19/11/1995
19/05/1996
19/11/1996
19/05/1997
19/11/1997
19/05/1998
19/11/1998
19/05/1999
19/11/1999
19/05/2000
19/11/2000
19/05/2001
19/11/2001
19/05/2002
19/11/2002
19/05/2003

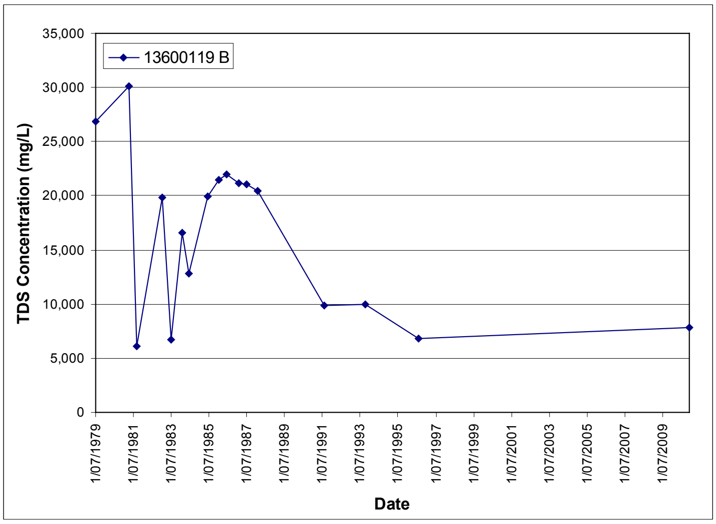

12600448 B
TDS Concentration (mg/L)
Date
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
18/10/1992
18/10/1993
18/10/1994
18/10/1995
18/10/1996
18/10/1997
18/10/1998
18/10/1999
18/10/2000
18/10/2001
18/10/2002
18/10/2003
18/10/2004
18/10/2005
18/10/2006

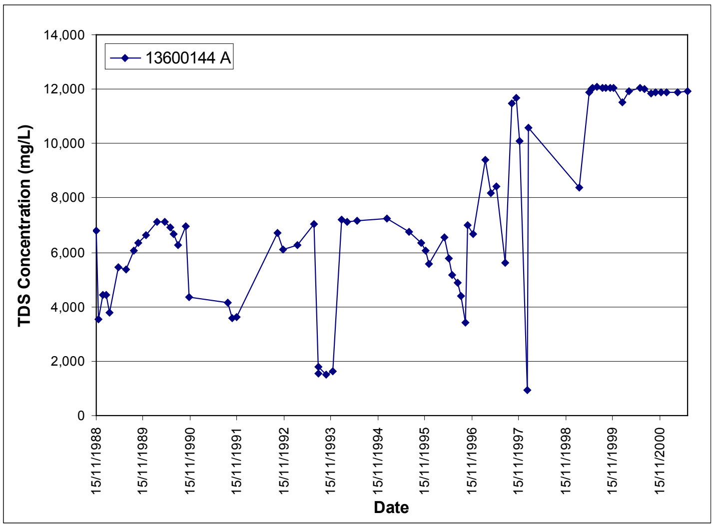

13500085 C
TDS Concentration (mg/L)
Date
0
2,000
4,000
6,000
8,000
10,000
12,000
1/05/1985
1/11/1985
1/05/1986
1/11/1986
1/05/1987
1/11/1987
1/05/1988
1/11/1988
1/05/1989
1/11/1989
1/05/1990
1/11/1990
1/05/1991
1/11/1991
1/05/1992
1/11/1992
1/05/1993

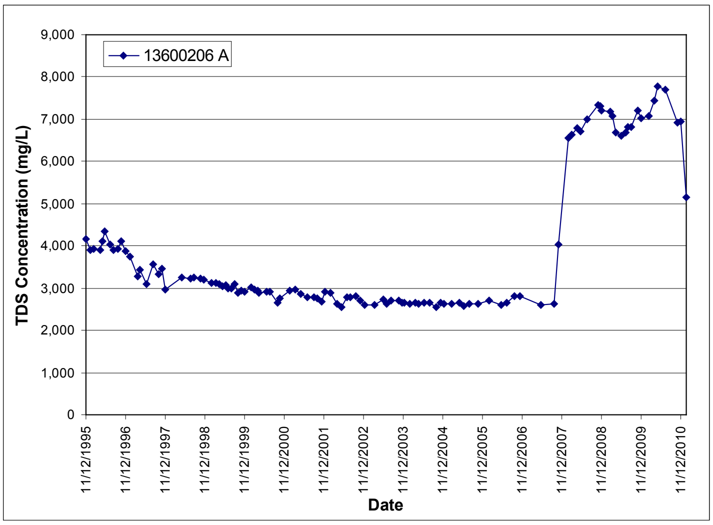

13600063 A
TDS Concentration (mg/L)
Date

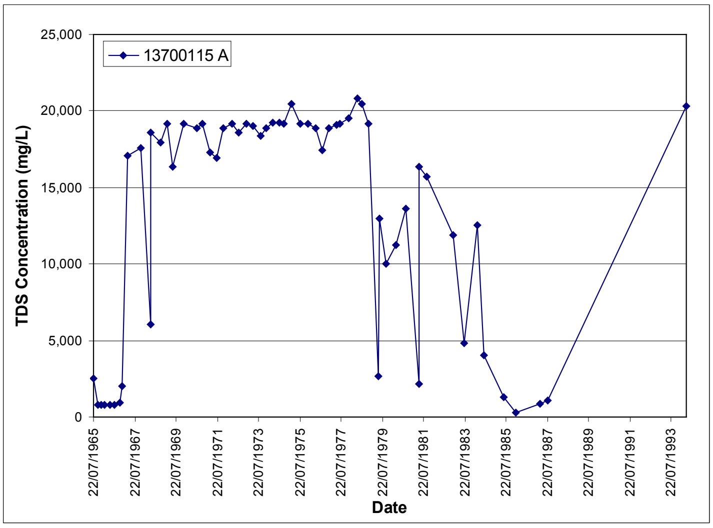

13600116 A
TDS Concentration (mg/L)
Date

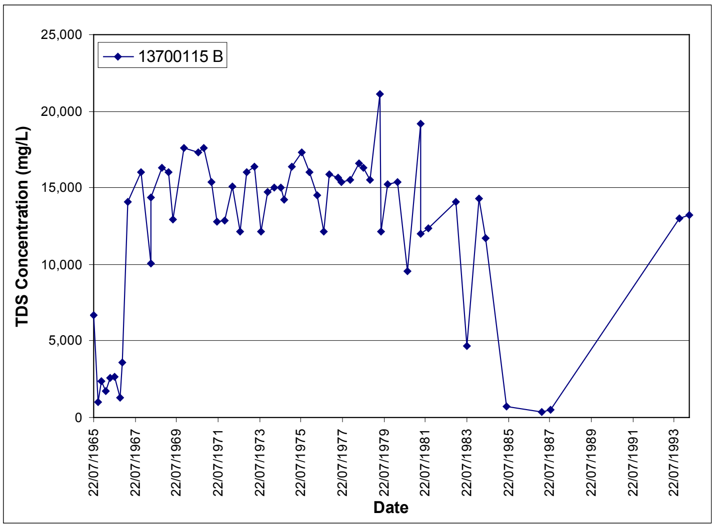

13600118 B
TDS Concentration (mg/L)
Date

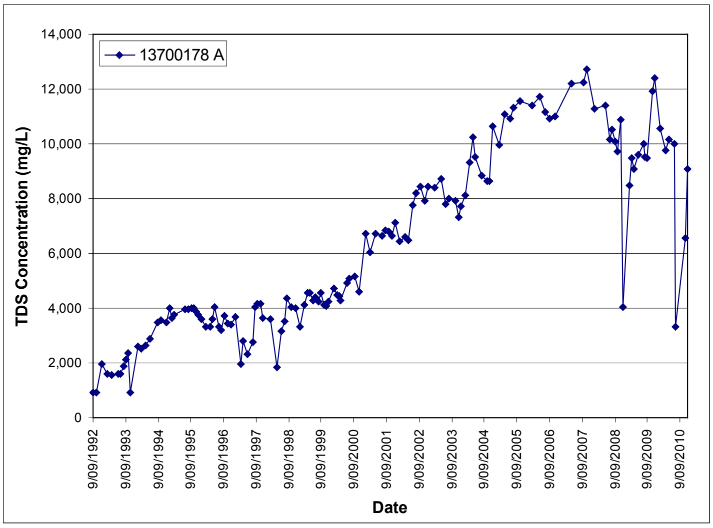

13600119 B
TDS Concentration (mg/L)
Date
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1/07/1979
1/07/1981
1/07/1983
1/07/1985
1/07/1987
1/07/1989
1/07/1991
1/07/1993
1/07/1995
1/07/1997
1/07/1999
1/07/2001
1/07/2003
1/07/2005
1/07/2007
1/07/2009

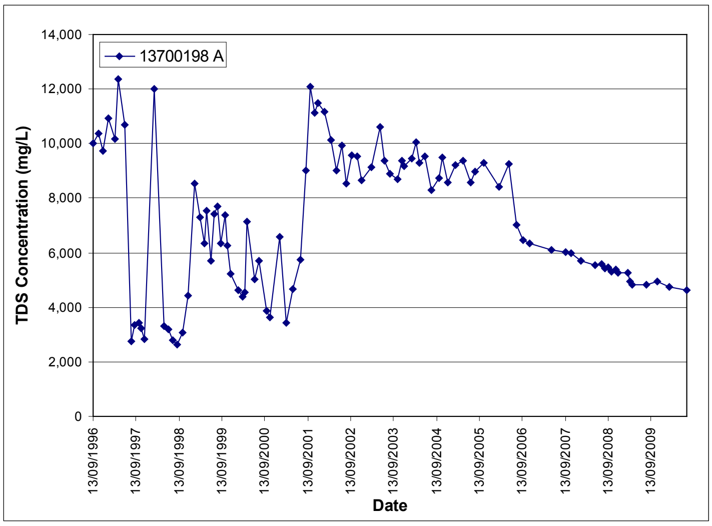

13600144 A
TDS Concentration (mg/L)
Date
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
15/11/1988
15/11/1989
15/11/1990
15/11/1991
15/11/1992
15/11/1993
15/11/1994
15/11/1995
15/11/1996
15/11/1997
15/11/1998
15/11/1999
15/11/2000

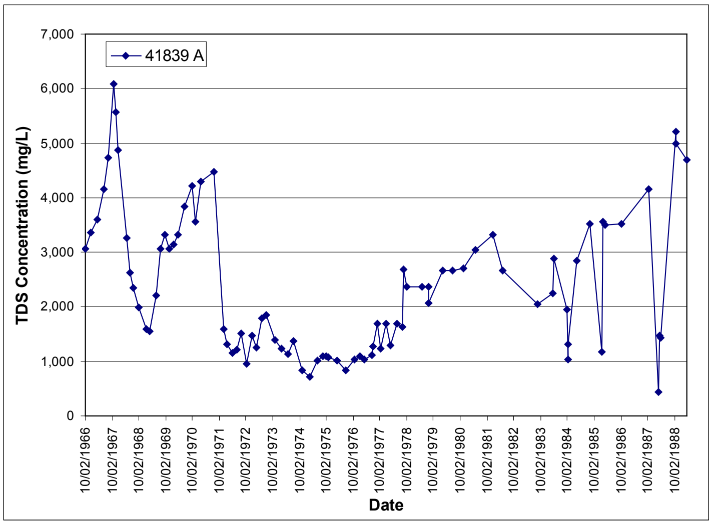

13600206 A
TDS Concentration (mg/L)
Date
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
11/12/1995
11/12/1996
11/12/1997
11/12/1998
11/12/1999
11/12/2000
11/12/2001
11/12/2002
11/12/2003
11/12/2004
11/12/2005
11/12/2006
11/12/2007
11/12/2008
11/12/2009
11/12/2010

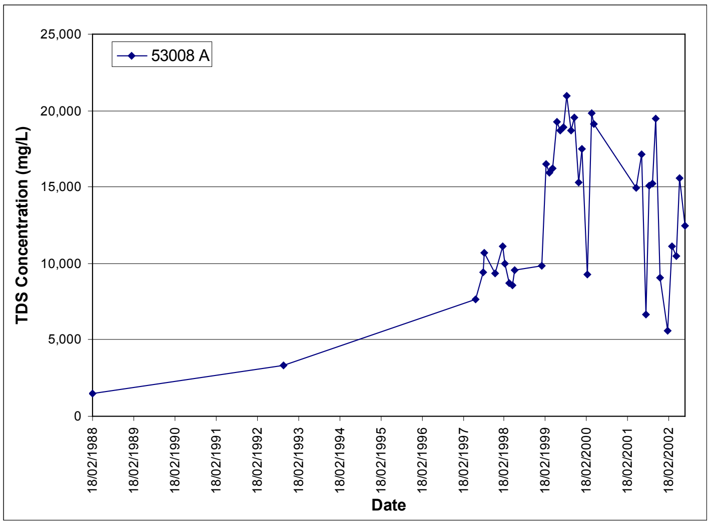

25,000
20,000
15,000
10,000
5,000
0
13700115 A
TDS Concentration (mg/L)
22/07/1965
22/07/1967
22/07/1969
22/07/1971
22/07/1973
22/07/1975
22/07/1977
22/07/1979
22/07/1981
22/07/1983
22/07/1985
22/07/1987
22/07/1989
22/07/1991
22/07/1993
Date

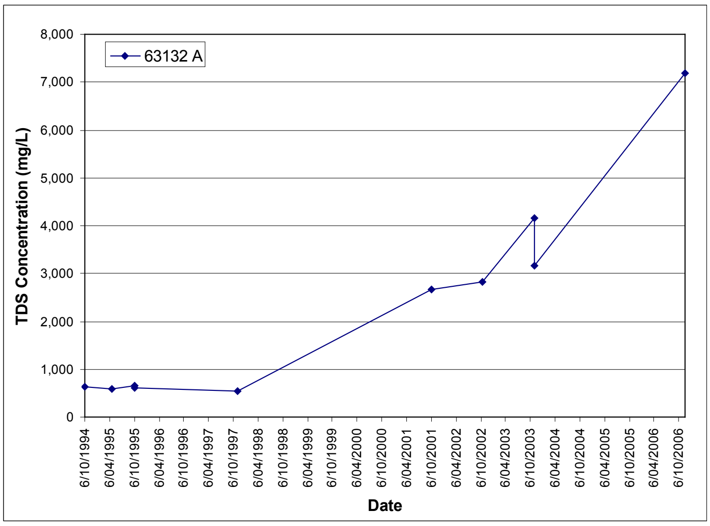

25,000
20,000
15,000
10,000
5,000
0
13700115 B
TDS Concentration (mg/L)
22/07/1965
22/07/1967
22/07/1969
22/07/1971
22/07/1973
22/07/1975
22/07/1977
22/07/1979
22/07/1981
22/07/1983
22/07/1985
22/07/1987
22/07/1989
22/07/1991
22/07/1993
Date


14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
13700178 A
TDS Concentration (mg/L)
9/09/1992
9/09/1993
9/09/1994
9/09/1995
9/09/1996
9/09/1997
9/09/1998
9/09/1999
9/09/2000
9/09/2001
9/09/2002
9/09/2003
9/09/2004
9/09/2005
9/09/2006
9/09/2007
9/09/2008
9/09/2009
9/09/2010
Date


13700198 A
TDS Concentration (mg/L)
Date


41839 A
TDS Concentration (mg/L)
Date


53008 A
TDS Concentration (mg/L)
Date


63132 A
TDS Concentration (mg/L)
Date
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
6/10/1994
6/04/1995
6/10/1995
6/04/1996
6/10/1996
6/04/1997
6/10/1997
6/04/1998
6/10/1998
6/04/1999
6/10/1999
6/04/2000
6/10/2000
6/04/2001
6/10/2001
6/04/2002
6/10/2002
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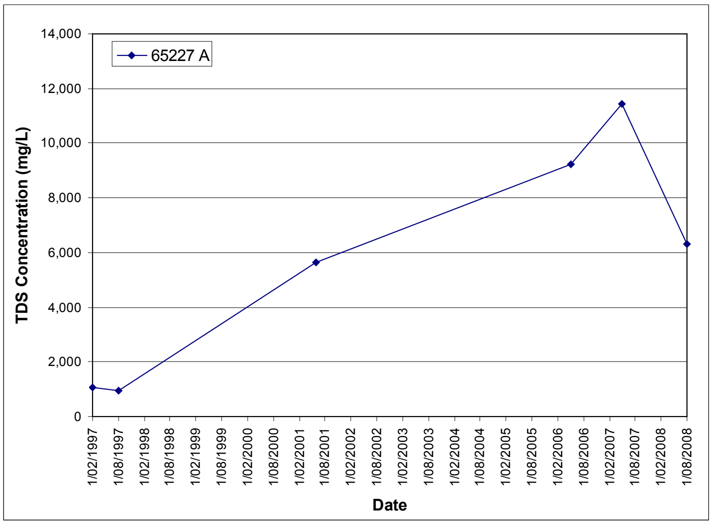
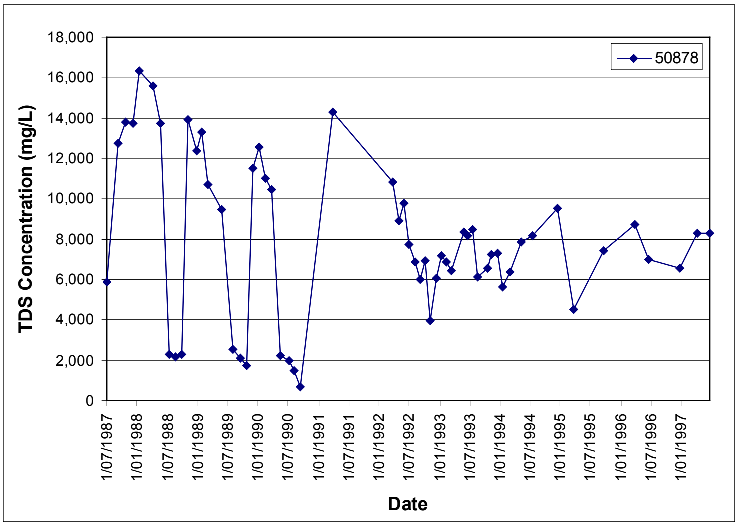
6/04/2006
6/10/2006


65227 A
TDS Concentration (mg/L)
Date
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1/02/1997
1/08/1997
1/02/1998
1/08/1998
1/02/1999
1/08/1999
1/02/2000
1/08/2000
1/02/2001
1/08/2001
1/02/2002
1/08/2002
1/02/2003
1/08/2003
1/02/2004
1/08/2004
1/02/2005
1/08/2005
1/02/2006
1/08/2006
1/02/2007
1/08/2007
1/02/2008
1/08/2008

Victoria


TDS Concentration (mg/L)
Date
50878
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1/07/1987
1/01/1988
1/07/1988
1/01/1989
1/07/1989
1/01/1990
1/07/1990
1/01/1991
1/07/1991
1/01/1992
1/07/1992
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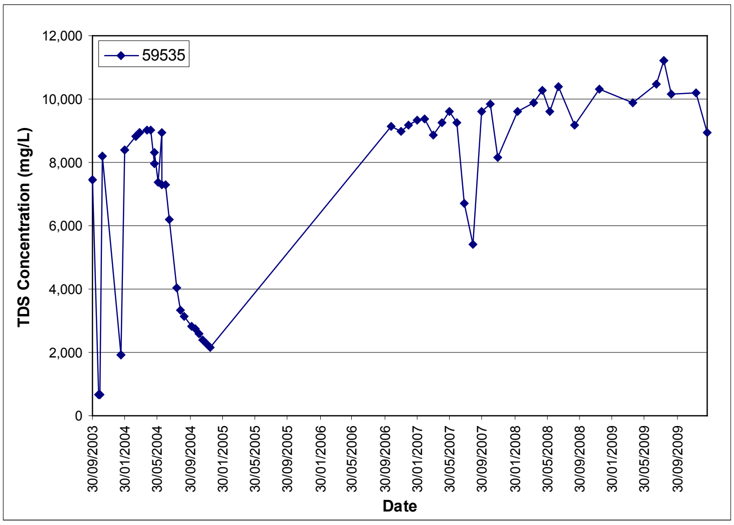
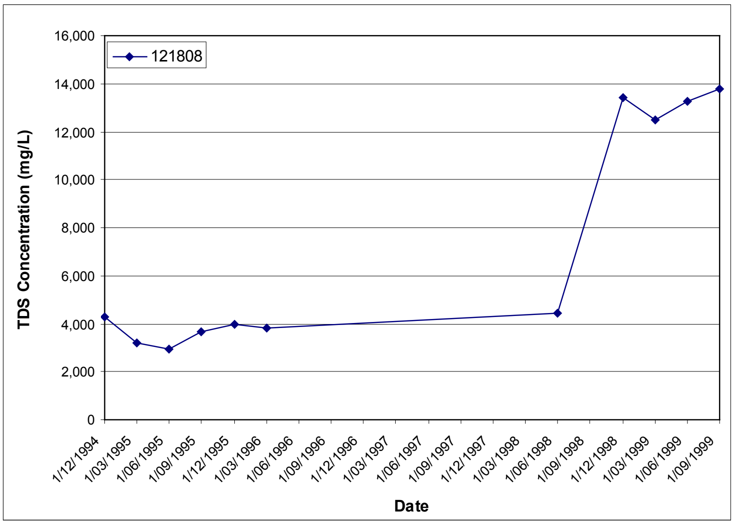
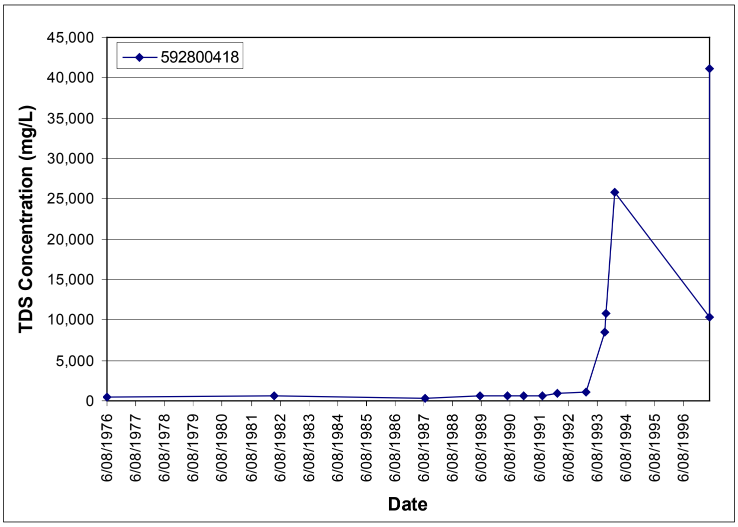
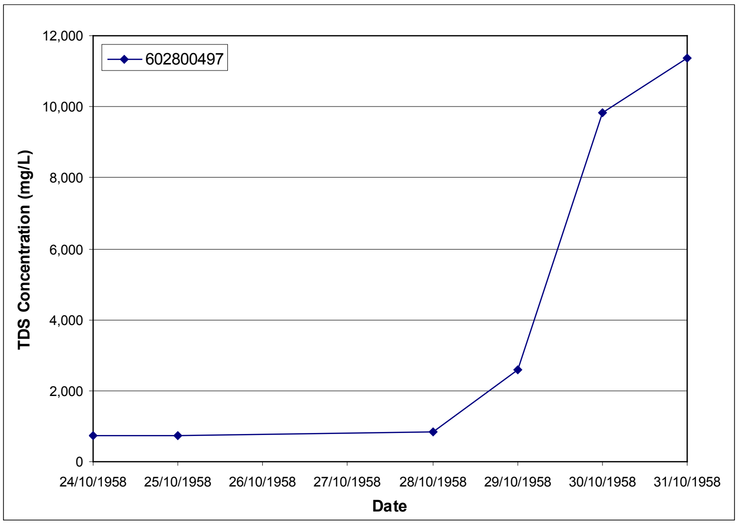
1/07/1996
1/01/1997

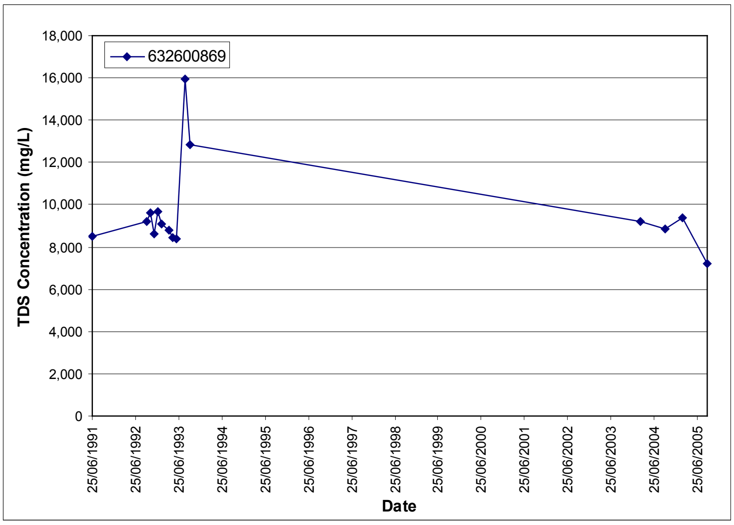

TDS Concentration (mg/L)
Date
59535
12,000
10,000
8,000
6,000
4,000
2,000
0
30/09/2003
30/01/2004
30/05/2004
30/09/2004
30/01/2005
30/05/2005
30/09/2005
30/01/2006
30/05/2006
30/09/2006
30/01/2007
30/05/2007
30/09/2007
30/01/2008
30/05/2008
30/09/2008
30/01/2009
30/05/2009
30/09/2009

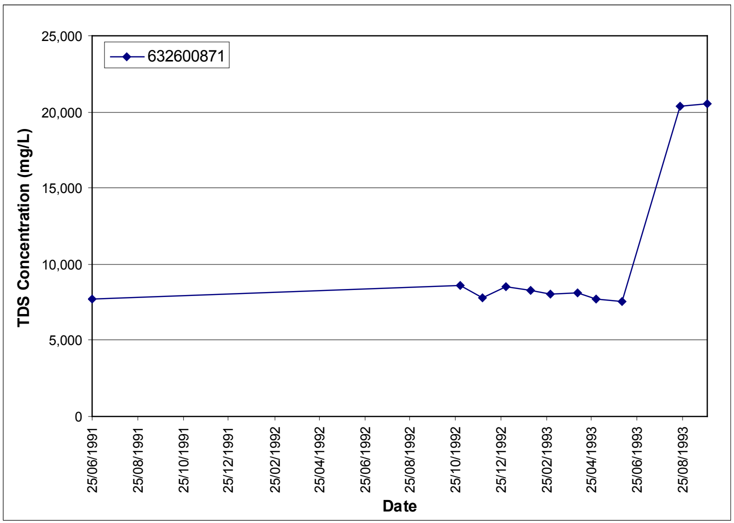

TDS Concentration (mg/L)
Date
121808
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1/12/1994
1/03/1995
1/06/1995
1/09/1995
1/12/1995
1/03/1996
1/06/1996
1/09/1996
1/12/1996
1/03/1997
1/06/1997
1/09/1997
1/12/1997
1/03/1998
1/06/1998
1/09/1998
1/12/1998
1/03/1999
1/06/1999
1/09/1999

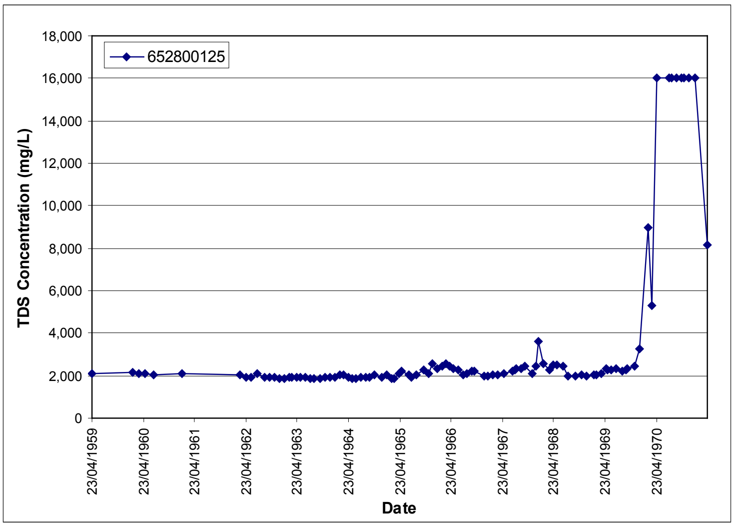
South Australia

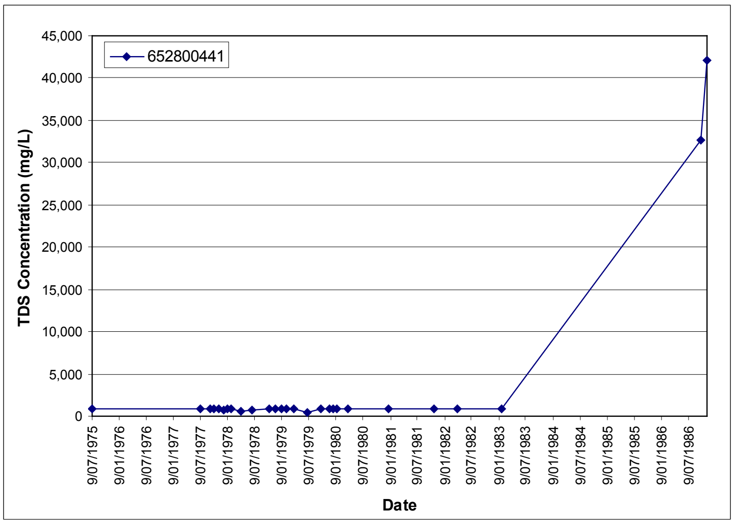


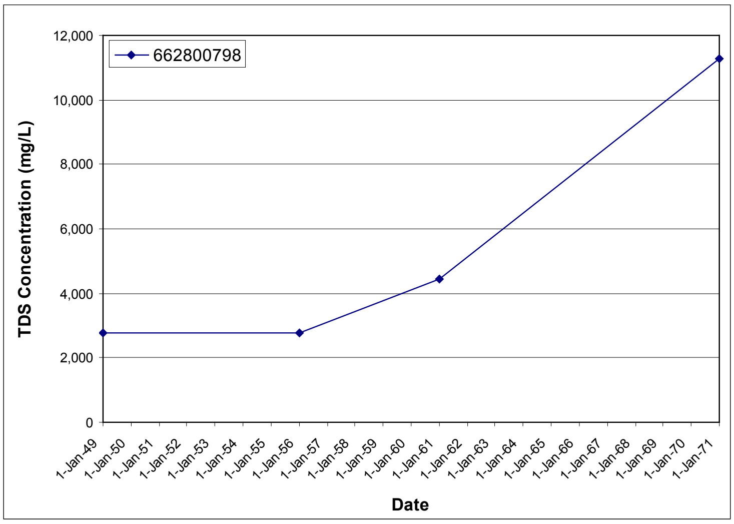


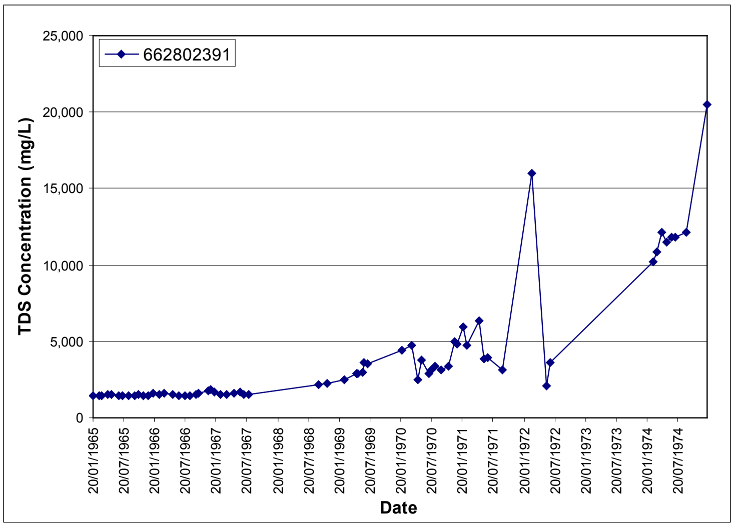


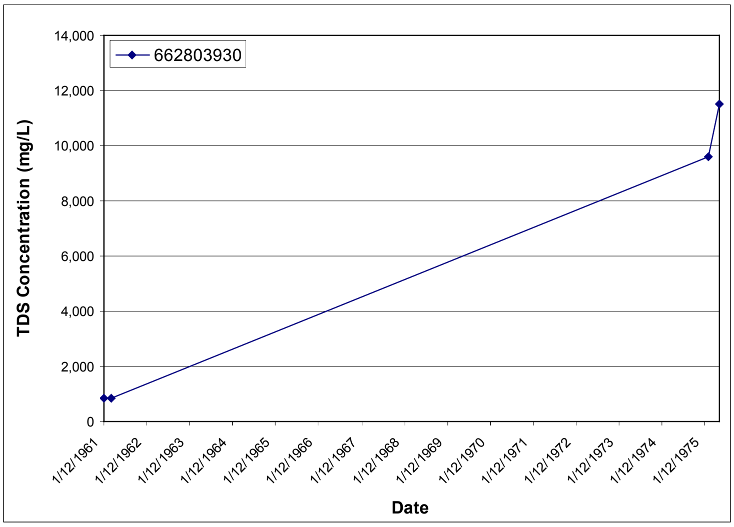

632600871
TDS Concentration (mg/L)
Date
25,000
20,000
15,000
10,000
5,000
0
25/06/1991
25/08/1991
25/10/1991
25/12/1991
25/02/1992
25/04/1992
25/06/1992
25/08/1992
25/10/1992
25/12/1992
25/02/1993
25/04/1993
25/06/1993
25/08/1993

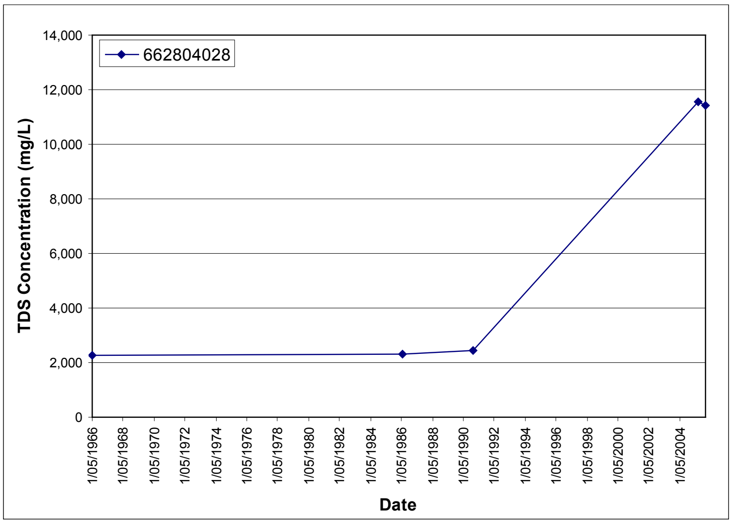

652800125
TDS Concentration (mg/L)
Date
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
23/04/1959
23/04/1960
23/04/1961
23/04/1962
23/04/1963
23/04/1964
23/04/1965
23/04/1966
23/04/1967
23/04/1968
23/04/1969
23/04/1970


652800441
TDS Concentration (mg/L)
Date
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
9/07/1975
9/01/1976
9/07/1976
9/01/1977
9/07/1977
9/01/1978
9/07/1978
9/01/1979
9/07/1979
9/01/1980
9/07/1980
9/01/1981
9/07/1981
9/01/1982
9/07/1982
9/01/1983
9/07/1983
9/01/1984
9/07/1984
9/01/1985
9/07/1985
9/01/1986
9/07/1986

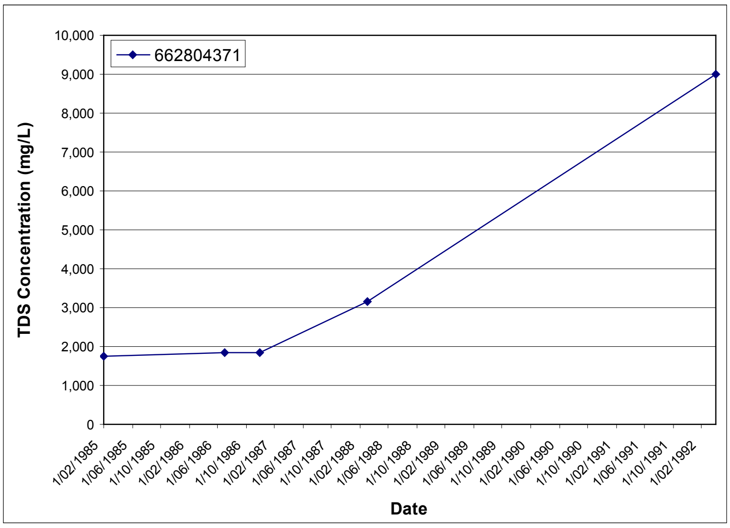

662800798
TDS Concentration (mg/L)
Date
12,000
10,000
8,000
6,000
4,000
2,000
0
1-Jan-49
1-Jan-50
1-Jan-51
1-Jan-52
1-Jan-53
1-Jan-54
1-Jan-55
1-Jan-56
1-Jan-57
1-Jan-58
1-Jan-59
1-Jan-60
1-Jan-61
1-Jan-62
1-Jan-63
1-Jan-64
1-Jan-65
1-Jan-66
1-Jan-67
1-Jan-68
1-Jan-69
1-Jan-70
1-Jan-71


662802391
TDS Concentration (mg/L)
Date
25,000
20,000
15,000
10,000
5,000
0
20/01/1965
20/07/1965
20/01/1966
20/07/1966
20/01/1967
20/07/1967
20/01/1968
20/07/1968
20/01/1969
20/07/1969
20/01/1970
20/07/1970
20/01/1971
20/07/1971
20/01/1972
20/07/1972
20/01/1973
20/07/1973
20/01/1974
20/07/1974

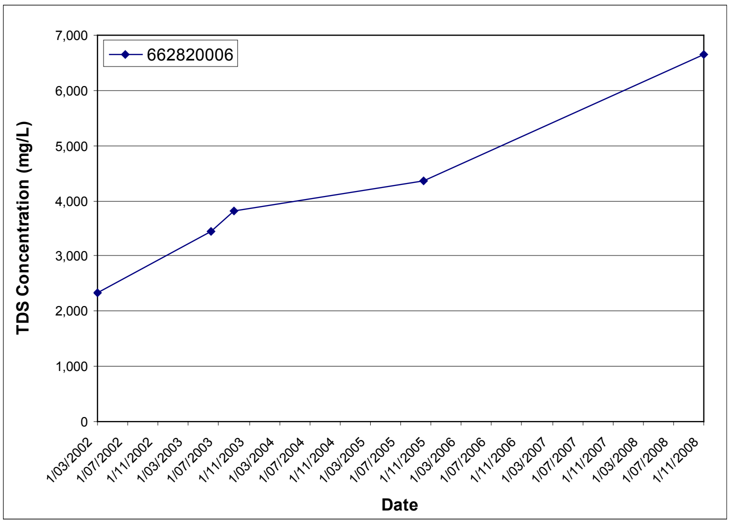

662803930
TDS Concentration (mg/L)
Date
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1/12/1961
1/12/1962
1/12/1963
1/12/1964
1/12/1965
1/12/1966
1/12/1967
1/12/1968
1/12/1969
1/12/1970
1/12/1971
1/12/1972
1/12/1973
1/12/1974
1/12/1975



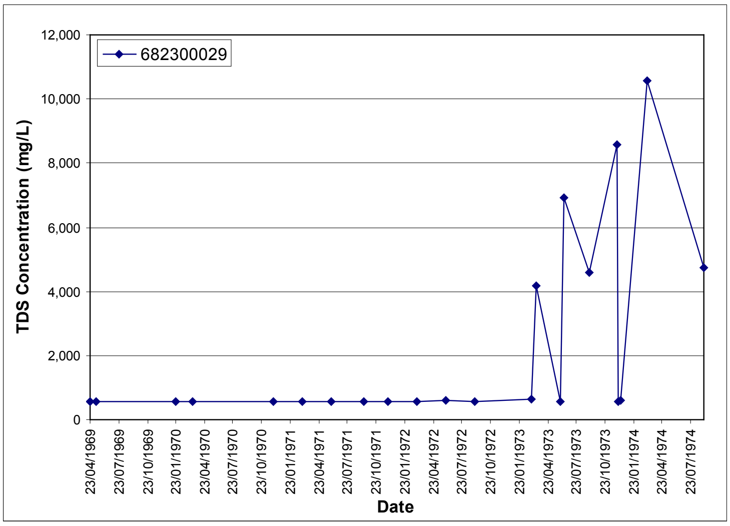
662804028
TDS Concentration (mg/L)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1/05/1966
1/05/1968
1/05/1970
1/05/1972
1/05/1974
1/05/1976
1/05/1978
1/05/1980
1/05/1982
1/05/1984
1/05/1986
1/05/1988
1/05/1990
1/05/1992
1/05/1994
1/05/1996
1/05/1998
1/05/2000
1/05/2002
1/05/2004
Date



662804371
TDS Concentration (mg/L)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1/02/1985
1/06/1985
1/10/1985
1/02/1986
1/06/1986
1/10/1986
1/02/1987
1/06/1987
1/10/1987
1/02/1988
1/06/1988
1/10/1988
1/02/1989
1/06/1989
1/10/1989
1/02/1990
1/06/1990
1/10/1990
1/02/1991
1/06/1991
1/10/1991
1/02/1992
Date



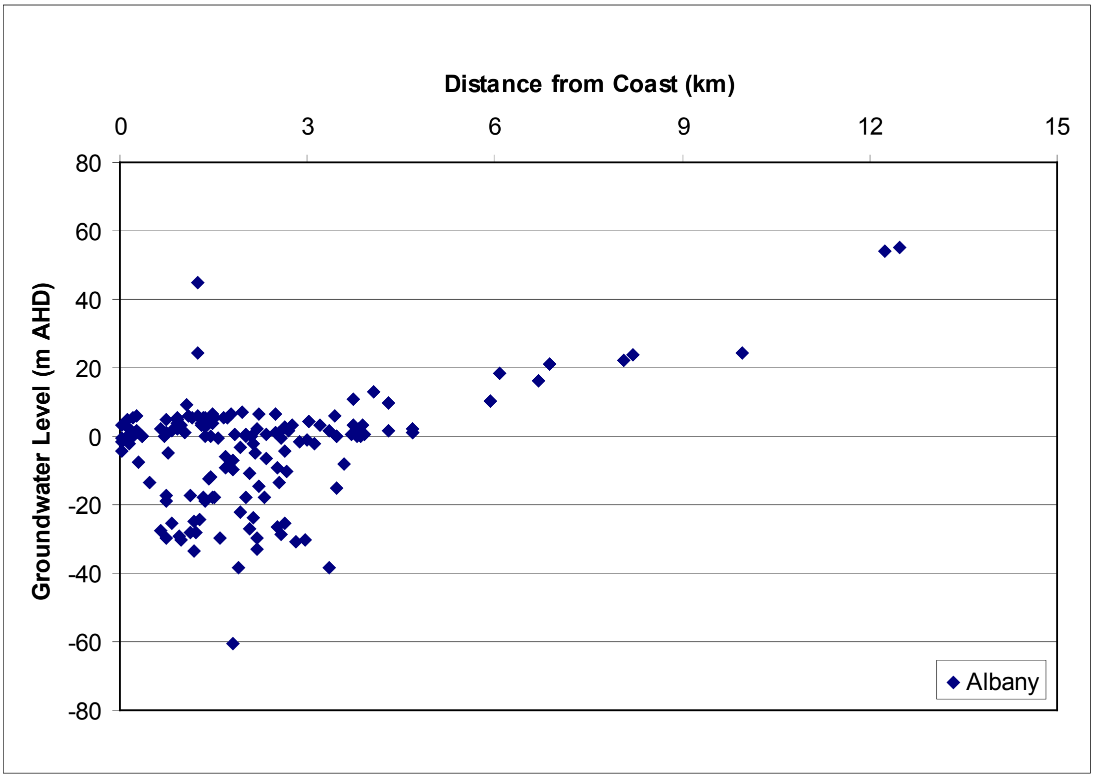
662820006
TDS Concentration (mg/L)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1/03/2002
1/07/2002
1/11/2002
1/03/2003
1/07/2003
1/11/2003
1/03/2004
1/07/2004
1/11/2004
1/03/2005
1/07/2005
1/11/2005
1/03/2006
1/07/2006
1/11/2006
1/03/2007
1/07/2007
1/11/2007
1/03/2008
1/07/2008
1/11/2008
Date

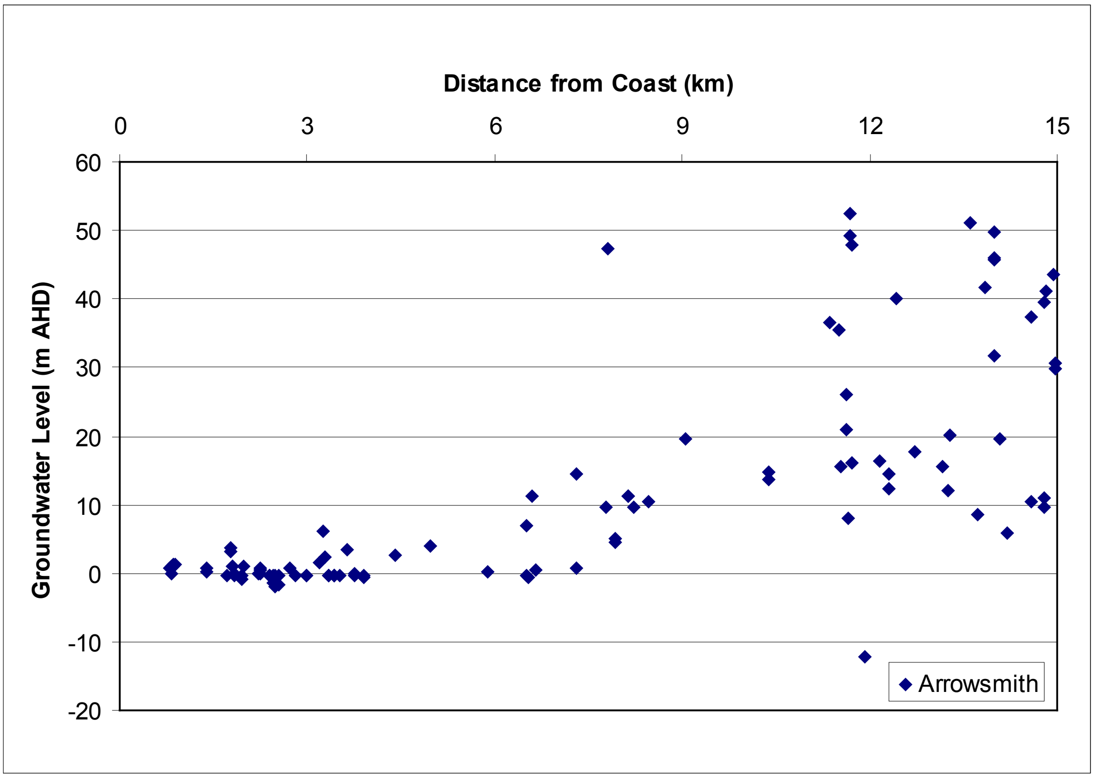


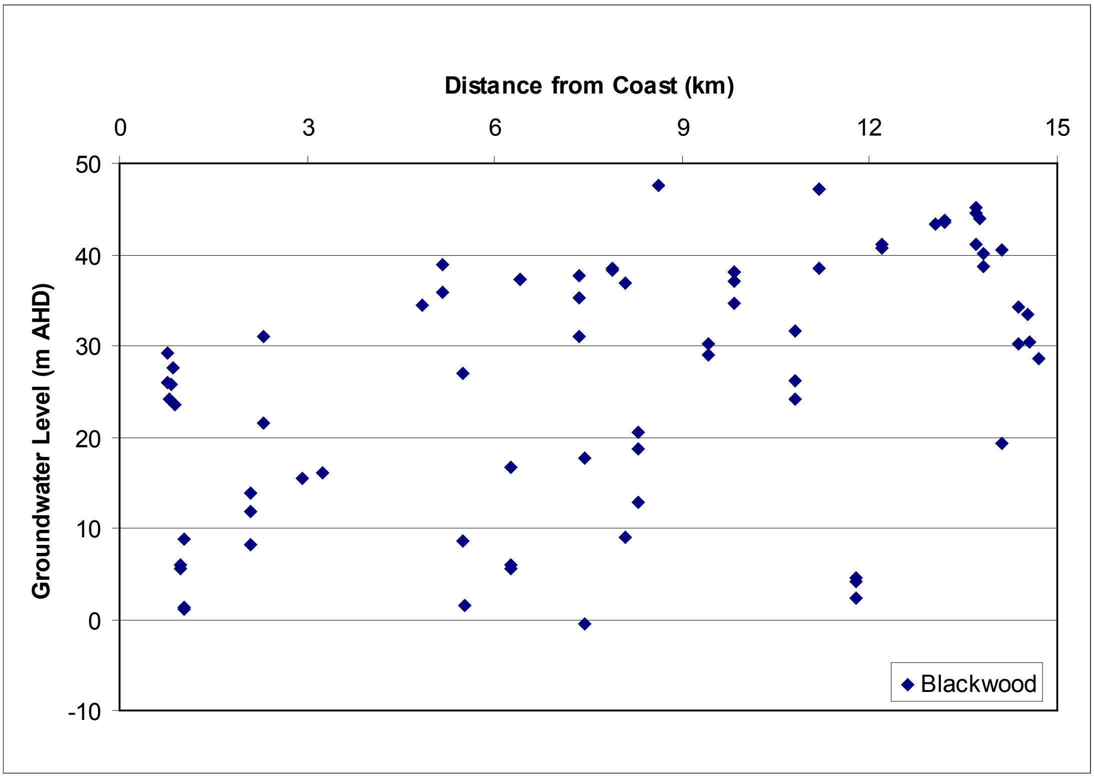
12,000
10,000
8,000
6,000
4,000
2,000
0
TDS Concentration (mg/L)
682300029
23/04/1969
23/07/1969
23/10/1969
23/01/1970
23/04/1970
23/07/1970
23/10/1970
23/01/1971
23/04/1971
23/07/1971
23/10/1971
23/01/1972
23/04/1972
23/07/1972
23/10/1972
23/01/1973
23/04/1973
23/07/1973
23/10/1973
23/01/1974
23/04/1974
23/07/1974
Date

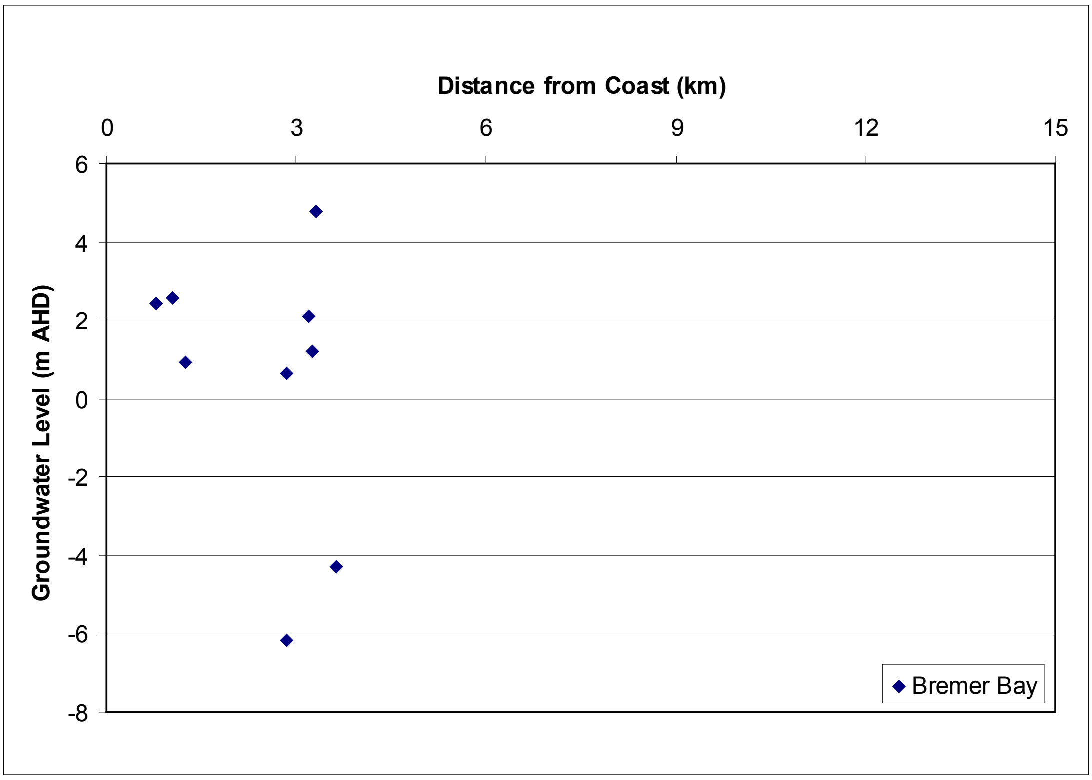
Appendix 2: Plots of minimum groundwater level (all dates) against distance of monitoring bore from coast

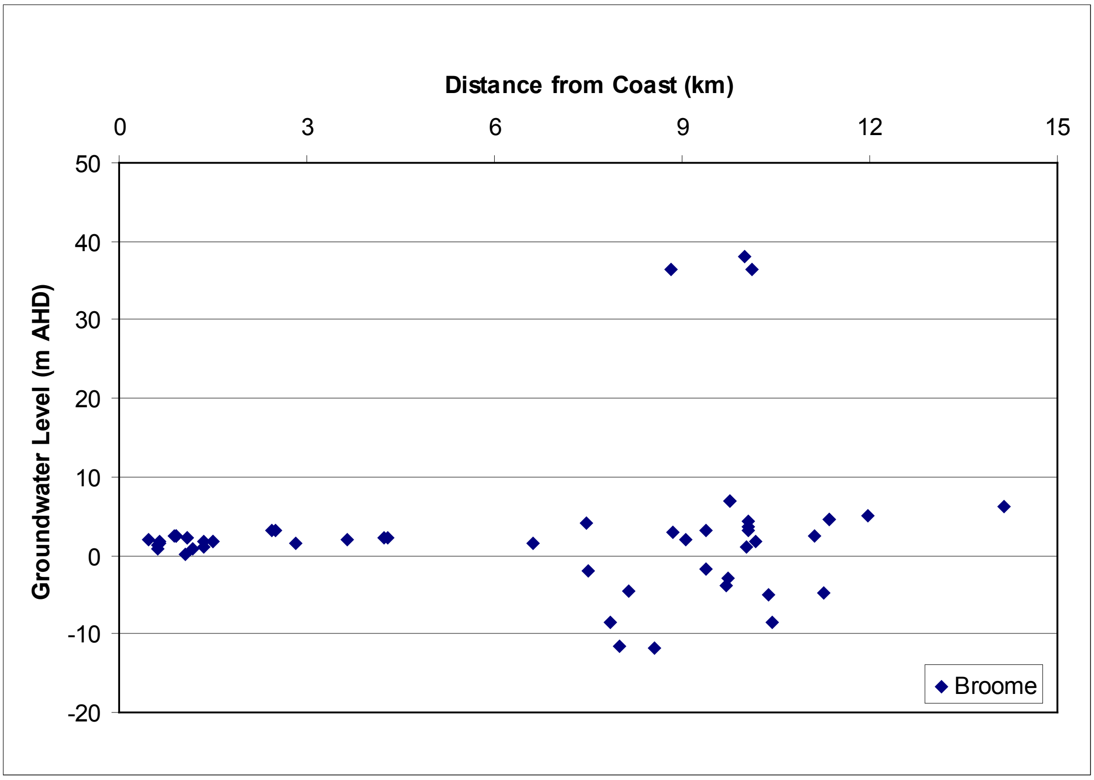
Western Australia

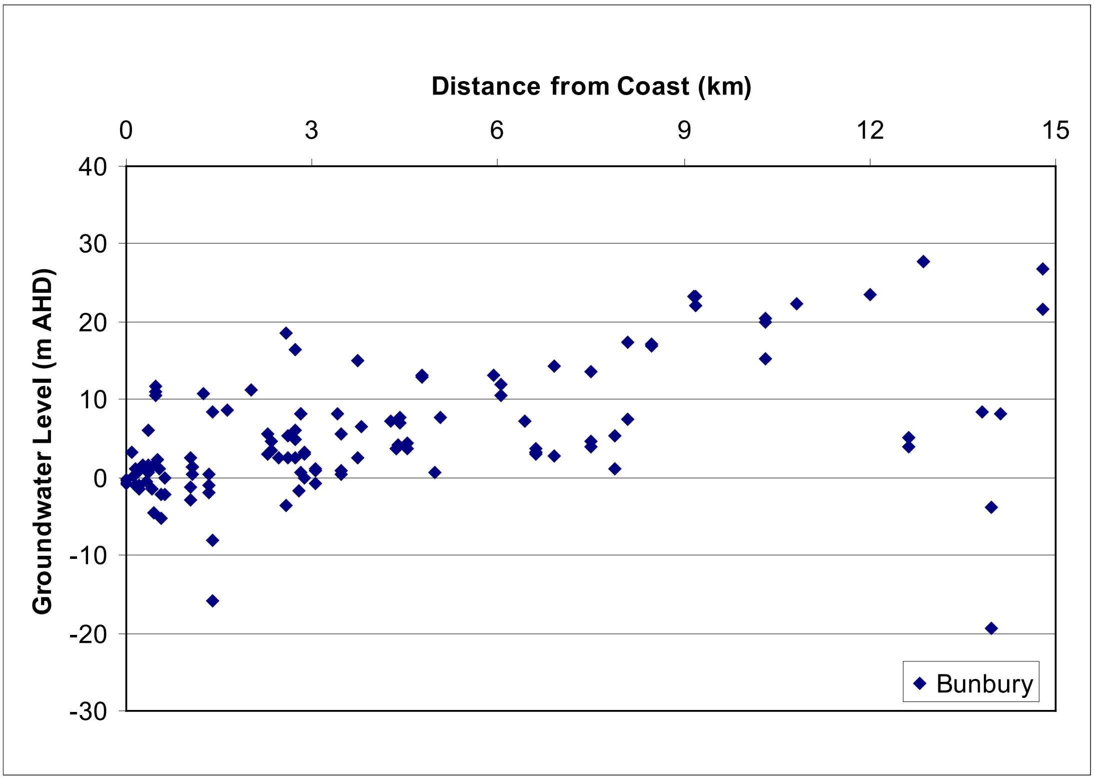


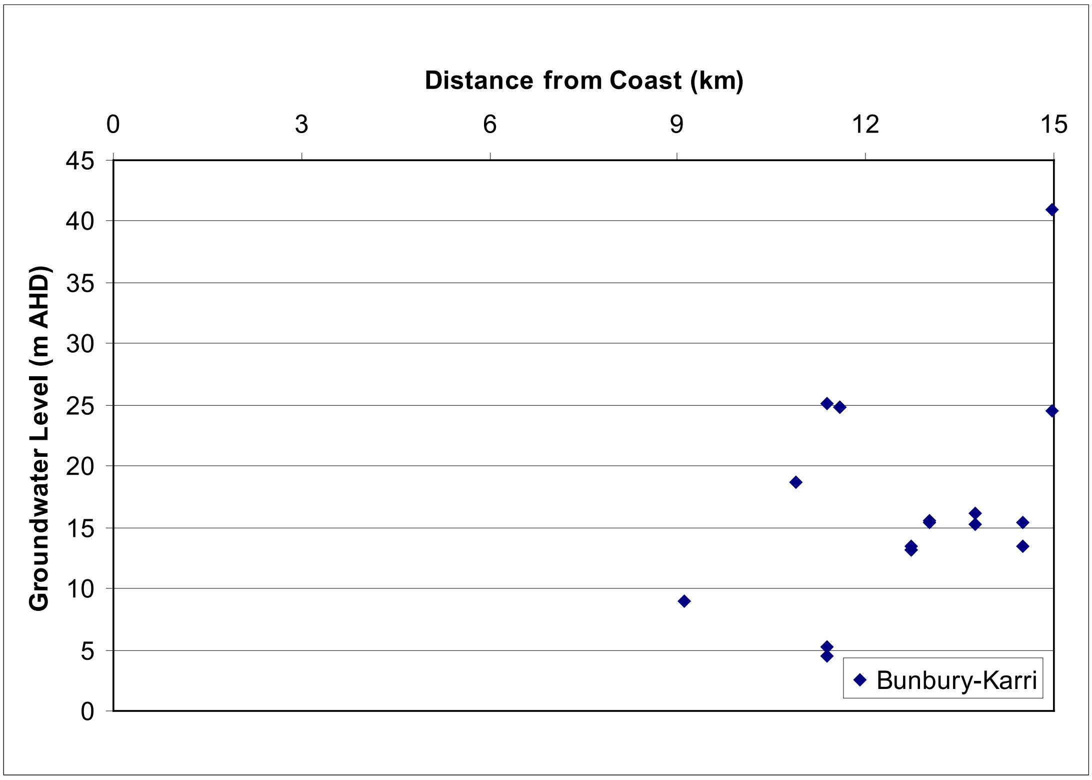

Distance from Coast (km)
0
3
6
9
12
15
60
50
40
30
20
10
0
-10
-20
Groundwater Level (m AHD)
Arrowsmith

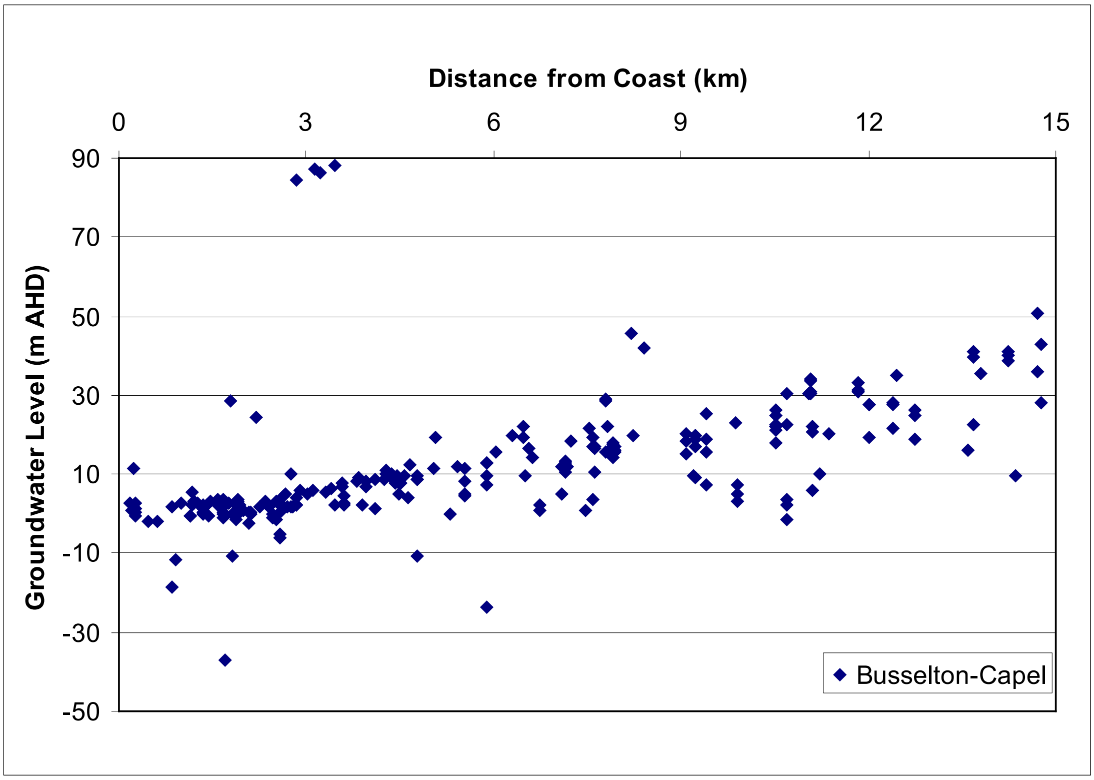

Distance from Coast (km)
0
3
6
9
12
15
50
40
30
20
10
0
-10
Groundwater Level (m AHD)
Blackwood

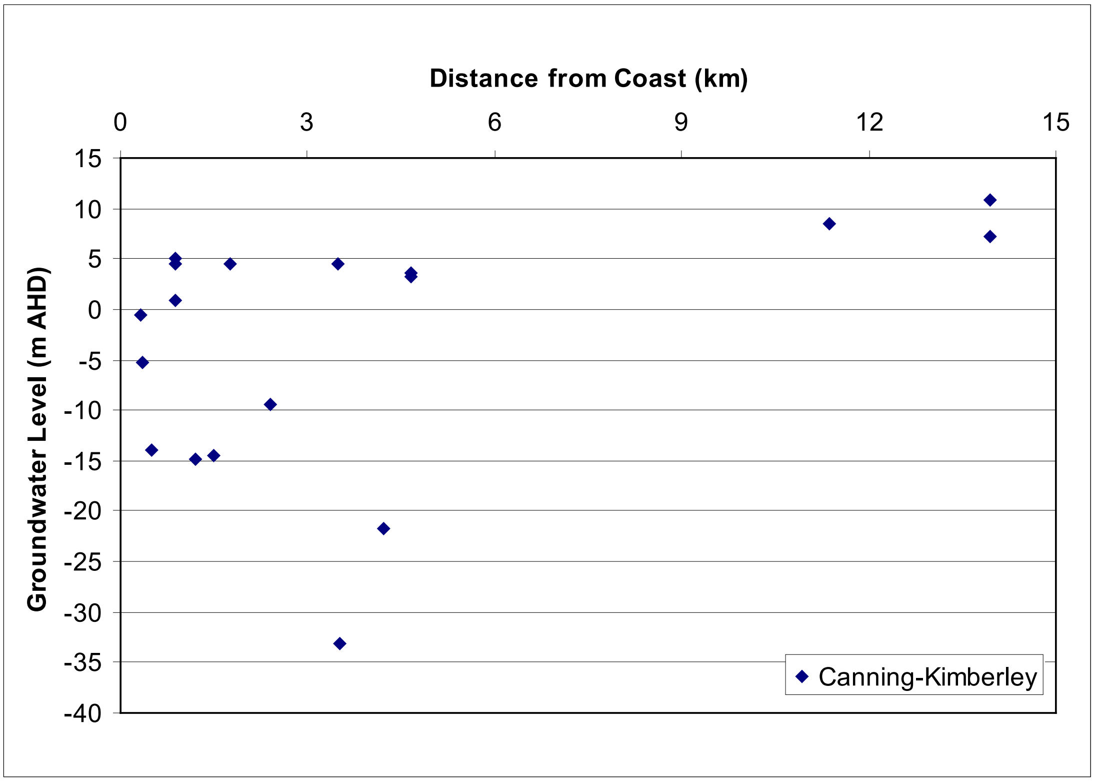

Distance from Coast (km)
0
3
6
9
12
15
6
4
2
0
-2
-4
-6
-8
Groundwater Level (m AHD)
Bremer Bay

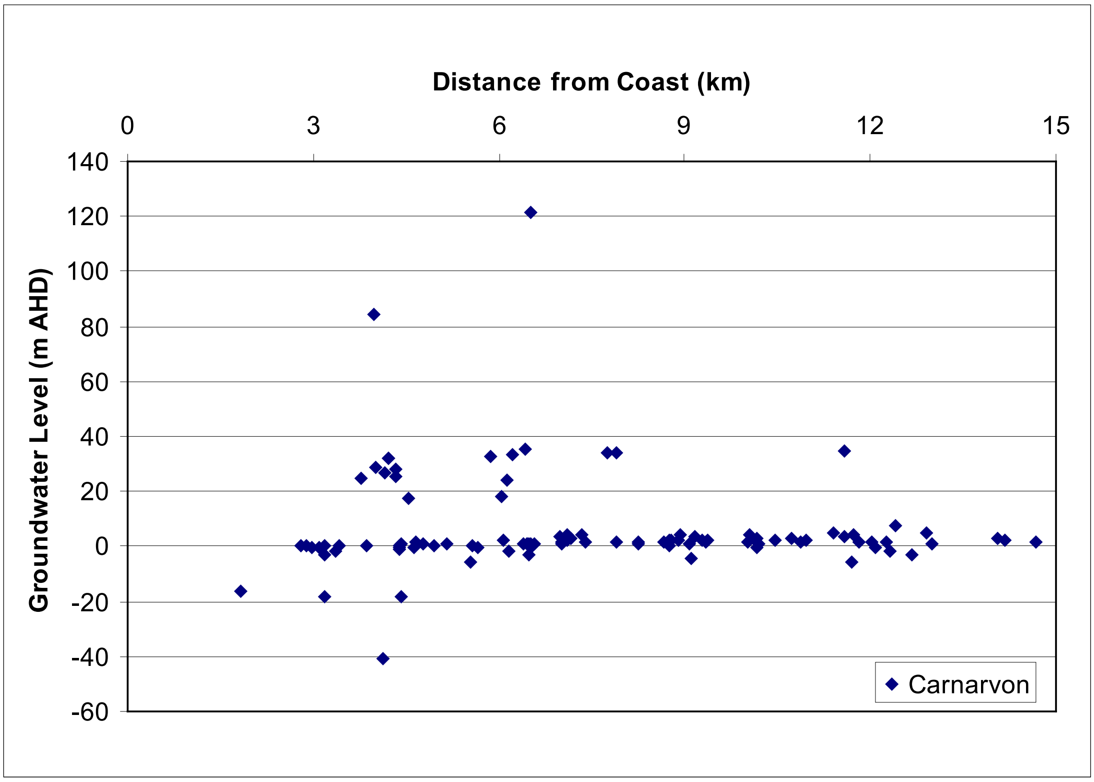

Distance from Coast (km)
0
3
6
9
12
15
50
40
30
20
10
0
-10
-20
Groundwater Level (m AHD)
Broome


Distance from Coast (km)
0
3
6
9
12
15
40
30
20
10
0
-10
-20
-30
Groundwater Level (m AHD)
Bunbury

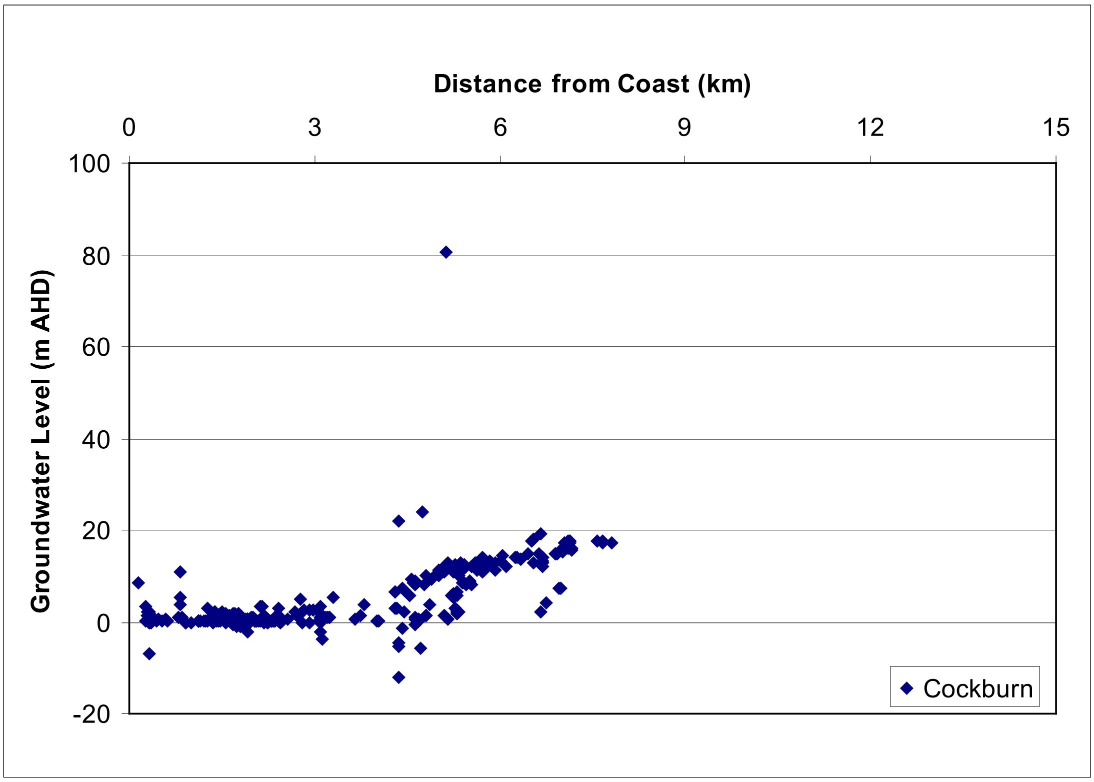

Distance from Coast (km)
0
3
6
9
12
15
45
40
35
30
25
20
15
10
5
0
Groundwater Level (m AHD)
Bunbury-Karri


Distance from Coast (km)
0
3
6
9
12
15
90
70
50
30
10
-10
-30
-50
Groundwater Level (m AHD)
Busselton-Capel

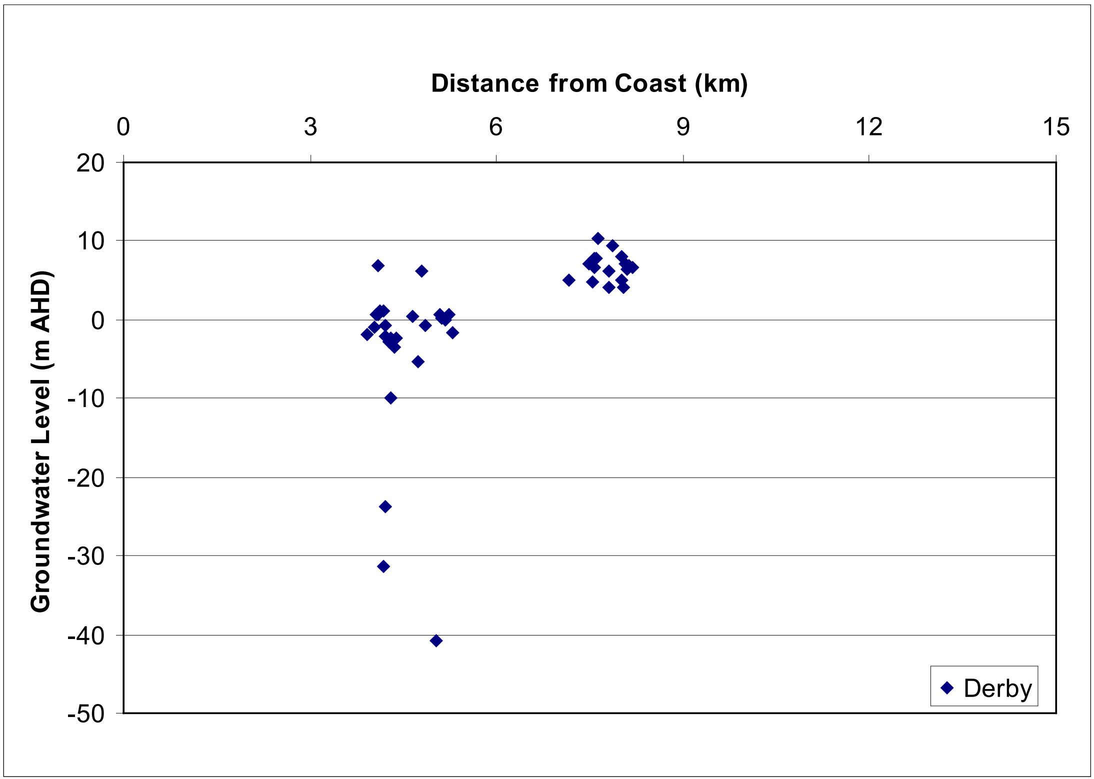

Distance from Coast (km)
0
3
6
9
12
15
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
Groundwater Level (m AHD)
Canning-Kimberley

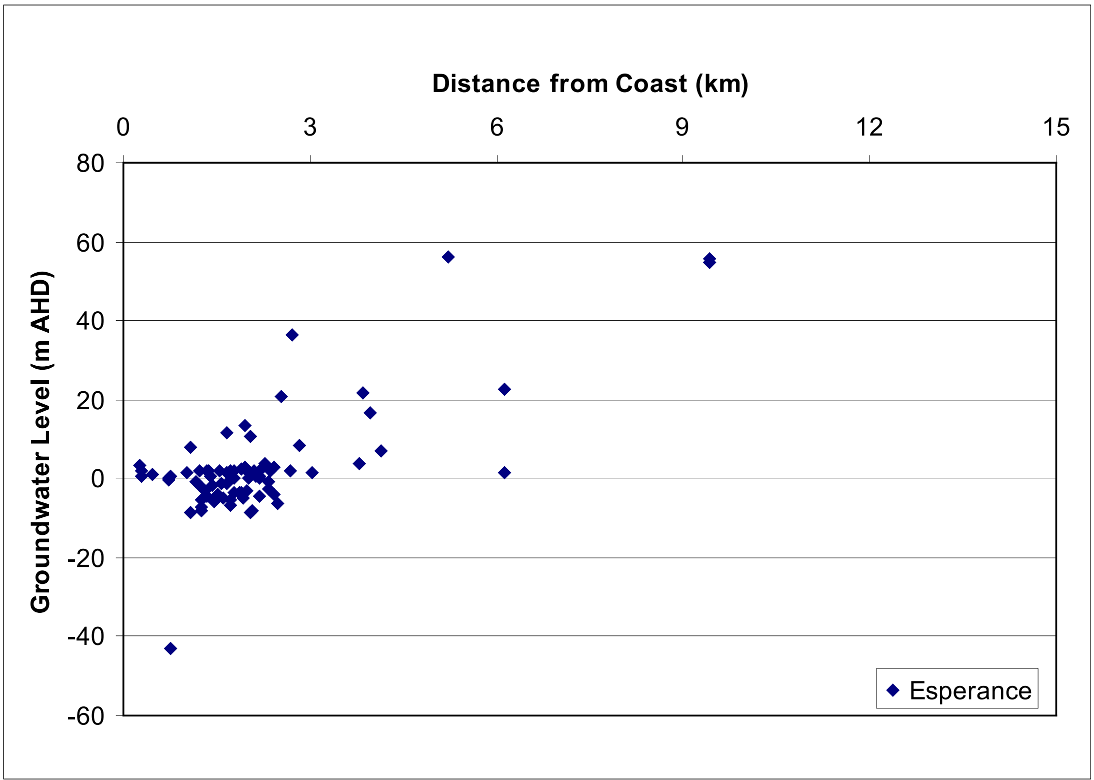


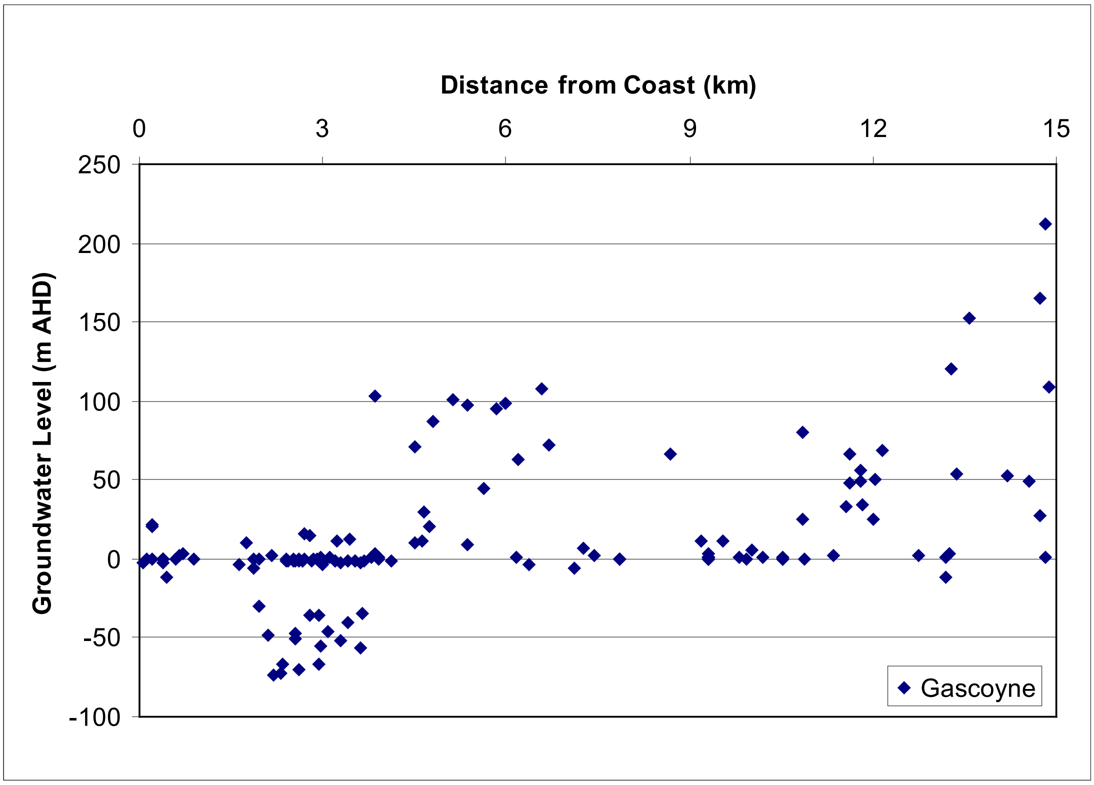
Distance from Coast (km)
0
3
6
9
12
15
140
120
100
80
60
40
20
0
-20
-40
-60
Groundwater Level (m AHD)
Carnarvon

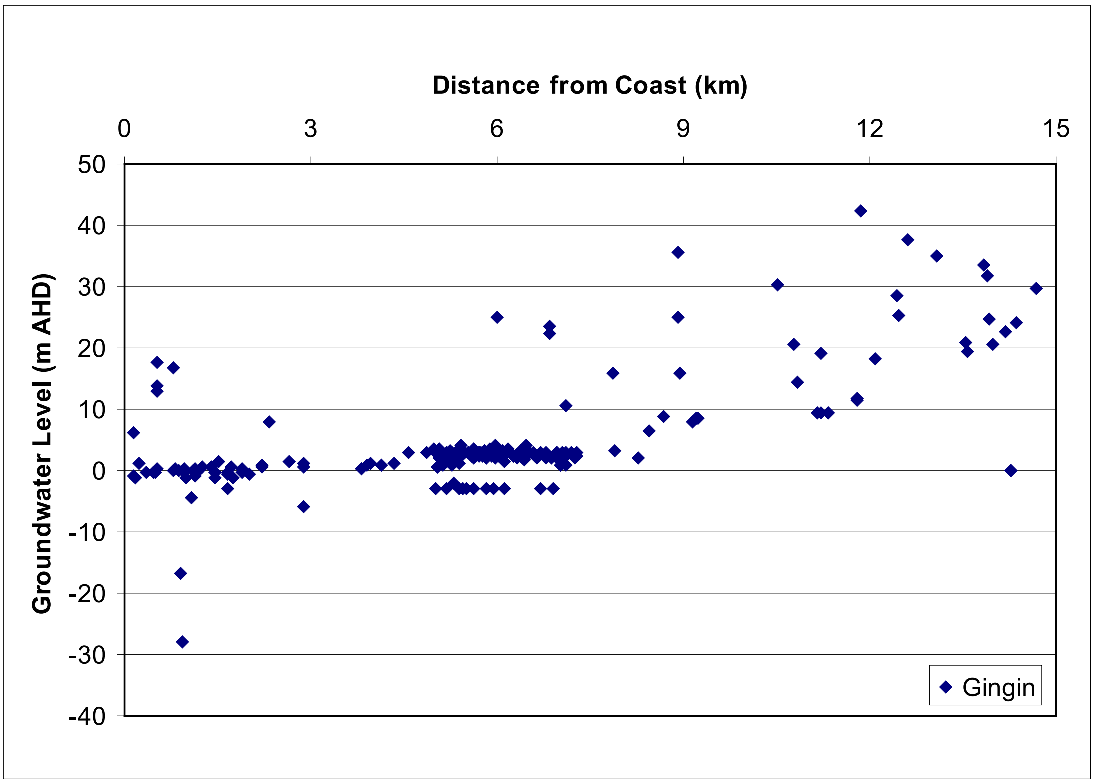


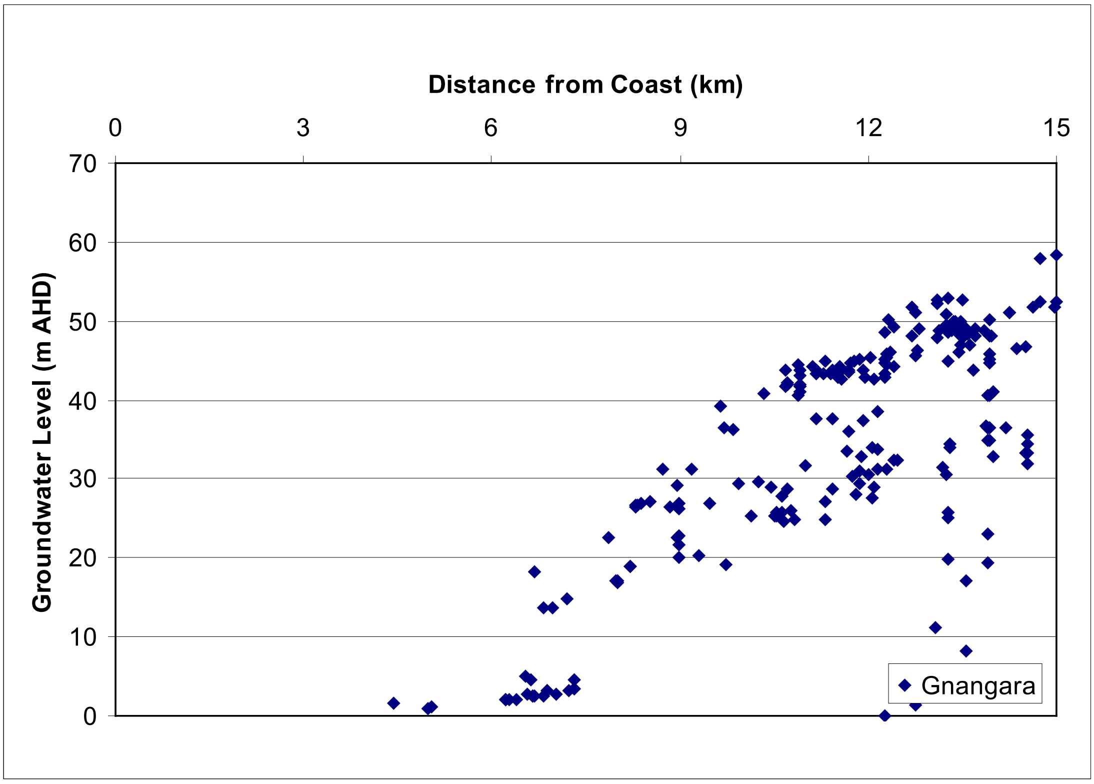
Distance from Coast (km)
0
3
6
9
12
15
100
80
60
40
20
0
-20
Groundwater Level (m AHD)
Cockburn


Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
20
10
0
-10
-20
-30
-40
-50
Derby

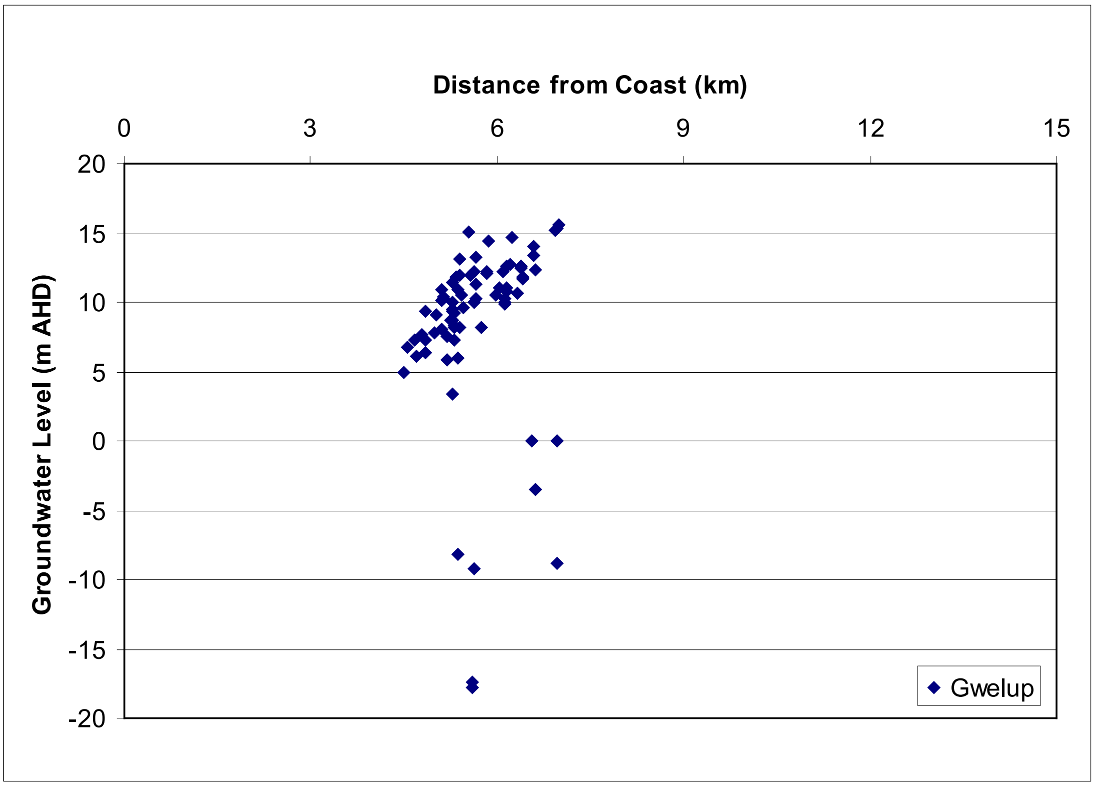

Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
80
60
40
20
0
-20
-40
-60
Esperance


Distance from Coast (km)
0
3
6
9
12
15
250
200
150
100
50
0
-50
-100
Groundwater Level (m AHD)
Gascoyne

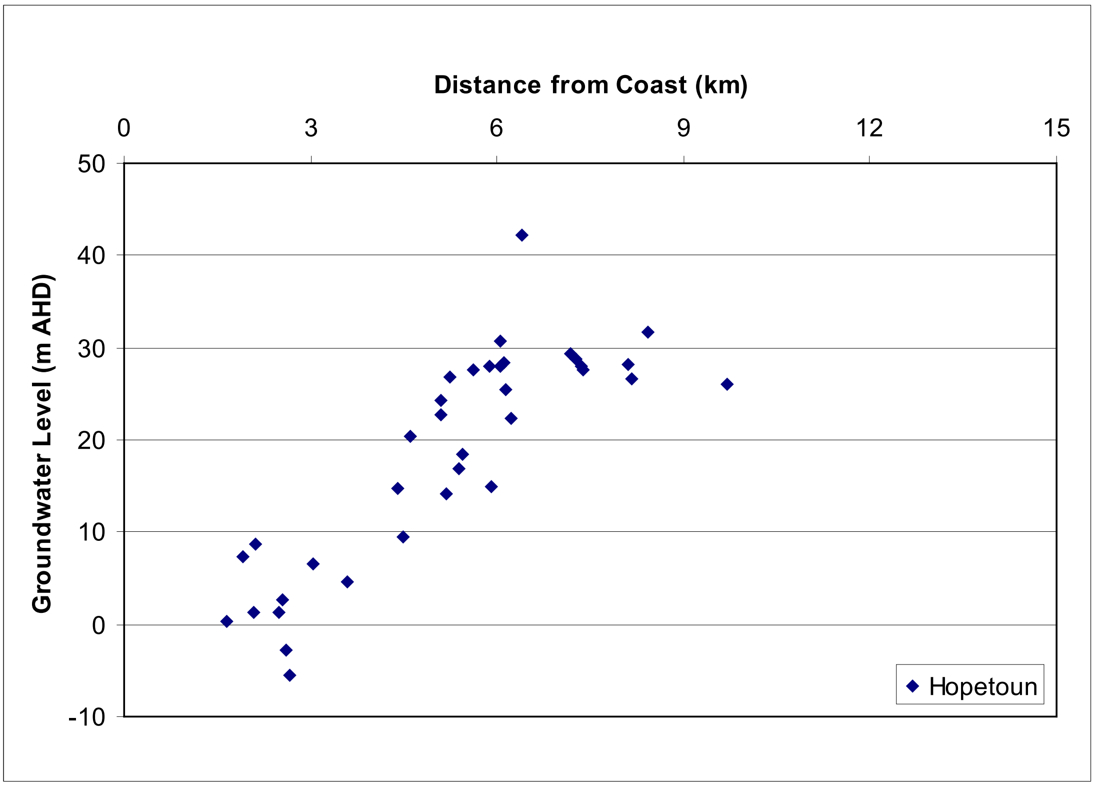

Distance from Coast (km)
0
3
6
9
12
15
50
40
30
20
10
0
-10
-20
-30
-40
Groundwater Level (m AHD)
Gingin



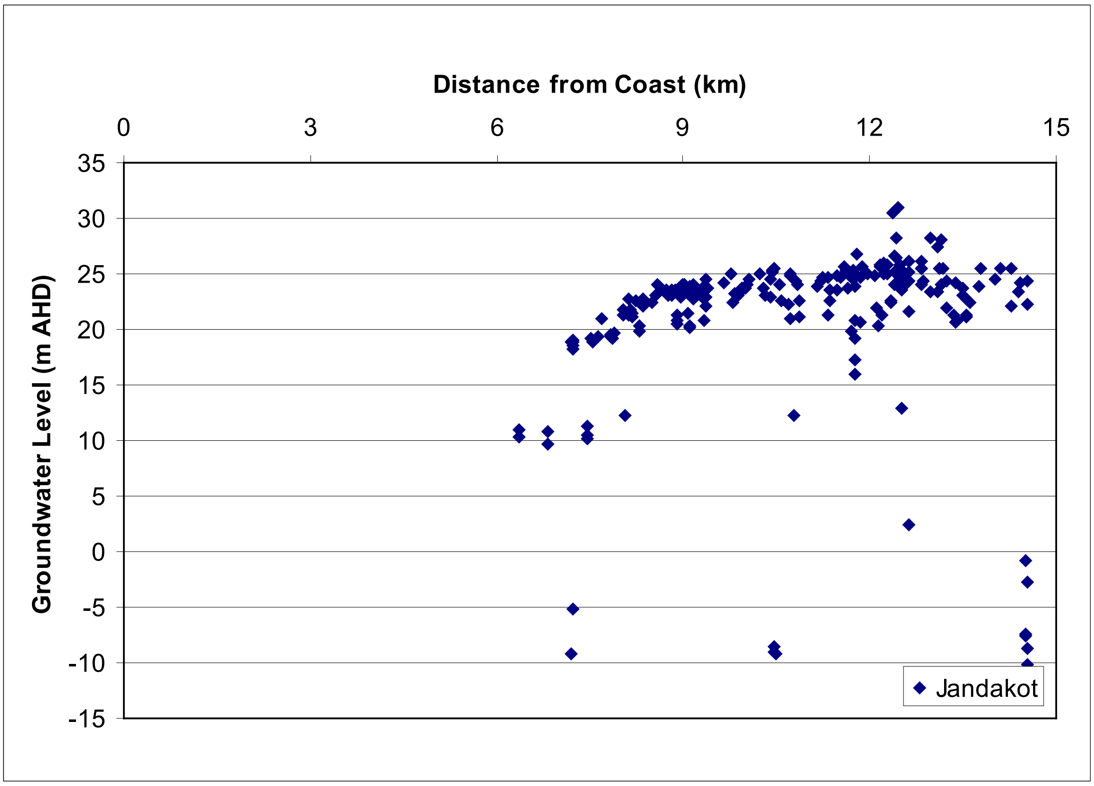
Distance from Coast (km)
0
3
6
9
12
15
70
60
50
40
30
20
10
0
Groundwater Level (m AHD)
Gnangara



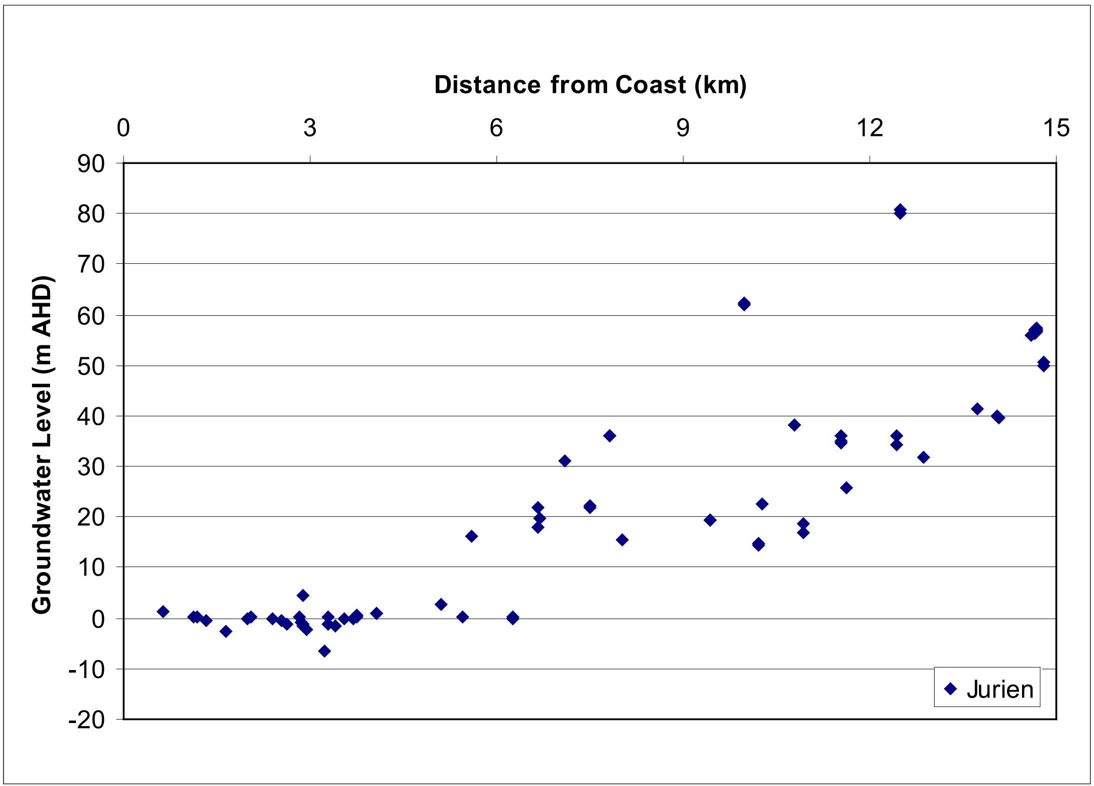
Distance from Coast (km)
0
3
6
9
12
15
20
15
10
5
0
-5
-10
-15
-20
Groundwater Level (m AHD)
Gwelup

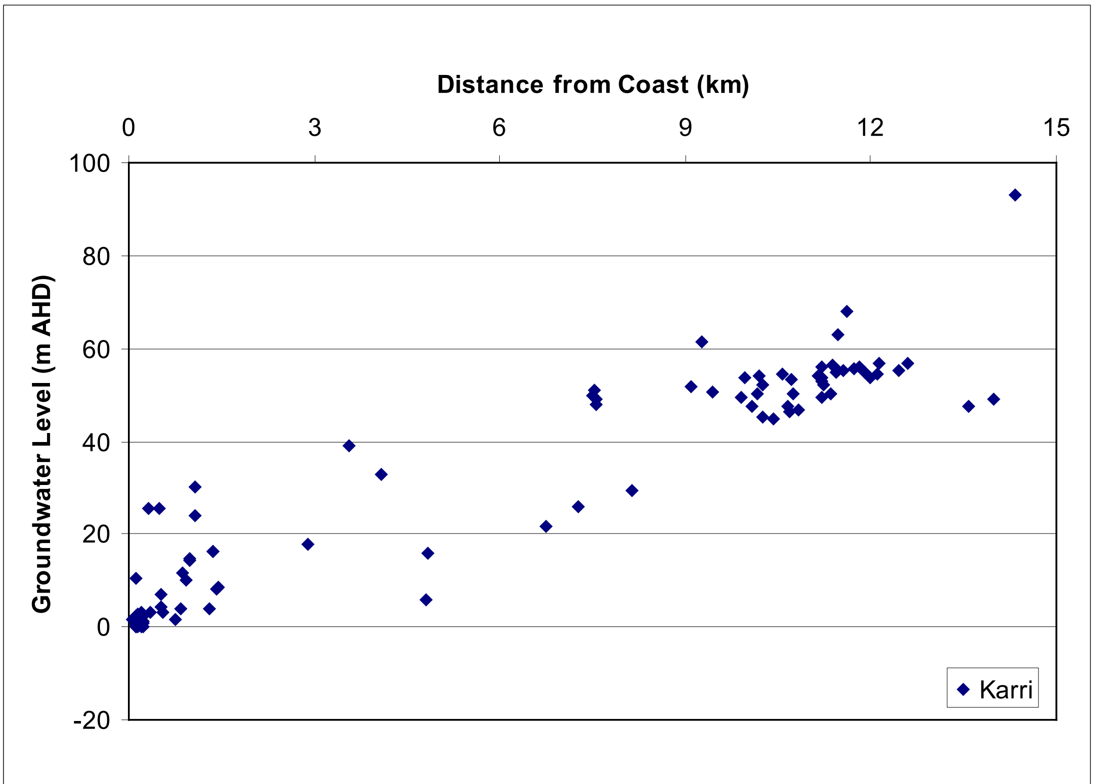


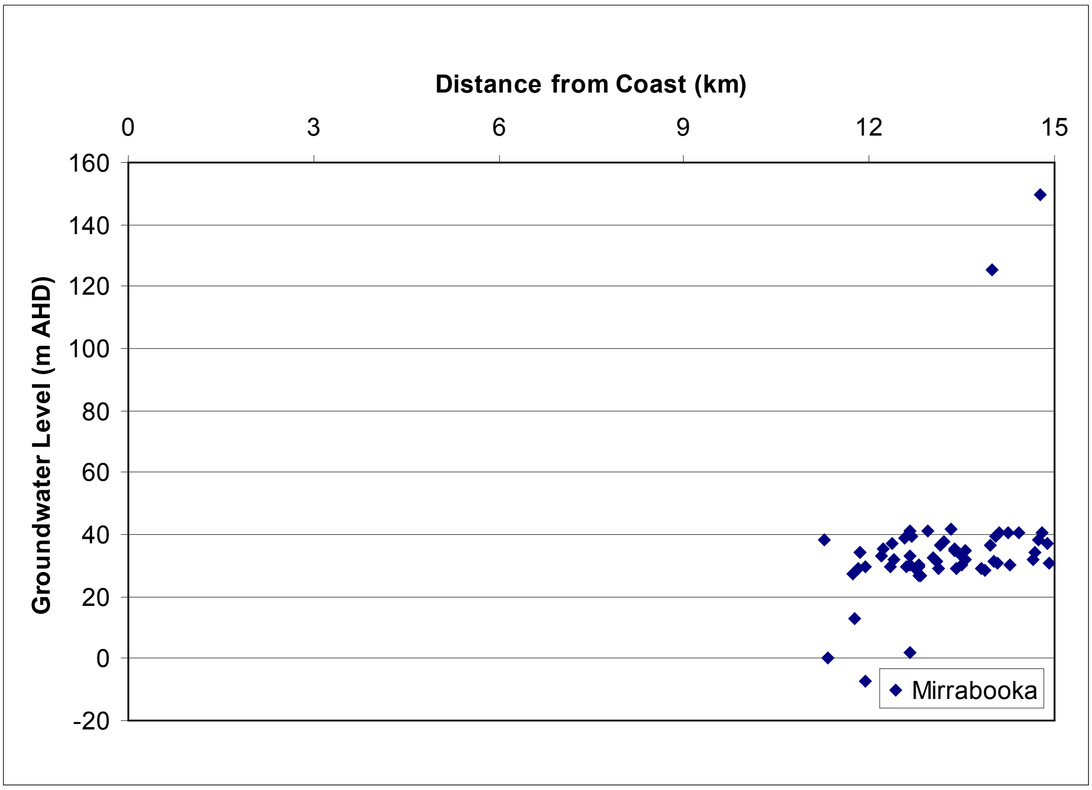
Distance from Coast (km)
0
3
6
9
12
15
50
40
30
20
10
0
-10
Groundwater Level (m AHD)
Hopetoun

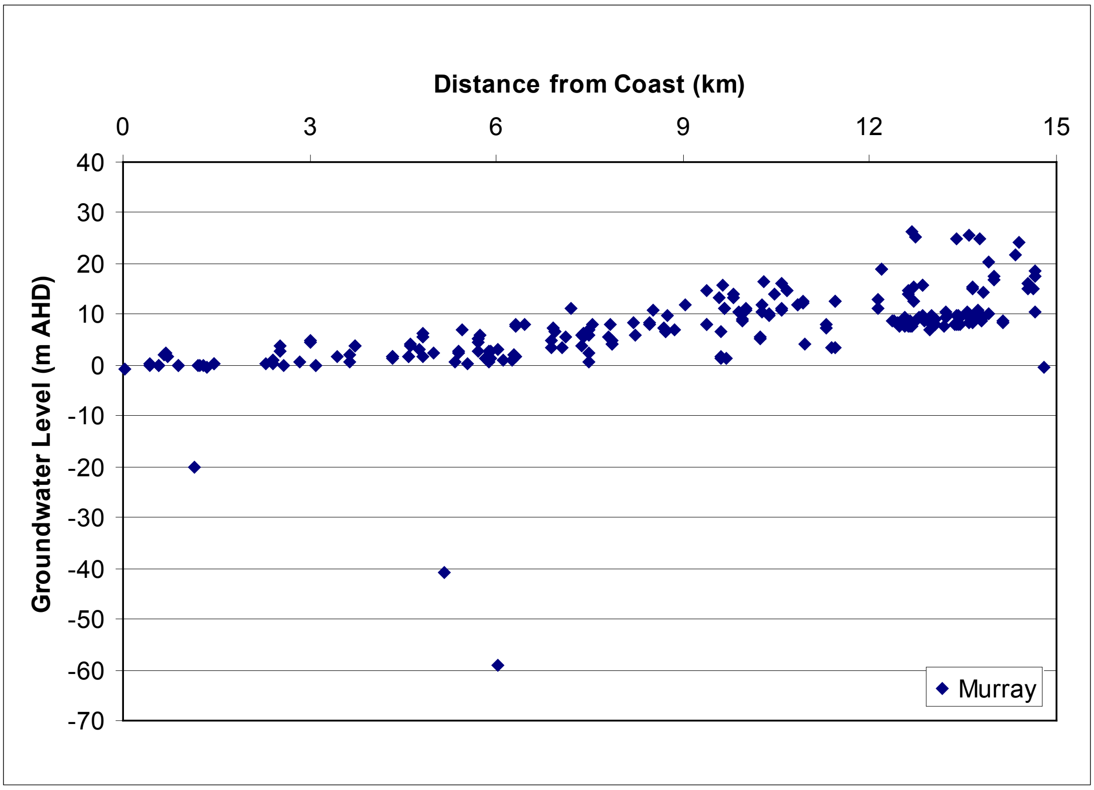


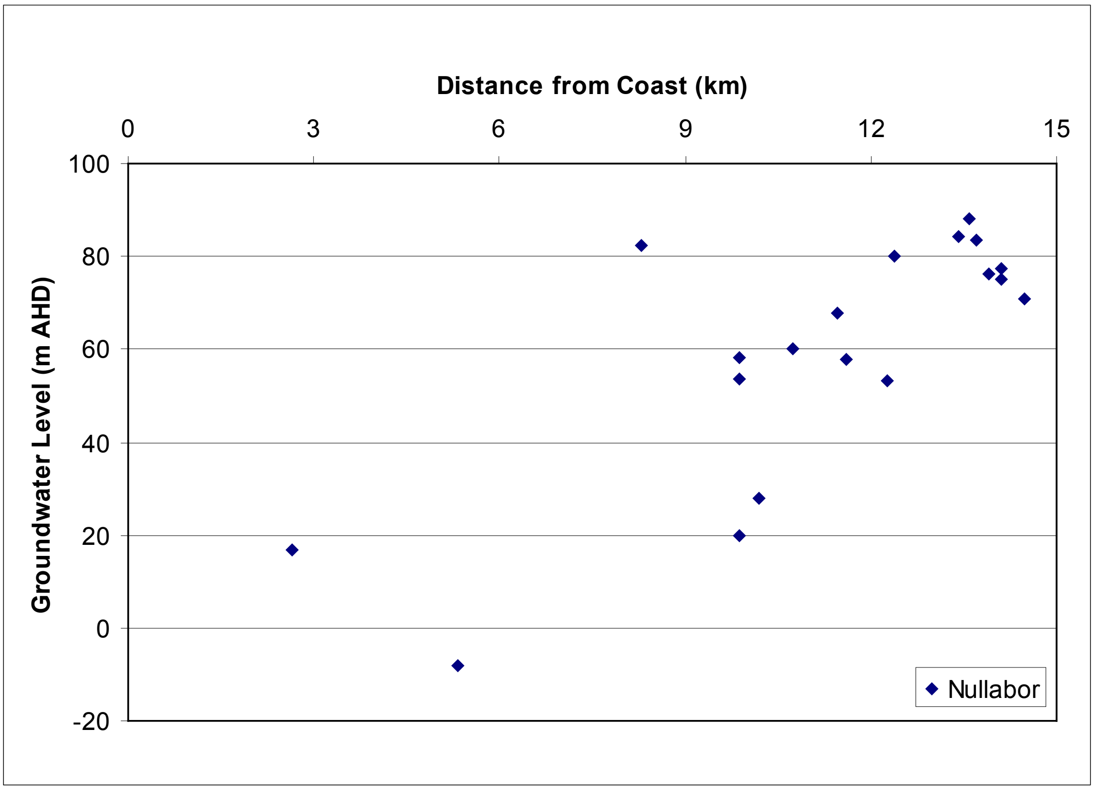
Distance from Coast (km)
0
3
6
9
12
15
35
30
25
20
15
10
5
0
-5
-10
-15
Groundwater Level (m AHD)
Jandakot


Distance from Coast (km)
0
3
6
9
12
15
90
80
70
60
50
40
30
20
10
0
-10
-20
Groundwater Level (m AHD)
Jurien

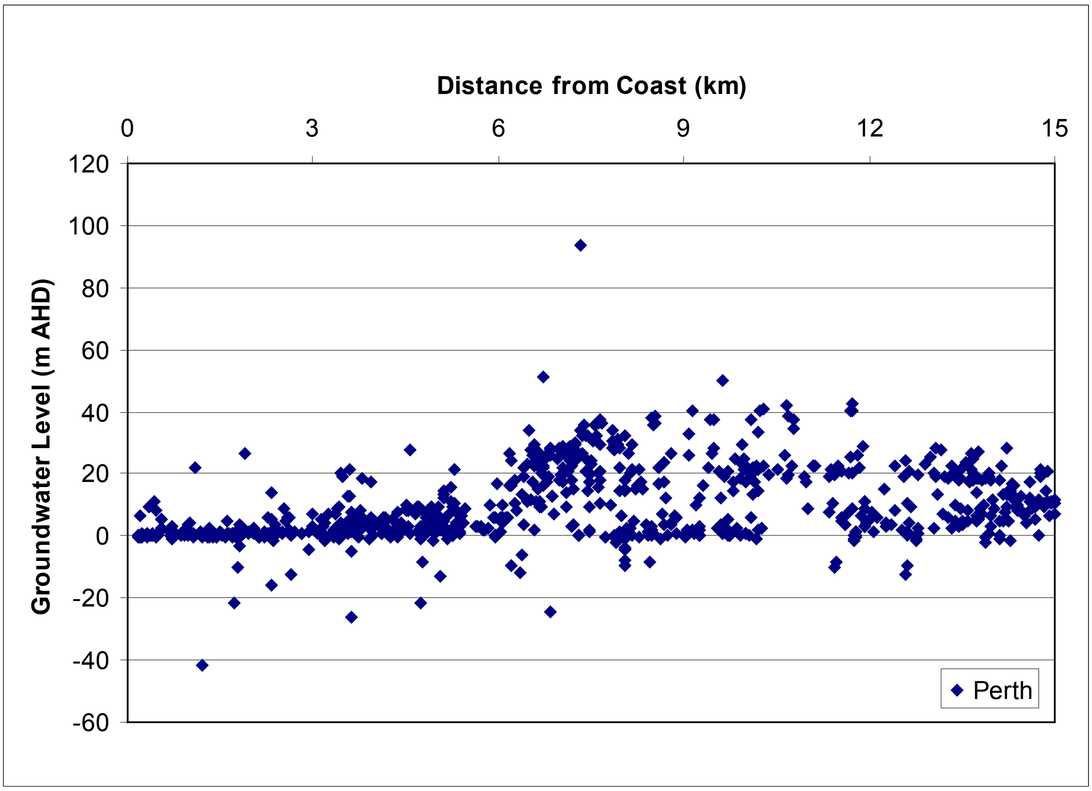

Distance from Coast (km)
0
3
6
9
12
15
100
80
60
40
20
0
-20
Groundwater Level (m AHD)
Karri


Distance from Coast (km)
0
3
6
9
12
15
160
140
120
100
80
60
40
20
0
-20
Groundwater Level (m AHD)
Mirrabooka

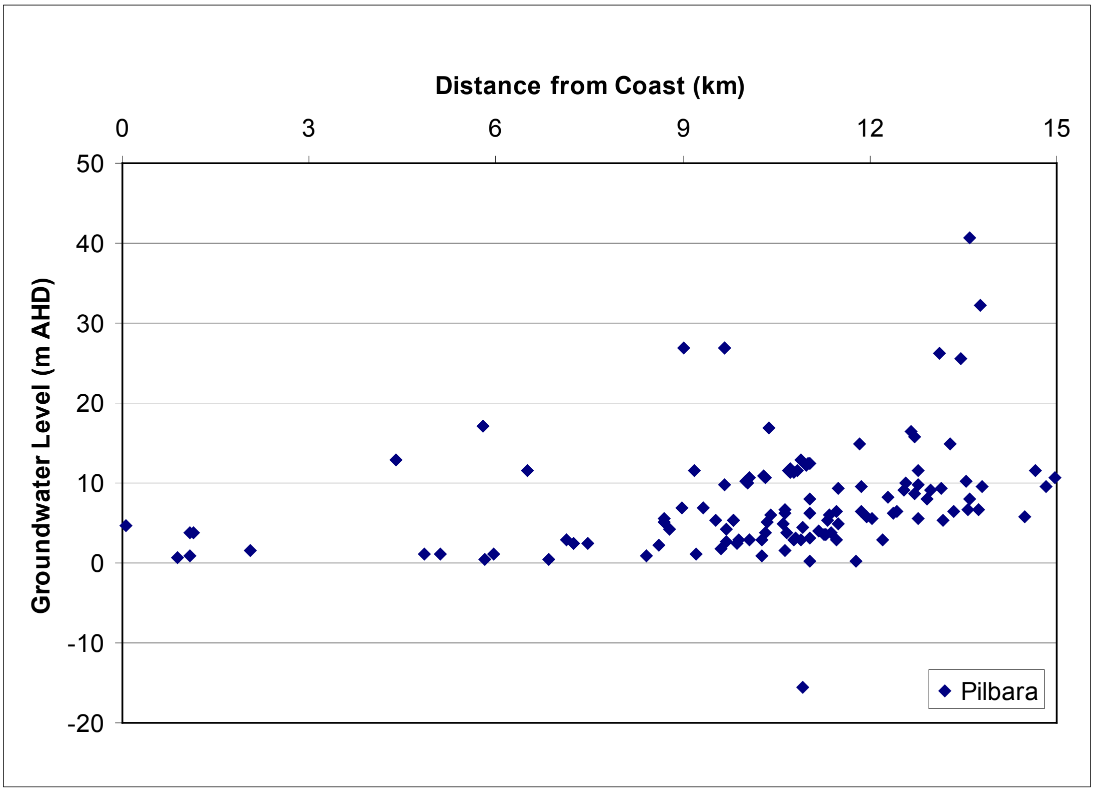

Distance from Coast (km)
0
3
6
9
12
15
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
Groundwater Level (m AHD)
Murray

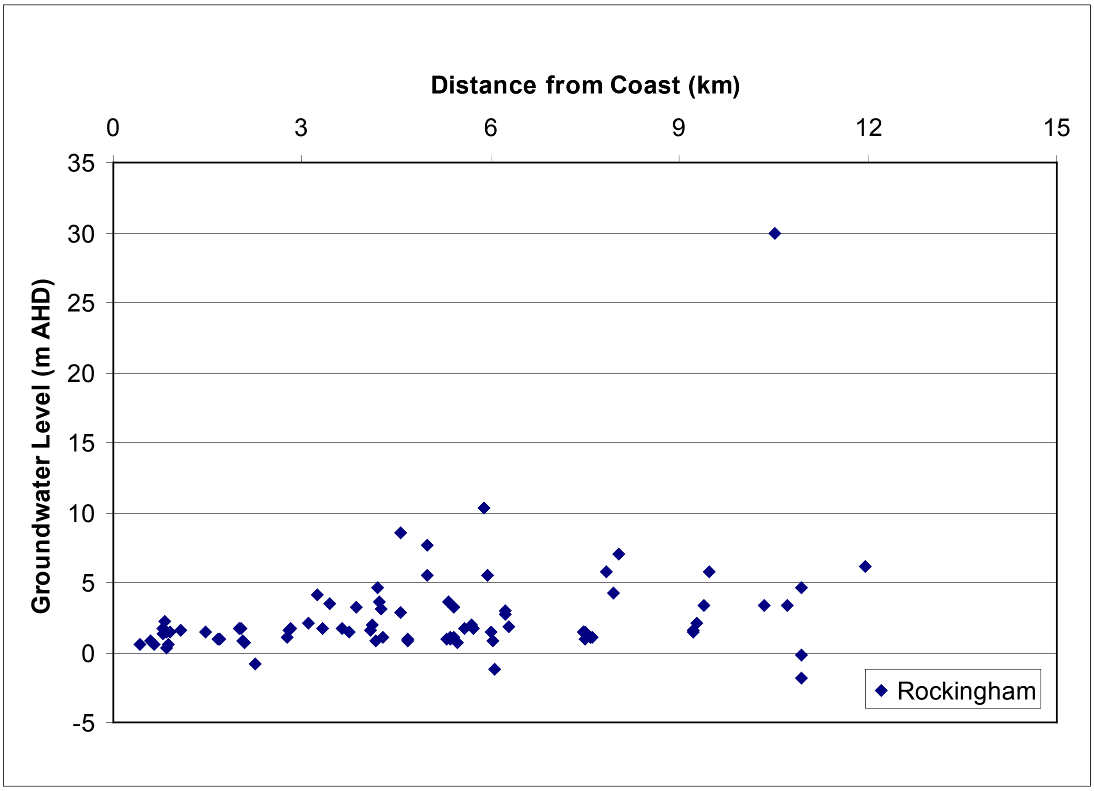


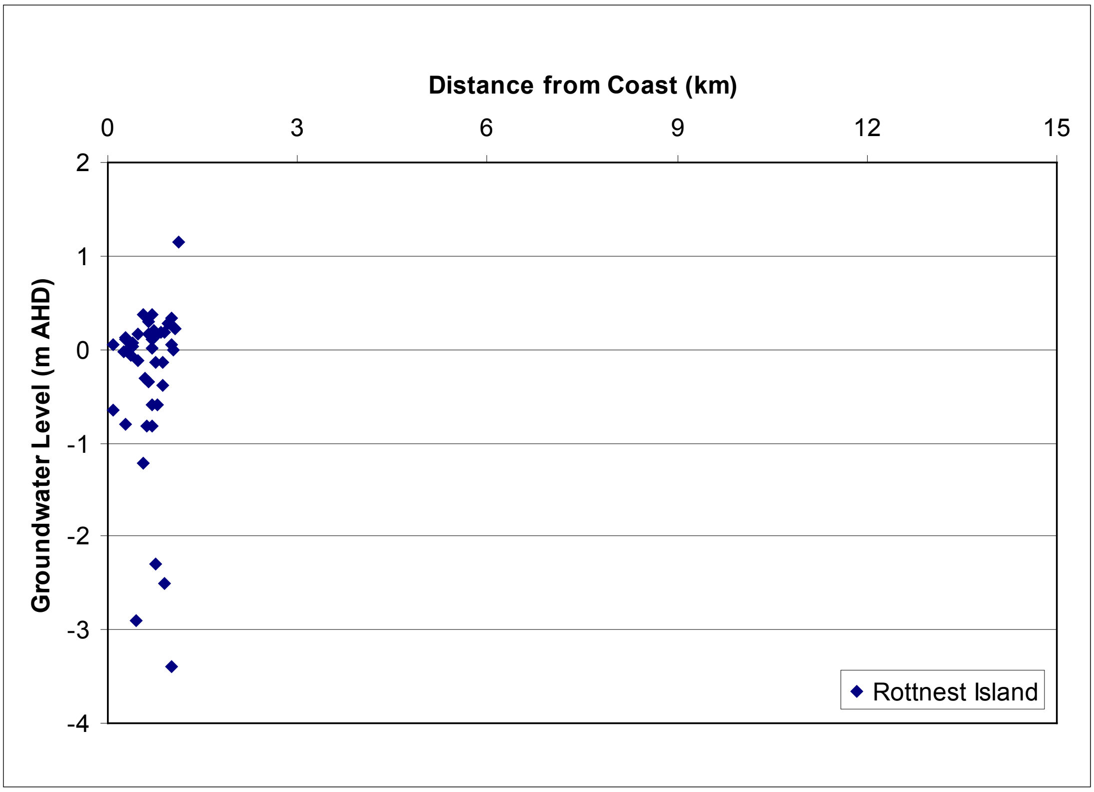
Distance from Coast (km)
0
3
6
9
12
15
100
80
60
40
20
0
-20
Groundwater Level (m AHD)
Nullabor



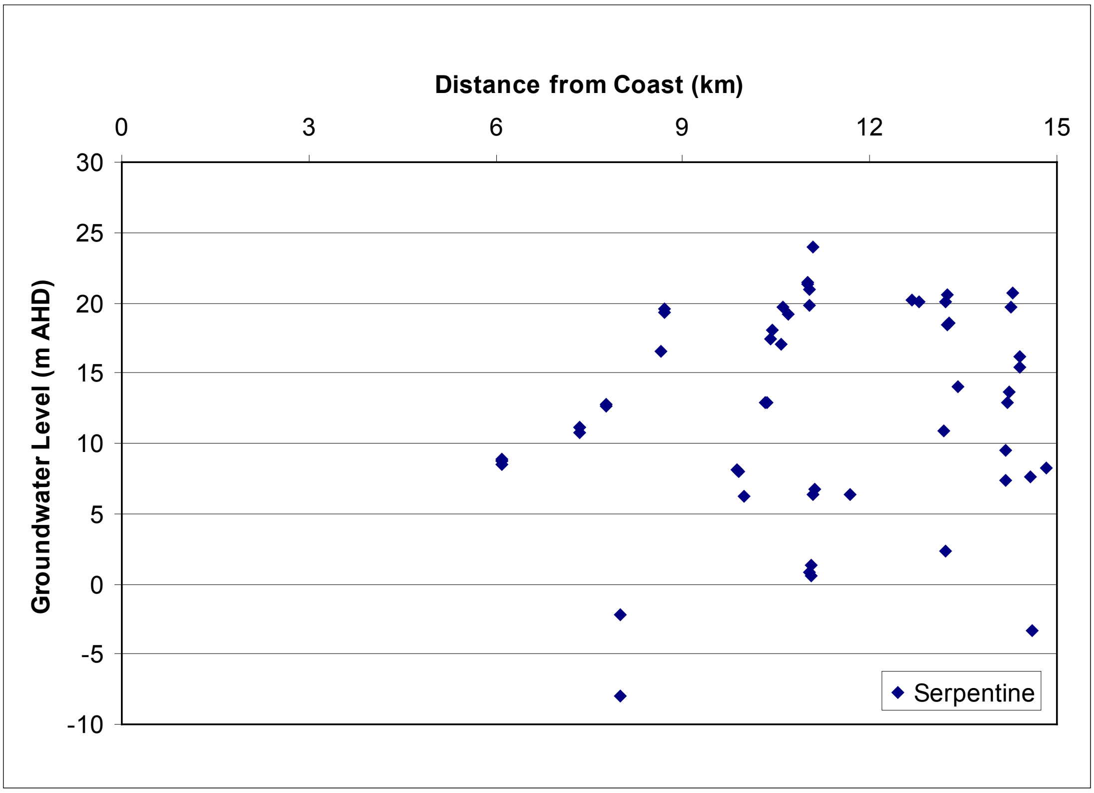
Distance from Coast (km)
0
3
6
9
12
15
120
100
80
60
40
20
0
-20
-40
-60
Groundwater Level (m AHD)
Perth


Distance from Coast (km)
0
3
6
9
12
15
50
40
30
20
10
0
-10
-20
Groundwater Level (m AHD)
Pilbara

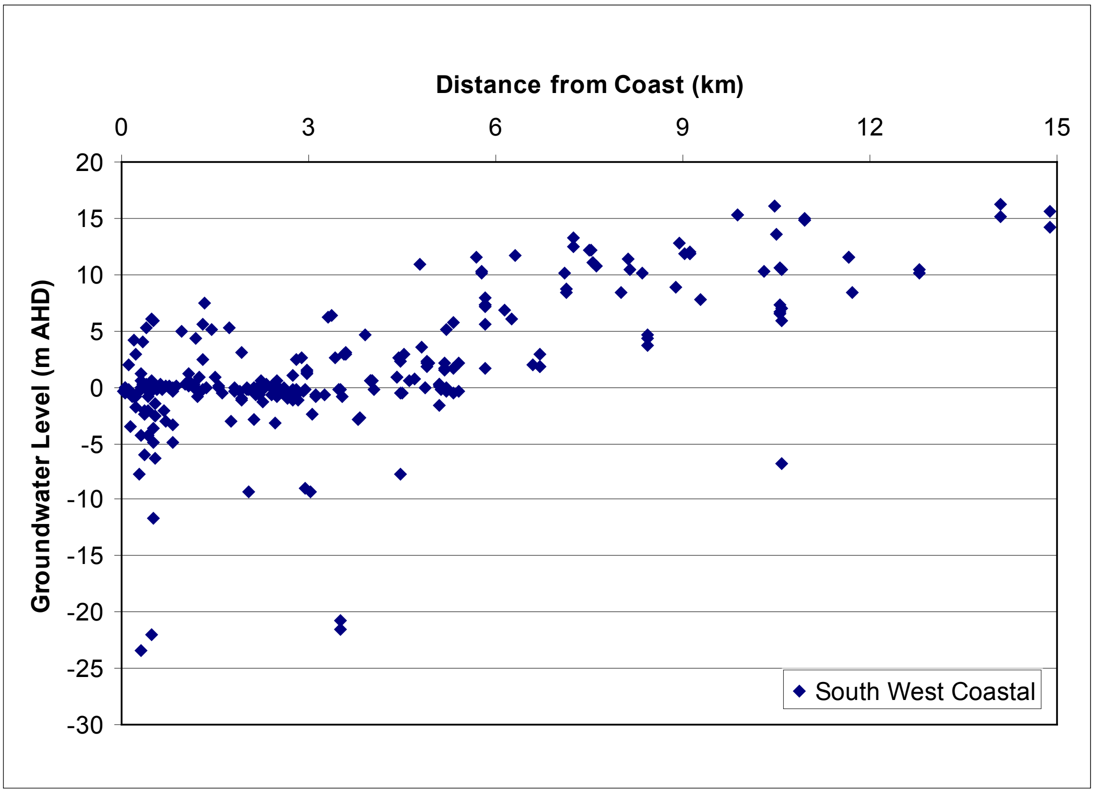

Distance from Coast (km)
0
3
6
9
12
15
35
30
25
20
15
10
5
0
-5
Groundwater Level (m AHD)
Rockingham

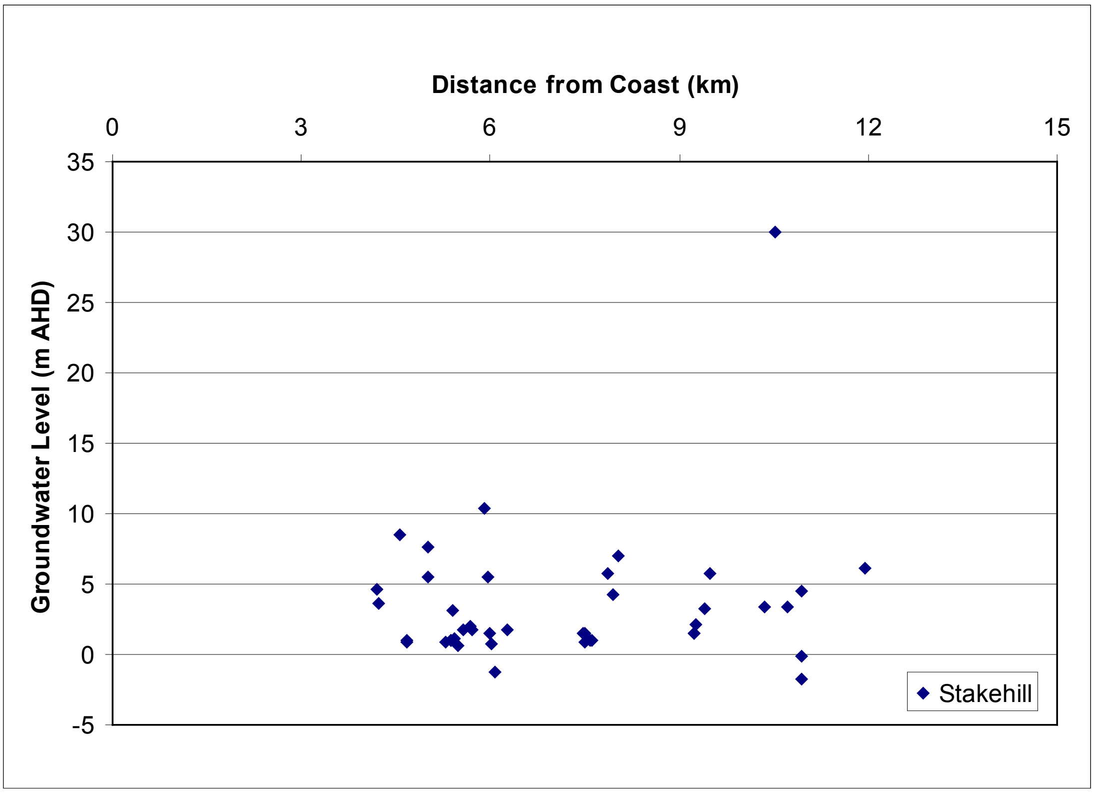


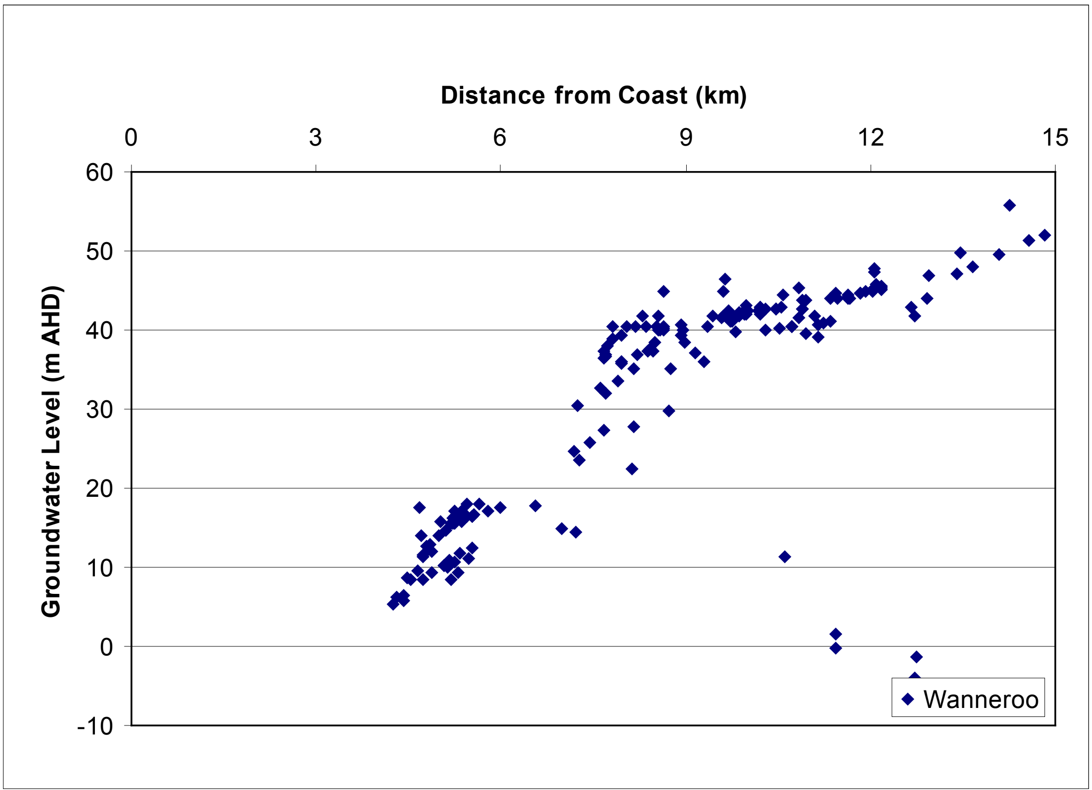
Distance from Coast (km)
0
3
6
9
12
15
2
1
0
-1
-2
-3
-4
Groundwater Level (m AHD)
Rottnest Island

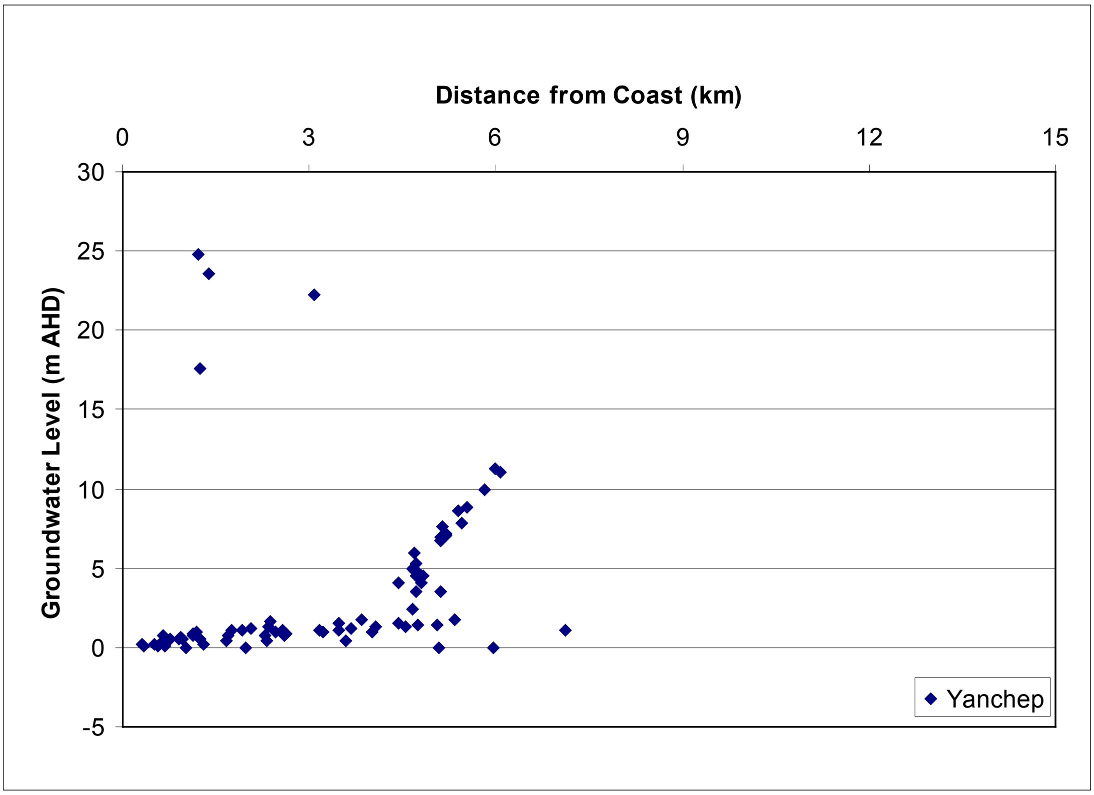


Distance from Coast (km)
0
3
6
9
12
15
30
25
20
15
10
5
0
-5
-10
Groundwater Level (m AHD)
Serpentine

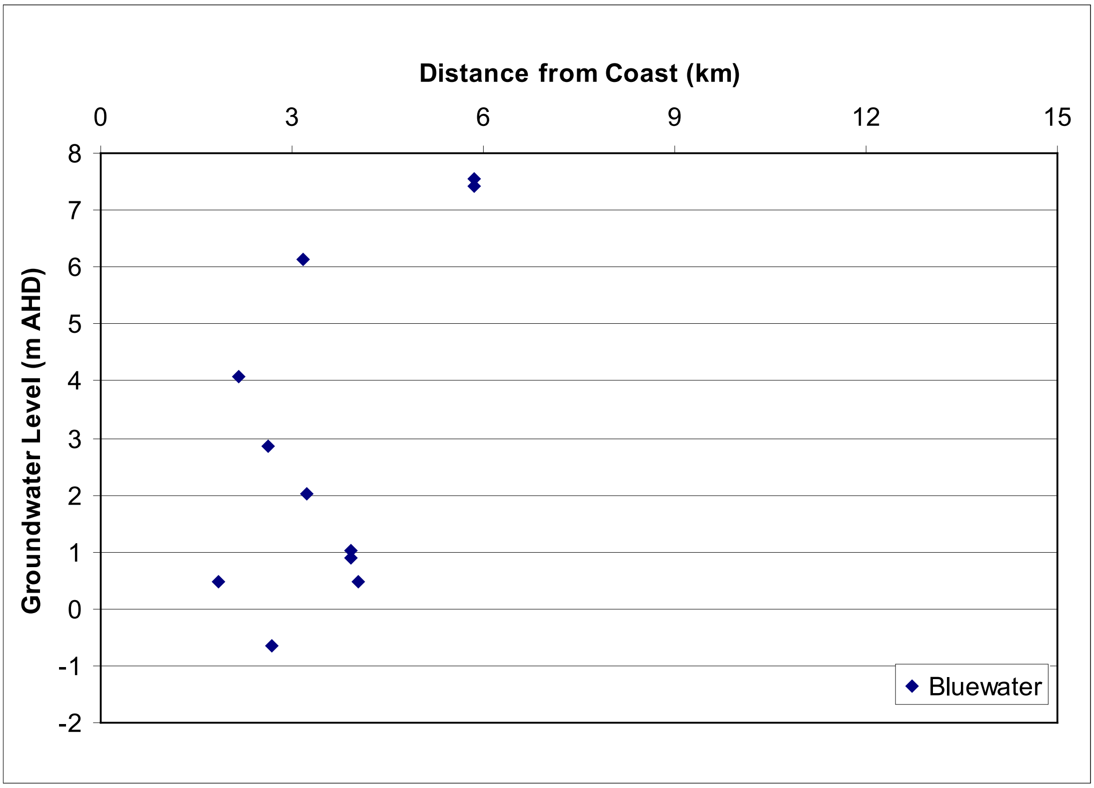

Distance from Coast (km)
0
3
6
9
12
15
20
15
10
5
0
-5
-10
-15
-20
-25
-30
Groundwater Level (m AHD)
South West Coastal

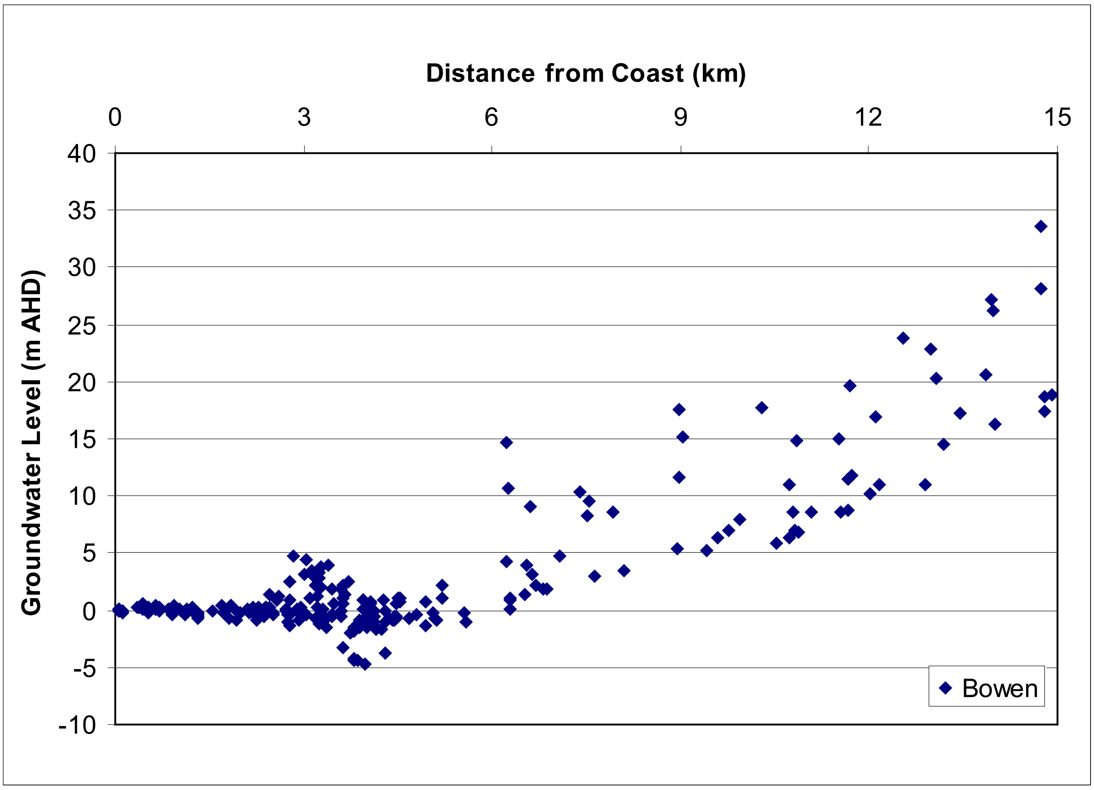

Distance from Coast (km)
0
3
6
9
12
15
35
30
25
20
15
10
5
0
-5
Groundwater Level (m AHD)
Stakehill

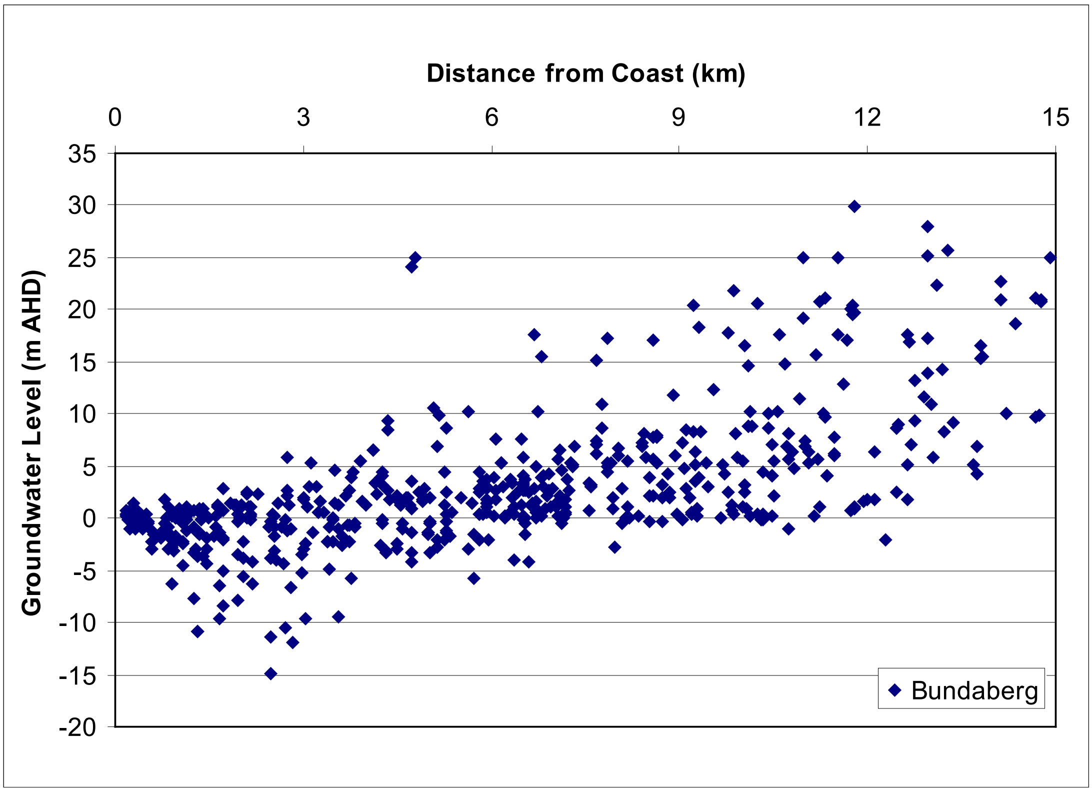

Distance from Coast (km)
0
3
6
9
12
15
60
50
40
30
20
10
0
-10
Groundwater Level (m AHD)
Wanneroo

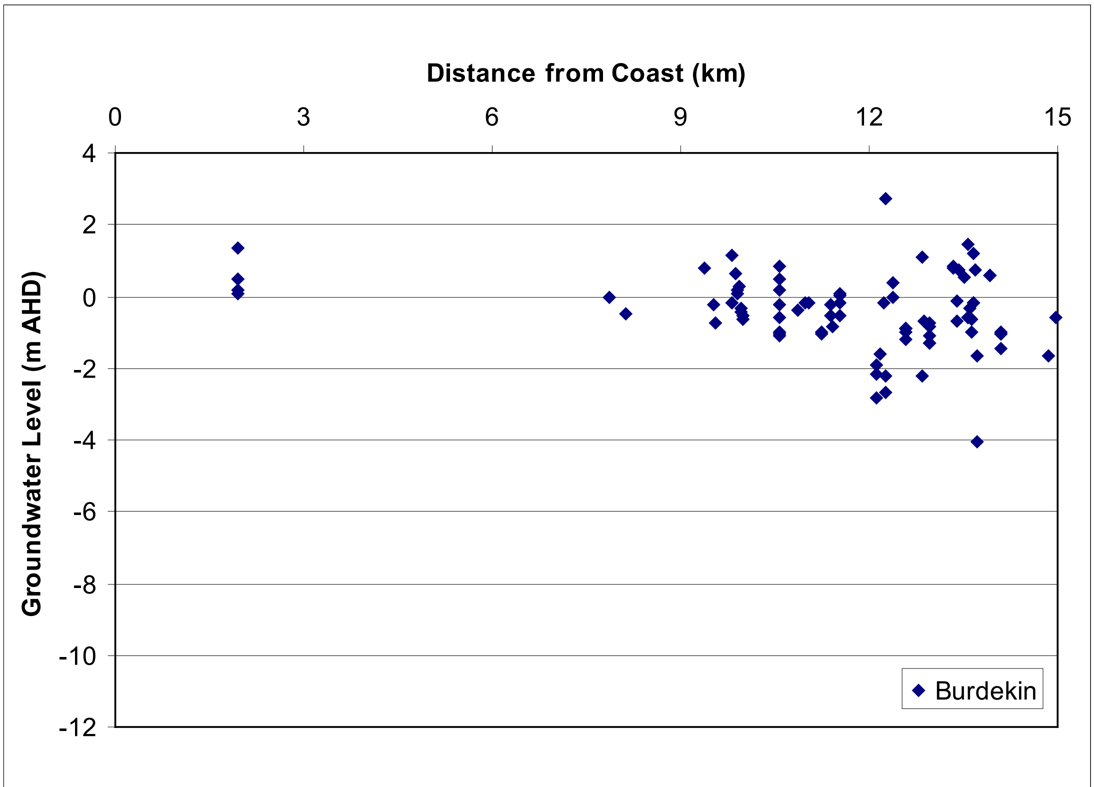

Distance from Coast (km)
0
3
6
9
12
15
30
25
20
15
10
5
0
-5
Groundwater Level (m AHD)
Yanchep

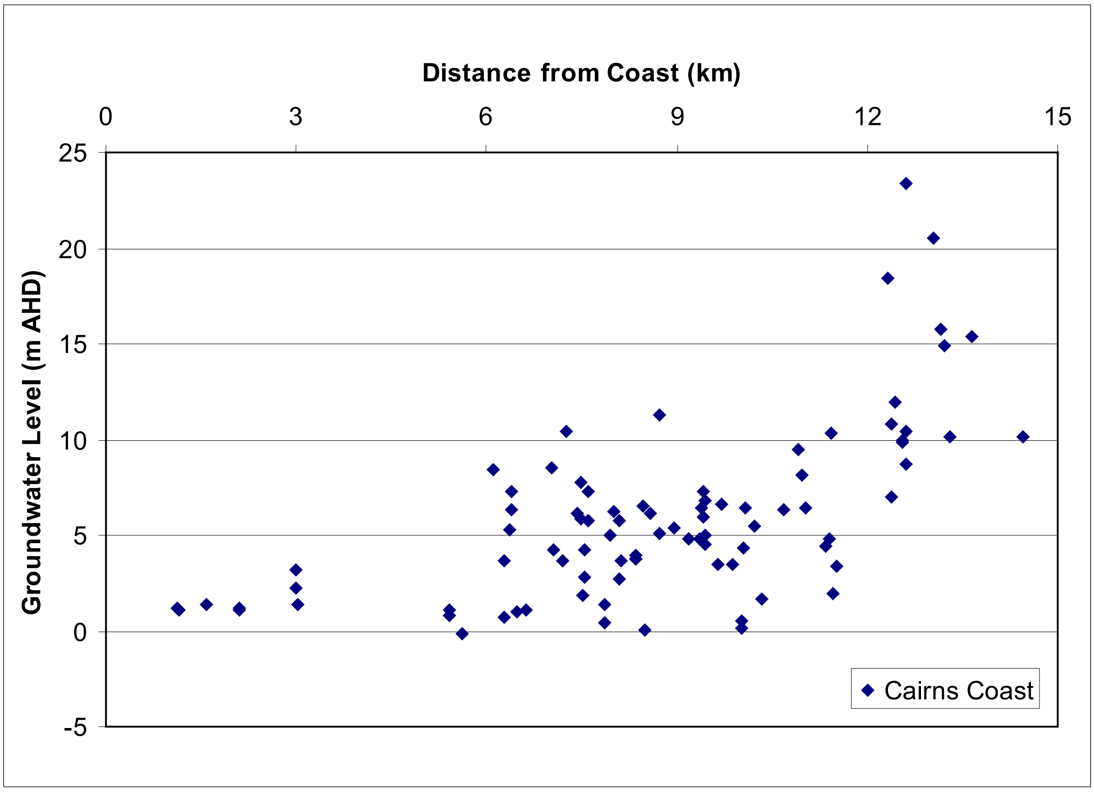
Queensland

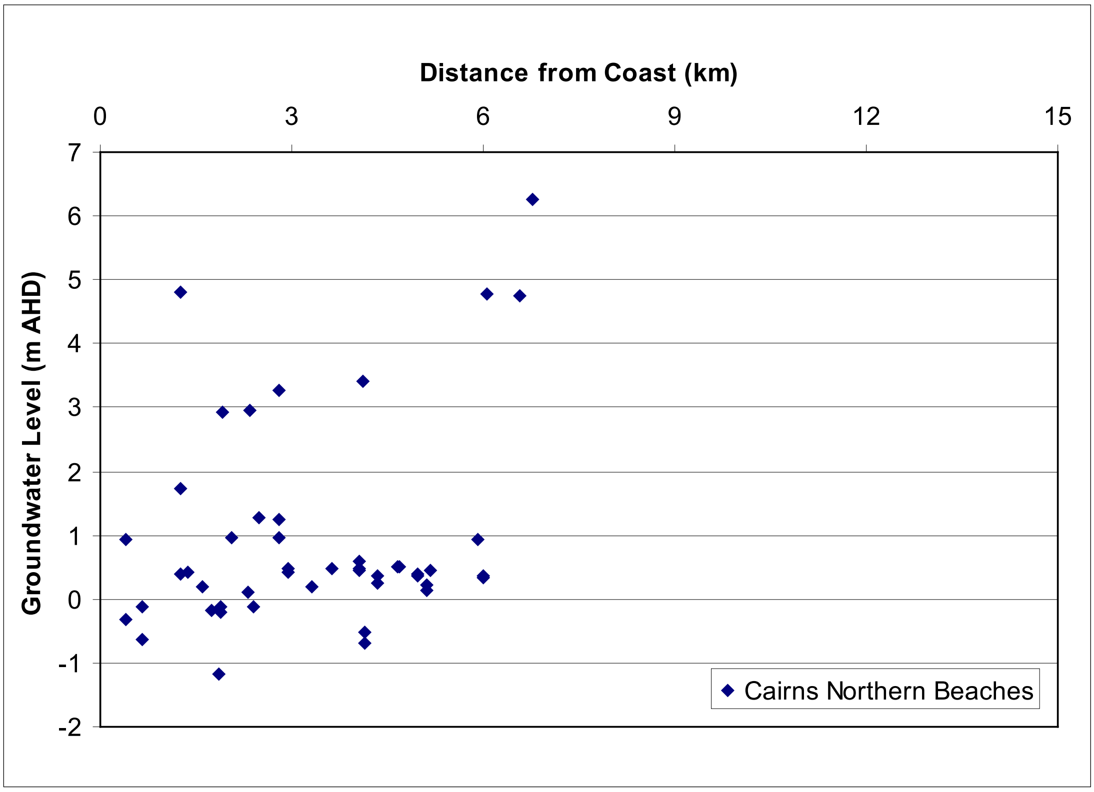

Distance from Coast (km)
0
3
6
9
12
15
8
7
6
5
4
3
2
1
0
-1
-2
Groundwater Level (m AHD)
Bluewater

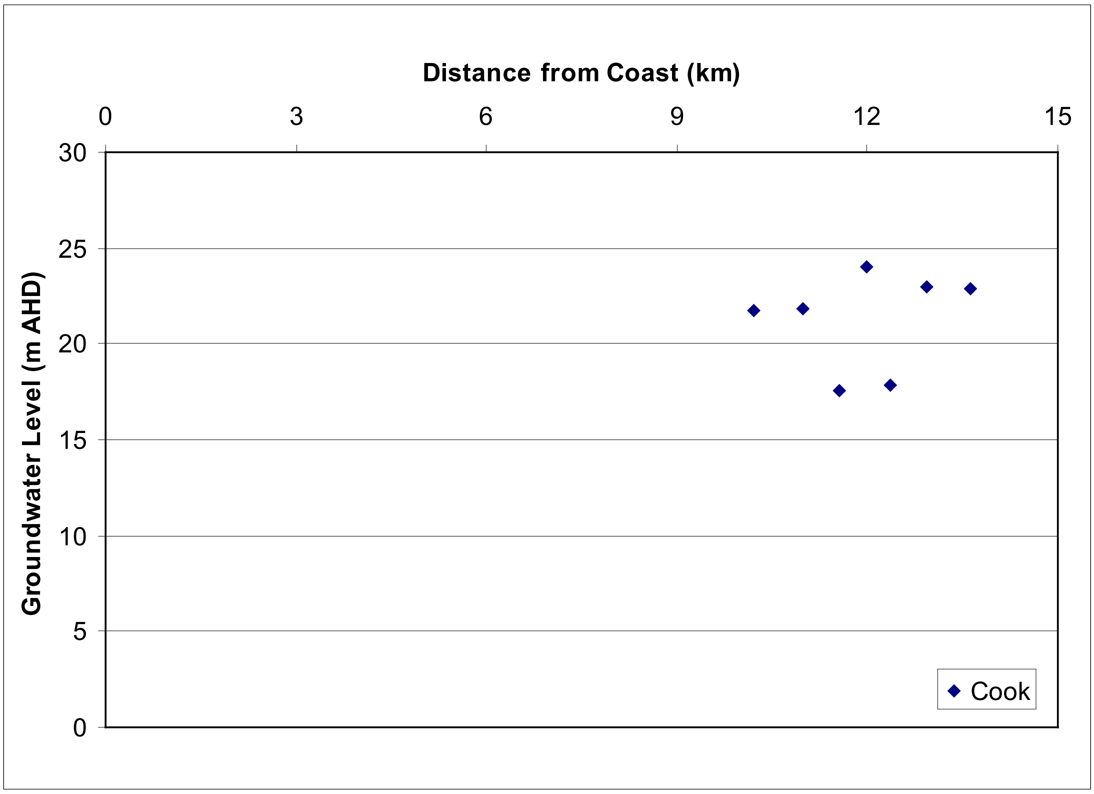

Distance from Coast (km)
0
3
6
9
12
15
40
35
30
25
20
15
10
5
0
-5
-10
Groundwater Level (m AHD)
Bowen

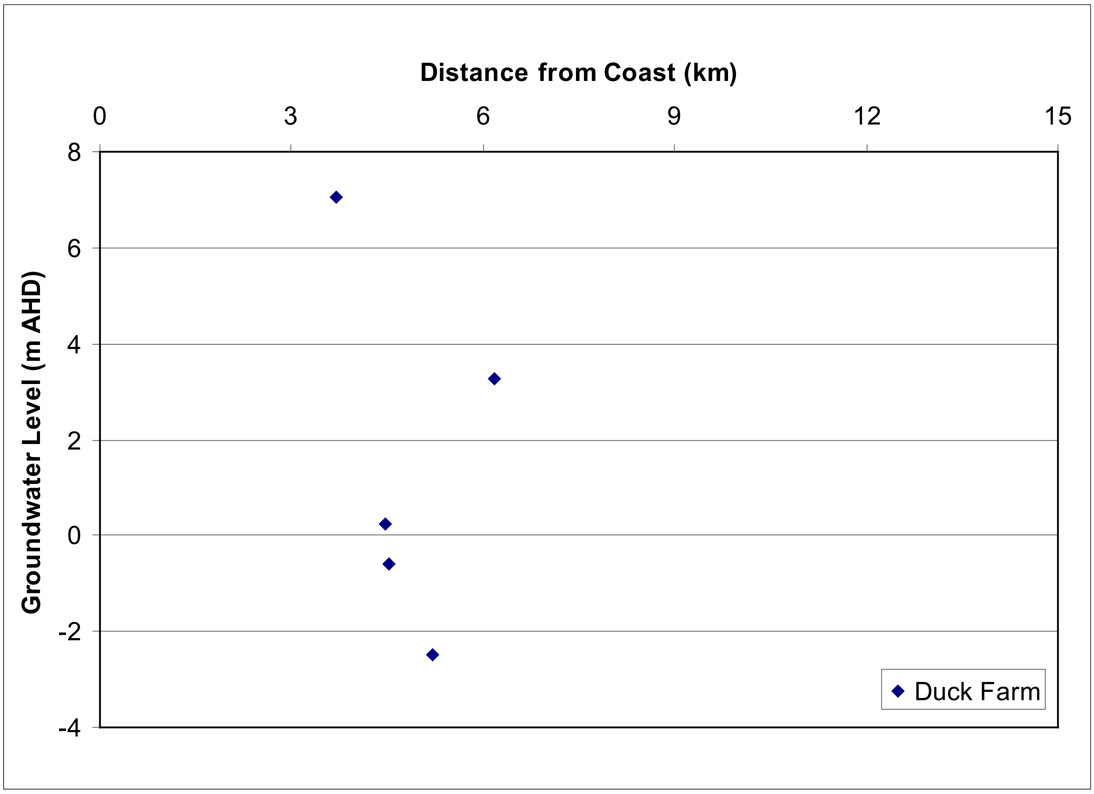

Distance from Coast (km)
0
3
6
9
12
15
35
30
25
20
15
10
5
0
-5
-10
-15
-20
Groundwater Level (m AHD)
Bundaberg

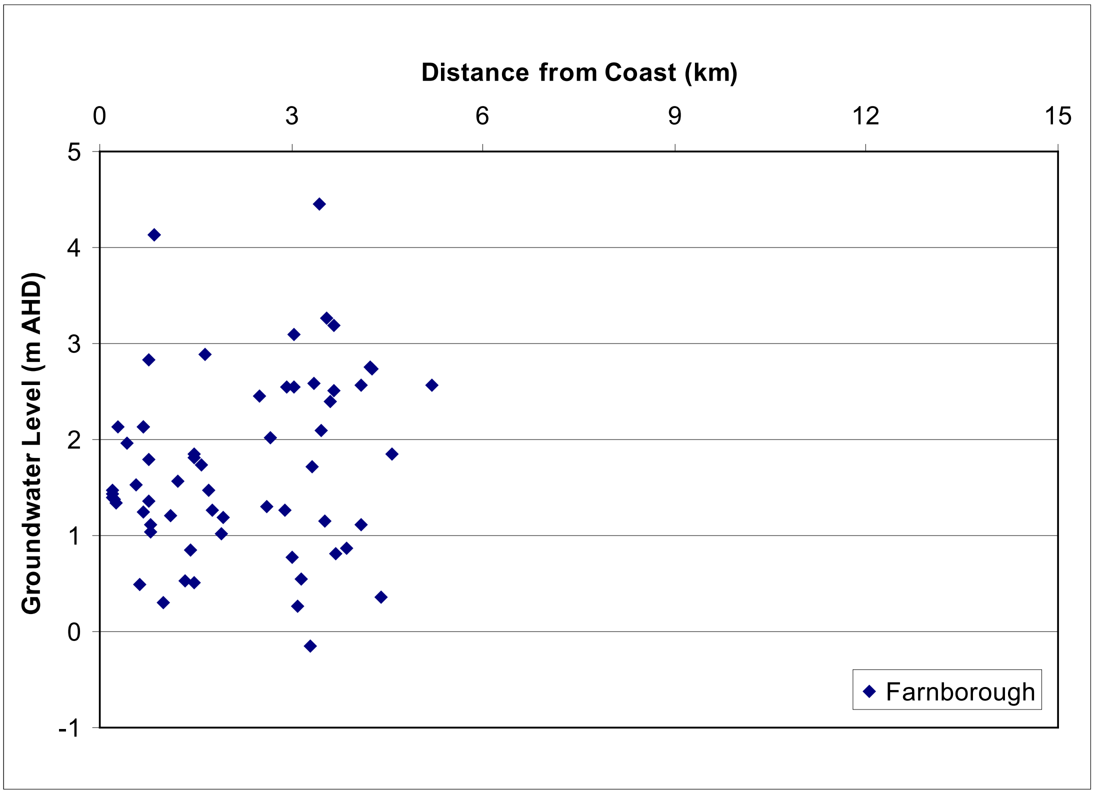

Distance from Coast (km)
0
3
6
9
12
15
4
2
0
-2
-4
-6
-8
-10
-12
Groundwater Level (m AHD)
Burdekin

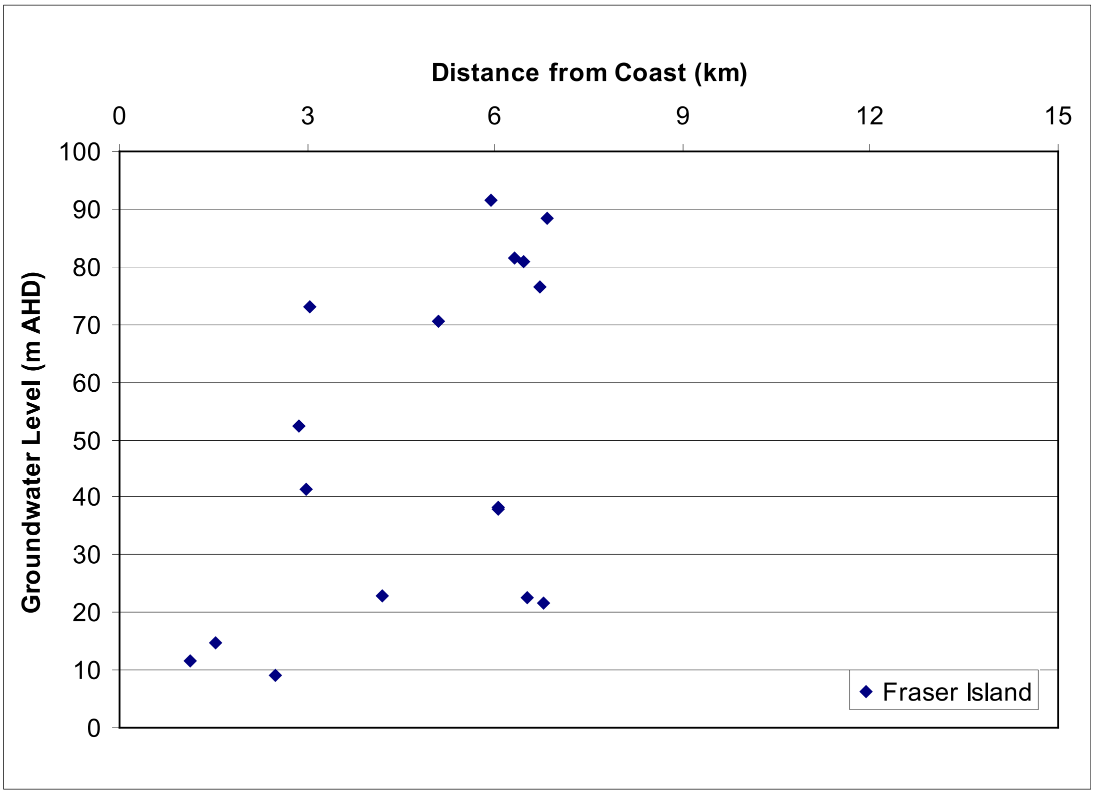

Distance from Coast (km)
0
3
6
9
12
15
25
20
15
10
5
0
-5
Groundwater Level (m AHD)
Cairns Coast

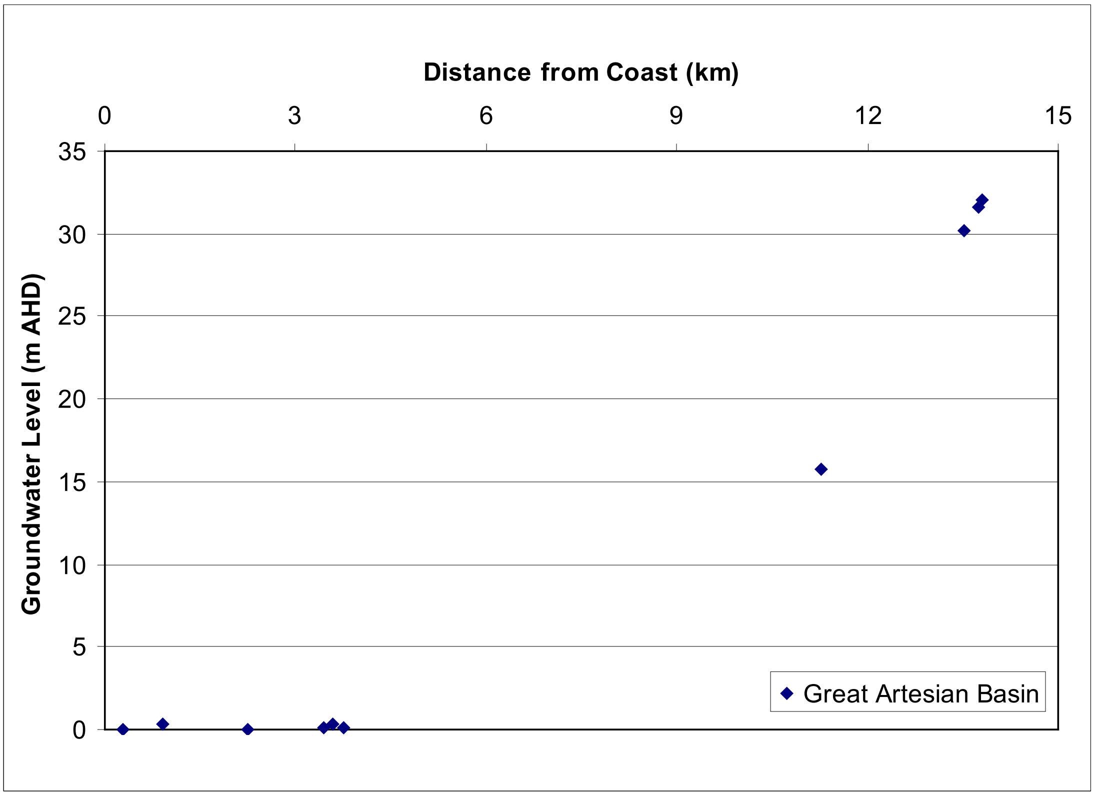

Distance from Coast (km)
0
3
6
9
12
15
7
6
5
4
3
2
1
0
-1
-2
Groundwater Level (m AHD)
Cairns Northern Beaches

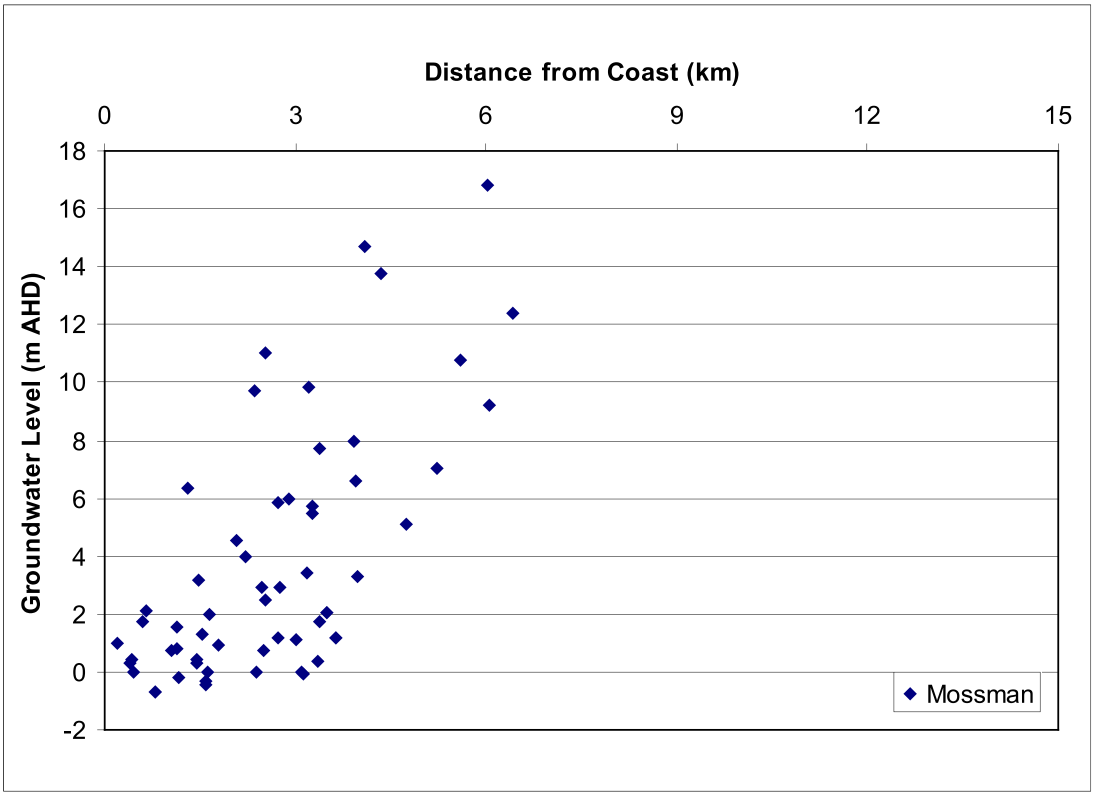

Distance from Coast (km)
0
3
6
9
12
15
30
25
20
15
10
5
0
Groundwater Level (m AHD)
Cook

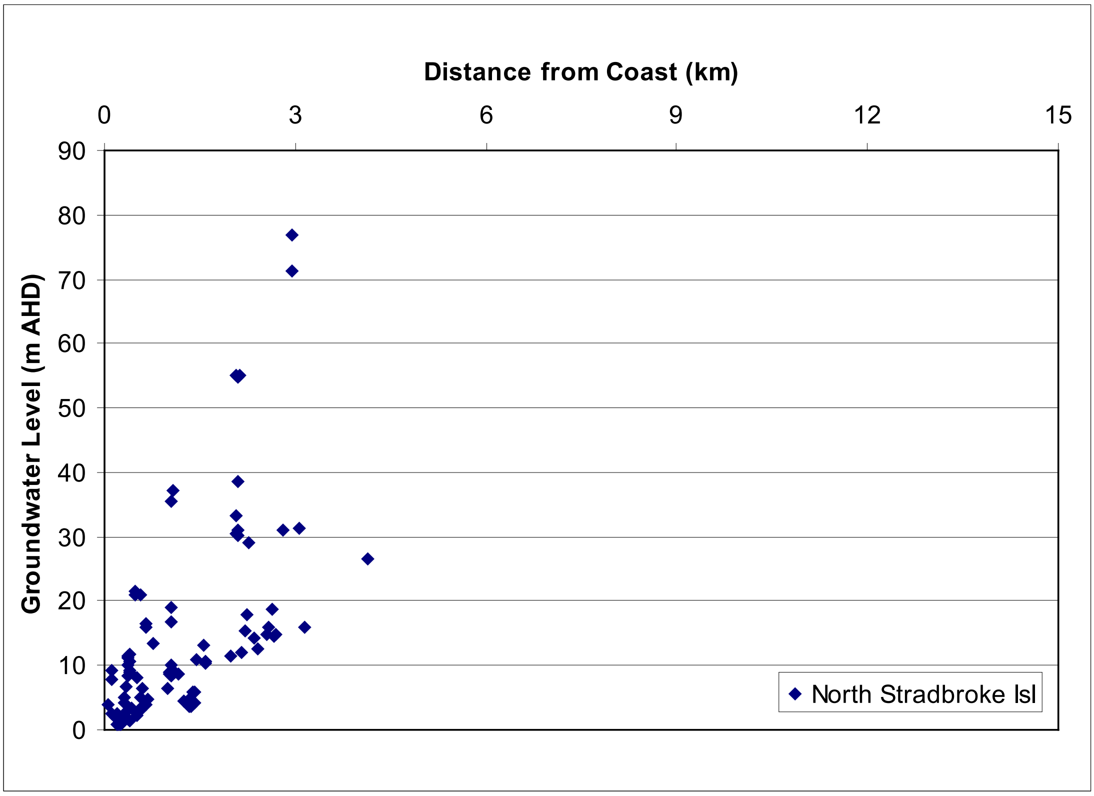

Distance from Coast (km)
0
3
6
9
12
15
8
6
4
2
0
-2
-4
Groundwater Level (m AHD)
Duck Farm

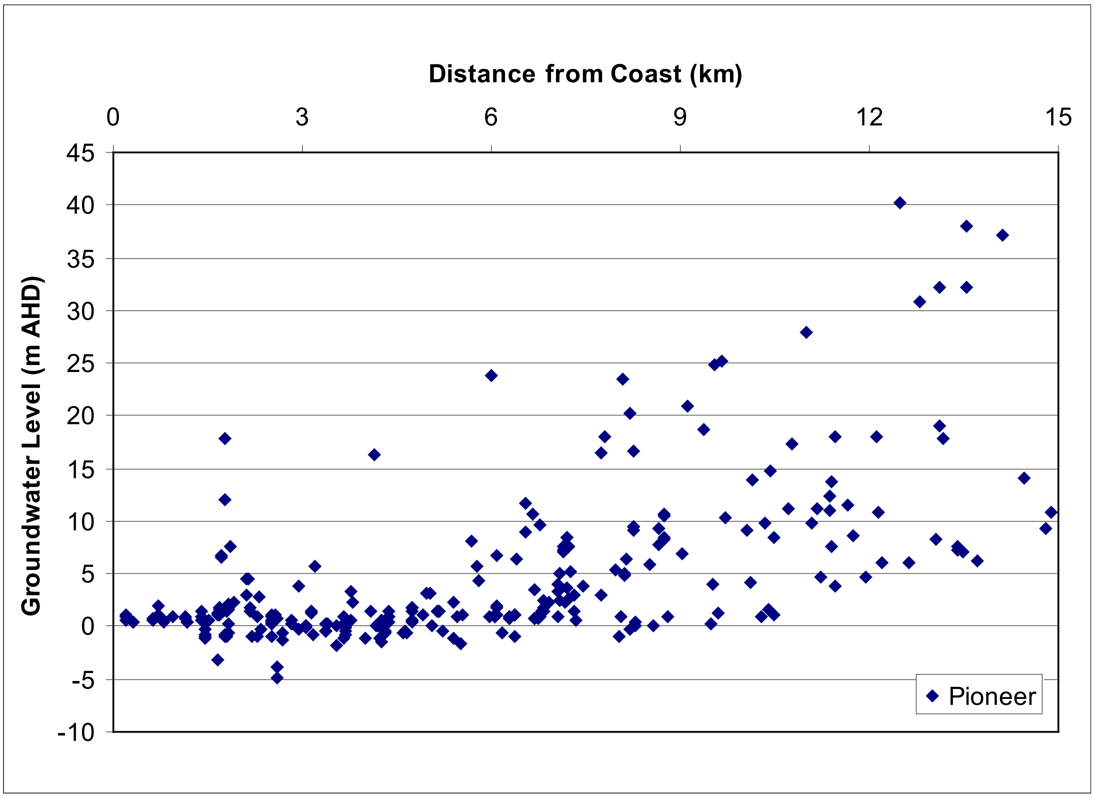

Distance from Coast (km)
0
3
6
9
12
15
5
4
3
2
1
0
-1
Groundwater Level (m AHD)
Farnborough


Distance from Coast (km)
0
3
6
9
12
15
100
90
80
70
60
50
40
30
20
10
0
Groundwater Level (m AHD)
Fraser Island


Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
35
30
25
20
15
10
5
0
Great Artesian Basin


Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
18
16
14
12
10
8
6
4
2
0
-2
Mossman


Distance from Coast (km)
0
3
6
9
12
15
90
80
70
60
50
40
30
20
10
0
Groundwater Level (m AHD)
North Stradbroke Isl


Distance from Coast (km)
0
3
6
9
12
15
45
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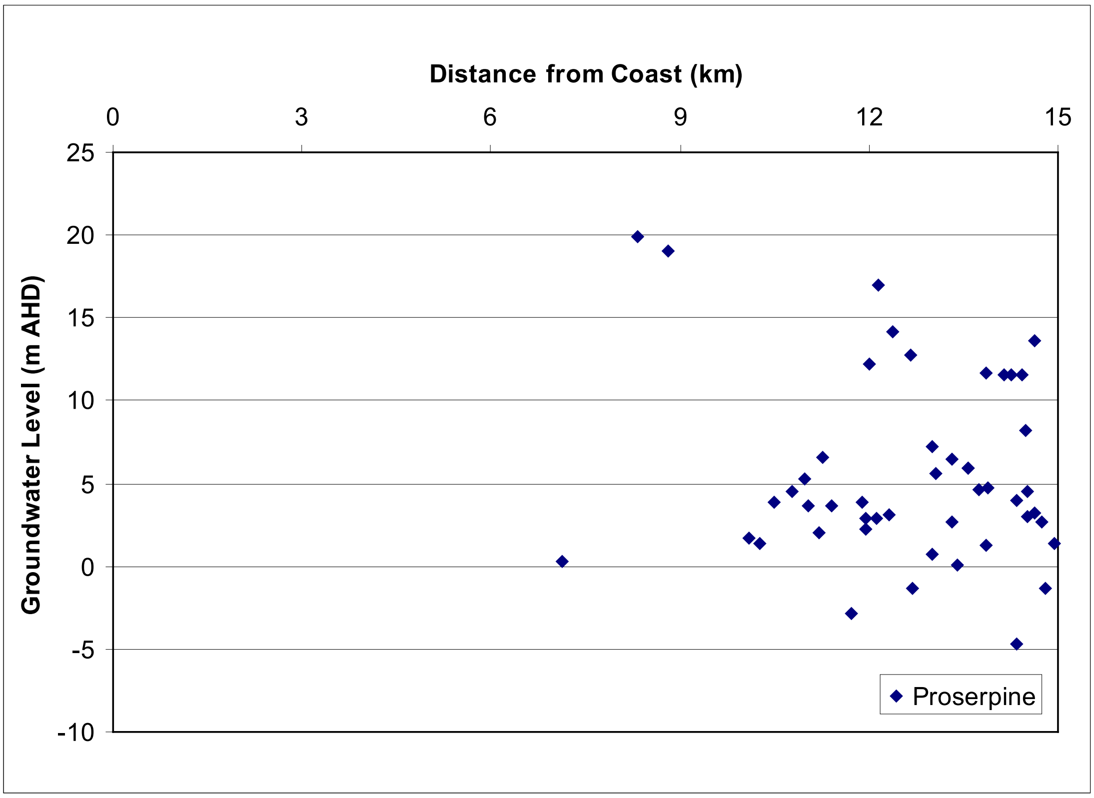
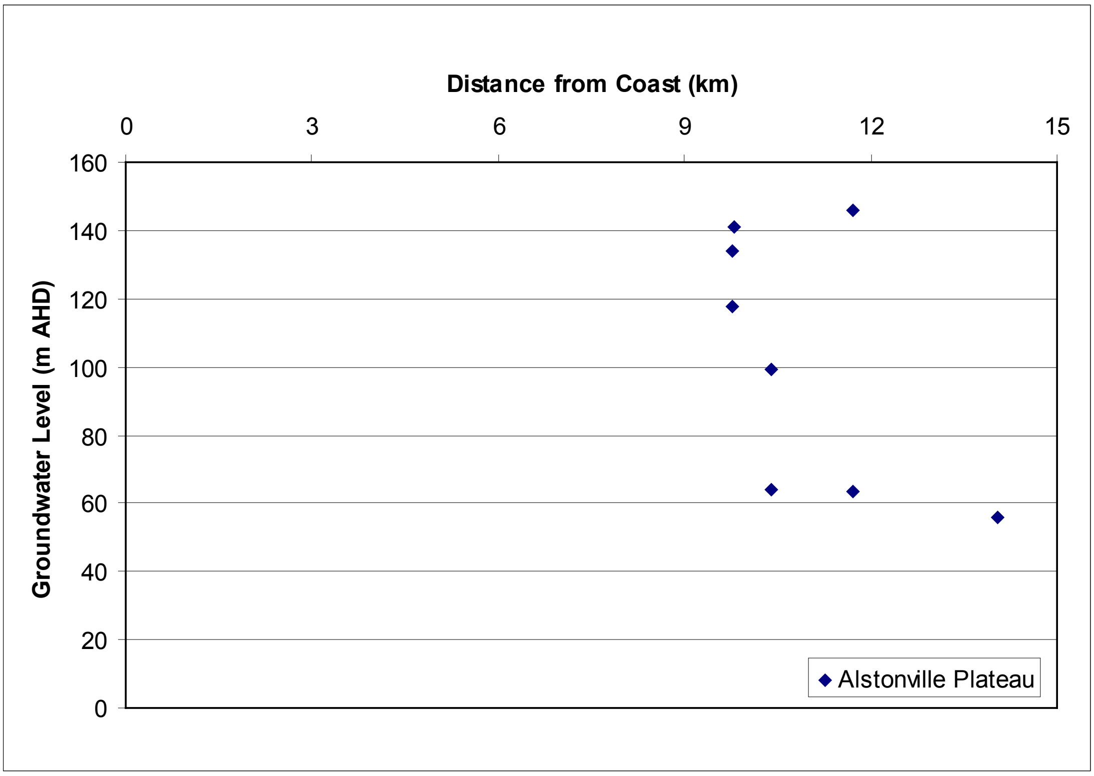
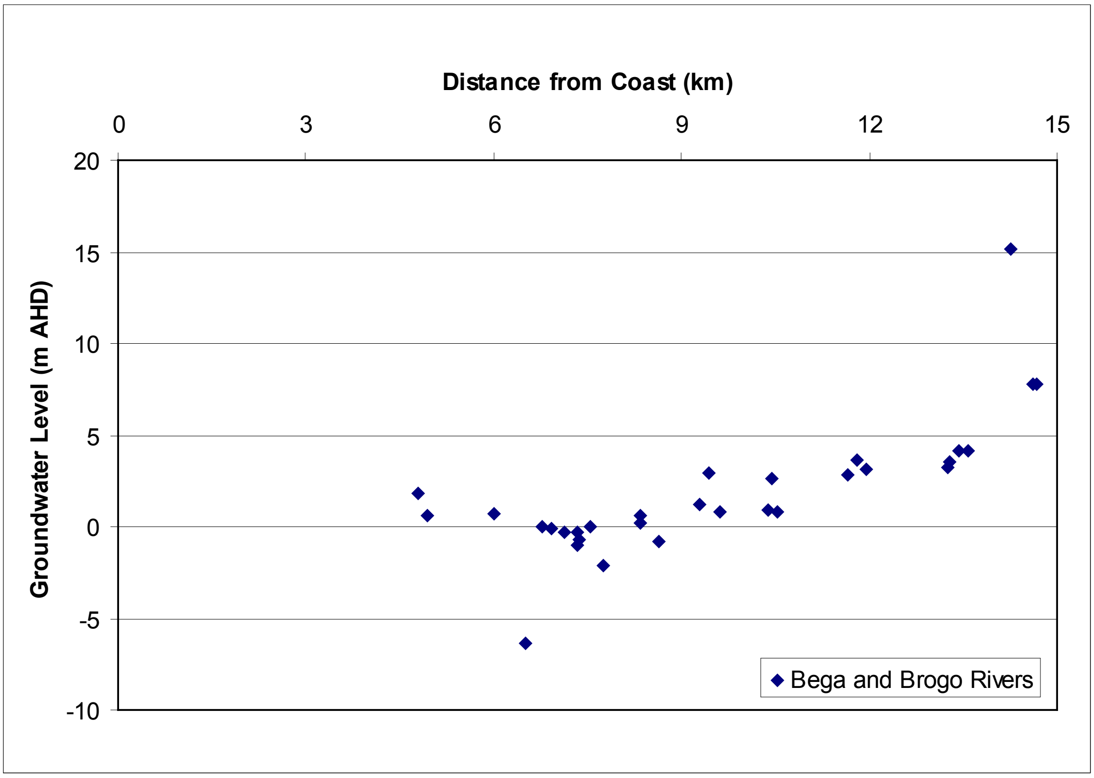
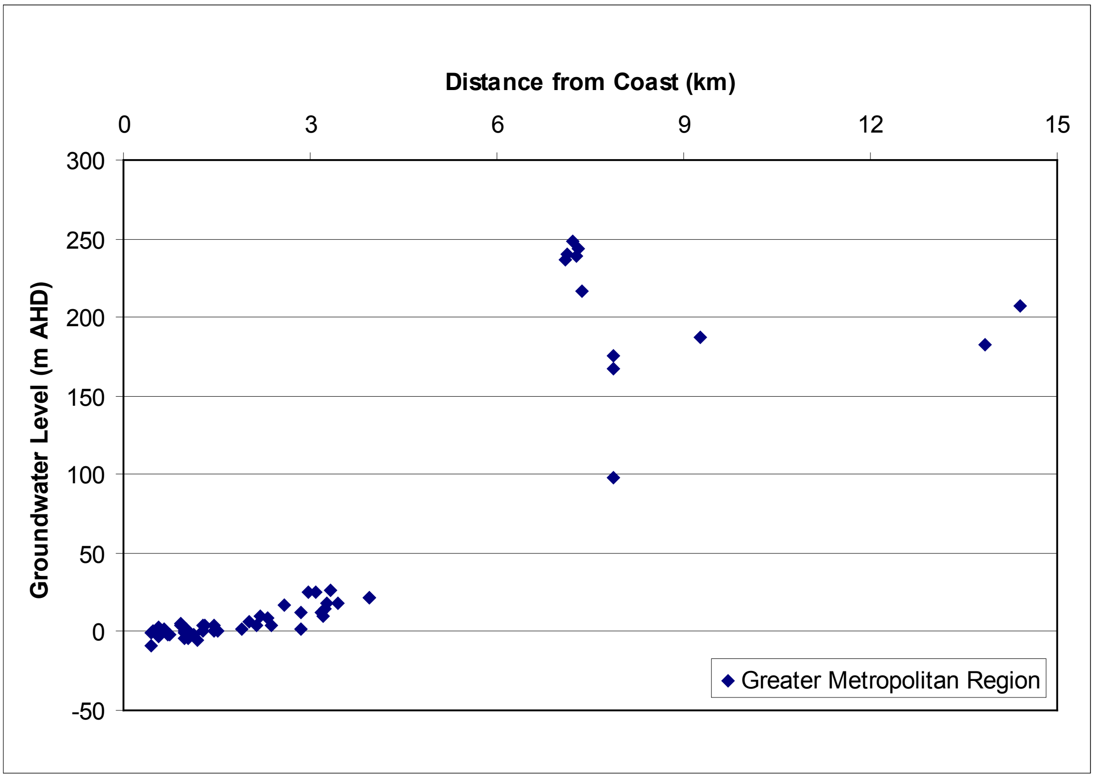
35
30
25
20
15
10
5
0
-5
-10
Groundwater Level (m AHD)
Pioneer

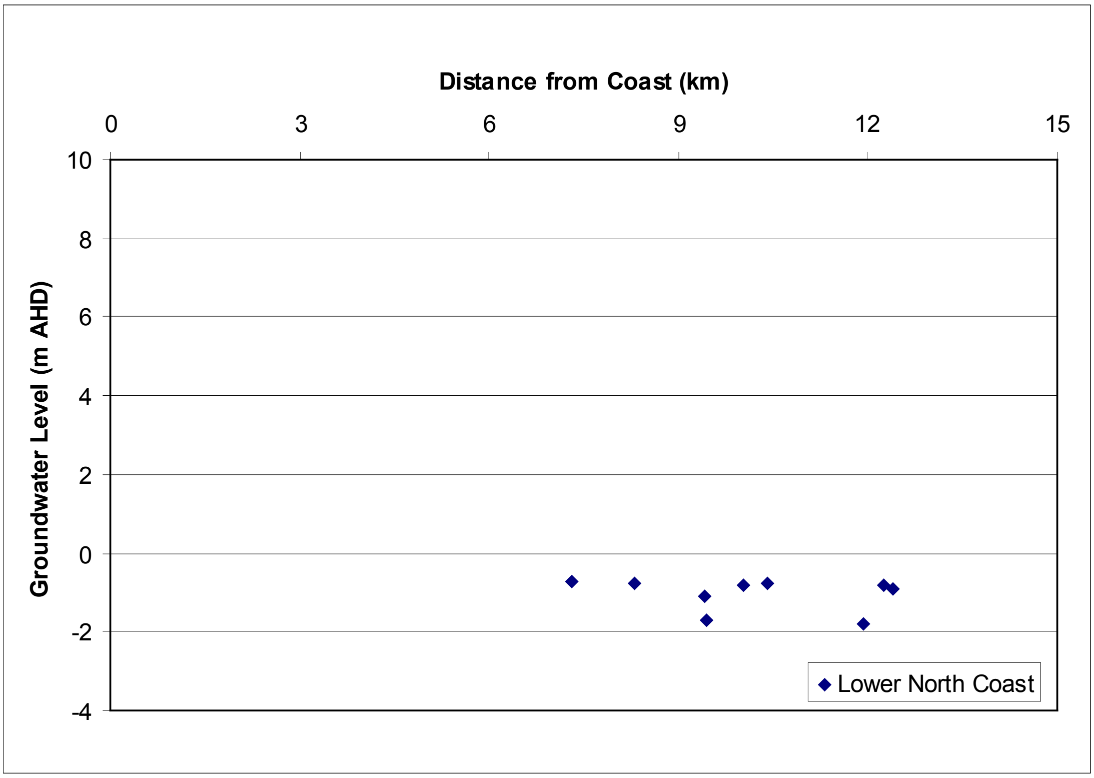

Distance from Coast (km)
0
3
6
9
12
15
25
20
15
10
5
0
-5
-10
Groundwater Level (m AHD)
Proserpine

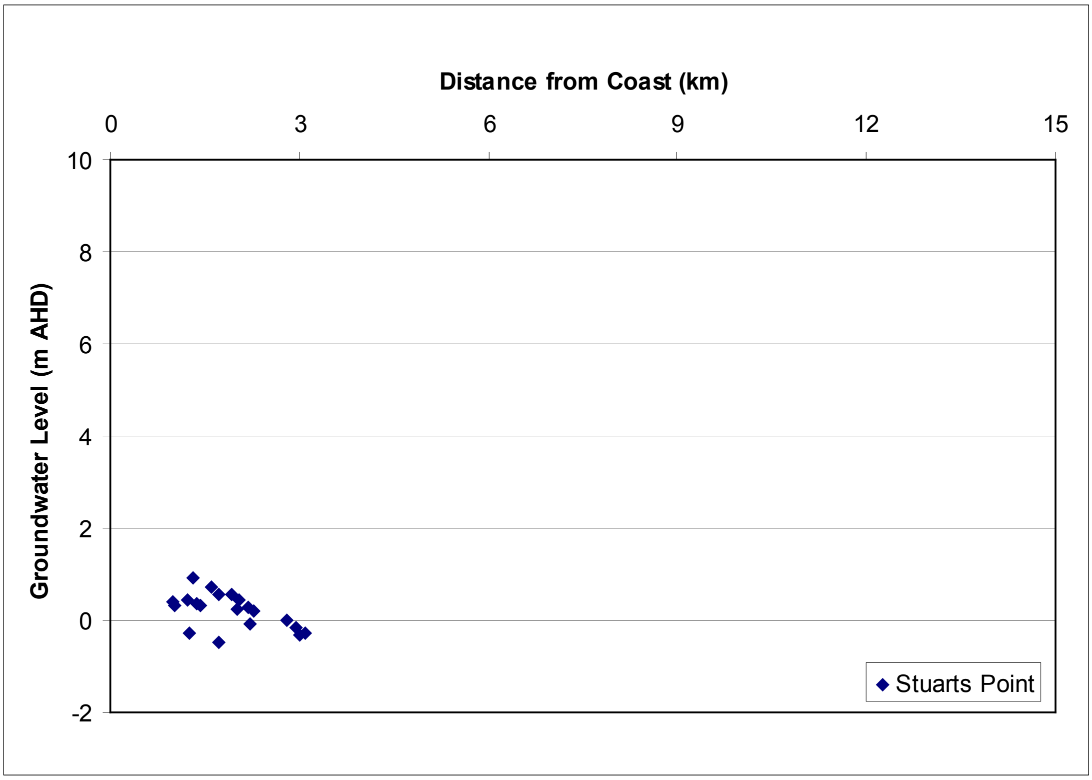
New South Wales

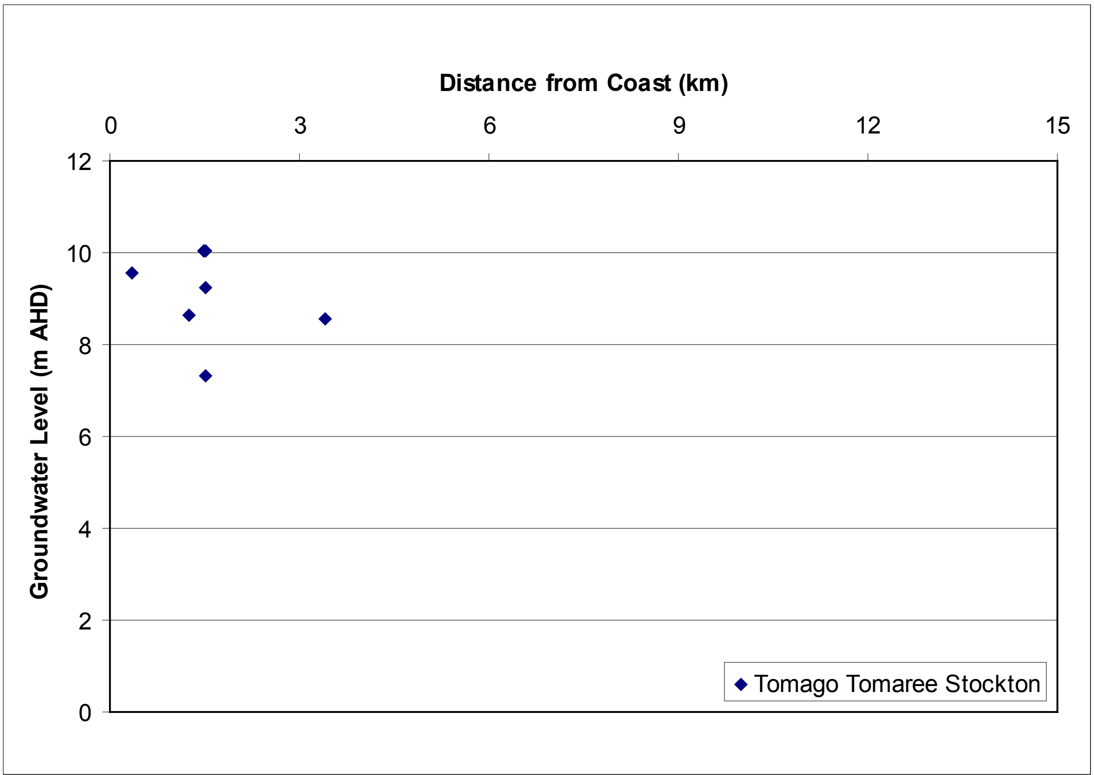




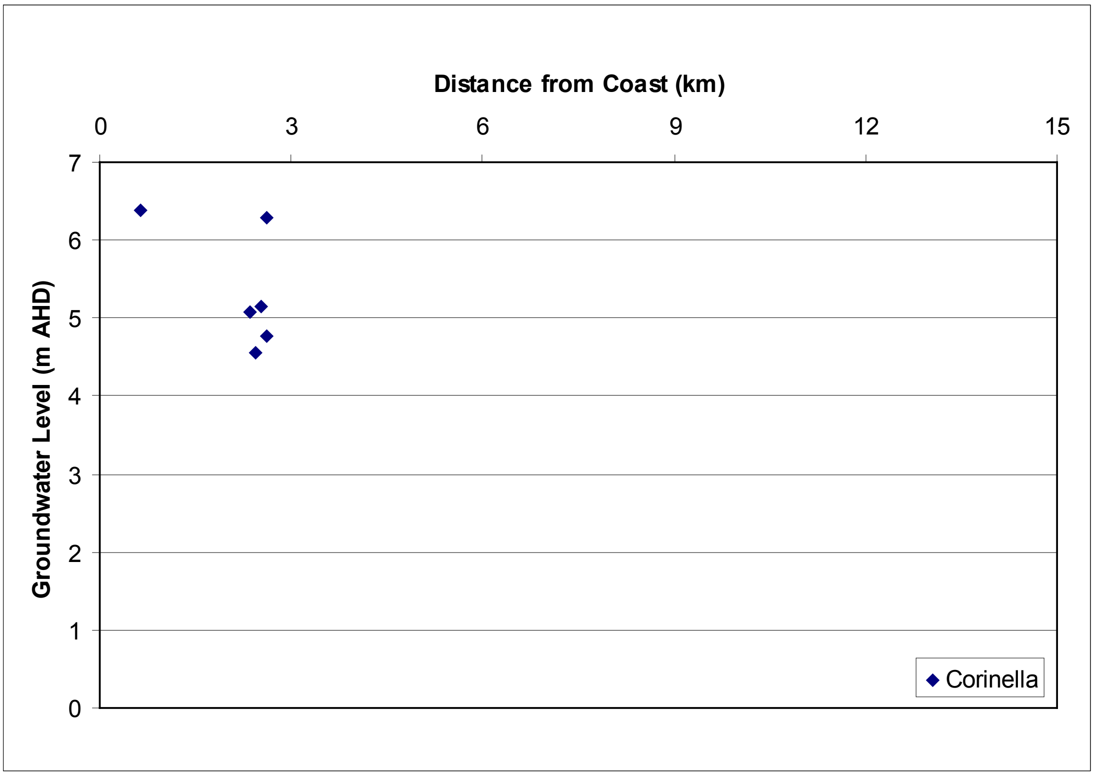

Distance from Coast (km)
0
3
6
9
12
15
300
250
200
150
100
50
0
-50
Groundwater Level (m AHD)
Greater Metropolitan Region

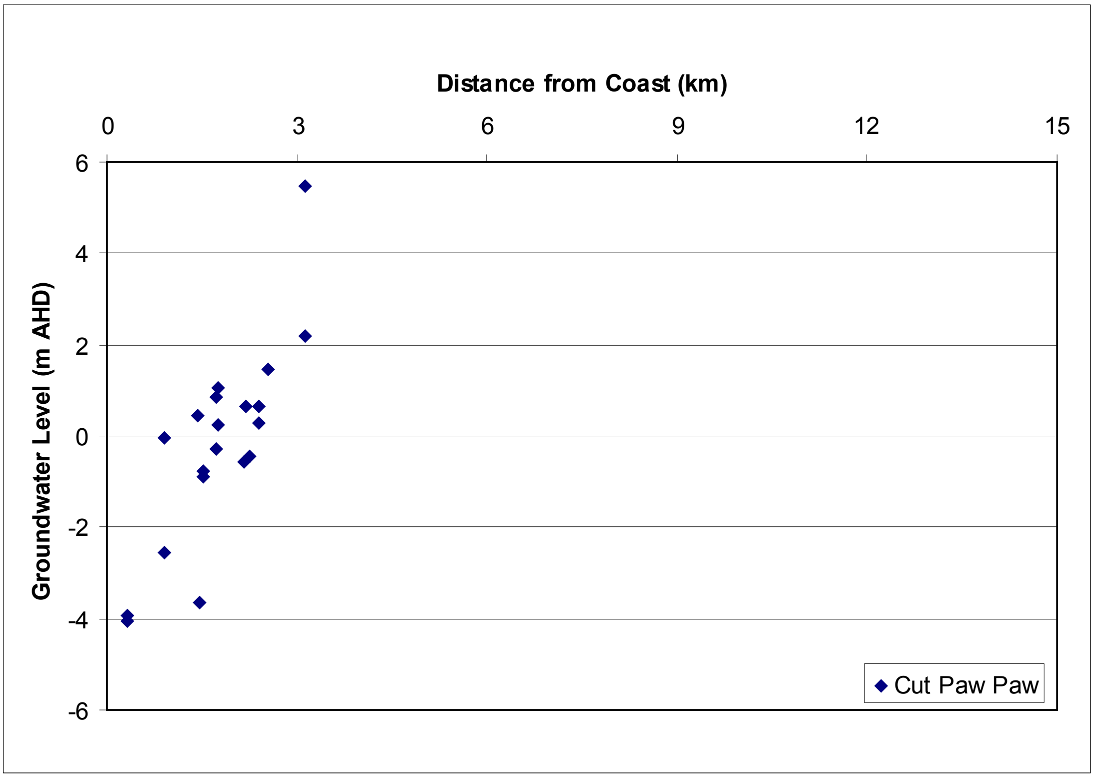

Distance from Coast (km)
0
3
6
9
12
15
10
8
6
4
2
0
-2
-4
Groundwater Level (m AHD)
Lower North Coast

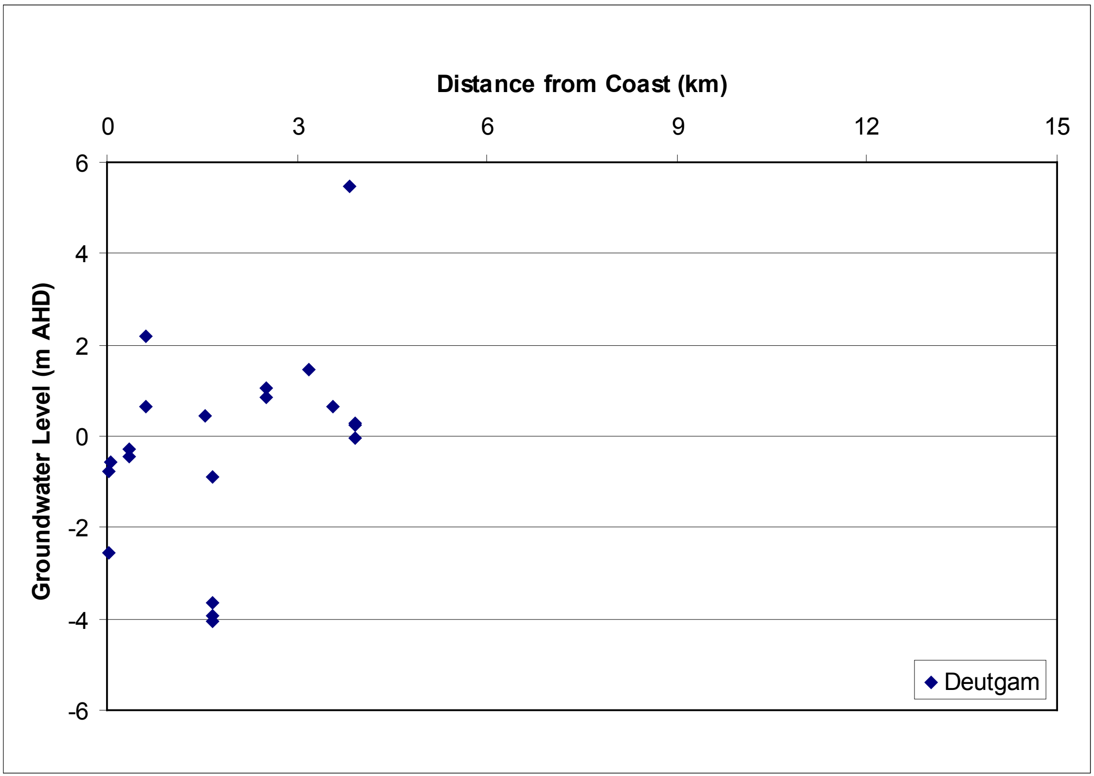

Distance from Coast (km)
0
3
6
9
12
15
10
8
6
4
2
0
-2
Groundwater Level (m AHD)
Stuarts Point

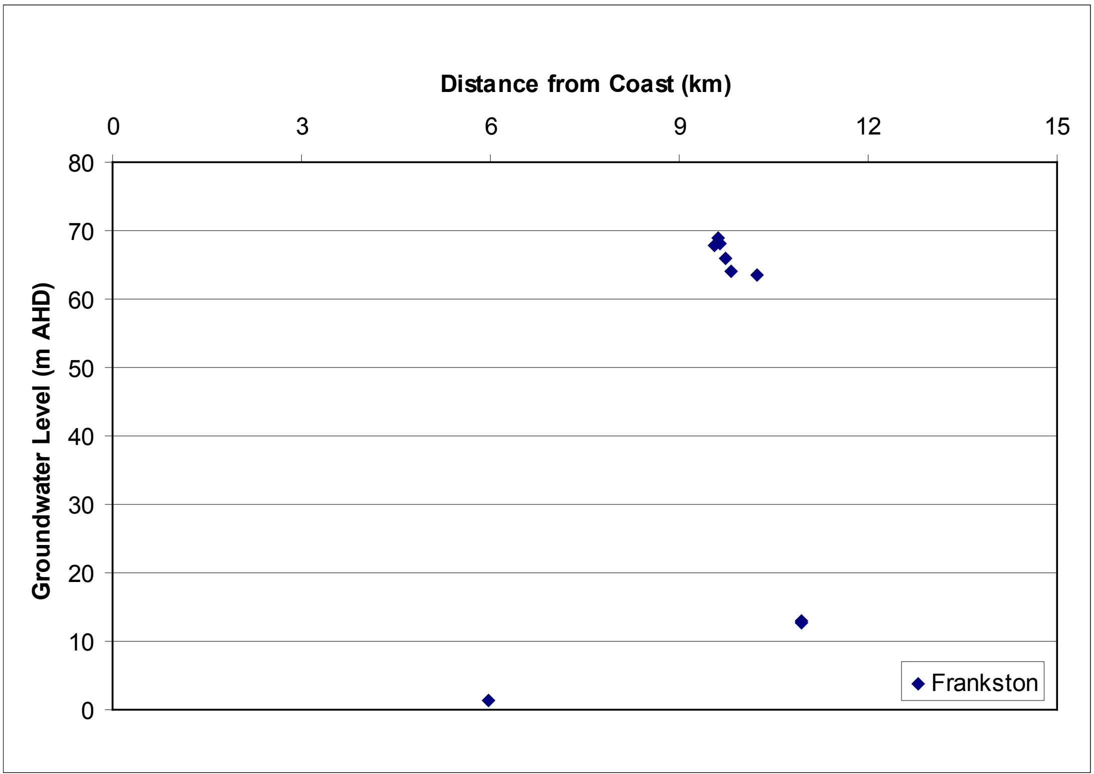

Distance from Coast (km)
0
3
6
9
12
15
12
10
8
6
4
2
0
Groundwater Level (m AHD)
Tomago Tomaree Stockton

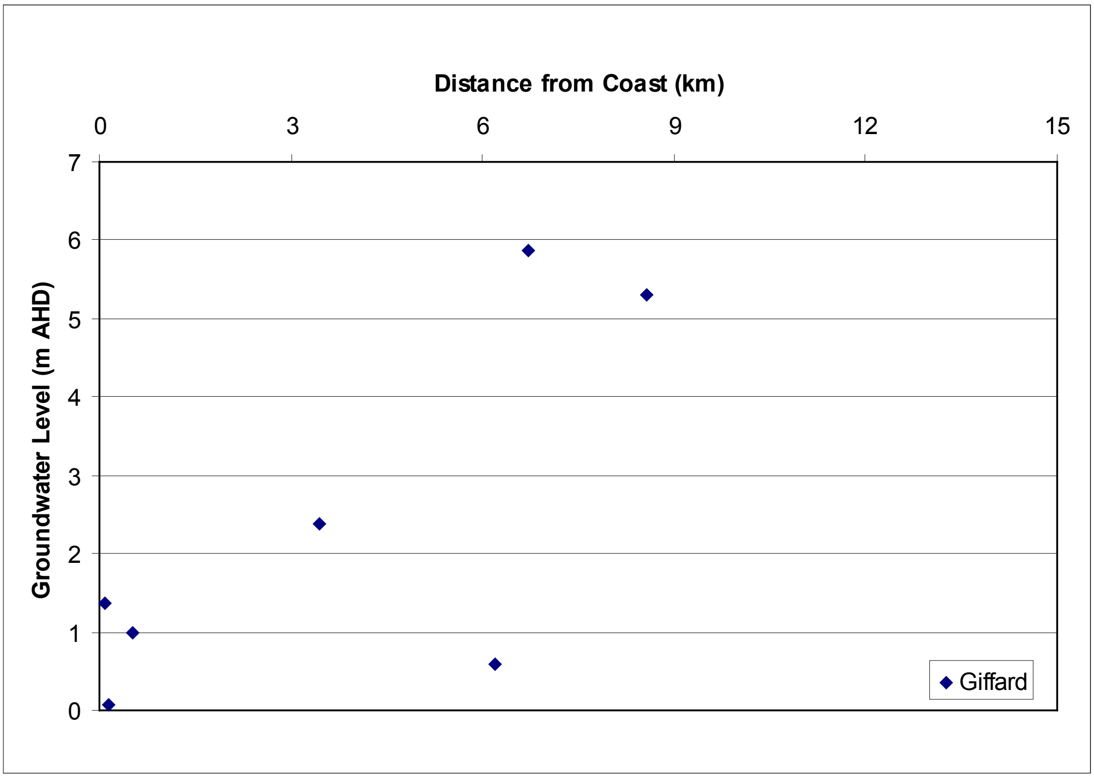
Victoria


Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
7
6
5
4
3
2
1
0
Corinella

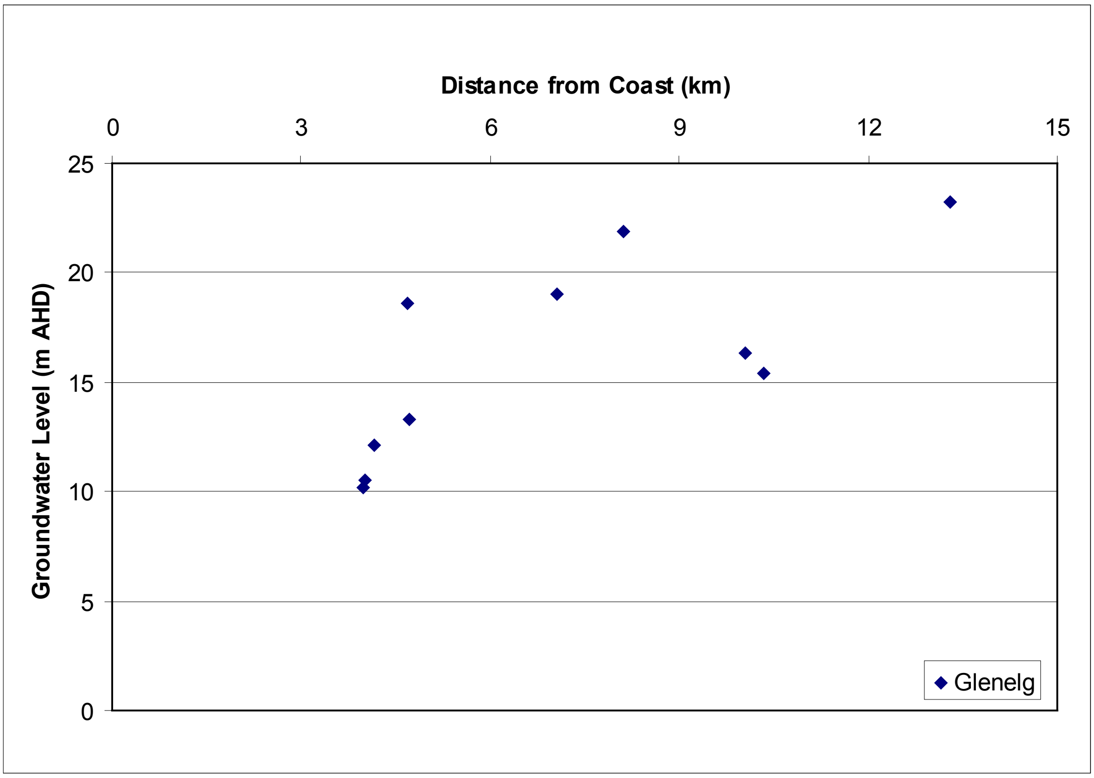

Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
6
4
2
0
-2
-4
-6
Cut Paw Paw


Distance from Coast (km)
0
3
6
9
12
15
6
4
2
0
-2
-4
-6
Groundwater Level (m AHD)
Deutgam

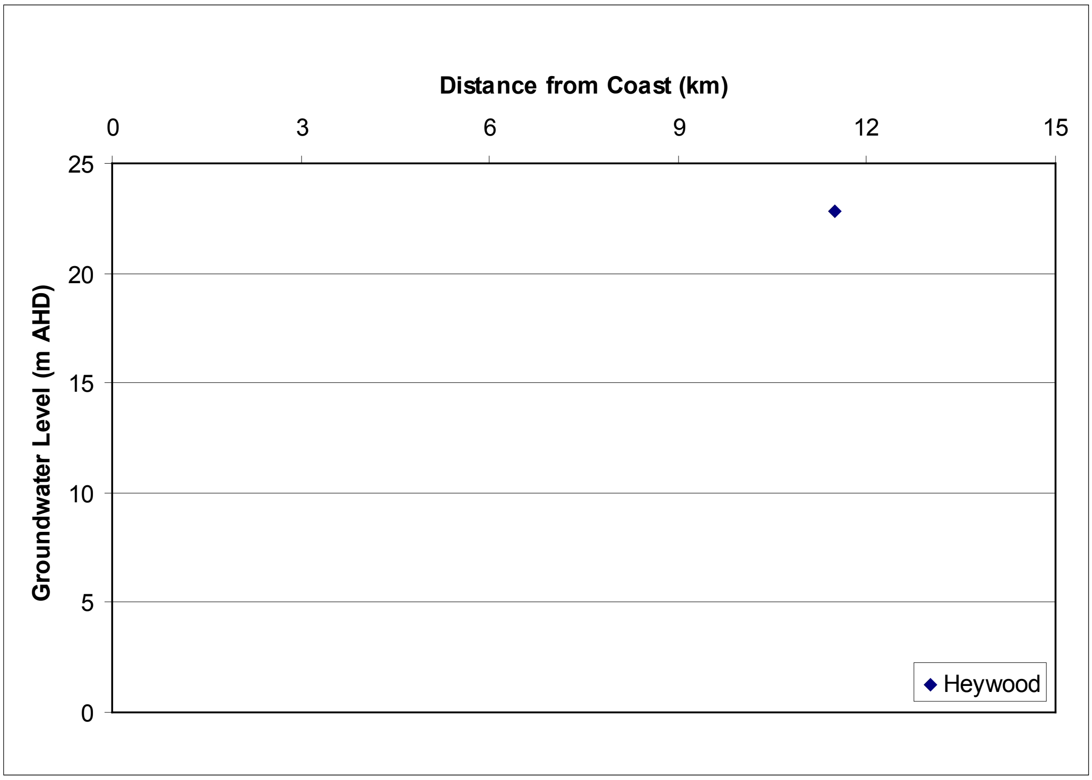

Distance from Coast (km)
0
3
6
9
12
15
80
70
60
50
40
30
20
10
0
Groundwater Level (m AHD)
Frankston

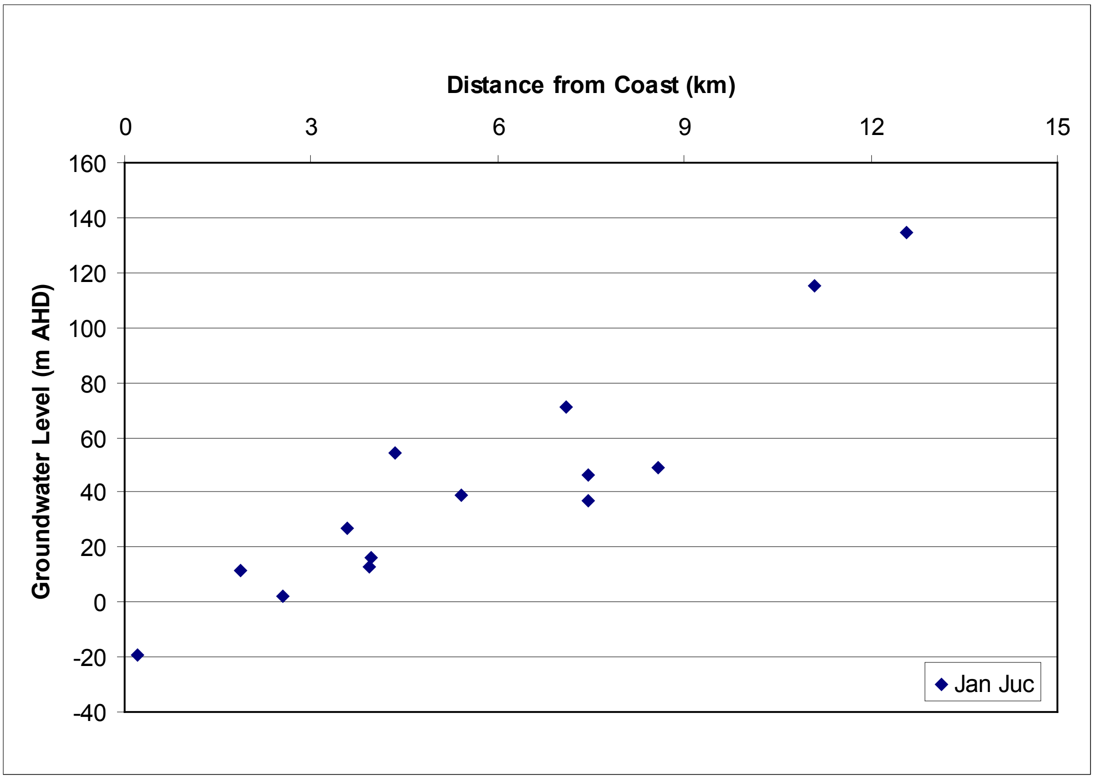


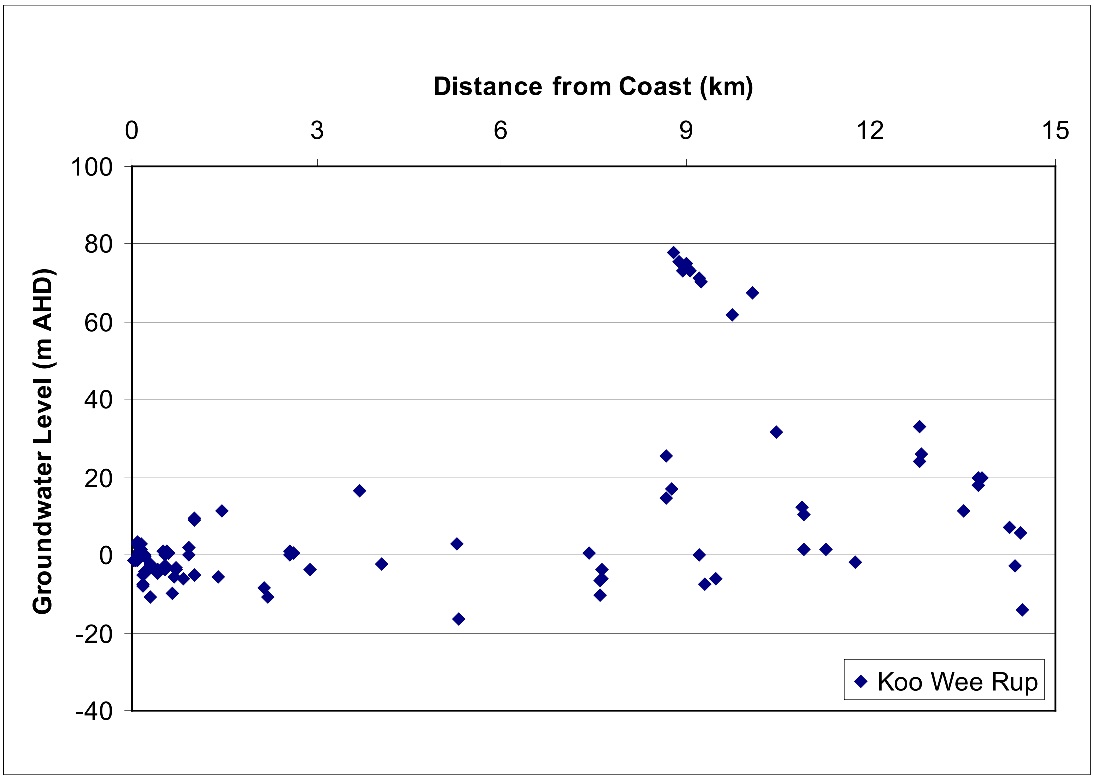
Distance from Coast (km)
0
3
6
9
12
15
7
6
5
4
3
2
1
0
Groundwater Level (m AHD)
Giffard

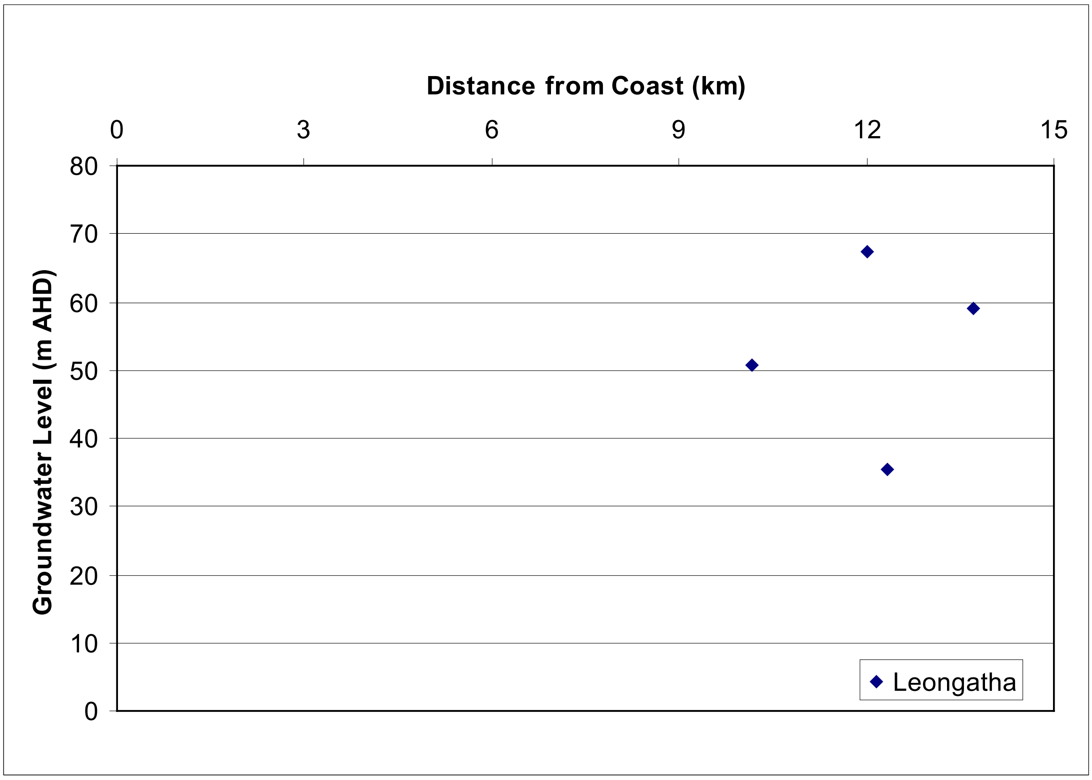


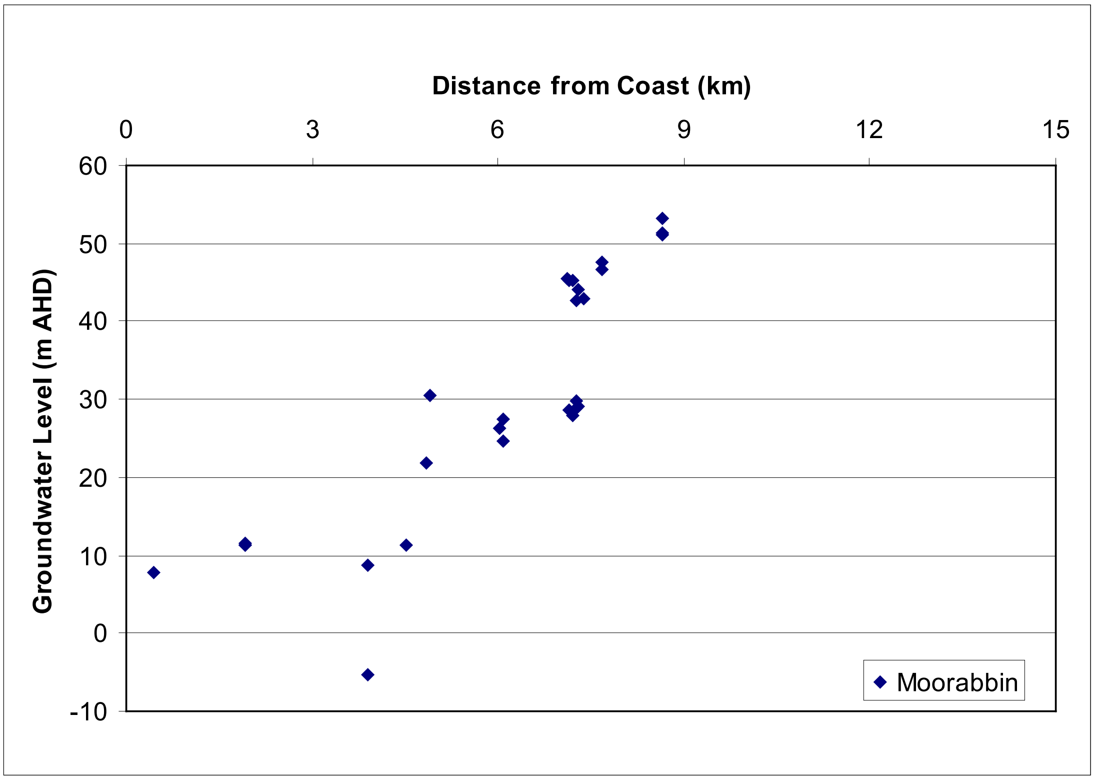
Distance from Coast (km)
0
3
6
9
12
15
25
20
15
10
5
0
Groundwater Level (m AHD)
Glenelg

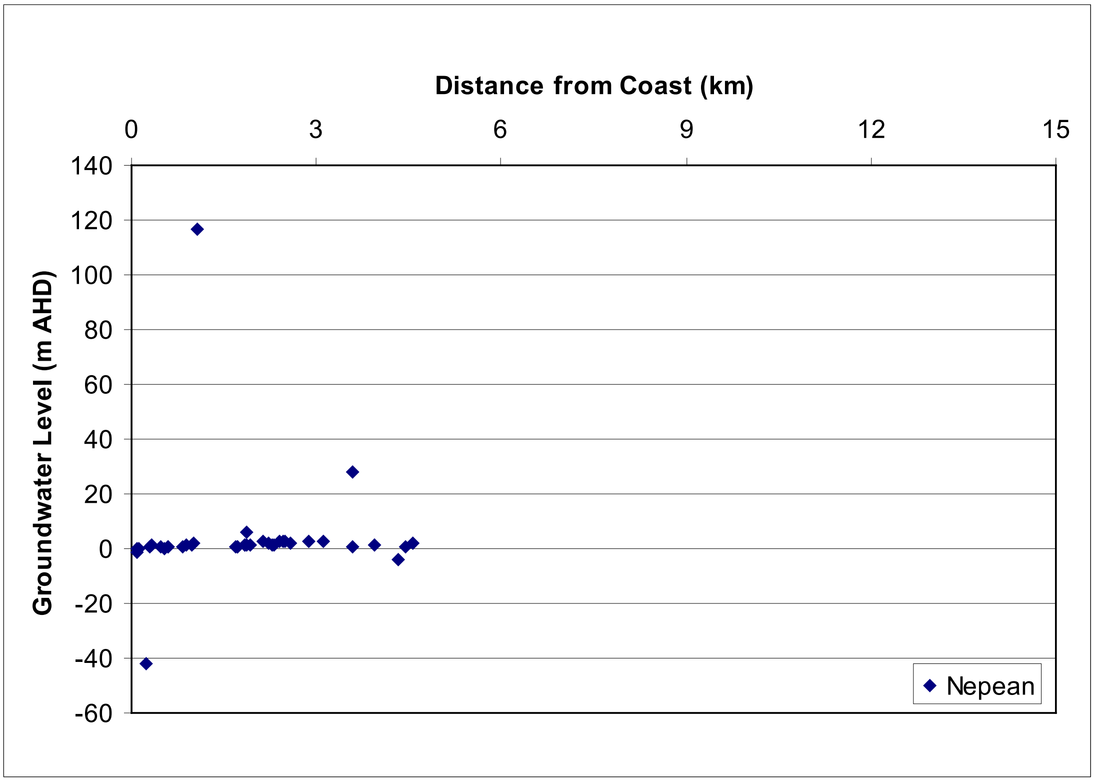

Distance from Coast (km)
0
3
6
9
12
15
25
20
15
10
5
0
Groundwater Level (m AHD)
Heywood

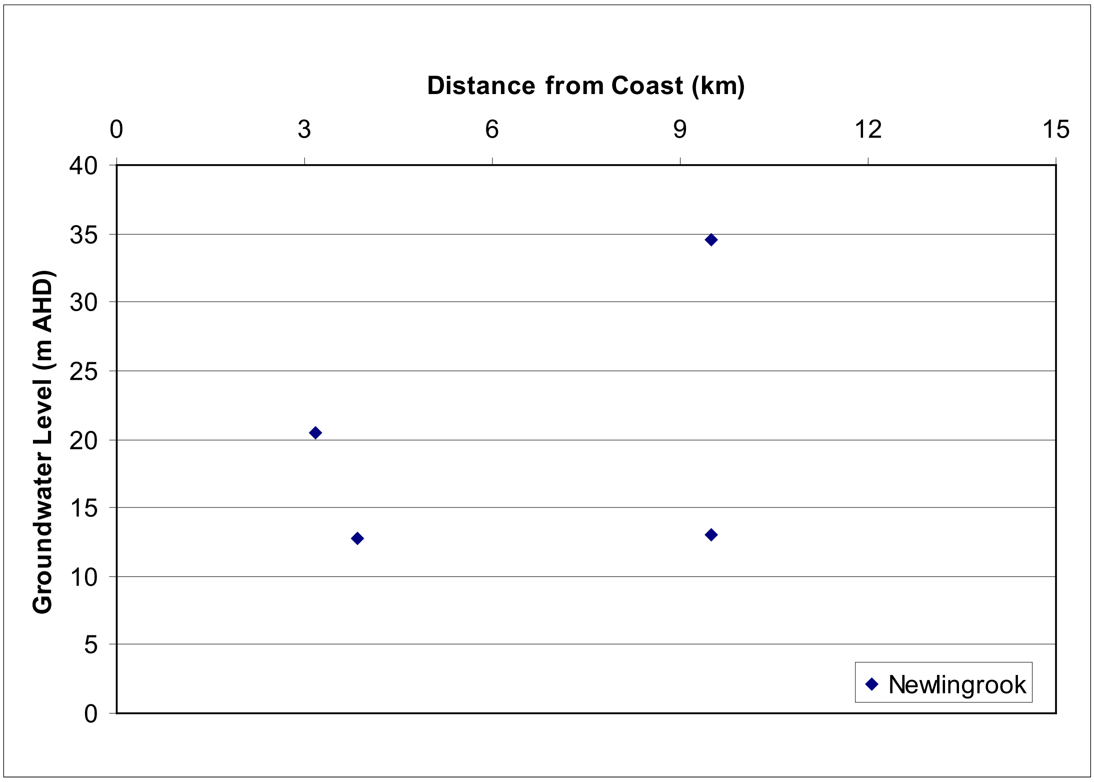

Distance from Coast (km)
0
3
6
9
12
15
160
140
120
100
80
60
40
20
0
-20
-40
Groundwater Level (m AHD)
Jan Juc

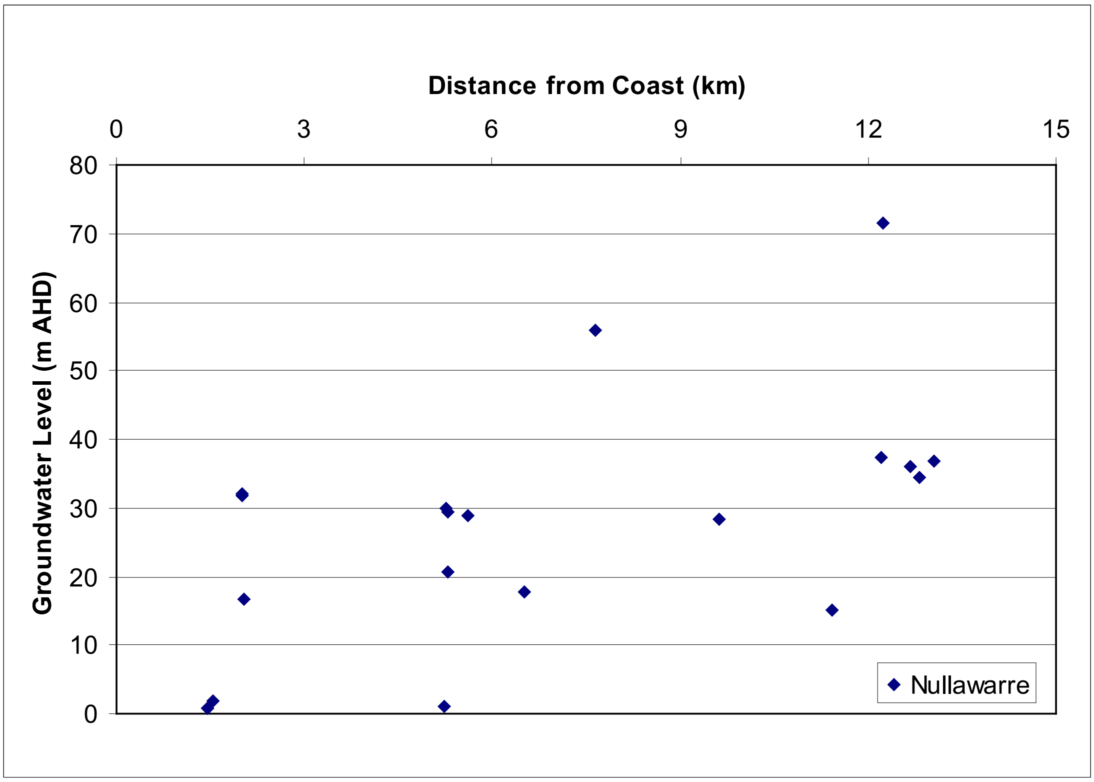

Distance from Coast (km)
0
3
6
9
12
15
100
80
60
40
20
0
-20
-40
Groundwater Level (m AHD)
Koo Wee Rup

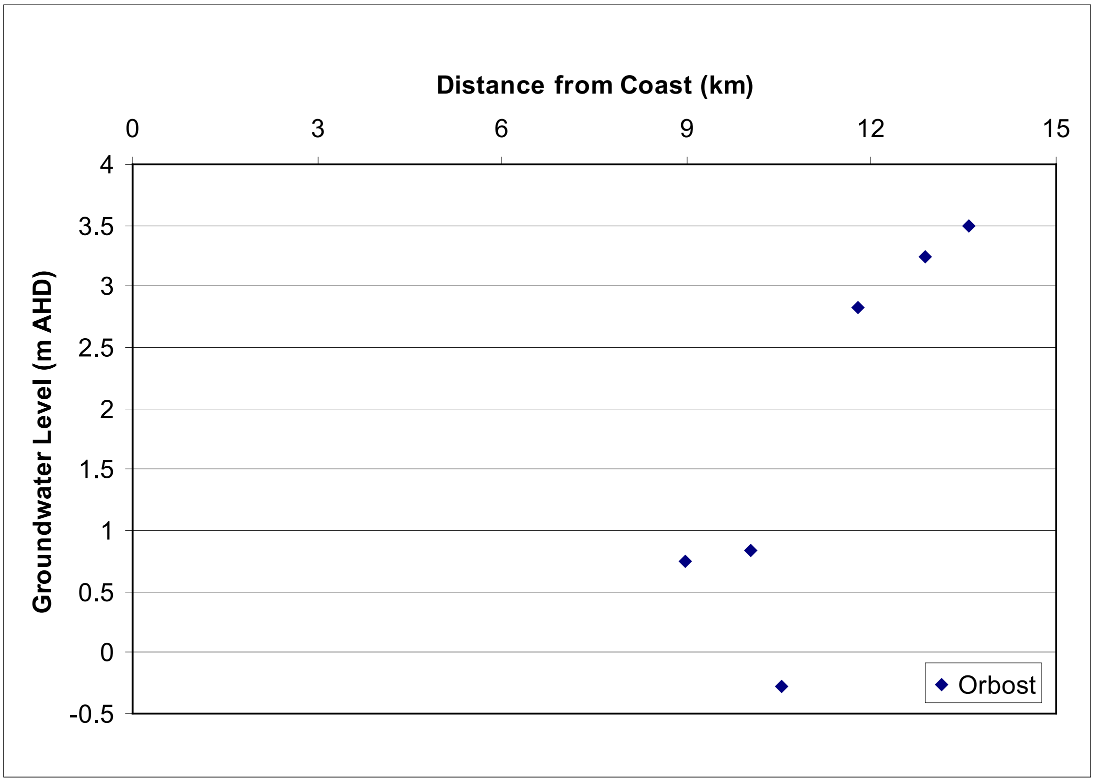

Distance from Coast (km)
0
3
6
9
12
15
80
70
60
50
40
30
20
10
0
Groundwater Level (m AHD)
Leongatha

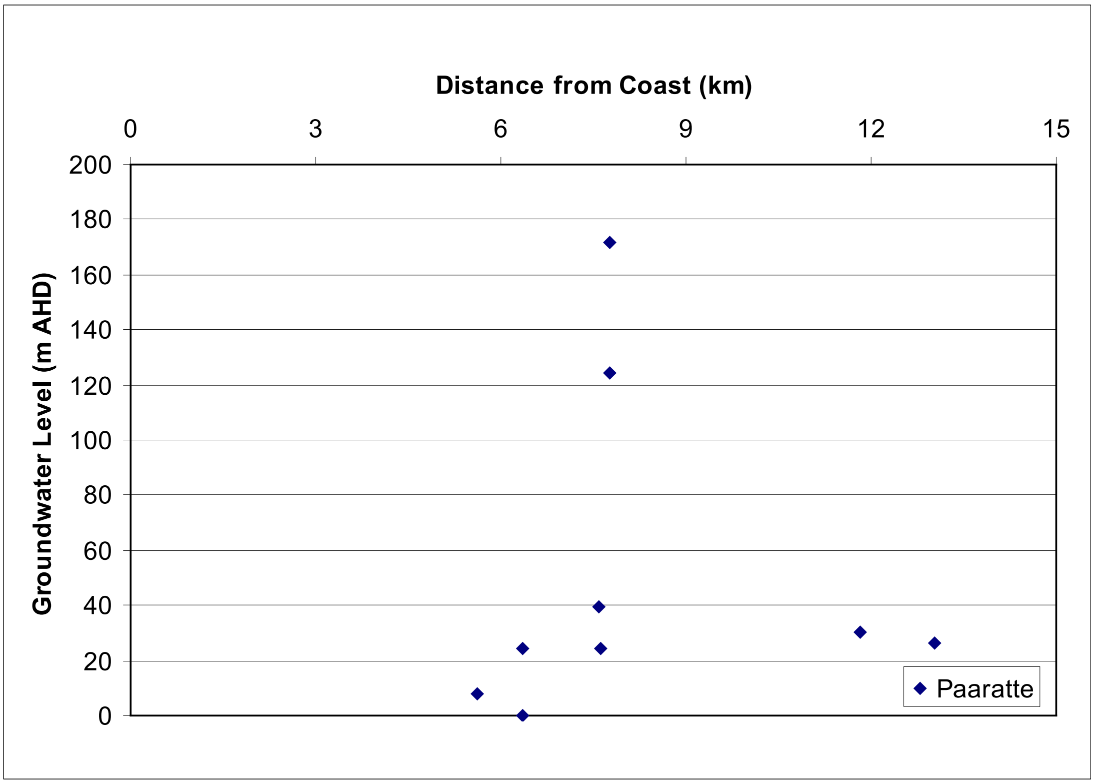

Distance from Coast (km)
0
3
6
9
12
15
60
50
40
30
20
10
0
-10
Groundwater Level (m AHD)
Moorabbin

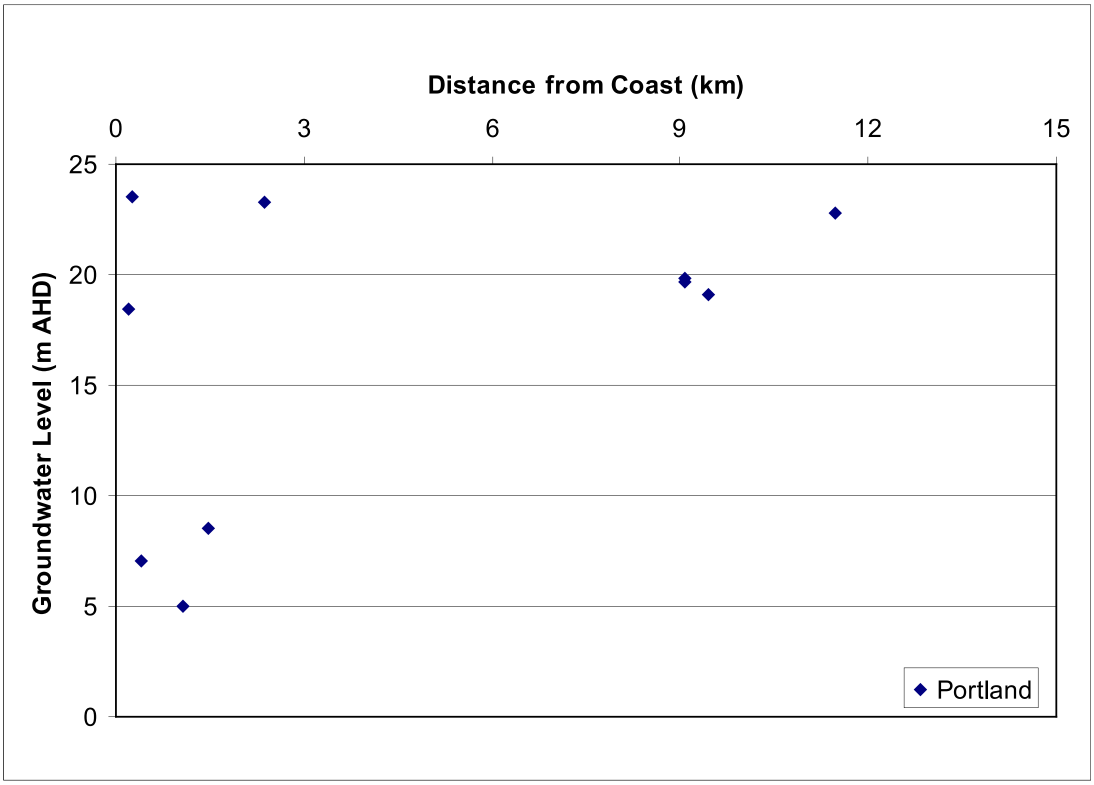

Distance from Coast (km)
0
3
6
9
12
15
140
120
100
80
60
40
20
0
-20
-40
-60
Groundwater Level (m AHD)
Nepean

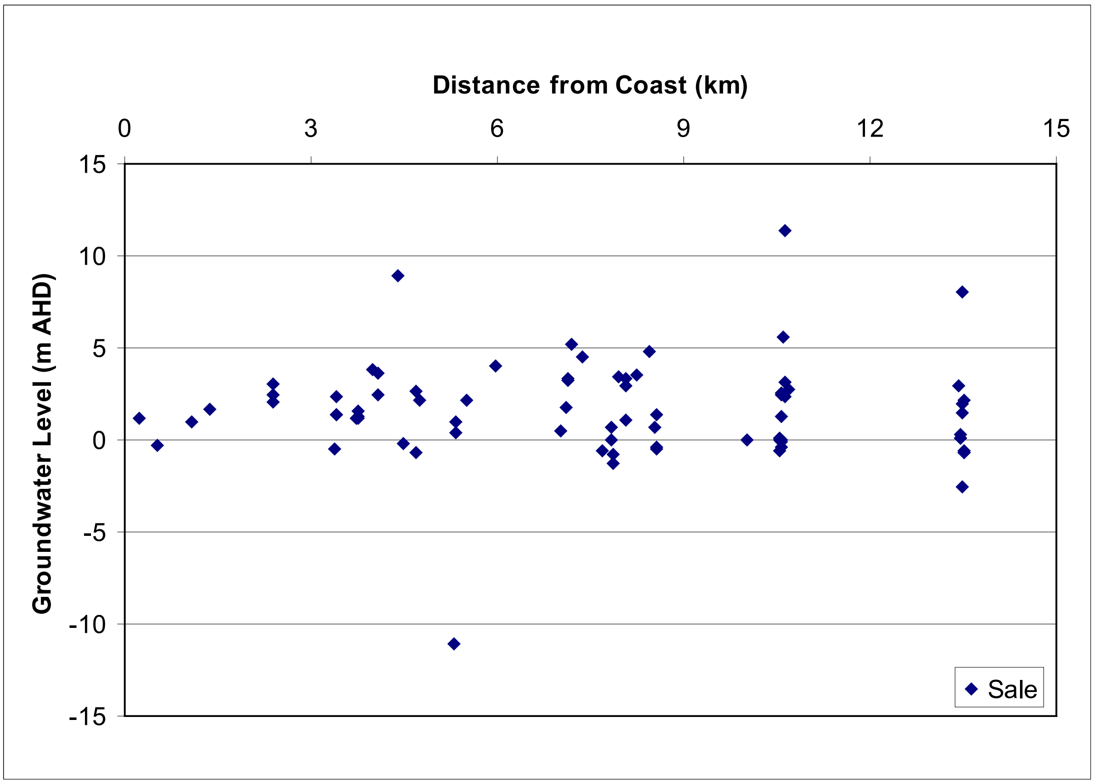

Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
40
35
30
25
20
15
10
5
0
Newlingrook

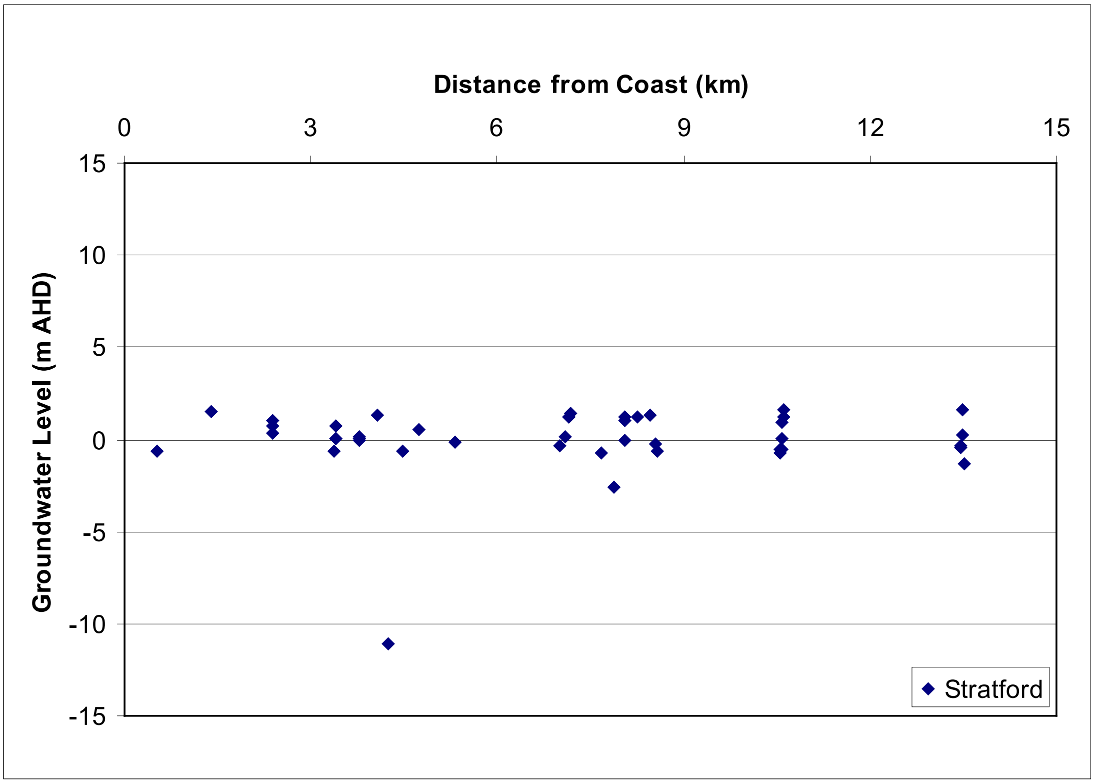

Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
80
70
60
50
40
30
20
10
0
Nullawarre

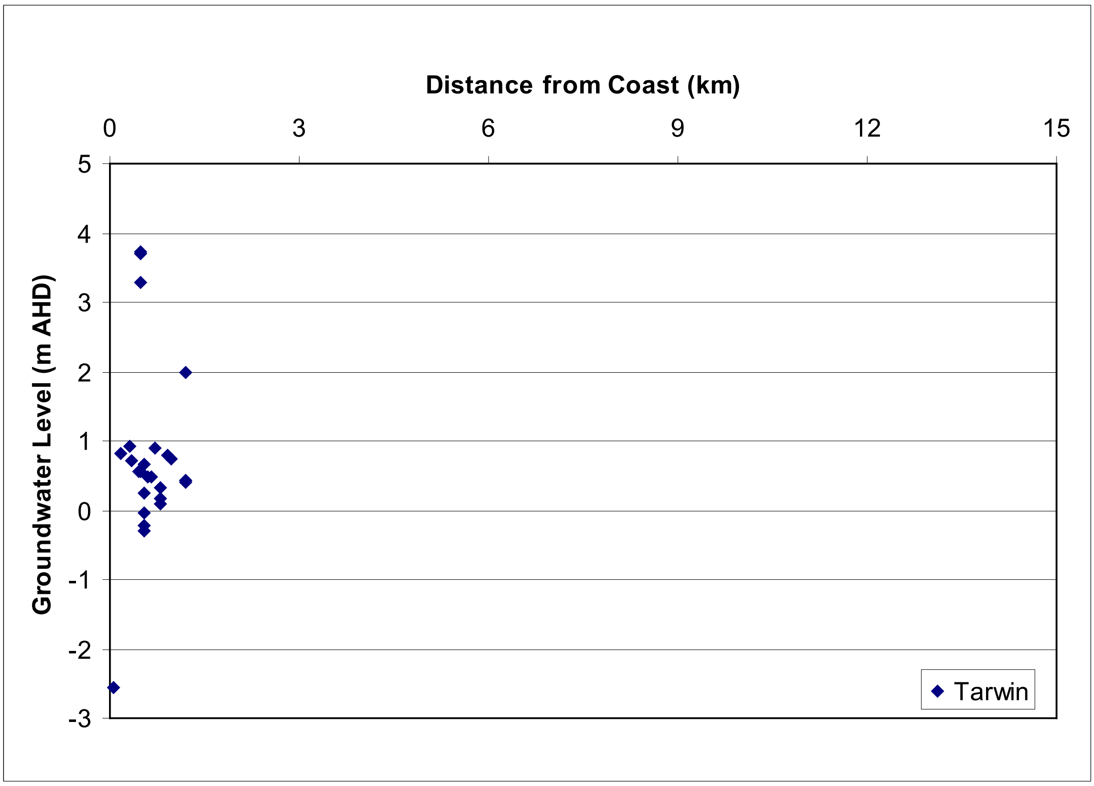

Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
Orbost

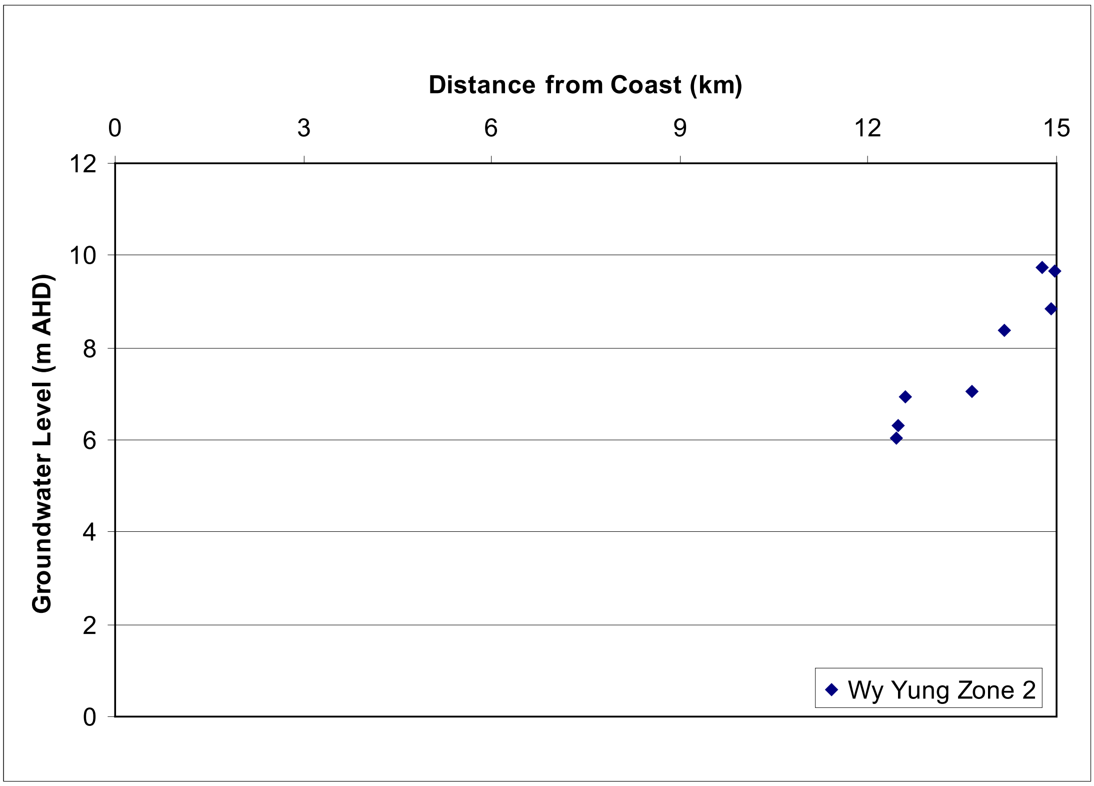

Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
200
180
160
140
120
100
80
60
40
20
0
Paaratte

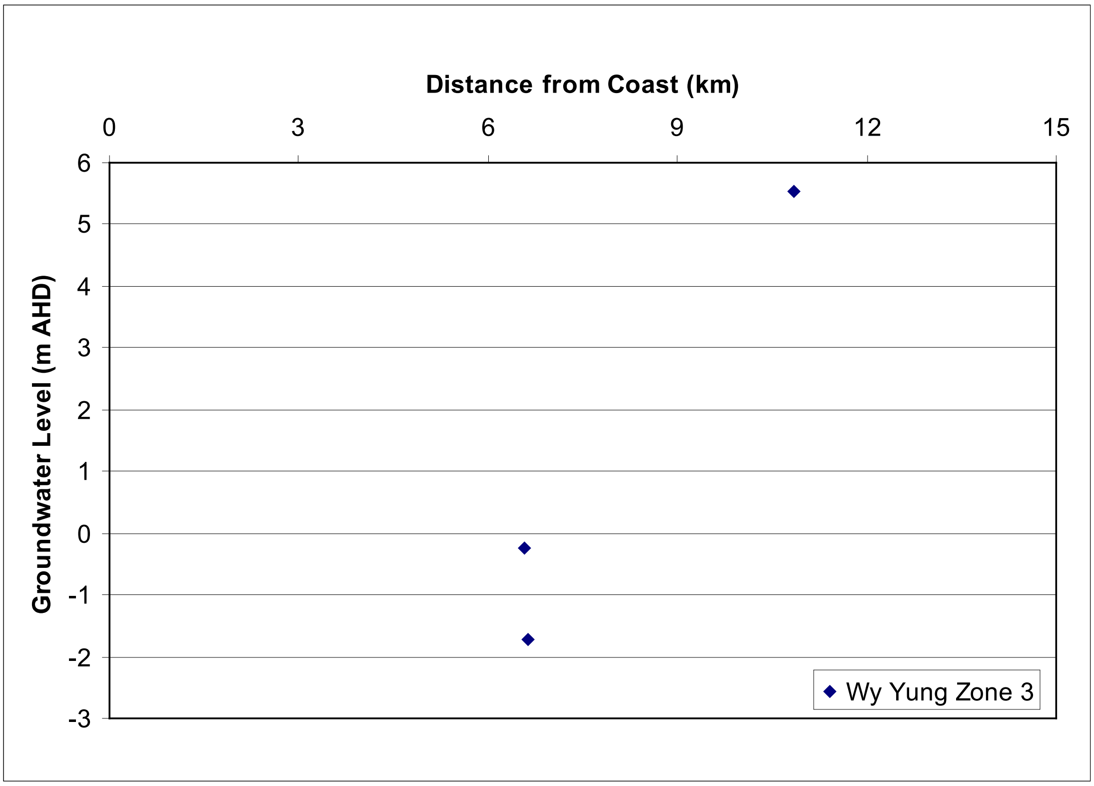

Distance from Coast (km)
0
3
6
9
12
15
25
20
15
10
5
0
Groundwater Level (m AHD)
Portland

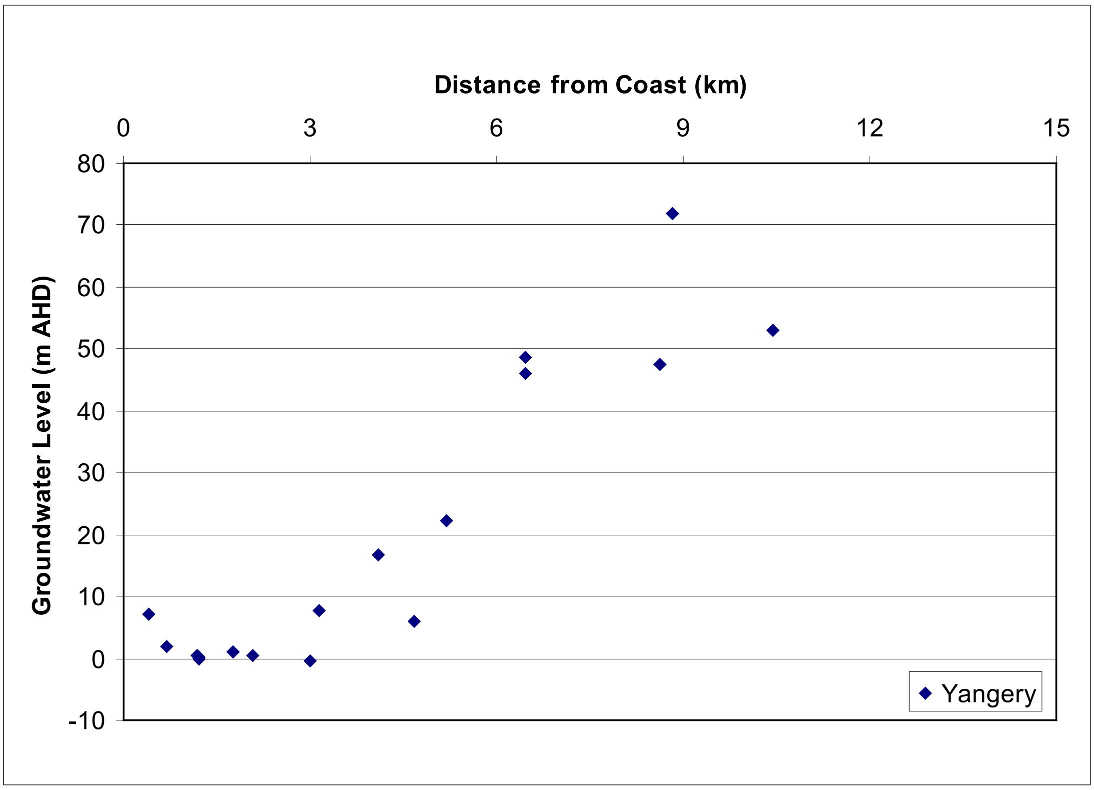

Distance from Coast (km)
0
3
6
9
12
15
15
10
5
0
-5
-10
-15
Groundwater Level (m AHD)
Sale

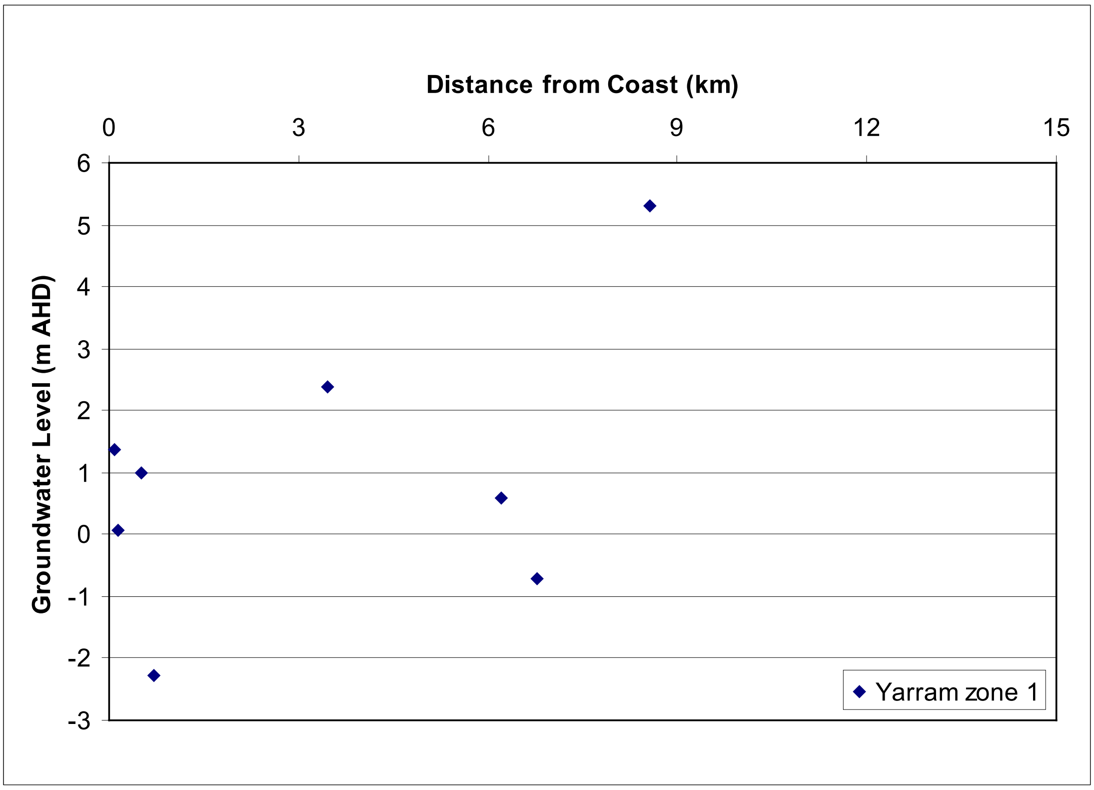

Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
15
10
5
0
-5
-10
-15
Stratford

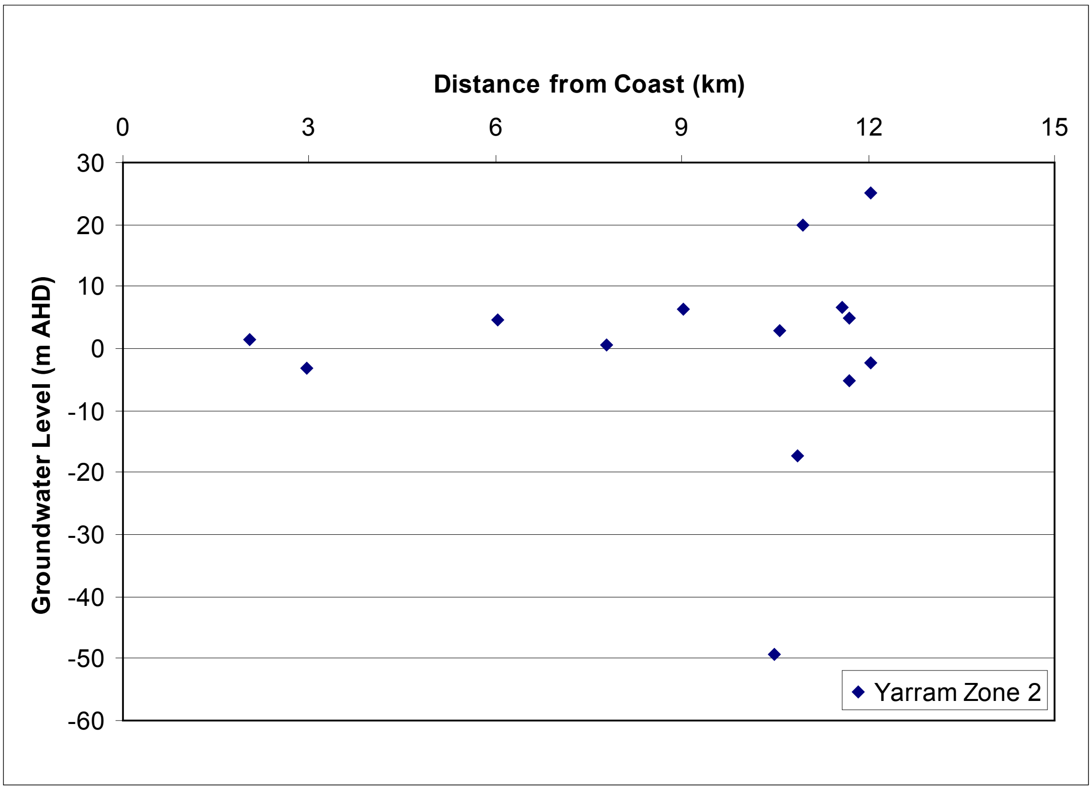

Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
5
4
3
2
1
0
-1
-2
-3
Tarwin


Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
12
10
8
6
4
2
0
Wy Yung Zone 2


Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
6
5
4
3
2
1
0
-1
-2
-3
Wy Yung Zone 3

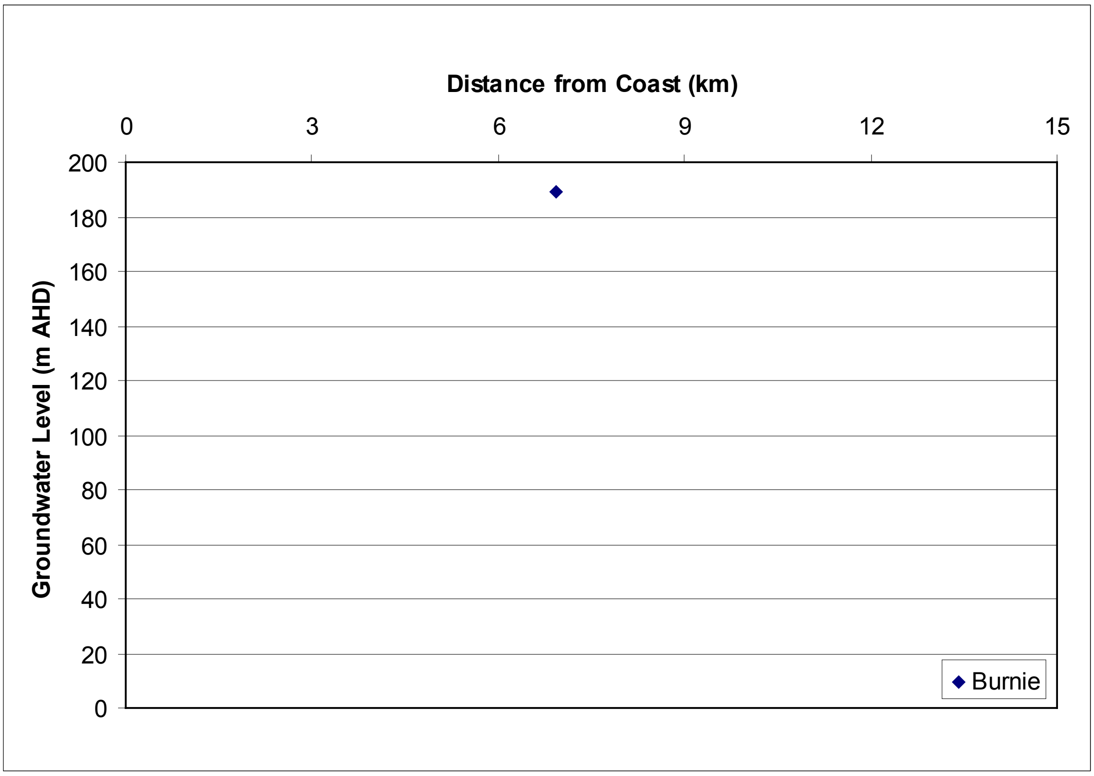

Distance from Coast (km)
0
3
6
9
12
15
80
70
60
50
40
30
20
10
0
-10
Groundwater Level (m AHD)
Yangery


Distance from Coast (km)
0
3
6
9
12
15
6
5
4
3
2
1
0
-1
-2
-3
Groundwater Level (m AHD)
Yarram zone 1

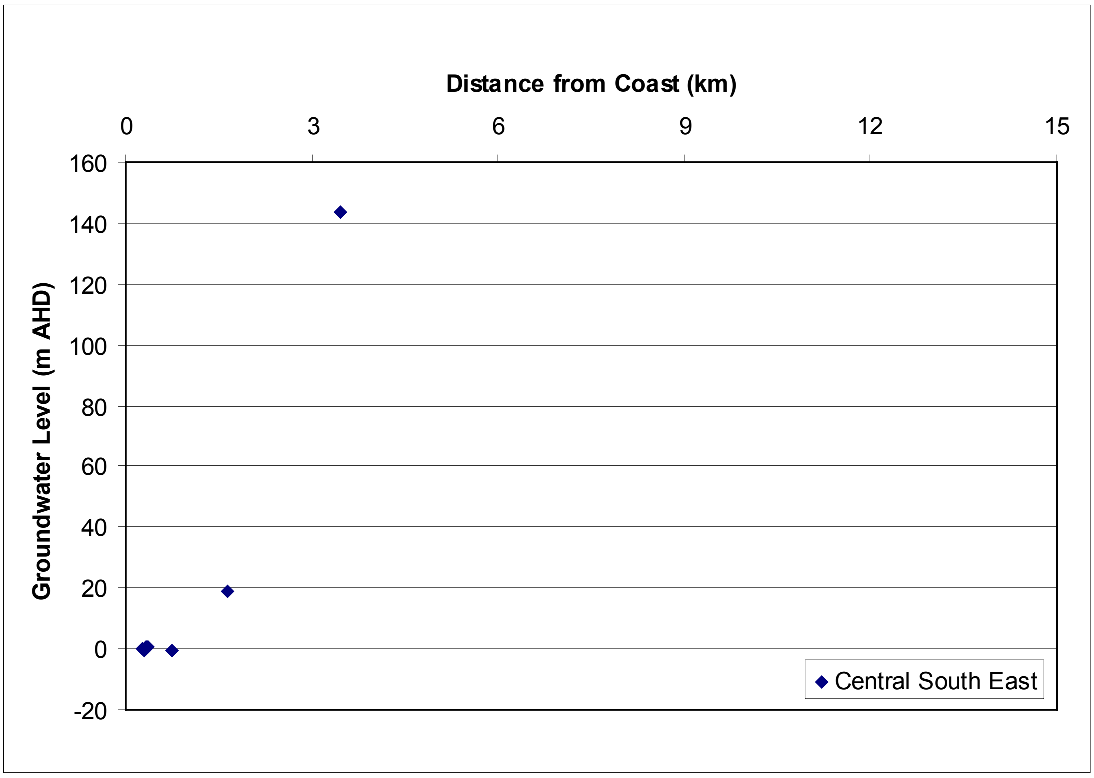


Distance from Coast (km)
0
3
6
9
12
15
30
20
10
0
-10
-20
-30
-40
-50
-60
Groundwater Level (m AHD)
Yarram Zone 2

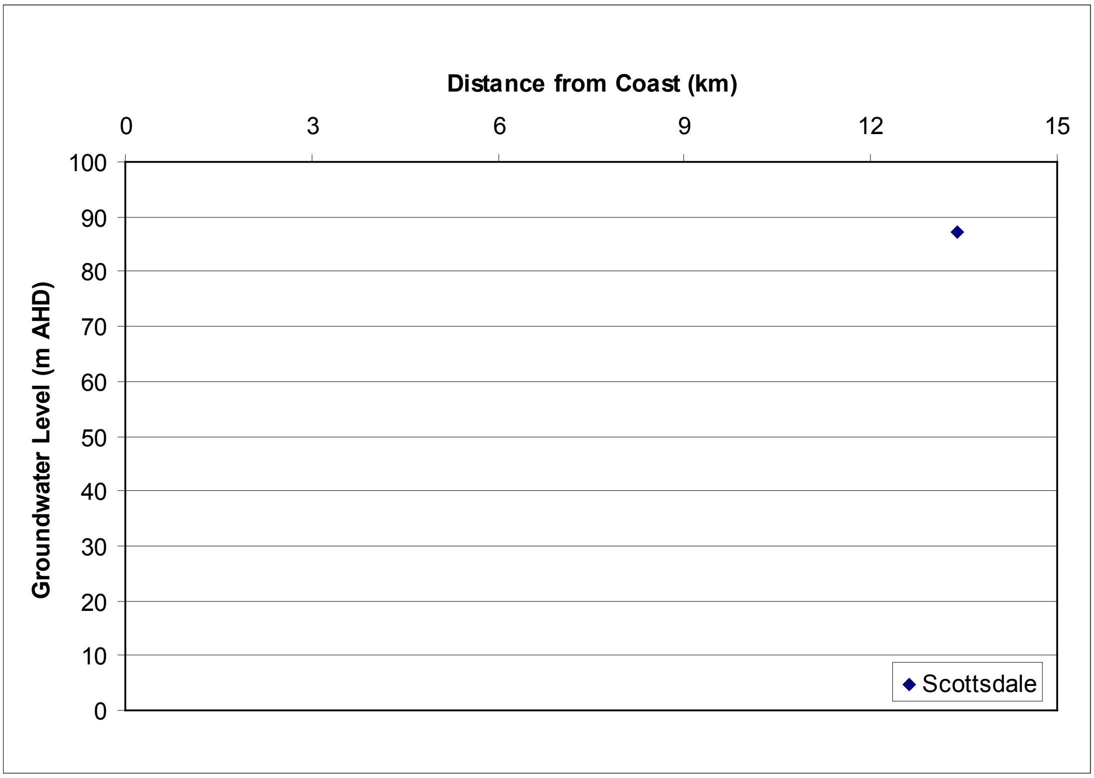
Tasmania

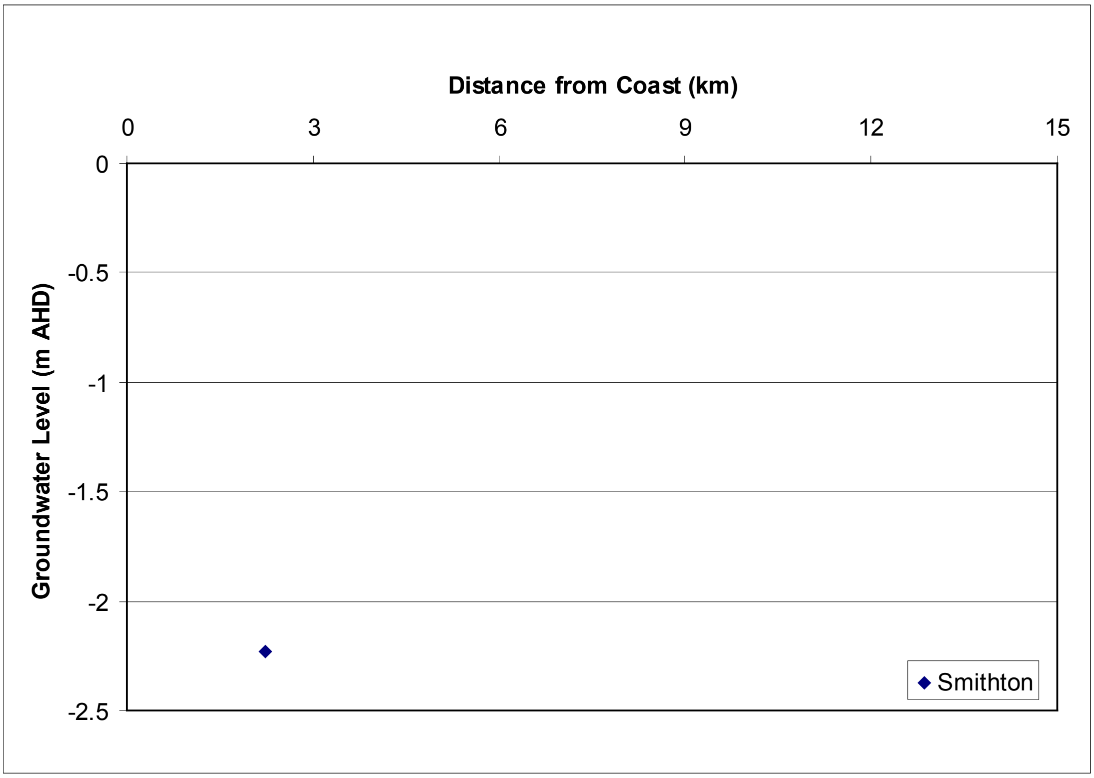


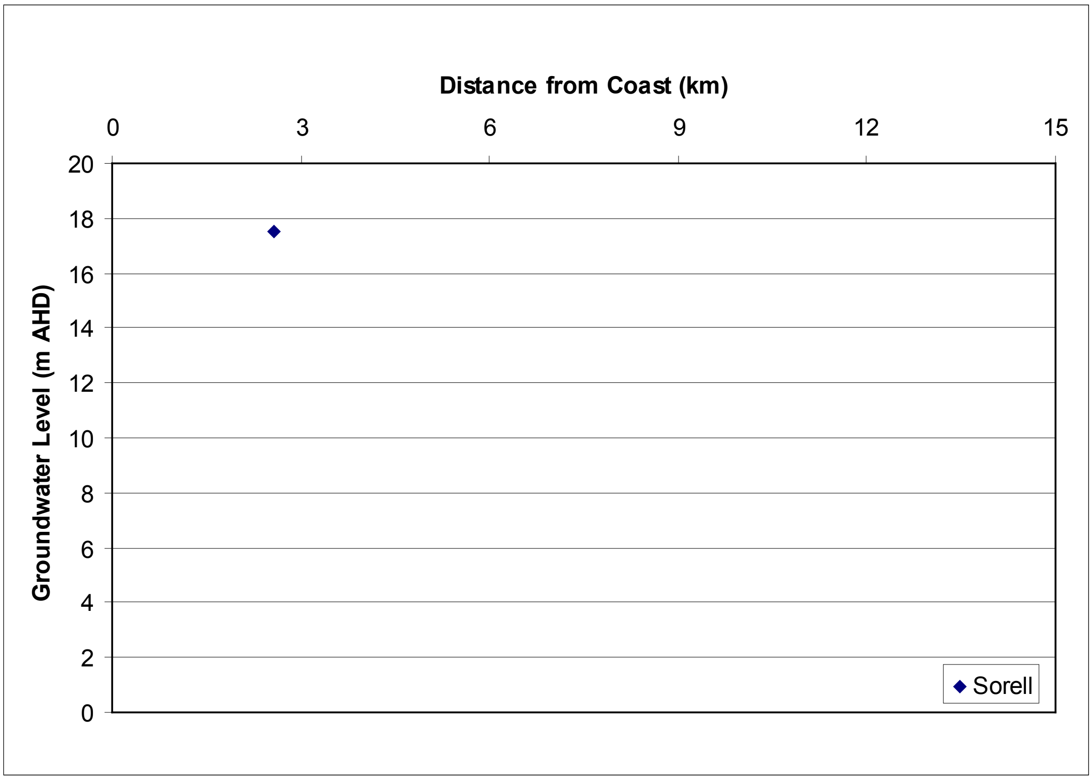
Distance from Coast (km)
0
3
6
9
12
15
200
180
160
140
120
100
80
60
40
20
0
Groundwater Level (m AHD)
Burnie

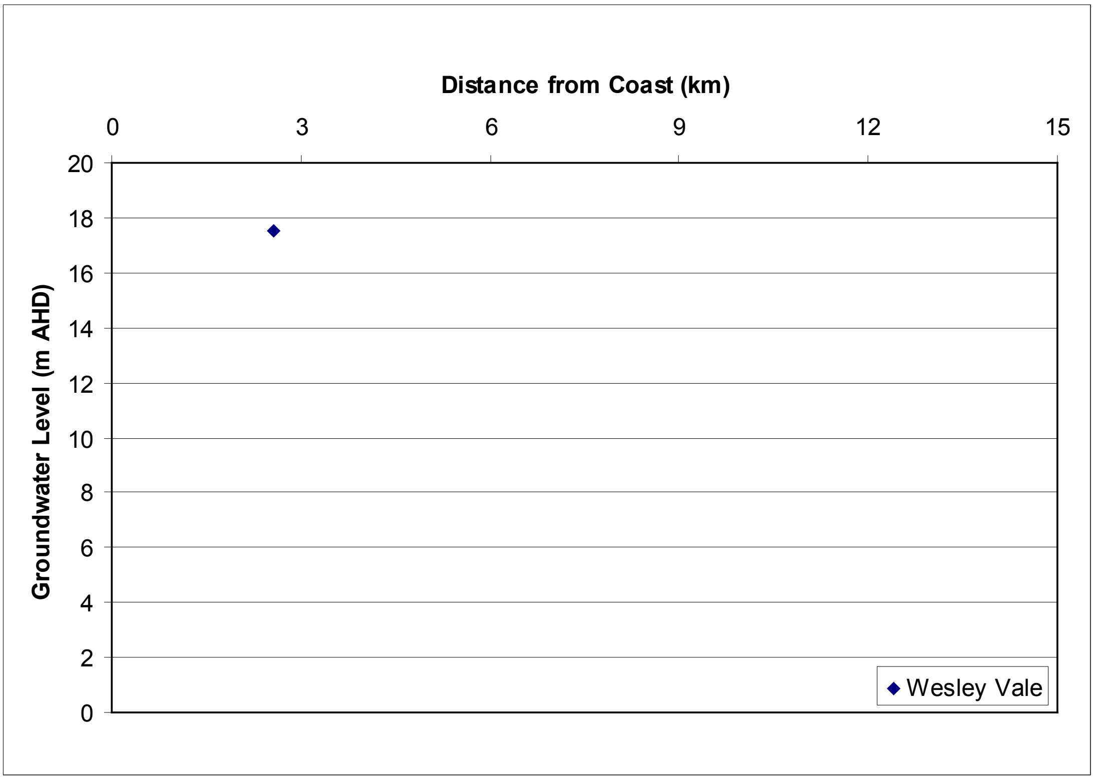


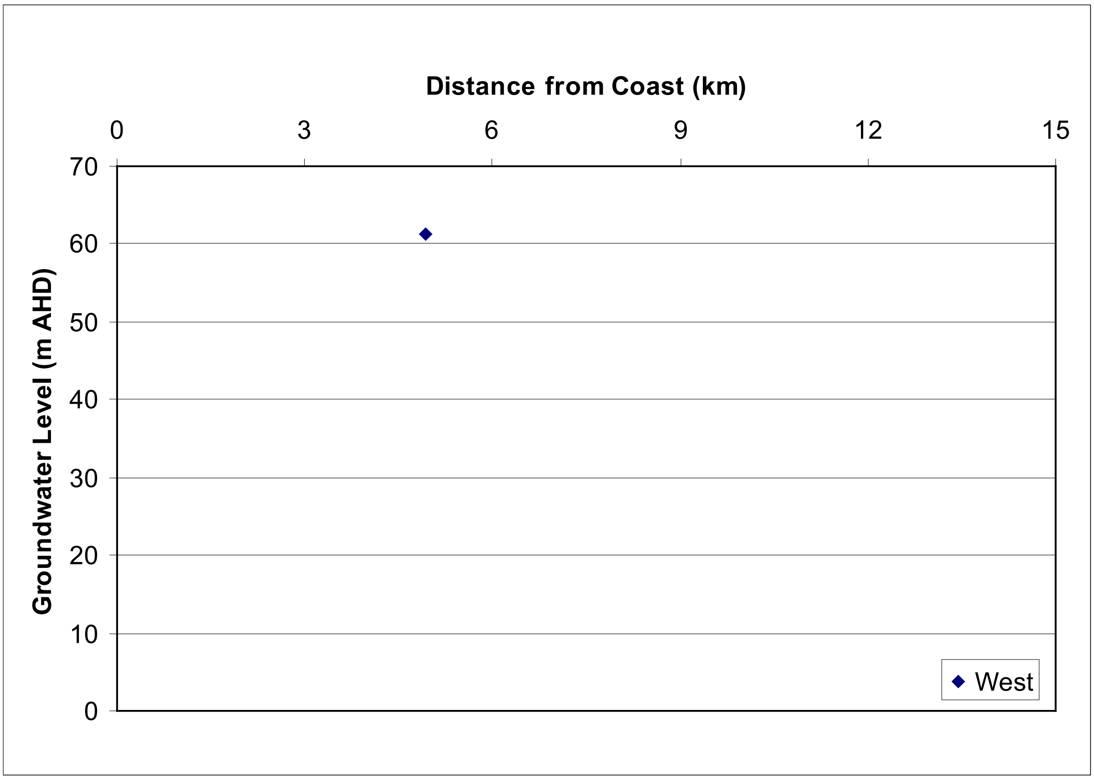
Distance from Coast (km)
0
3
6
9
12
15
160
140
120
100
80
60
40
20
0
-20
Groundwater Level (m AHD)
Central South East


Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
100
90
80
70
60
50
40
30
20
10
0
Scottsdale


Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
0
-0.5
-1
-1.5
-2
-2.5
Smithton

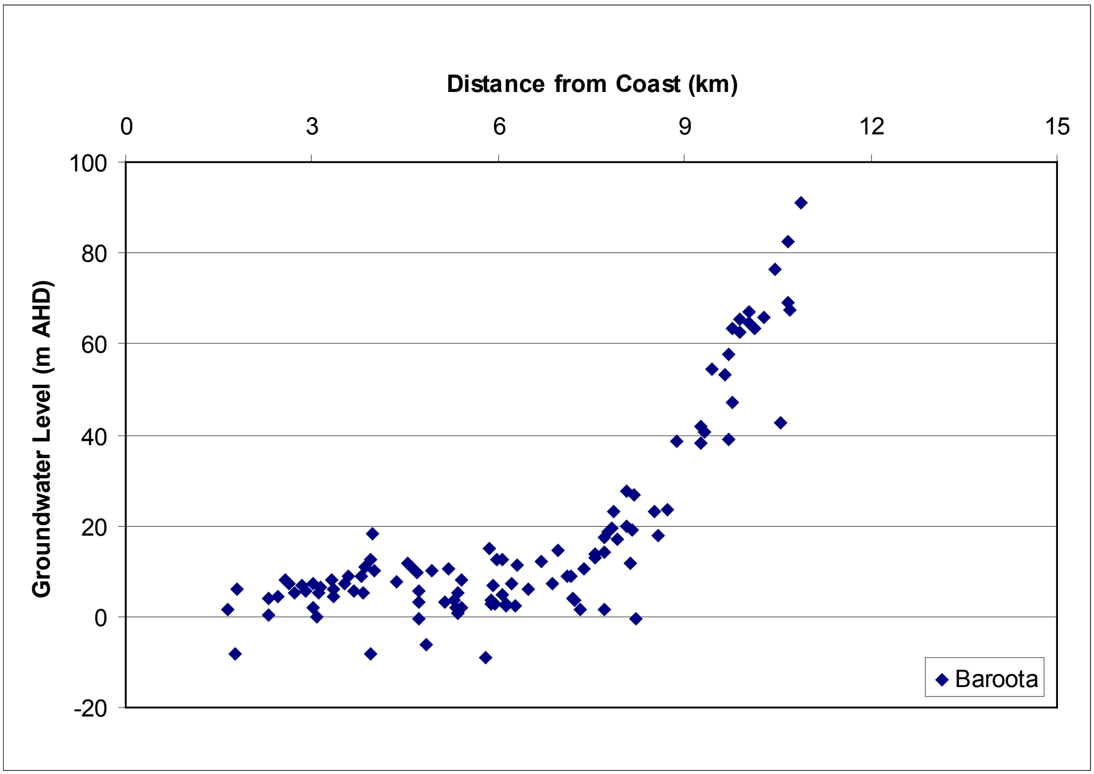

Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
20
18
16
14
12
10
8
6
4
2
0
Sorell

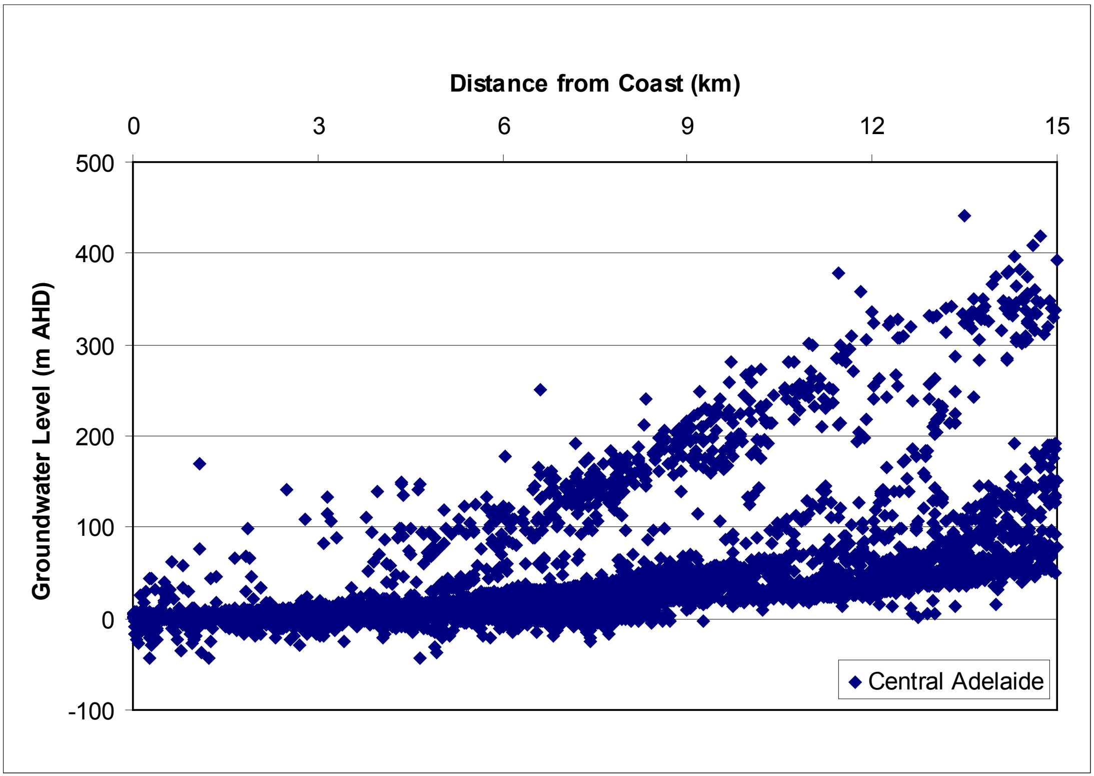

Distance from Coast (km)
0
3
6
9
12
15
Groundwater Level (m AHD)
20
18
16
14
12
10
8
6
4
2
0
Wesley Vale

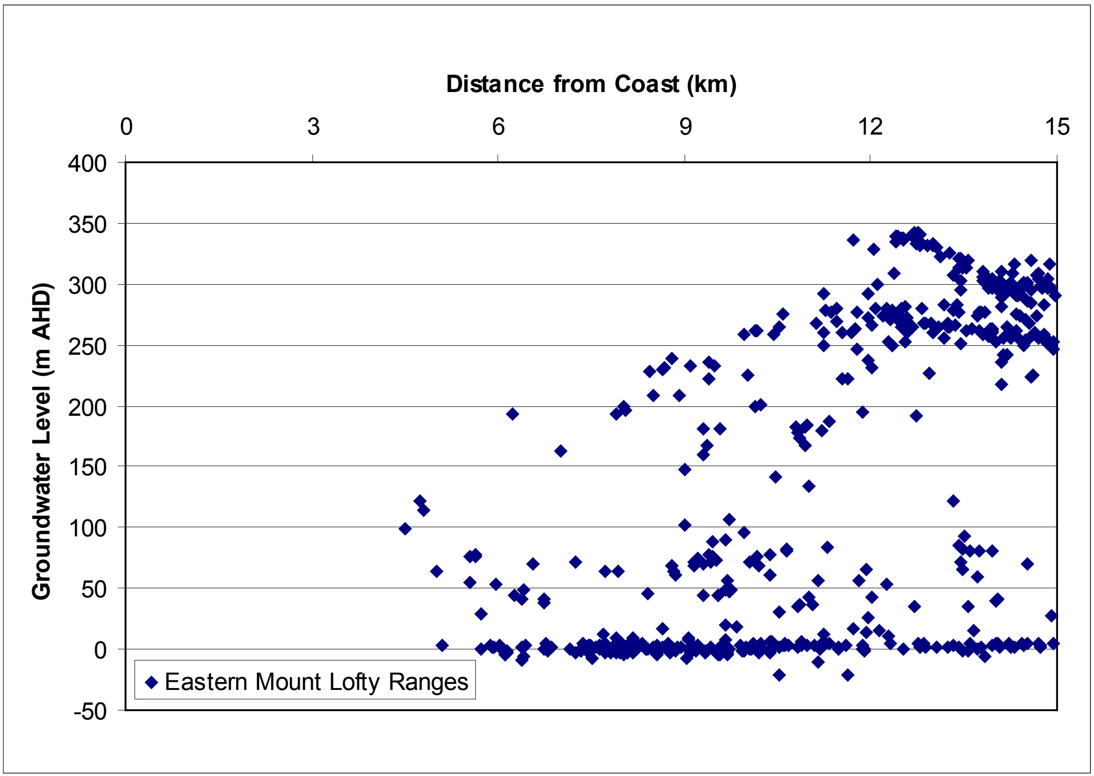


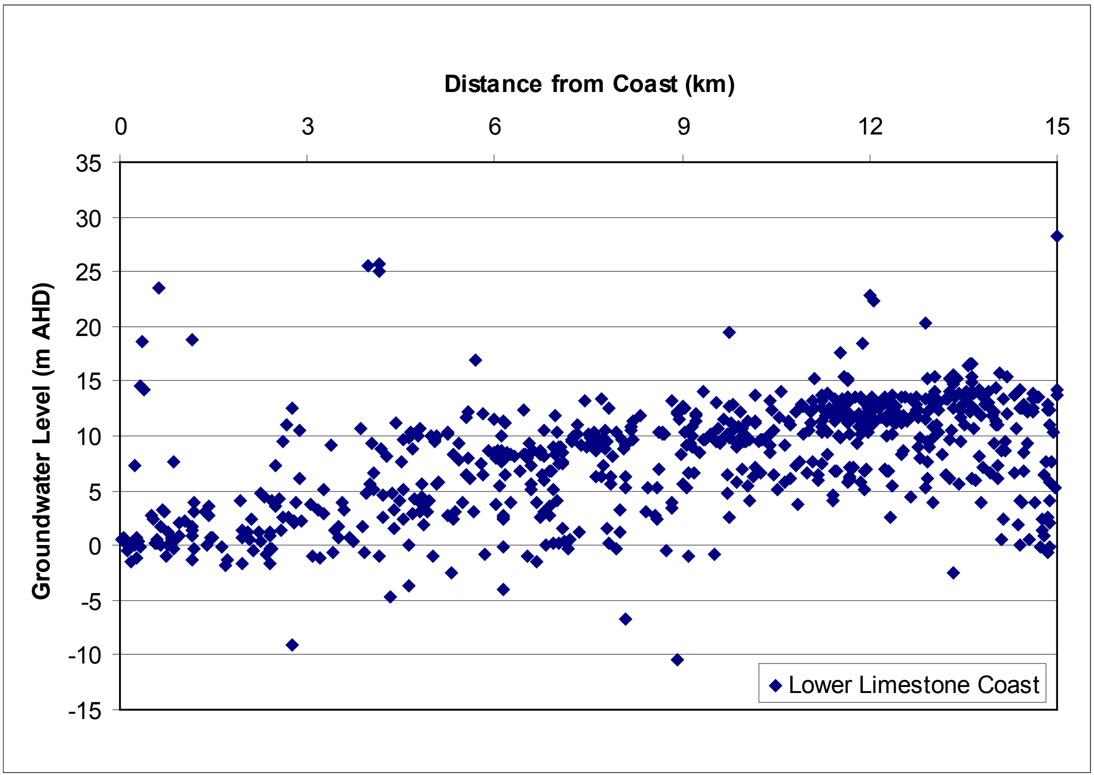
Distance from Coast (km)
0
3
6
9
12
15
70
60
50
40
30
20
10
0
Groundwater Level (m AHD)
West

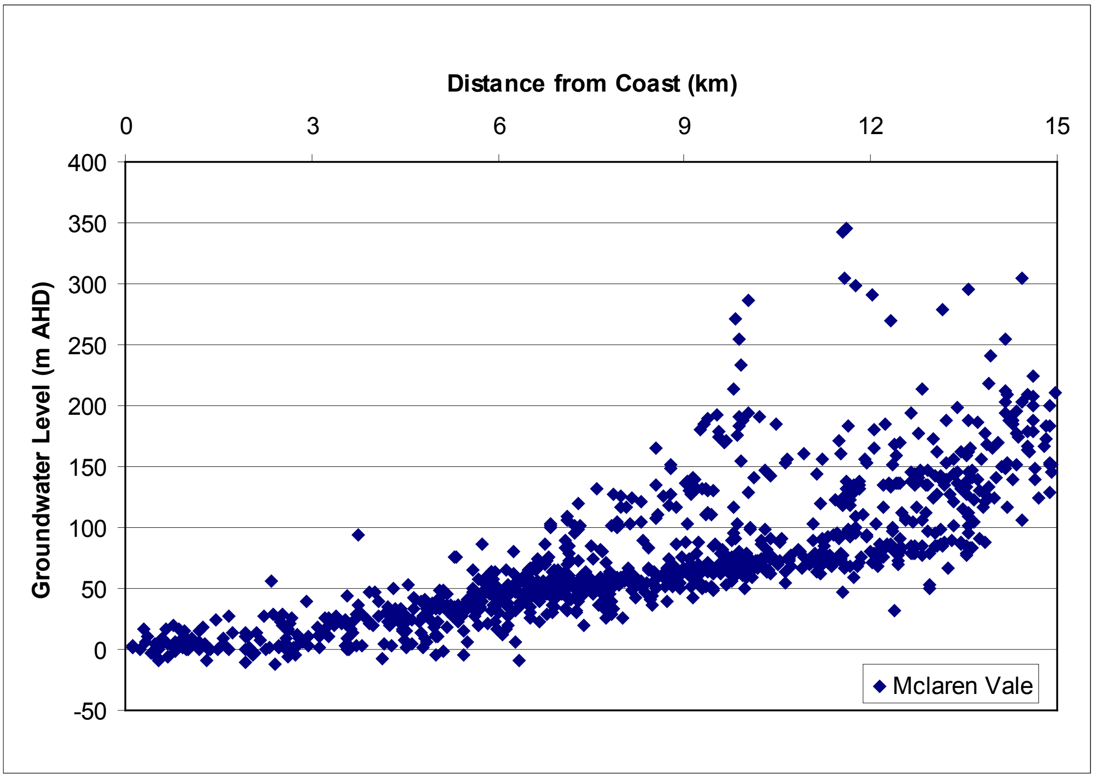
South Australia



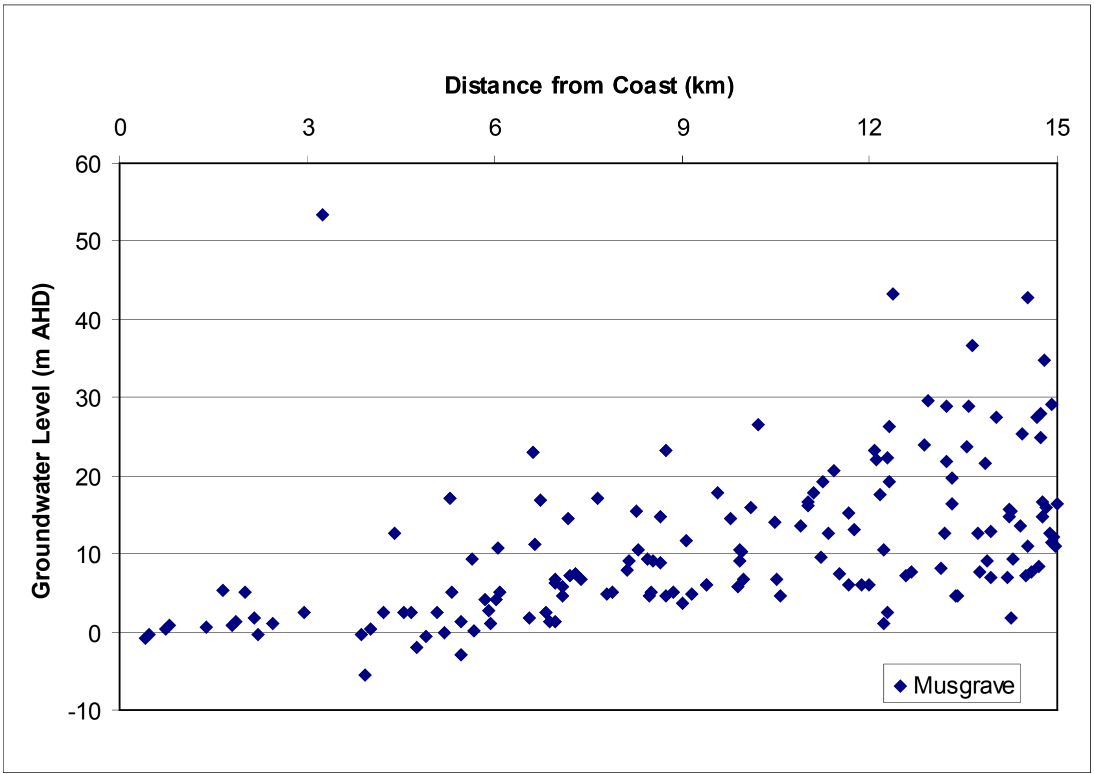



Distance from Coast (km)
0
3
6
9
12
15
400
350
300
250
200
150
100
50
0
-50
Groundwater Level (m AHD)
Eastern Mount Lofty Ranges

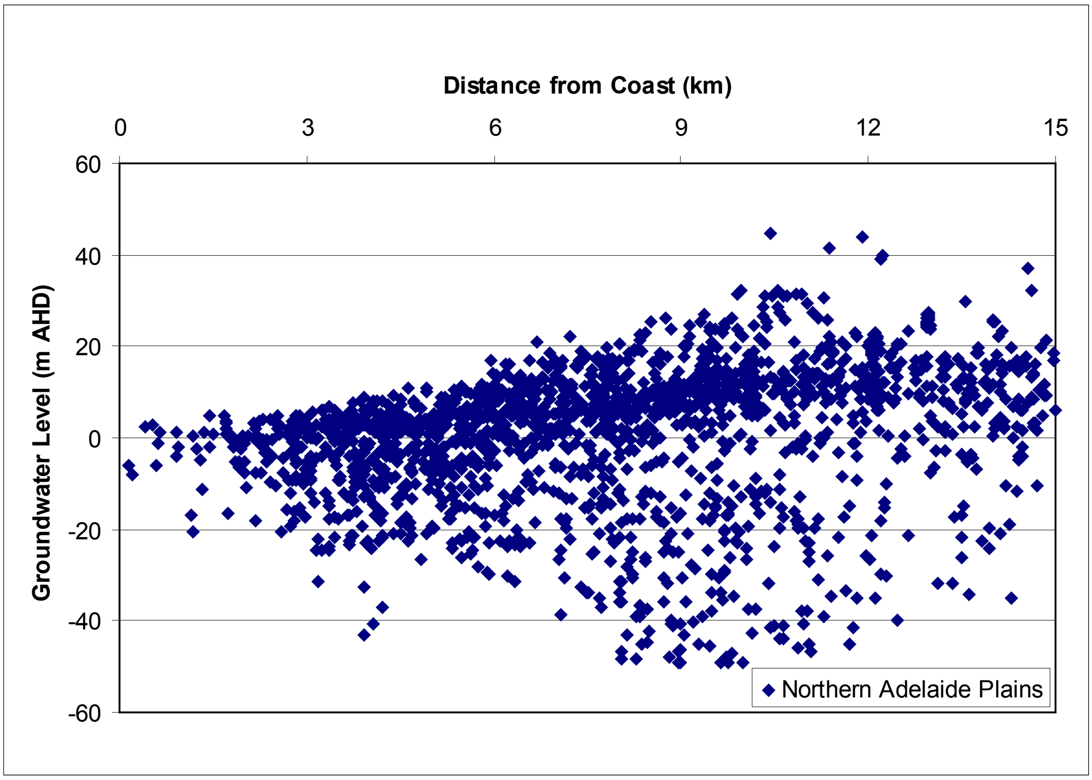

Distance from Coast (km)
0
3
6
9
12
15
35
30
25
20
15
10
5
0
-5
-10
-15
Groundwater Level (m AHD)
Lower Limestone Coast

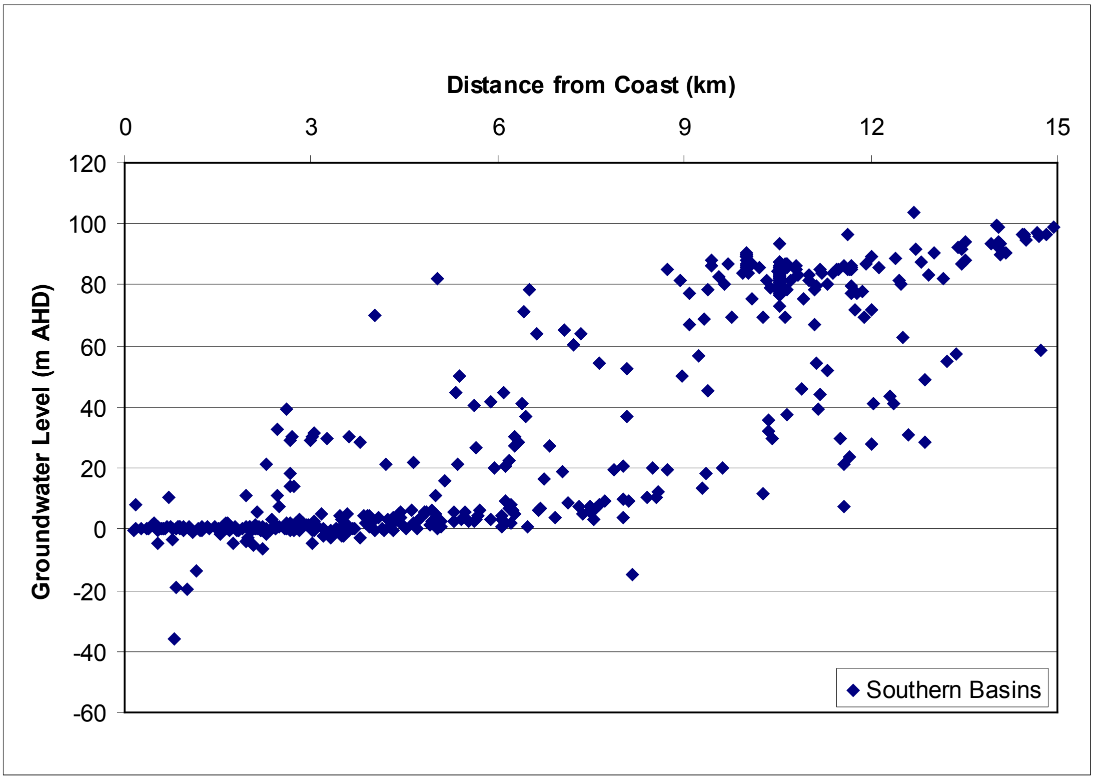


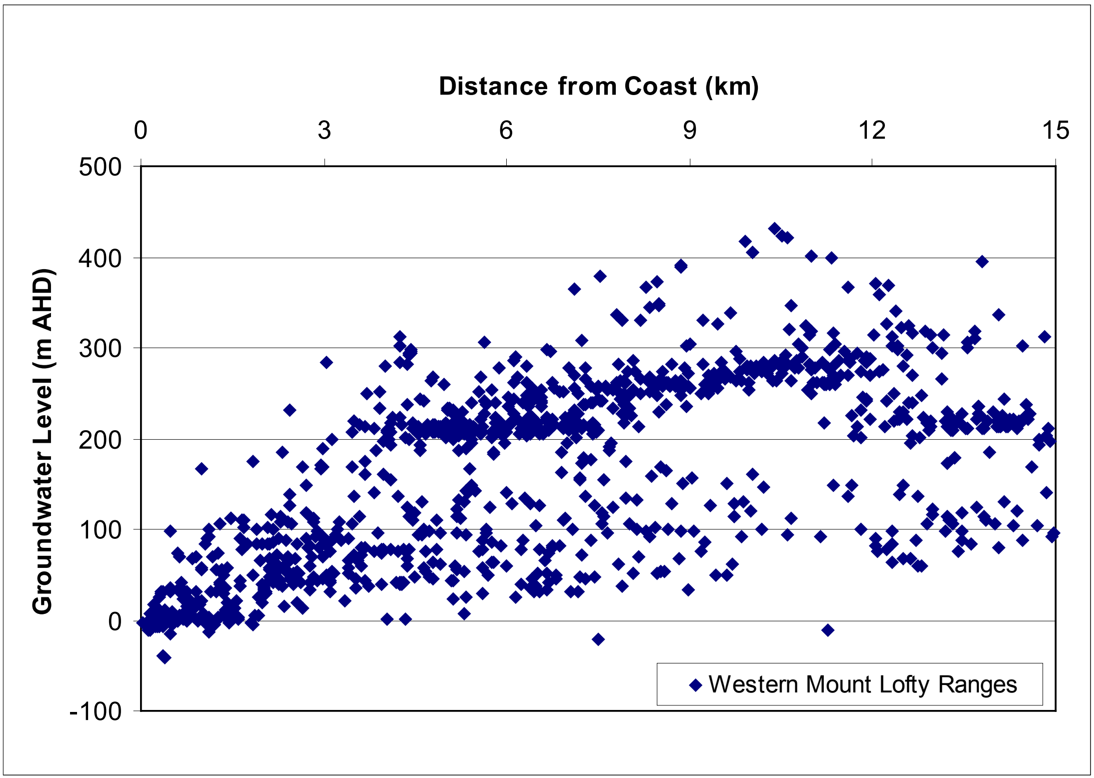
Distance from Coast (km)
0
3
6
9
12
15
400
350
300
250
200
150
100
50
0
-50
Groundwater Level (m AHD)
Mclaren Vale



Distance from Coast (km)
0
3
6
9
12
15
60
50
40
30
20
10
0
-10
Groundwater Level (m AHD)
Musgrave


Distance from Coast (km)
0
3
6
9
12
15
60
40
20
0
-20
-40
-60
Groundwater Level (m AHD)
Northern Adelaide Plains


Distance from Coast (km)
0
3
6
9
12
15
120
100
80
60
40
20
0
-20
-40
-60
Groundwater Level (m AHD)
Southern Basins

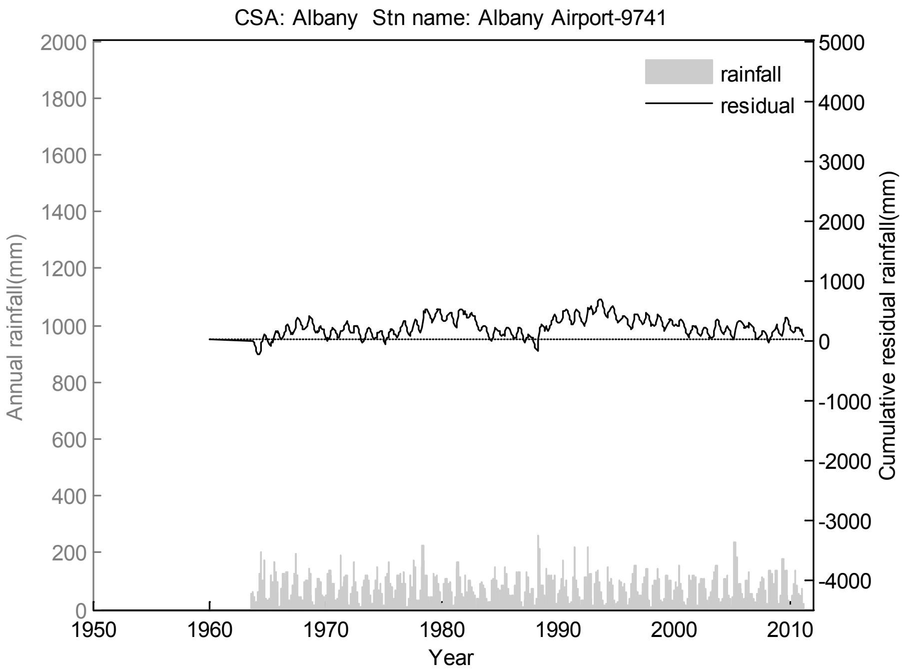

Distance from Coast (km)
0
3
6
9
12
15
500
400
300
200
100
0
-100
Groundwater Level (m AHD)
Western Mount Lofty Ranges

Appendix 3: Plots of cumulative residual rainfall

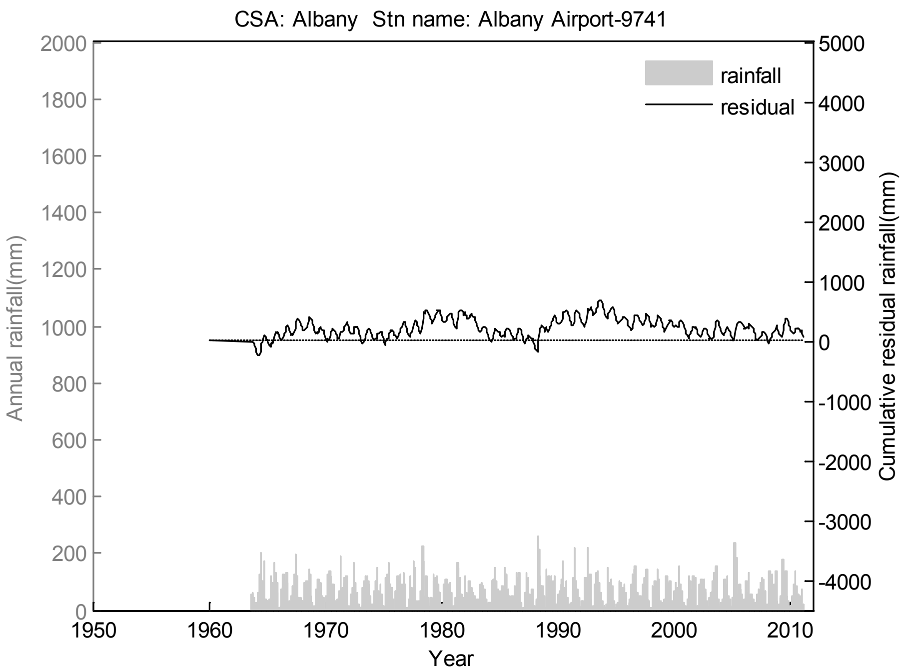
The following plots show annual rainfall and the cumulative deviation of monthly rainfall from the historical mean at representative rainfall stations in respective GMAs: (source: monthly rainfall data from Bureau of Meteorology).

Western Australia

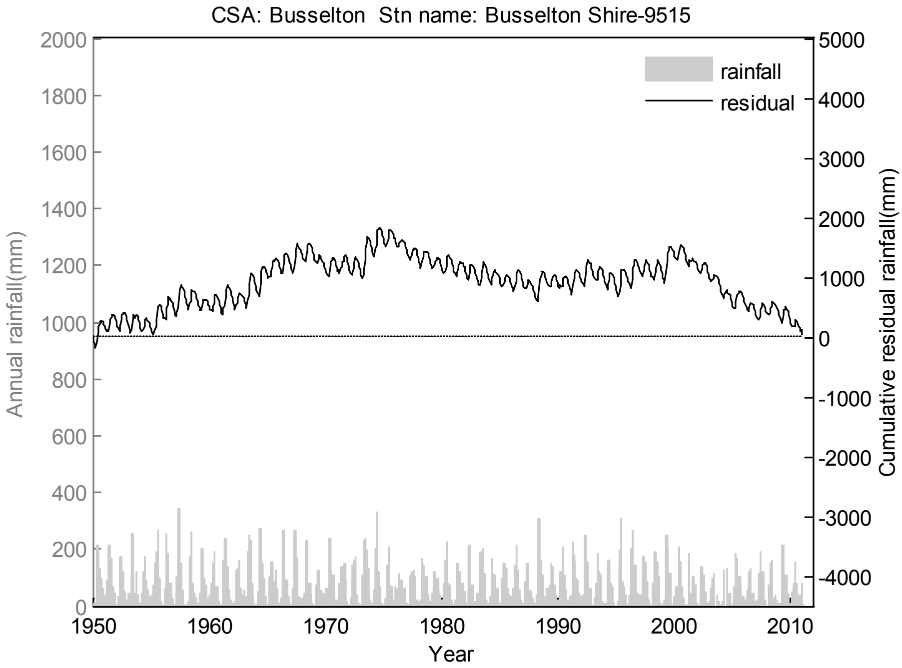
Albany



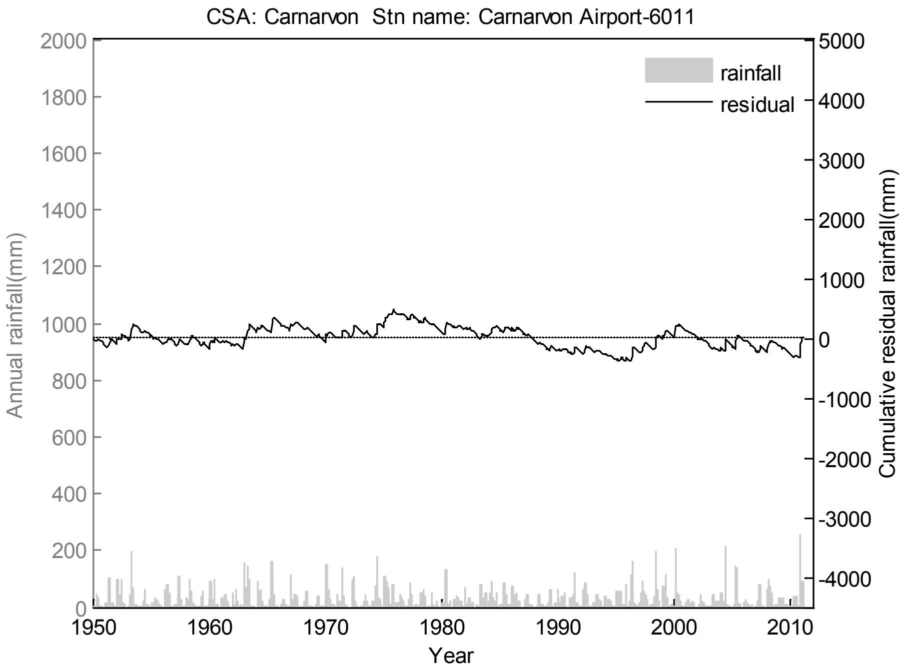
Broome


CSA: Albany Stn name: Albany Airport-9741
rainfall
residual
Annual rainfall(mm)
Cumulative residual rainfall(mm)
Year

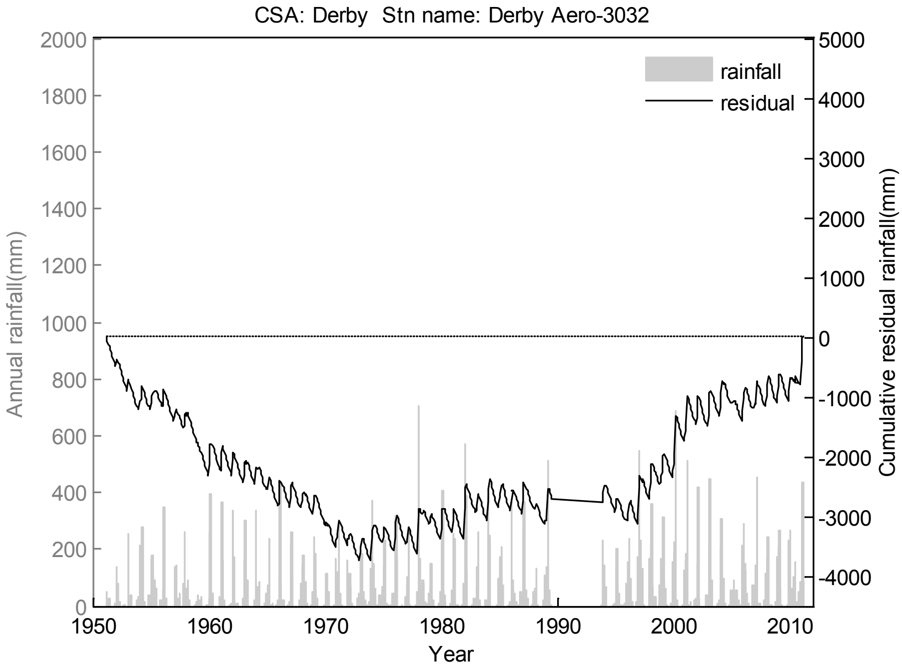
Busselton



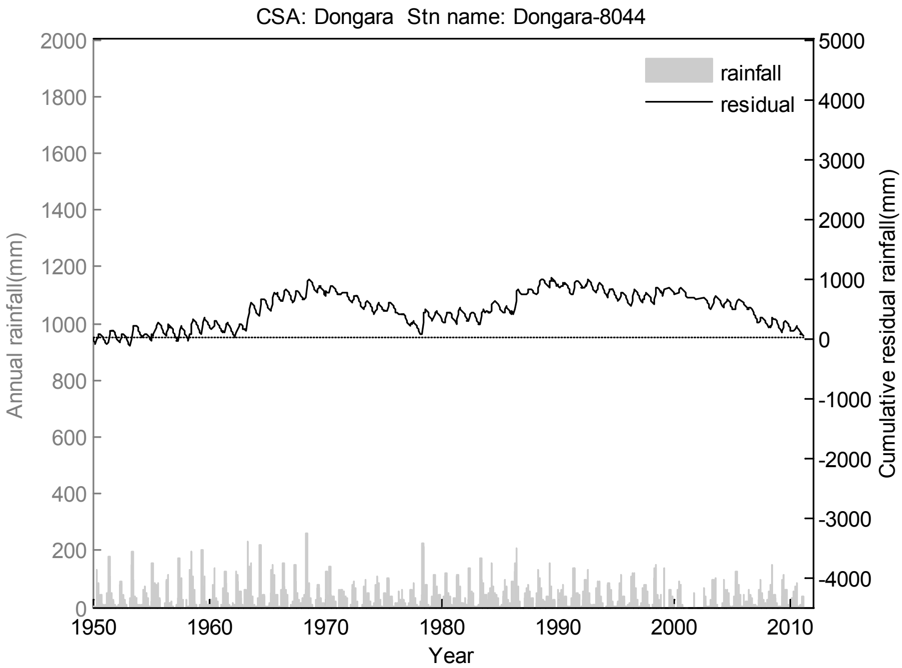
Carnarvon



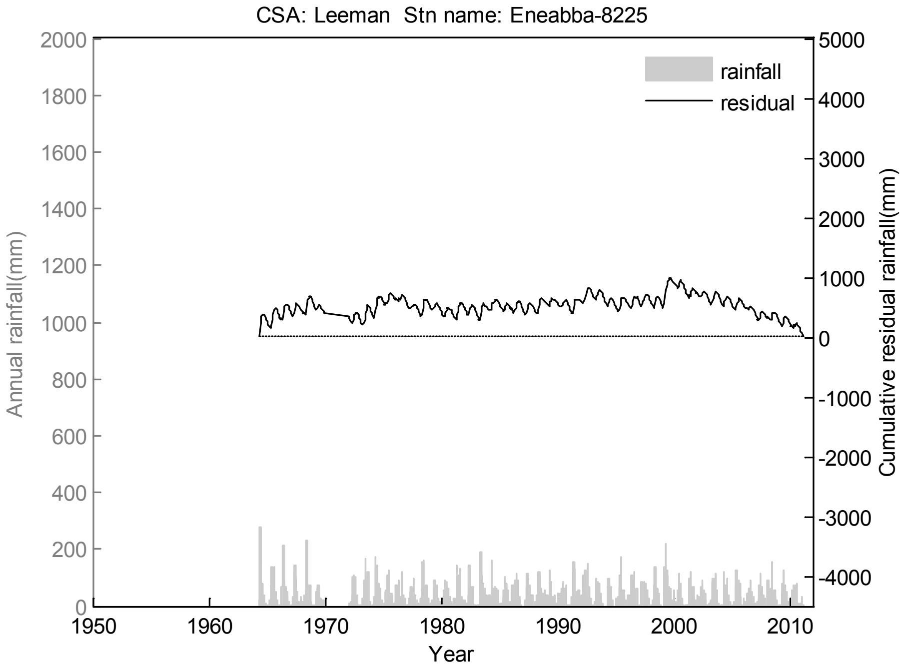
Derby



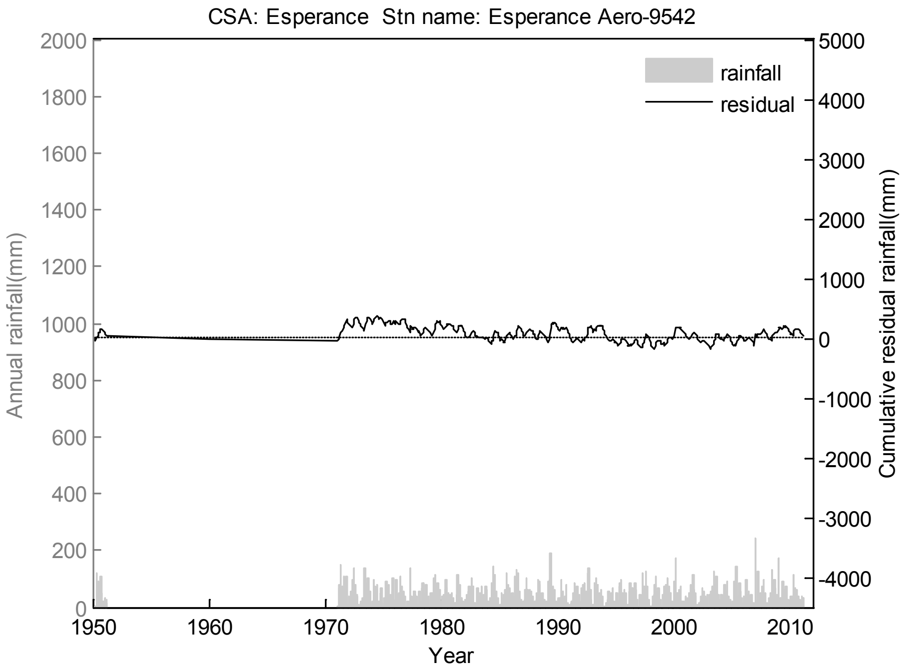
Dongara



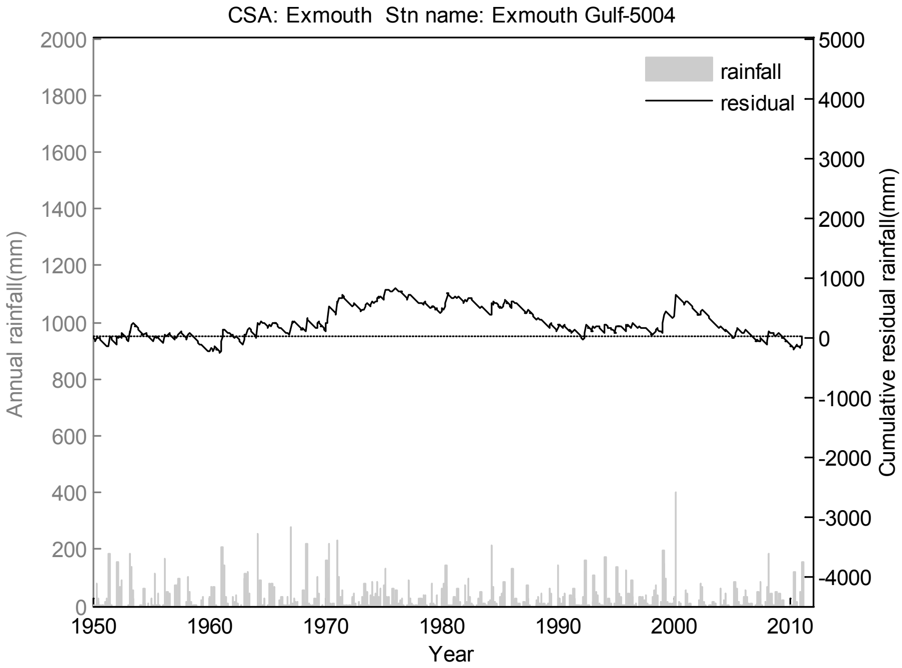
Leeman



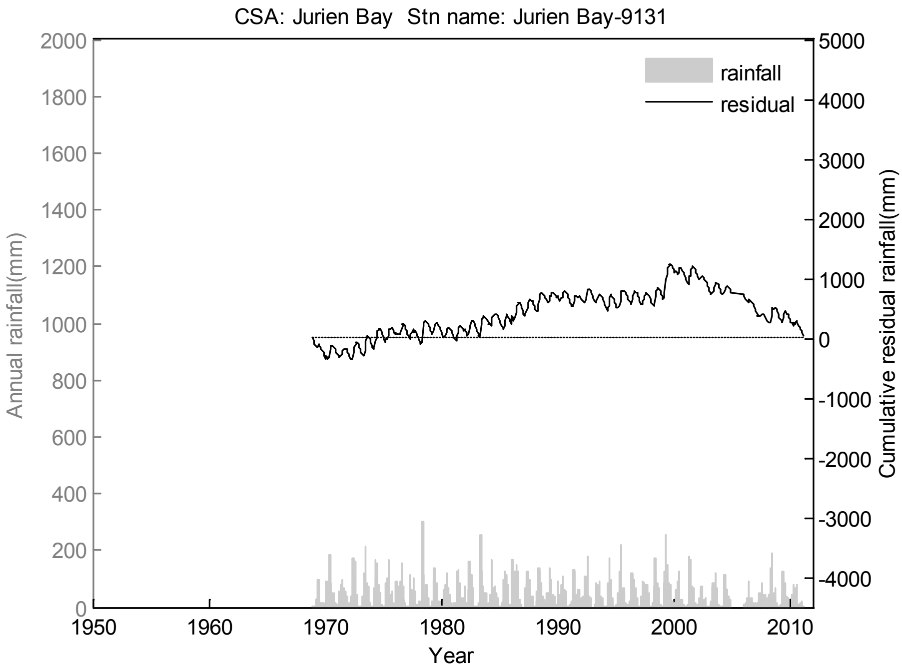
Esperance



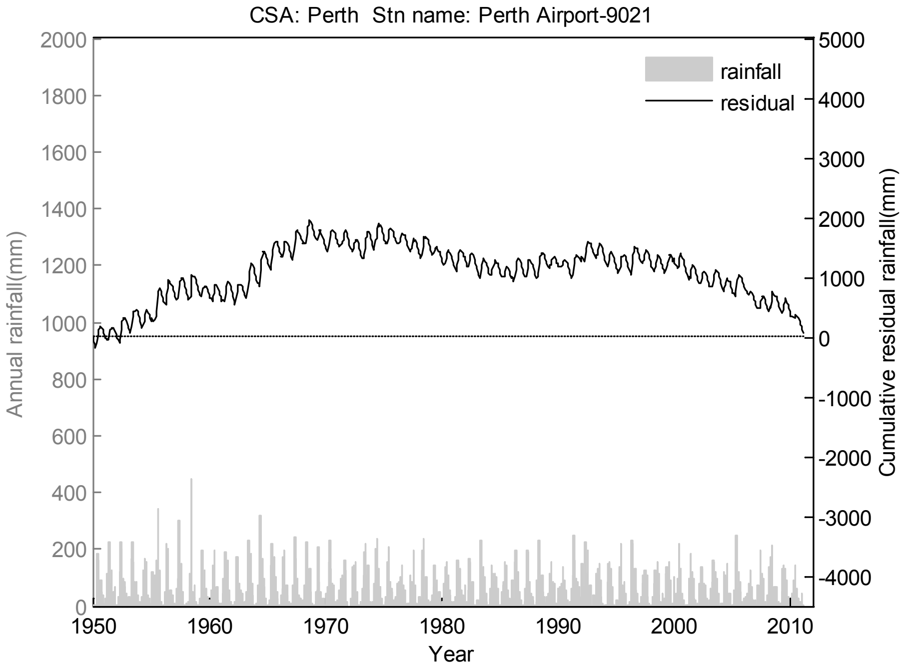
Exmouth



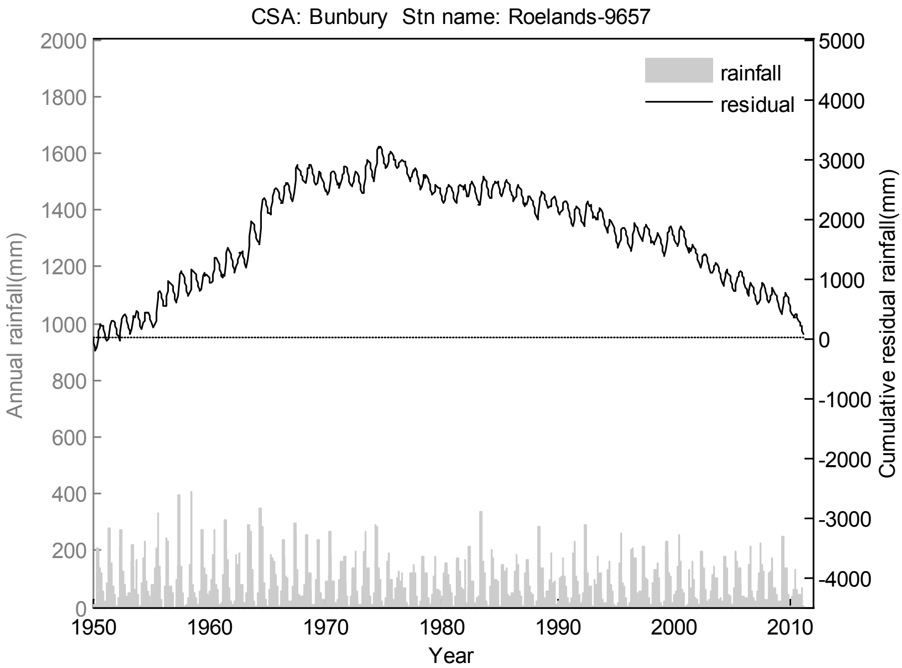
Jurien Bay



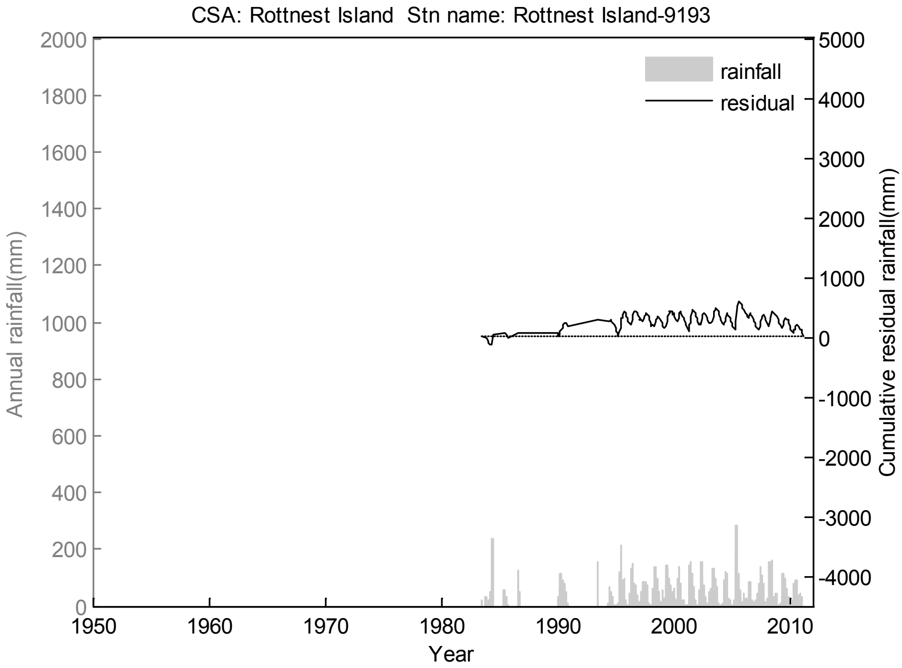
Perth



Bunbury

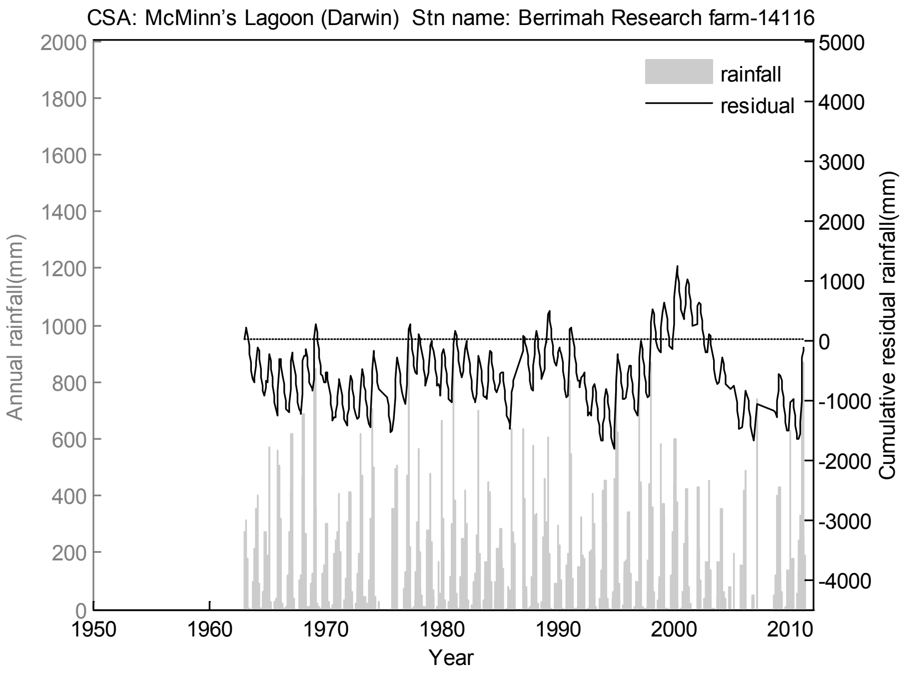


Rottnest Island

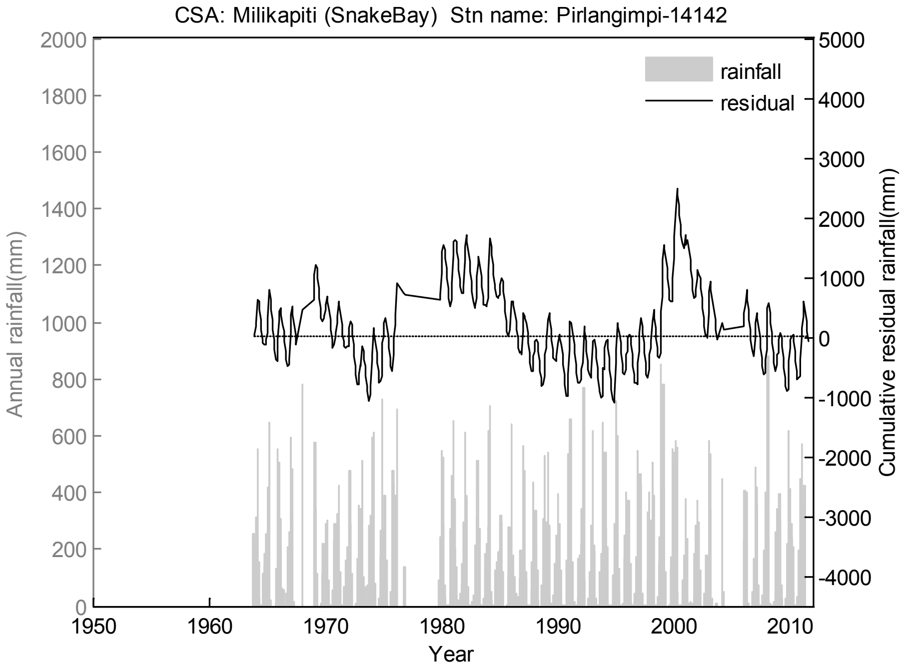


Northern Territory

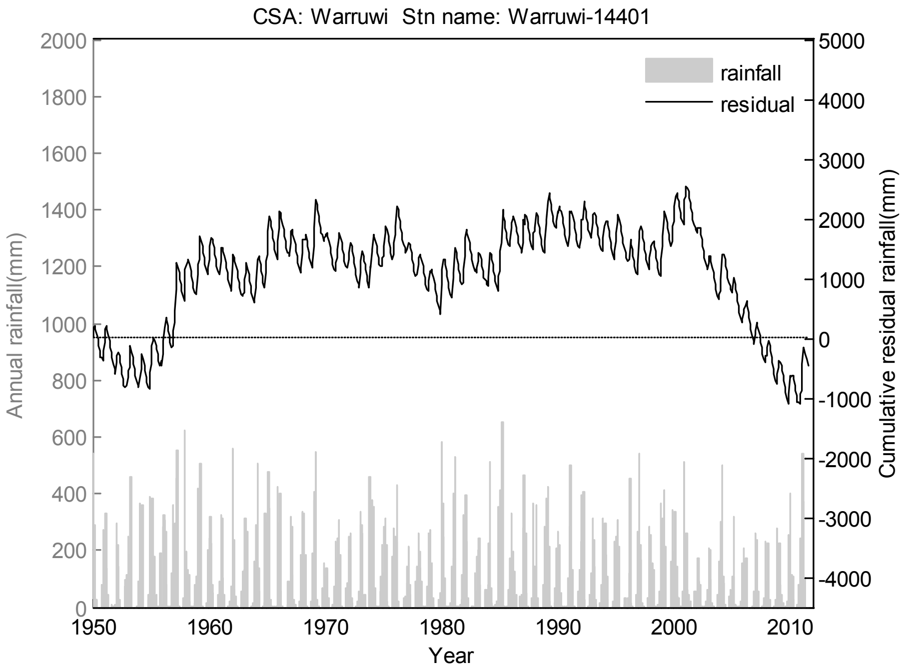
Darwin



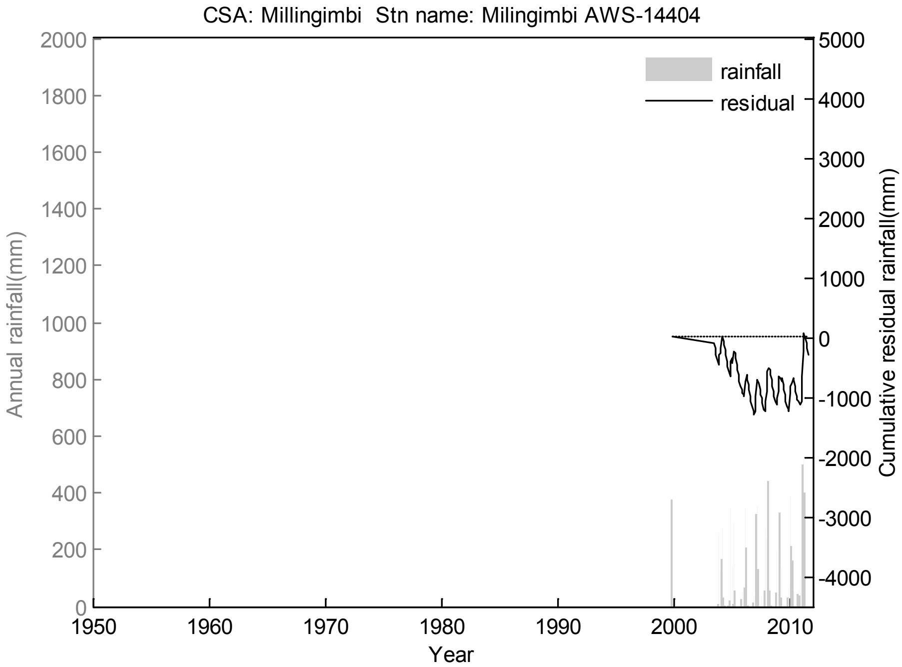
Snake Bay



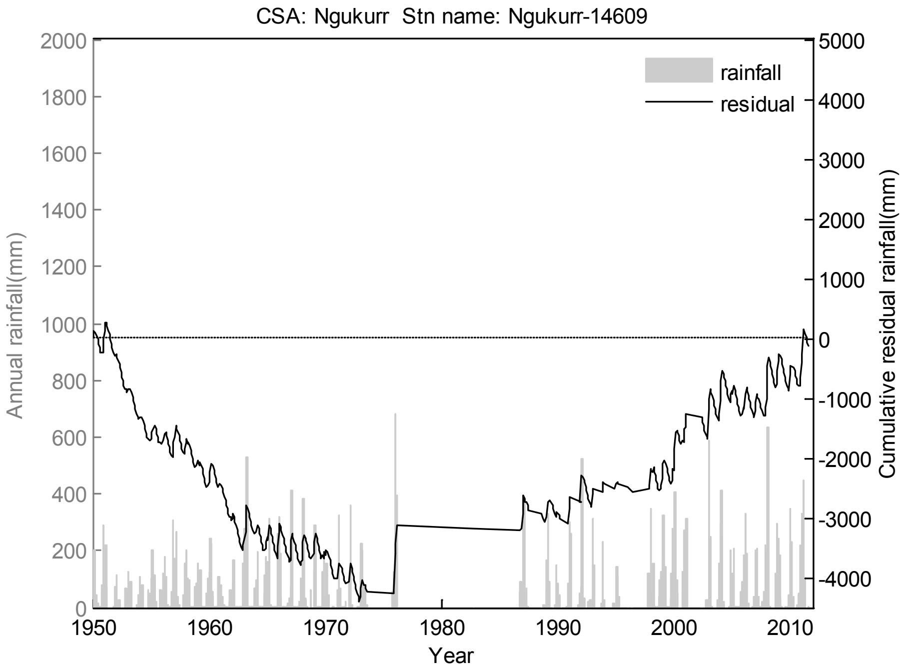
Warruwi



Milingimbi

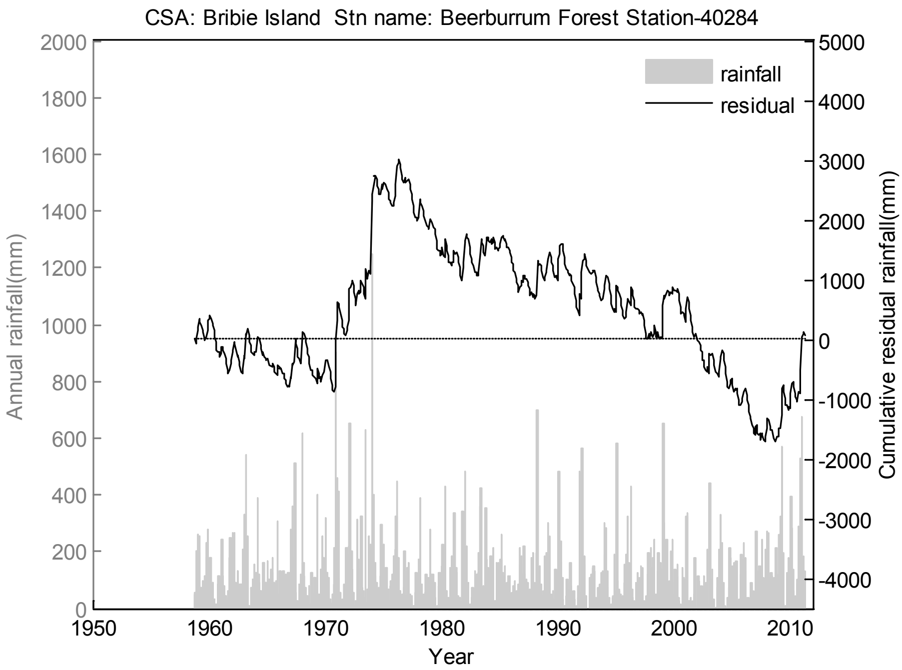


Ngukurr

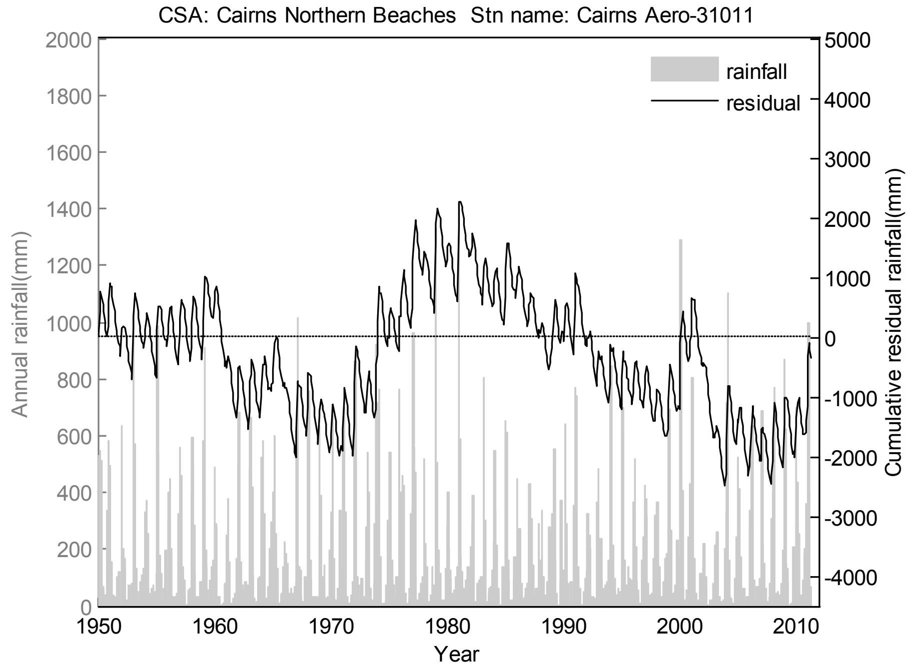


Queensland

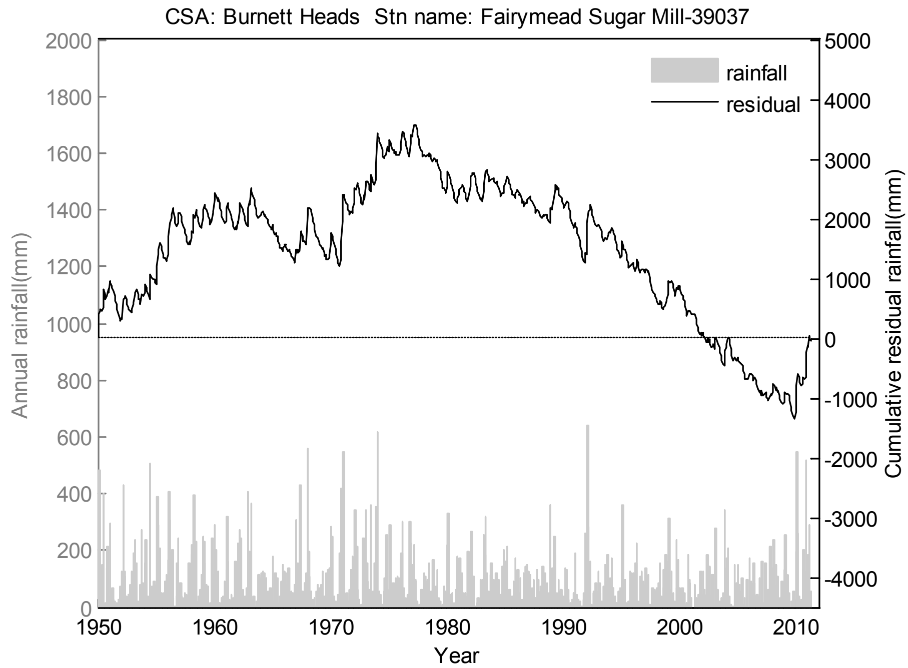
Bribie Island



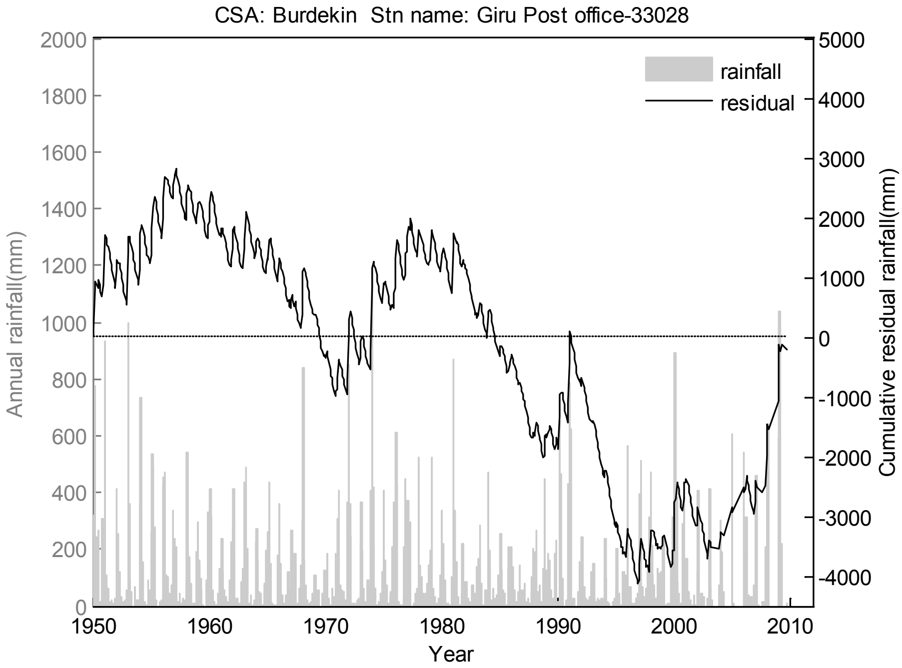
Cairns



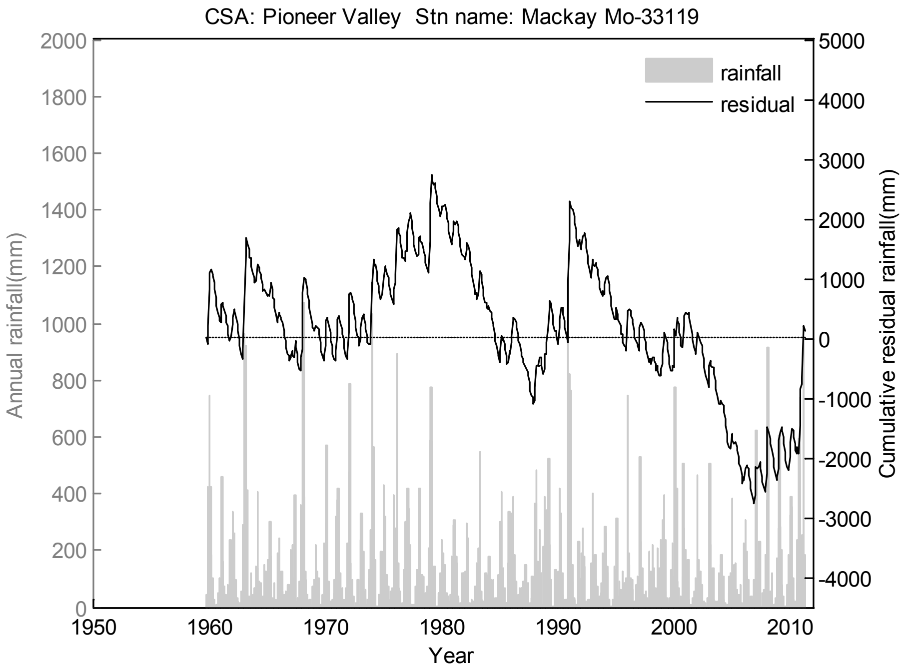
Burnett Heads



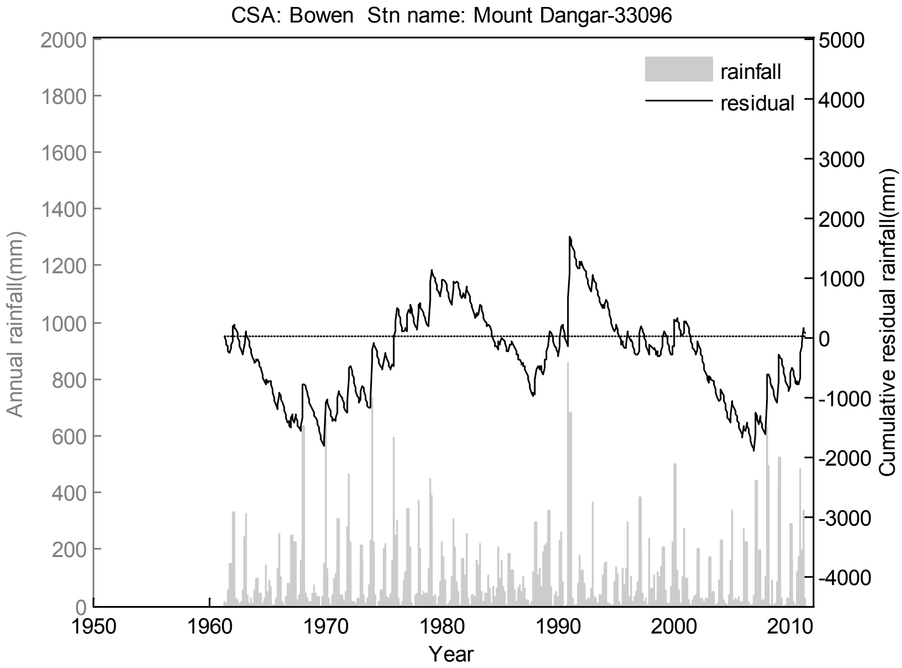
Burdekin



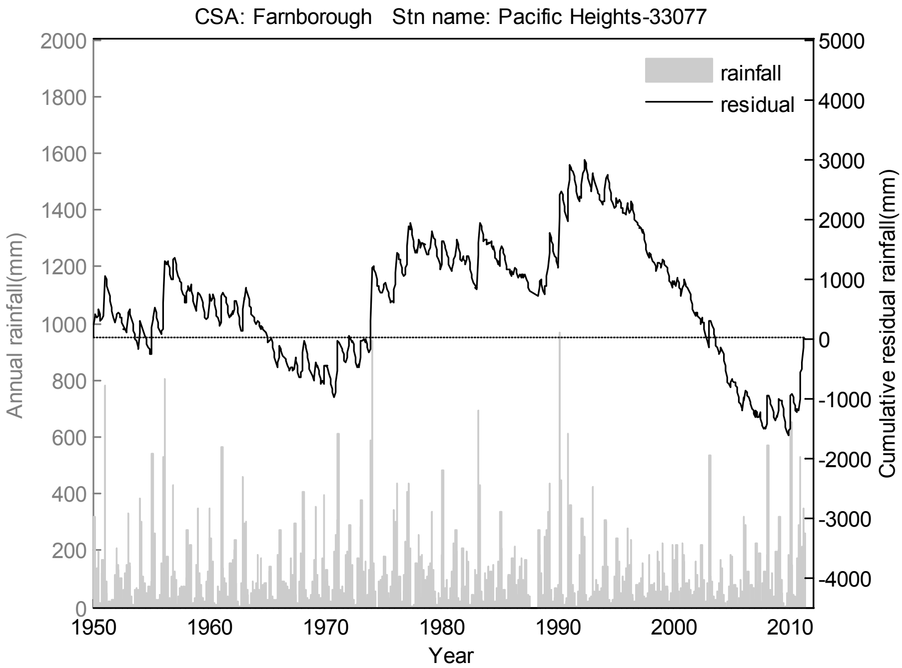
Mackay



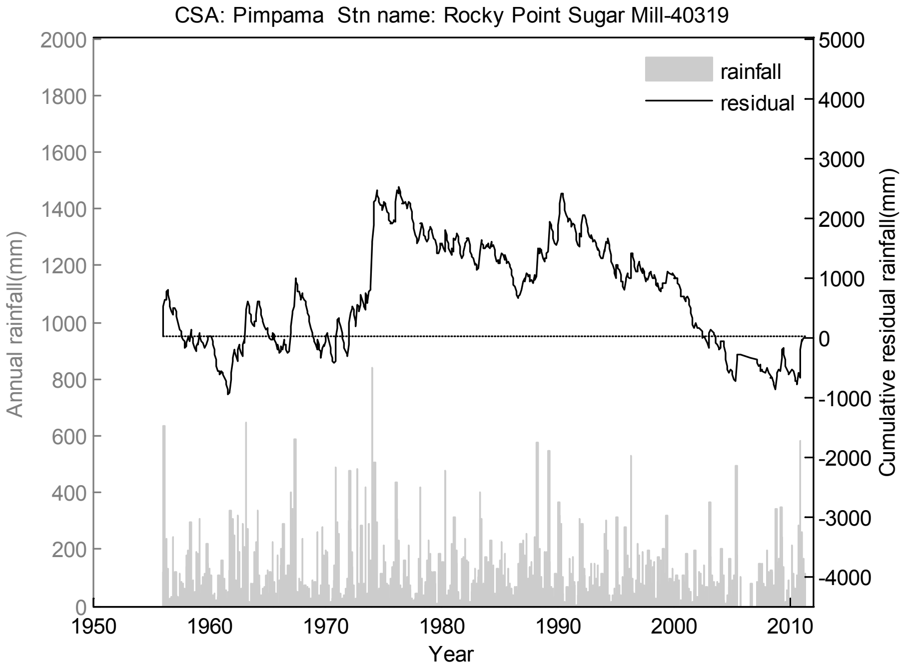
Bowen



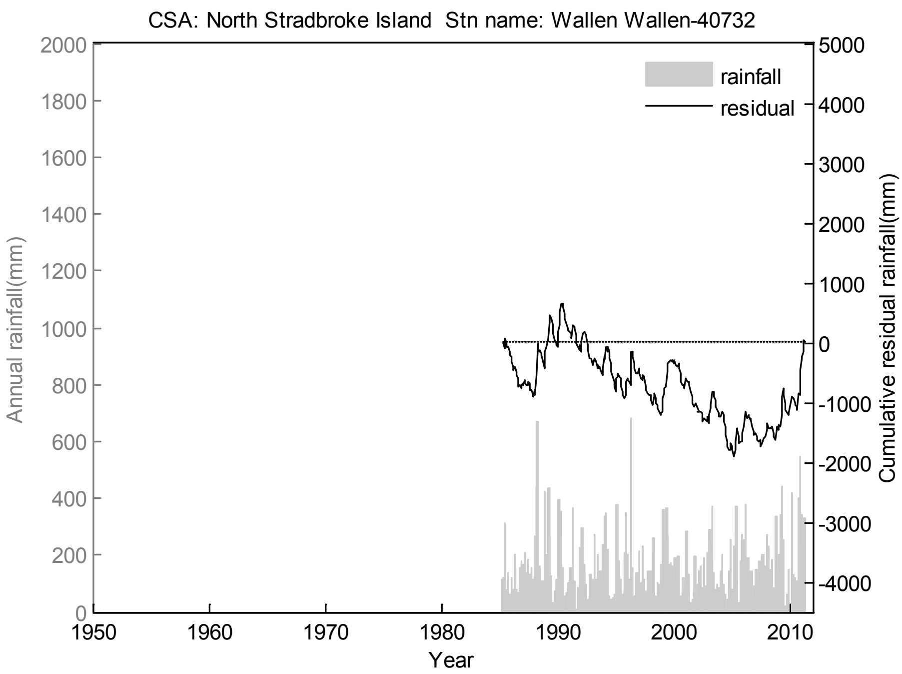
Farnborough



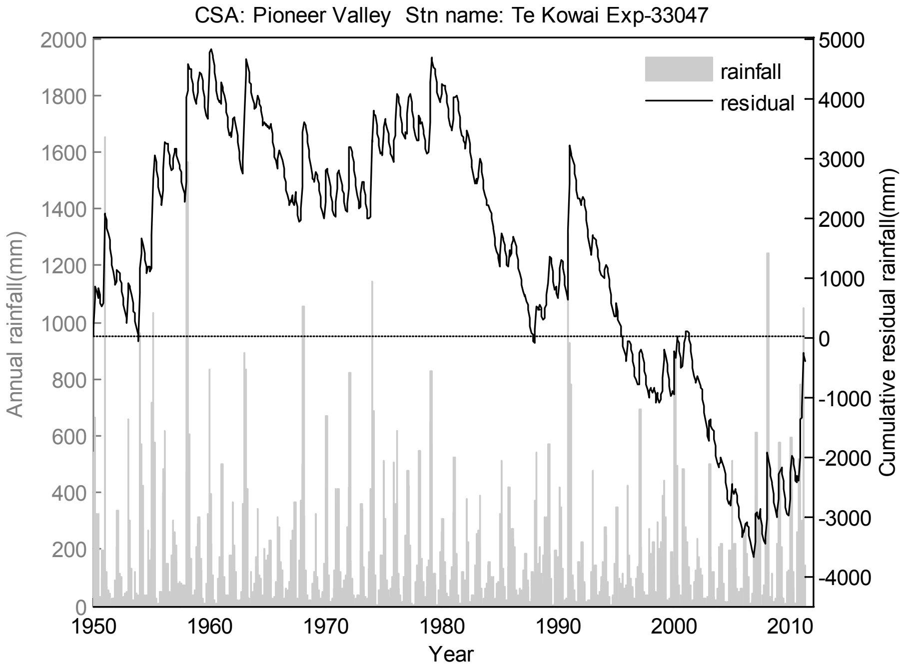
Pimpama



North Stradbroke Island

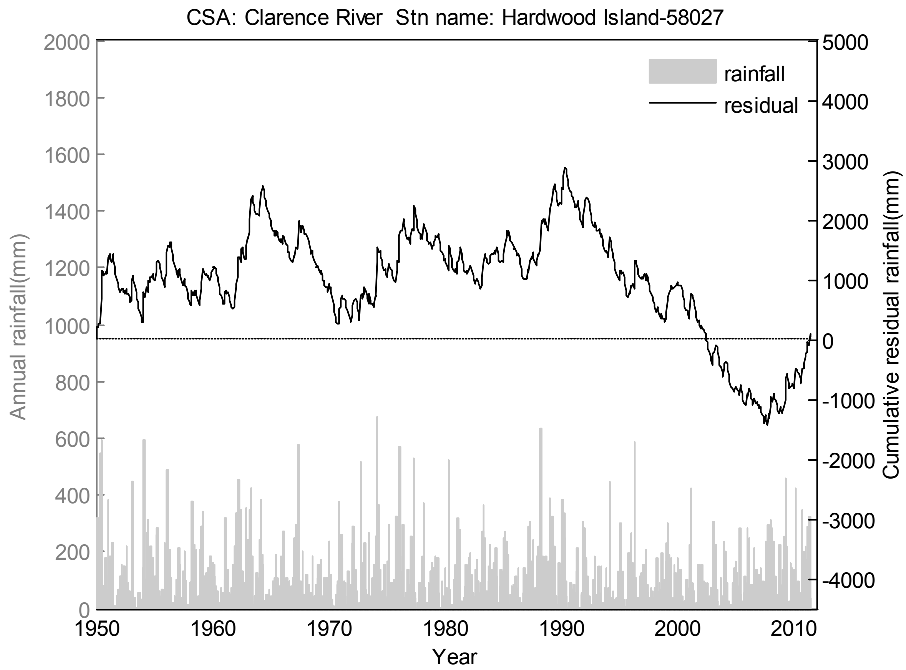


Pioneer Valley

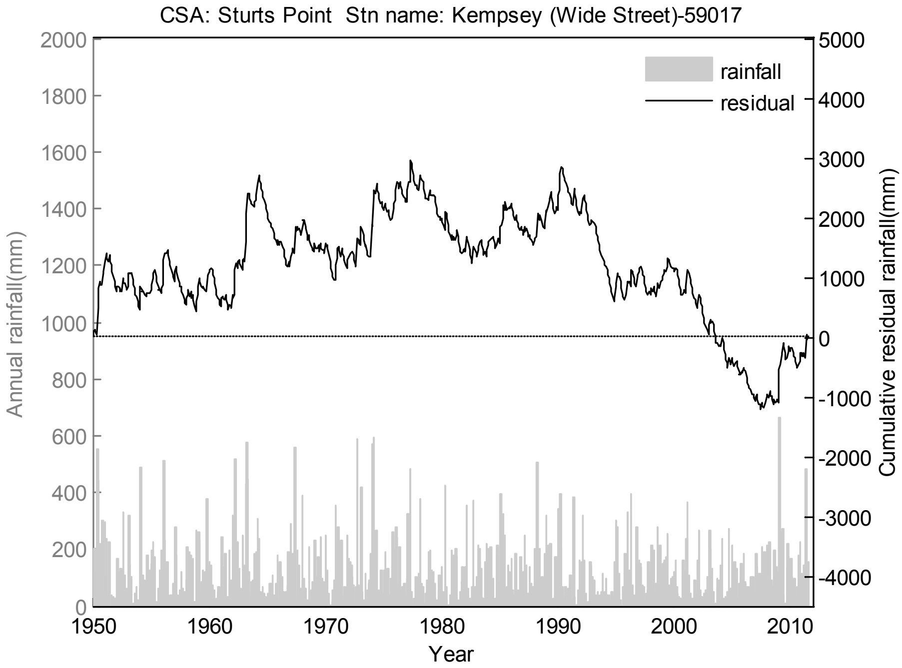


New South Wales

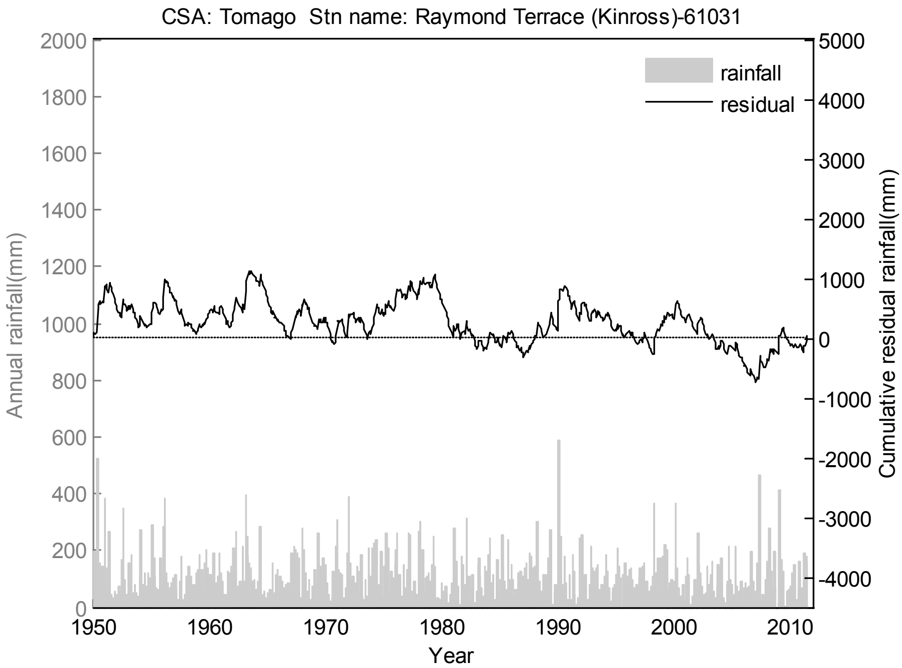
Harwood Island (Clarence River)



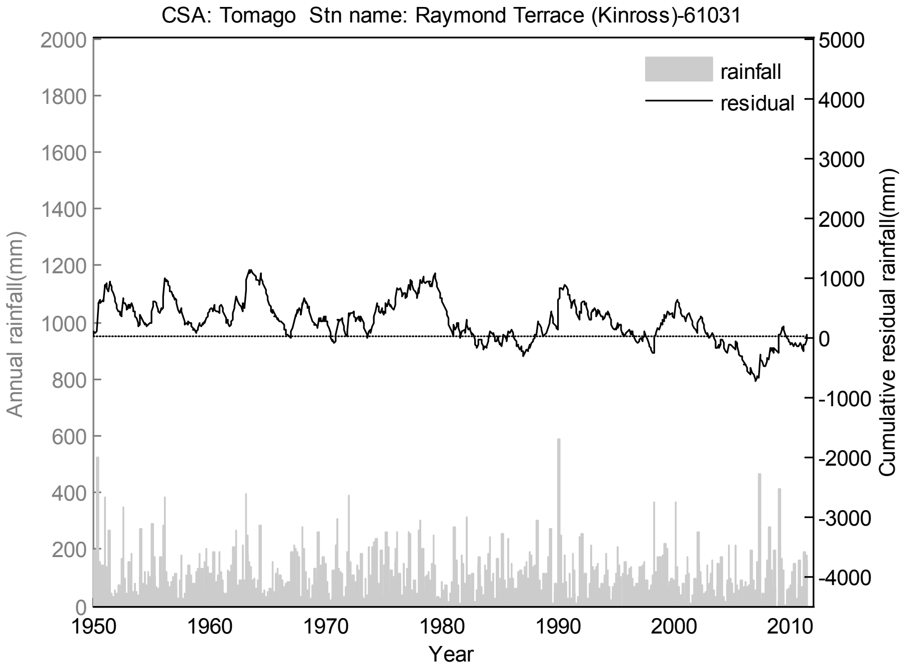
Kempsey (Stuarts Point)



Raymond Terrace (Tomago)

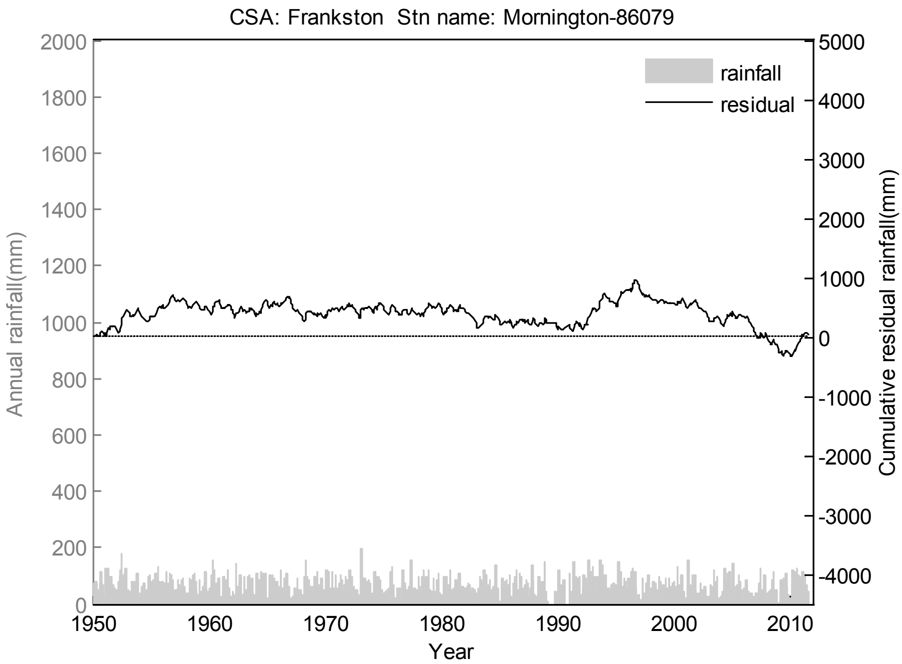


Sydney Botanic Gardens (Botany Sands)

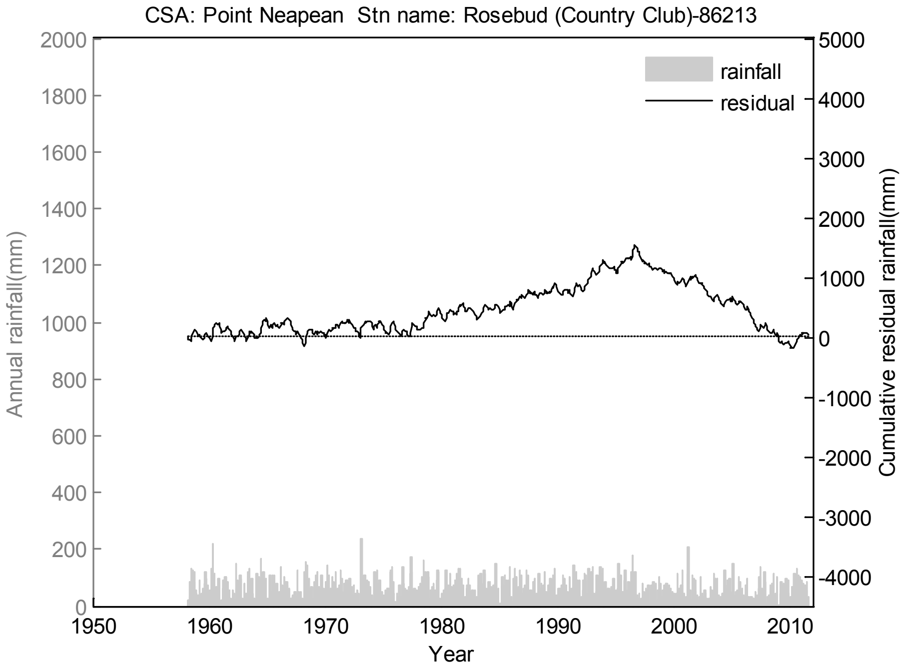


Victoria

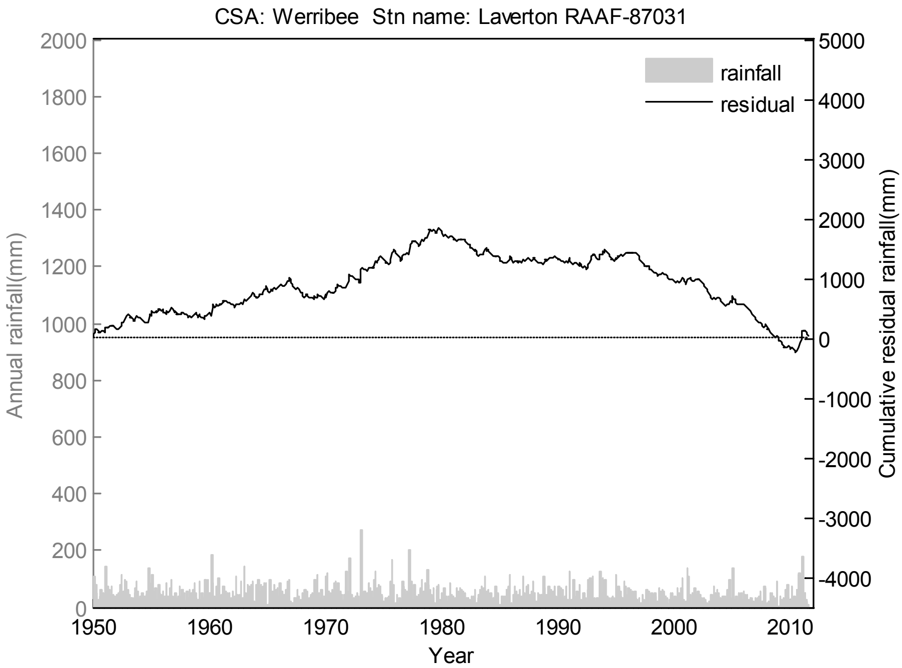
Frankston



Point Nepean

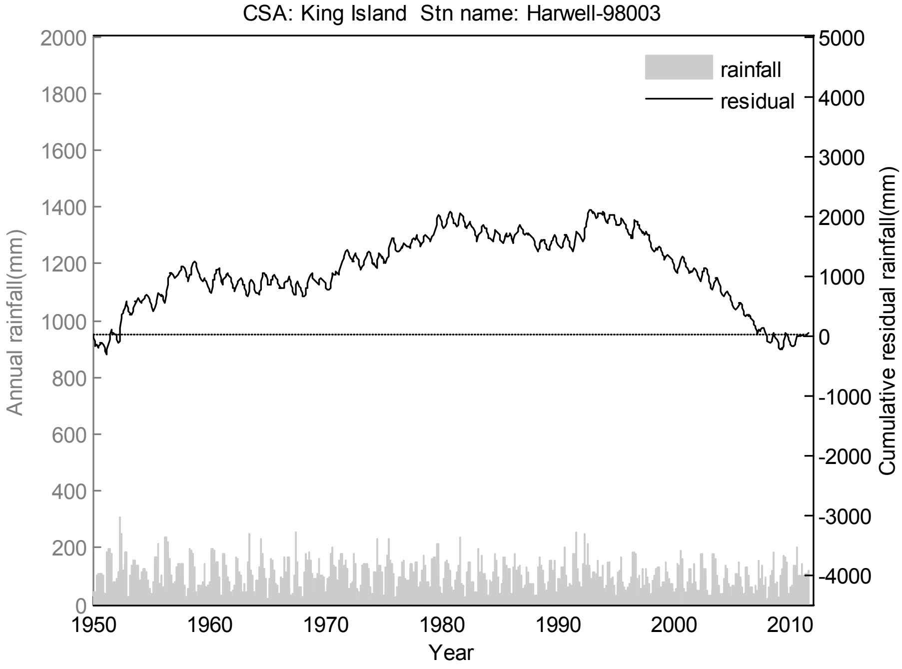


Werribee

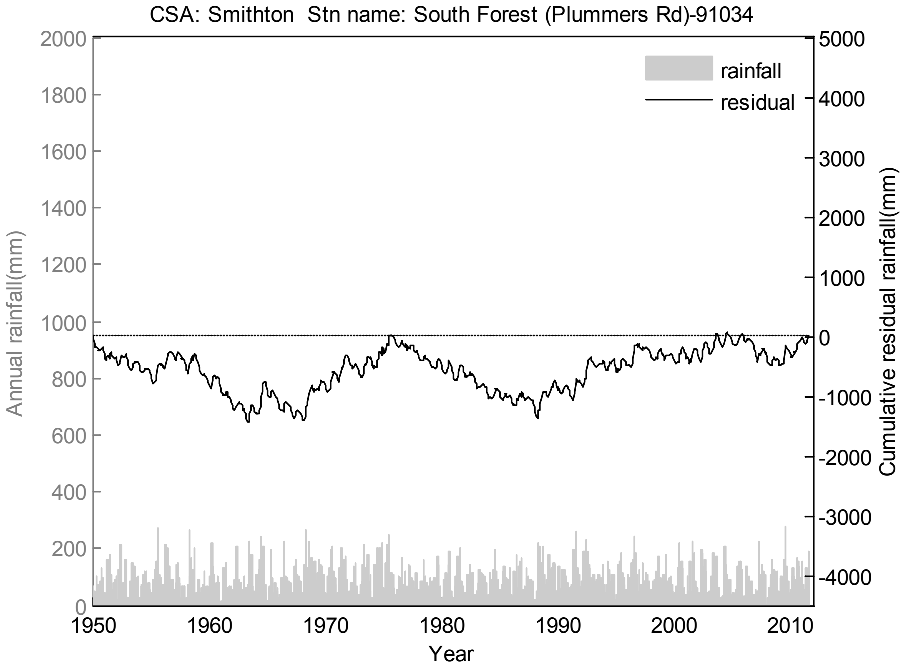


Tasmania

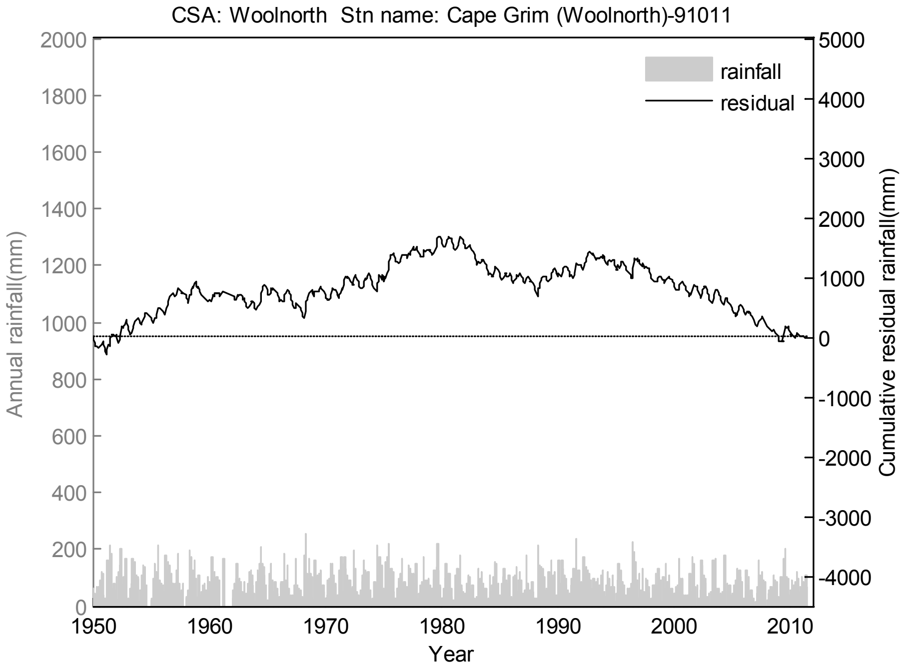
King Island



Smithton

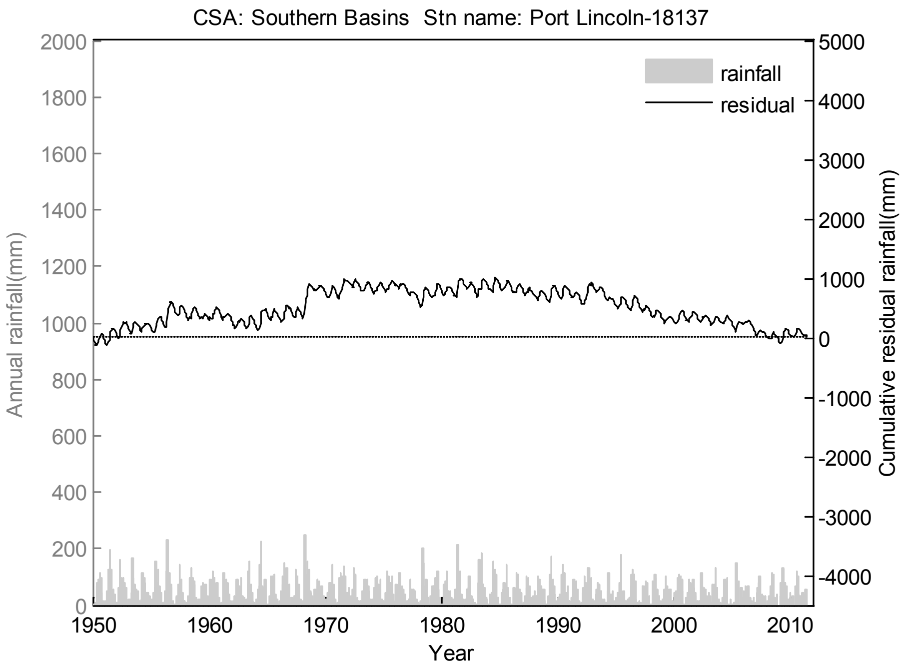


Woolnorth

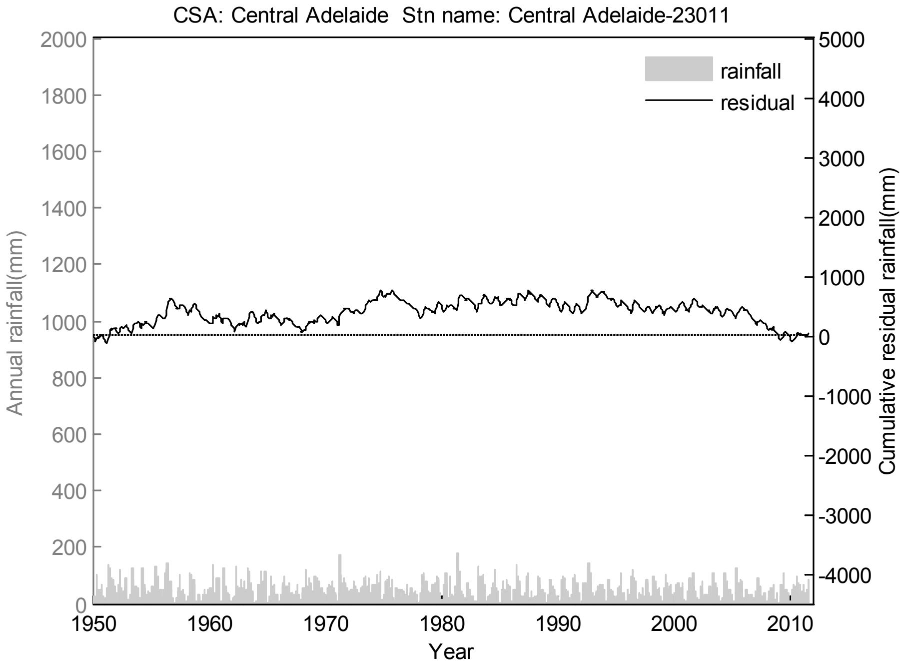

CSA: Woolnorth Stn name: Cape Grim (Woolnorth)-91011
rainfall
residual
Annual rainfall(mm)
Cumulative residual rainfall(mm)
Year
2000
1800
1600
1400
1200
1000
800
600
400
200
0
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
1950
1960
1970
1980
1990
2000
2010

South Australia

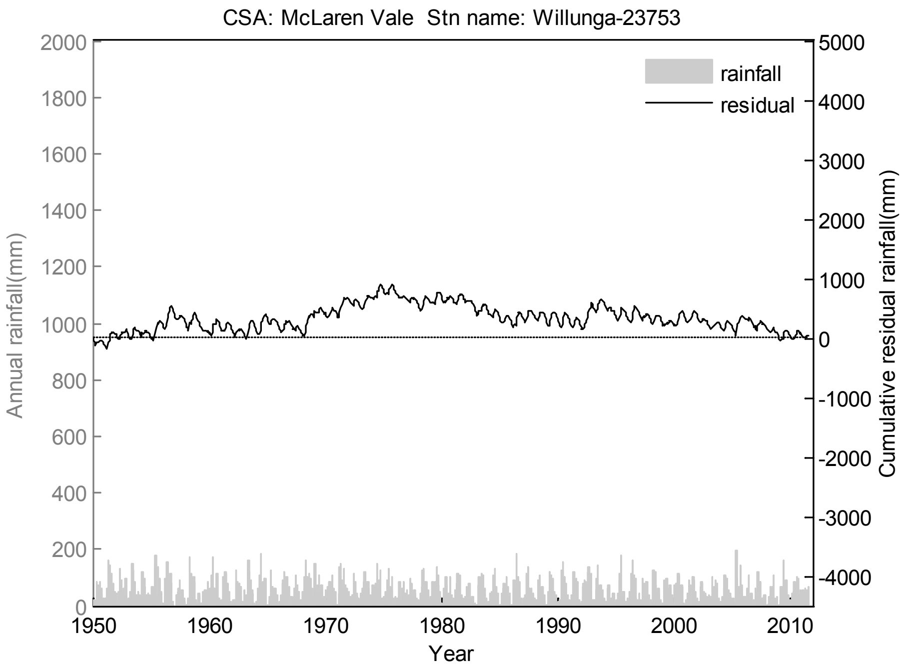
Southern Basins



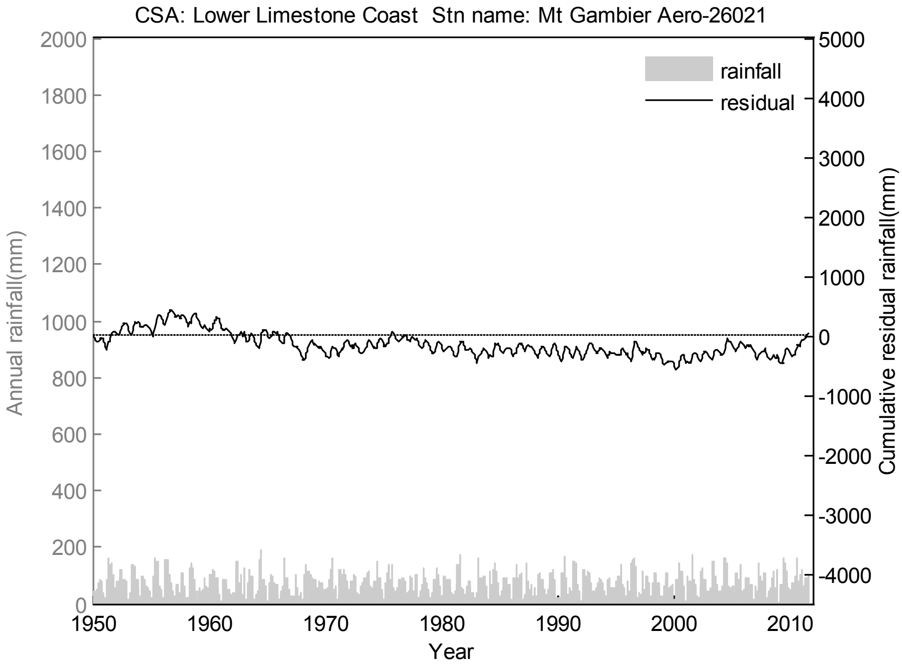
Central Adelaide



McLaren Vale



Lower Limestone Coast



Le Fevre