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Stream salinity status and trends in south-west Western Australia

STREAM SALINITY STATUS AND TRENDS IN SOUTH-WEST WESTERN AUSTRALIA

by

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Map

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Summary

This is the first overview of stream salinity across the south-west of Western Australia since 1988. More than half of the rivers analysed in this study are now marginal in quality, brackish or saline, and only 44% of the south-west rivers are still fresh. Stream salinity was still rising at many of the sites analysed. Sixty-six percent of the analysed rivers had higher salinities in the last 10 years (1993–2002) than in the previous 10 (1983–92). Part of the reason for the higher salinity was lower rainfall over the last 10 years.

The stream salinity status and trends of four study areas of the South West Drainage Division of Western Australia — South Coast, South West, Swan–Avon and Northern Agricultural — were assessed. These areas roughly correspond with the Natural Resource Management regions, with some Avon rivers studied being part of the Swan Catchment Council's area. Data from river gauging stations were analysed to calculate means and trends for salinity, salt load and flow as well as salt output/input ratios. The data included were generally from frequent and regular sampling regimes, although some less frequently collected data were included to calculate estimates for key sites. The 1993–2002 mean salinity was used to define the status of a river or creek.

The extent of clearing in the river catchments, their rainfall, topography and geology are discussed in explaining salinity and trends. In general, stream salinity increased with the percentage of the catchment area cleared of perennial vegetation. The rainfall zone within which each catchment lies was also significant, with clearing in lower rainfall zones producing much higher salinities than clearing in higher rainfall zones. Topography and geology also controlled how severely clearing raised stream salinity. As a result of these factors, water in streams originating near the coast of the south-west corner was fresh, had higher salinities in the northern parts along the west coast, still higher salinities on the south coast east of Albany and highest in the flat, low rainfall inland areas.

Trend analyses separated the impacts of rising salinity due to lower rainfall from the delayed effects of clearing native vegetation. The trend analyses reported in this study focus on the effects of clearing.

The calculations across the study areas showed a rising (positive) salinity trend in some catchments (e.g. the Brockman and Murray rivers), no statistically significant trends in some (e.g. the Warren and Moore rivers) and even decreasing trends in others (e.g. the Denmark and Collie rivers). During the period 1983–1992, salinity trends were mostly positive, except in very well forested or very high rainfall catchments. Most of the current decreasing trends were found in the Water Resource Recovery Catchments (WRRCs). The levelling off of salinity in many river basins and the change from statistically significant increasing trends to statistically not significant trends may be the first indications that salinity is reaching a new equilibrium. However, the effects of long-term climate variability, such as the lower rainfall experienced in many parts of the south-west, may also be influencing the absence of significant rising trends in recent years.

Each year, on average, the combined flow of south-west rivers to the ocean was estimated to be 4700 GL and the salt carried by them to be about 7.5 million tonnes. It would require 625 000 12-tonne farm trucks a year or more than 1700 per day to carry this mass of salt. Each year rainfall and dry fallout deposited only about a million tonnes of salt on the catchments of the south-west.

Each year, on average, the Avon River, up to the Walyunga gauging station, exported 1.5 million tonnes of salt (mean 1993–2002) and the Blackwood River, up to the Hut Pool gauging station, one million tonnes (mean 1993–2002). By comparison, the entire Murray-Darling system, with an average flow ten times that of the Avon River, discharges about the same amount of salt as the Avon.

Conclusions

- The risk of stream salinisation after clearing depended primarily on the amount of salt stored in the soil of the catchment. For most areas outside the coastal plain there was a close relationship between soil salt storage and mean annual rainfall. For areas with more than 1100 mm of mean annual rainfall, clearing was unlikely to cause stream salinities to increase beyond 500 mg/L TDS. However, for areas with mean annual rainfall below 1100 mm, there was a risk of significant stream salinity rises after permanent land use changes such as clearing. Other risk factors for higher stream salinities were topography (flat poorly-drained landscapes) and underlying geology (less permeable sediments).
- The pattern of salinity around the south-west was a band of generally fresh watercourses originating in the higher rainfall (> 900 mm) uncleared areas near the coast between Mundaring and Albany pierced by large saline rivers with their headwaters in low rainfall, extensively cleared catchments of the Wheatbelt and fresher downstream than at their headwaters. Watercourses east of the band had salinities that increased progressively as rainfall decreased.
- Approximately 44% of the flow out to sea each year was fresh, 10% marginal, 21% brackish, about 20% moderately saline, 3% saline and 2% highly saline.
- Salinity in many rivers was rising more slowly in the 1990s than before, and there were some early indications of salinities peaking and stabilising. It was not possible to establish the cause of this pattern, especially without further evaluation of the effects of decadal variability of rainfall on stream salinities.
- Sixty-six percent of the analysed rivers had higher salinities in the last 10 years (1993–2002) than in the previous 10 (1983–1992). There was a complex interaction between salinity and climate, and some of the increases were the result of lower rainfall in the last 10 years than in the last 28 years. Climate change cannot be dismissed and further work is needed to assess the impacts of any climate changes on stream salinity in south-west Western Australia.
- A much richer data record, and hence significantly greater levels of monitoring, is required to calculate trends than to calculate averages. More focused monitoring programs are required to determine at what sites more detailed trend analyses are needed. Currently there are very few sites outside the WRRCs (Collie, Denmark, Warren, Kent and Helena) with appropriate monitoring programs.
- Salt output/input ratios indicated that forested catchments were either accumulating salt or only losing small amounts. Following clearing, output/input ratios exceeded one when mean annual rainfall was lower than 1000 mm. In river systems with large salt lakes which rarely overflow, outputs were unlikely to exceed inputs even if the catchments had been cleared.
- The high rate of salt exported from cleared catchments will eventually result in stream salinities dropping to levels where salt outputs equal salt inputs from rain and dry fallout. The time required is probably centuries for higher rainfall areas but thousands of years for lower rainfall areas (< 500 mm of mean annual rainfall). If the target is fresh water (drinking quality water rather than predisturbance salinities which were often lower) then it may take only decades rather than centuries for streams in higher rainfall areas to become fresh again.
- Over the last 20 years, stream salinities of forested catchments were either unchanged or decreasing.
- Targeted salinity control programs, such as the Water Resource Recovery Catchments (WRRCs) program, have been successful in slowing the rise of salinity in the Kent River, stabilising salinity in the Warren River and decreasing salinity in the Denmark and Collie rivers.

Recommendations

- Repeat this study on a 10-year cycle to maintain up-to-date knowledge of stream salinity across the south-west of Western Australia.
- Assess the stream salinity implications, particularly for rivers such as the Avon, of Land Monitor predictions that the area with shallow watertables will increase by 400%.
- Investigate further the interactions between decadal climate variability, climate change, and land use change and assess their relative impacts on stream salinity trends.
- Develop a better understanding of the variations of salinity along the major rivers. The processes involved are complex with influences such as stratification and storage in lakes, infiltration and groundwater contributions. Considering the prediction of hugely increased areas of shallow watertables, the influence of salt lakes on stream salinity should in particular be evaluated.
- Update data for, and check the relationship between, salt fall and distance from the coast. This report used a regional relationship developed in the 1970s but with the recent shift in climate this relationship may have changed.
- Establish focused monitoring programs to assess the status and trend of stream salinity that meet local needs for data and the broader goals of water resource assessment. Priority areas are considered to include the lower rainfall areas of the Swan-Avon, Northern Agricultural and South Coast study areas.

1 Introduction

1.1 Background

Rising stream salinity was first reported (informally) in Western Australia prior to 1900. Over the last century stream salinity around the south-west of the state rose and became a major water resource problem with serious ecological implications. It is now well known that the salinity problems in the south-west of Western Australia are largely the result of rising groundwater due to extensive clearing (Burvill 1947; Malcolm 1982; Schofield et al. 1988; Ruprecht & Schofield, 1991).

The Shannon River remains in its natural state (L Pen)

Salt affected land in the Avon Basin (T Sparks)

Stream salinity and the associated dryland salinisation will produce increasingly serious environmental, economic and social consequences if not addressed. Without intervention, salinity is predicted to cause the extinction of about 450 plant species endemic to the region. Three-quarters of the region's waterbird species will also severely decline. Up to $400 million will be lost per year in agricultural production by 2050. There will also be increased flood risk in many areas and the life expectancy of sealed roads will decrease by as much as 75%. The social impacts are more difficult to quantify but will include a decline in rural population, loss of business (existing and potential), the cost of rural infrastructure if farms become unprofitable and increased health problems due to stress on families affected by the change (State Salinity Council 2000).

The development of agriculture in Western Australia relied heavily on clearing large tracts of land. Originally the trees intercepted rain and removed water from the soil. When the trees were removed this water seeped down through the soil to the watertable instead. The watertable rose until it intersected streambeds and discharged onto other low-lying areas. The rising water brought with it salt that had built up in the soil and groundwater over thousands of years (Peck & Williamson 1987).

There have been several reviews of stream salinisation across Western Australia (Peck et al. 1983; Public Works Department 1978; Public Works Department 1979; Schofield et al. 1988). This report provides an up-to-date review of the stream salinity situation across the south-west of Western Australia.

This study assessed the current stream salinity and trends of four areas of the South West Drainage Division of Western Australia: South Coast, South West, Swan–Avon and Northern Agricultural. These roughly correspond with the Natural Resource Management regions.

1.2 Objectives

The objectives were to provide an overview and broad analysis of stream salinity across the south-west of Western Australia by reporting on:

- salinity levels using recent decadal means for salinity (1983–1992, 1993–2002). The most recent means were also used to classify the status of sites as fresh, marginal, saline etc.
- the salinity, salt load and flow trends
- the salt balance of catchments using salt output/input ratios
- salinity levels and trends in forested catchments, major rivers and Water Resource Recovery Catchments.

1.3 A brief history of agriculture in the Wheatbelt

The first parts of the land in Western Australia to be developed for agriculture were the Wheatbelt valleys. Before European settlement Aboriginal people occupied these areas. Sandalwood cutters and pastoralists joined them between 1830 and 1890. The former did well initially but by 1848 the accessible timber was depleted (Stratham 1981). Pastoralism was less successful and mostly focused on the grassy areas in the Kimberley, Pilbara and Murchison (Burvill 1979) which were easier to develop than the densely wooded lands east of the Avon Valley.

After 1890 the population grew rapidly with the discovery of gold, but then began to decrease after production peaked in 1903. The government tried to attract ex-goldminers to farming to maintain the population and ensure economic development in the state. Land was classified as ‘first class’, ‘second class’ or ‘third class’ and blocks were sold on the condition that they would be developed for agriculture (Powell 1998). First targeted for development was the first class land — the Wheatbelt valleys with their modest but relatively sure rainfall, deep loamy soils and their woodlands which were comparatively easy to clear (Frost & Burnside

Broadacre clearing near a large floodway in the Avon Basin (L Pen)

2002). Some second class land was developed but none of the third class land which consisted of the light lands, and sandplains between the valleys (Burvill 1979). Wheat production increased rapidly and only slowed with the advent of World War I and the consequent loss of manpower (Appleyard 1981).

The development of the Wheatbelt valleys was also helped by the development of railways. To limit earthworks, narrow gauge rails were used and this tended to direct the railway lines through the areas of gentlest grade — the Wheatbelt valleys. These were also the areas with soils suitable for the construction of the earth tanks needed to store rainfall and runoff for locomotive operation (Frost & Burnside 2002). Now, the Wheatbelt valleys are the lands most prone to salinity problems.

The Great Depression slowed the development of the Wheatbelt, and many who could no longer make a living abandoned their farms in the 1930s. The onset of World War II in 1939 worsened problems with labour and fuel shortages (Frost & Burnside 2002).

It was only in the 1950s that agriculture began to improve again and the extent of clearing increased. The areas of cleared land more than doubled over the 1950s and 1960s (Burvill 1979). It was during this time and the early 1970s that most of the remaining second class land and almost all of the available third class land was cleared. The availability of cheap fuel, research into farming methods and rapidly improving machinery also aided development (Burvill 1979). By 1980, most of the land that could be used for agriculture in the Wheatbelt had been cleared and was being farmed (Frost & Burnside 2002). There was some later development of land in the early 1980s in Esperance, and coastal areas of the Northern Agricultural Study Area were cleared in the last 30–40 years.

1.4 A brief history of stream salinity

Salty river water is not a new problem in Western Australia and is not all the result of European settlement (Schofield et al. 1988). Before large-scale colonization, the south-west region, especially in the inland areas, already had many brackish streams and saline lakes (Schofield et al. 1988). For example, Mr EH Hargraves (1863a, b) noted high stream salinities when he travelled from Jerramungup to the Murchison in search of gold. He reported that Western Australian rivers were ‘beds of salt, pools of brine and brackish water’ with the exception of the rivers flowing west from the Darling Range.

European settlement resulted in rising stream salinities. Salinity in the Mundaring Reservoir rose over the period 1904–08 (Reynoldson 1909). Reynoldson concluded that this was caused by ring-barking trees and cultivation in the catchment. Ring-barking stopped and the salinity dropped. In 1912, Wood (1924) found that the Blackwood River near Bridgetown had become too salty for use in steam engines. Since then salinity in the Blackwood River at Bridgetown has increased by about 300%.

A salt scald in the Helena catchment, the catchment of the Mundaring Reservoir (T Sparks)

Bleazby (1917) also noted the rising stream salinity with salinisation of railway reservoirs. When he investigated the problem he found that nearly all the reservoir catchments, where ring-barked trees had been cleared, produced unsuitably high salinity water (430 mg/L), whereas in vegetated catchments salinity remained very low (86–143 mg/L).

Wood (1924) put forward the conceptual model of how stream salinity develops — a model that still applies today. He proposed that the high concentration of salt in the soil and groundwater was due to oceanic salt continuously brought inland and deposited via rain and dry fallout, and that the removal of trees allowed much more water to percolate to the salty groundwater, which then rose bringing salts to the surface. Others argued that the salt was a result of earlier inundation by the sea. But Wood (1924) contested this, since there was ‘no evidence of saline beds such as might be expected if the sea had been over the land in recent geological times’. Another hypothesis — that weathering of country rocks was responsible — was disproved because the rocks contained insufficient chloride concentrations to account for the high concentrations in the water (Wood 1924). In fact, the relative compositions of chlorides and other ions in the water closely match those of rainwater (Loh et al. 1983) and seawater (Table 1.1).

Today, the widely accepted theory of the origin of salts is still similar to that of Wood (1924). The salt is derived from very fine spray formed by strong breezes across the tops of waves. The water evaporates and a fine residue of salt is carried inland by the persistent south-westerly winds in the area. Finally, the salt is deposited on the land via rainfall, dew or dry fallout. This theory has been supported by Wood’s own work in 1924, by Cryer (1986) and by studies in Europe and America. Hingston (1958) and Hingston and Gailitis (1976) also showed decreasing chloride concentrations with distance from the coast.

At first, the problems of stream salinisation were small because the population was low, mechanical means of clearing land had not been developed and the land was hard to clear because of the slopes (Schofield et al. 1988). However, over the last century there has been extensive clearing, with the most rapid periods of clearing for development being 1900–30 and 1955–85 (Schofield et al. 1988).

The salt problem emerged as a land salinisation problem which was first recorded in 1907 (Schofield et al. 1988). Patterson (1917), a lecturer at the University of Western Australia, concluded that certain areas had too much salt in the soil for profitable use but he was criticised, and the land was released anyway. In the 1930s and 1940s soil surveys indicated that salt problems were developing in the areas he had pin-pointed (Schofield et al. 1988).

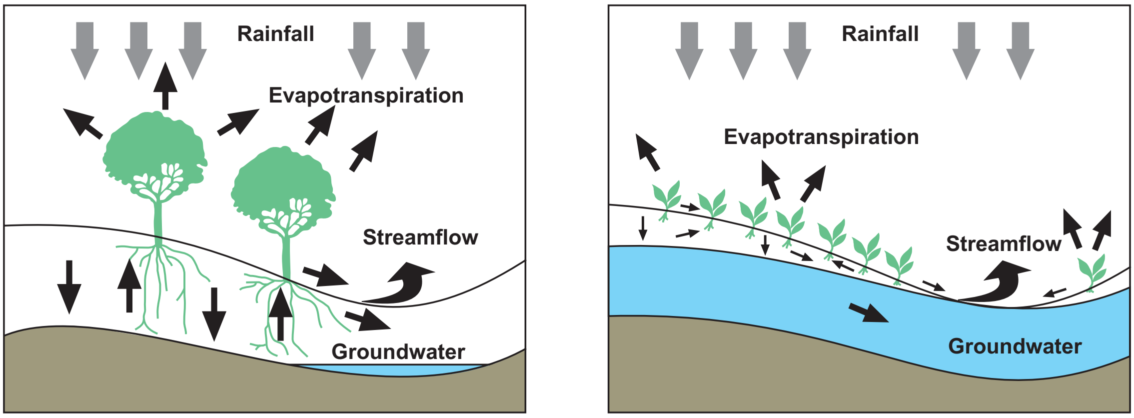
As more and more land was released for agriculture, concerns about rising salinity were frequently raised but the demand for new land was so great that these were overridden. It was also a condition of purchase of the land that it all had to be cleared. Consequently, large contiguous blocks of land were totally cleared.

The problem of water salinisation was first acted on when salinity in the Mundaring Reservoir began to rise (Schofield et al. 1988). Ring-barking of trees in the catchment stopped and this solved this problem. Surprisingly, concerns about stream salinisation were then dormant for a number of decades. When the demand for water increased rapidly from the 1950s onwards, widespread concerns about the effects of stream salinity again arose. The ecological effects were only considered seriously after the environmental issues received more public attention in the 1960s and 1970s (Schofield et al. 1988).

1.5 The process of stream salinisation

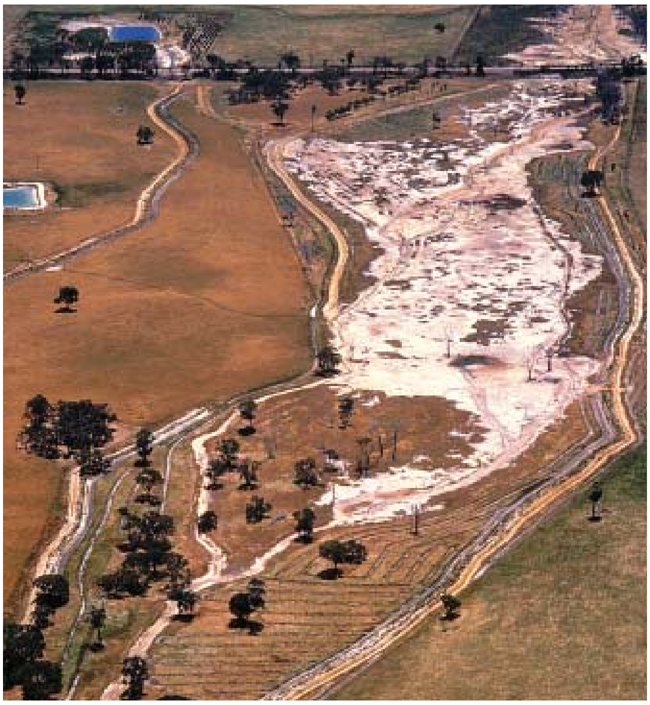
This report deals only with secondary or human-induced salinisation. As mentioned previously, some lakes and streams in WA are naturally brackish or saline — called primary or natural salinisation and the result of long-term influences of natural processes. The salt in the streams of Western Australia is mostly the result of secondary salinisation because of groundwater rising after the clearing of native vegetation (Schofield et al. 1988). Groundwater rise can also result from irrigation of agricultural land.

Stream salinity should not be confused with land salinity. Land salinity or dryland salinity (or salinisation) refers to salt in the soil or the effects of shallow salty groundwater on the soil when it rises by capillary action. Stream salinity is also affected by groundwater levels: when shallow groundwater discharges to streams and lakes. Some methods of dealing with dryland salinity, such as using deep drains, do not decrease stream salinity, and may even increase it by directing more of the groundwater along the drains and into streams and other watercourses. This has been noted in data from Spencers Gully in the east Collie River catchment (pers. comm. Shawan Dogramaci, Department of Environment).



Before clearing		After clearing
650–750 mm	Rainfall	650–750 mm
640–720 mm	Evapotranspiration	580–660 mm
10–30 mm	Streamflow	70–90 mm
0.01 kg/m^2	Salt input	0.01 kg/m^2
0.001–0.005 kg/m^2	Salt output	0.3–0.5 kg/m^2

Figure 1.1 Typical water and salt balance changes after clearing in a catchment with about 700 mm of mean annual rainfall



Salt scalding in a floodway (L Pen)

Figure 1.1 illustrates the typical effects of clearing on the water and salt balance in Western Australian catchments (Government of Western Australia 1996). Evapotranspiration decreases and streamflow increases substantially. Once groundwater is adding to streamflow the salt output increases dramatically. Salt has accumulated in the soils and groundwater of Western Australia over thousands of years. Salt enters the atmosphere when strong breezes over the ocean lash the waves and create a very fine spray. This spray evaporates leaving a fine residue of salt which is transported inland by the persistent south-westerly winds in the region. It is then deposited on the ground by dry fallout, dew or rainfall (Schofield et al. 1988).

Salt collects in the soil and groundwater (Schofield et al. 1988). Some of the rain becomes surface runoff and some percolates into the soil profile taking with it salt accumulated on the land surface by dry fallout or evaporation. There is little change to the chemistry of rainwater during its passage through tree crowns and litter layers of forest areas (Raison & Khanna 1982). In undisturbed areas groundwater recharge is usually a very small proportion of rainfall.

When land is cleared of native vegetation, the water balance is changed and salinisation may occur. Trees and other deep-rooted perennial vegetation are no longer present to intercept as much rain or take up as much water from the soil. This alters the water balance in favour of increased groundwater recharge resulting in rising groundwater levels. Eventually groundwater may intersect the ground surface in valleys or streambeds resulting in discharge to the streams and increasing stream salinity, salt load and flow. Factors affecting the rate of groundwater rise include: rainfall, the extent of clearing in the river catchment, topography, the type of vegetation or land use after clearing, underlying geology, soil depth and soil type.

1.6 Factors influencing stream salinity

Factors affecting how stream salinities increase after clearing include: rainfall, how much the groundwater rises, how saline the groundwater is, soil salt storage, geology, soil depth and soil type.

The risk of salinisation is generally higher in areas with lower mean annual rainfall because salt storage in the soil typically increases with decreasing mean annual rainfall. Thus, the mean annual rainfall is considered to be a major indicator of salinity risk (Stokes et al. 1980). Salt storages increase from 17 kg/m^2 TDS at a mean annual rainfall of 1000 mm to 95 kg/m^2 at 600 mm of mean annual rainfall (Fig. 1.2). Below 600 mm of mean annual rainfall there is considerable variability, with some specific data indicating higher values, such as at Cuballing (460 mm of mean annual rainfall), where the salt storage range was 0.9–71 kg/m^2 TDS for depths ranging from 3 m to 215 m (Salama et al. 1993a).

It may seem contradictory that salt storage is higher in low rainfall areas usually further inland as salt in the landscape is brought in from the ocean by wind and rain, and salt concentration in rain decreases with distance from the coast. However, the mass of salt stored in the soil profile is influenced by factors such as the mass of salt fall, annual rainfall, depth of soil, presence of a saturated zone, soil properties and topographic characteristics. The mix of these factors results in a general trend of soil salt storage increasing with distance from the coast, mostly due to the decreasing annual rainfall. Lower rainfall means less export and throughflow of salt from the soil profile and, before clearing, groundwater in low rainfall areas was typically not connected to the streamzones (Fig. 1.1).

The salt stored in the soil profiles of wetter catchments (mean annual rainfall > 1200 mm) is equivalent to about 700 years of accumulation of the present input of rain (Johnston 1981). For catchments with mean annual rainfall of 700 mm the average time for accumulation is 7700 years. George and Coleman (2002) reported on two studies from low-rainfall areas (300 mm of mean annual rainfall) which had taken 33 000–40 000 years to accumulate the soil salt storage.

McFarlane and George (1992) concluded, from a study of two Wheatbelt catchments, that salt storage was also directly linked to landscape type, showing ranges from 24.7 kg/m^2 TDS in upland soils to 2131 kg/m^2 in valley palaeodrainage channels.

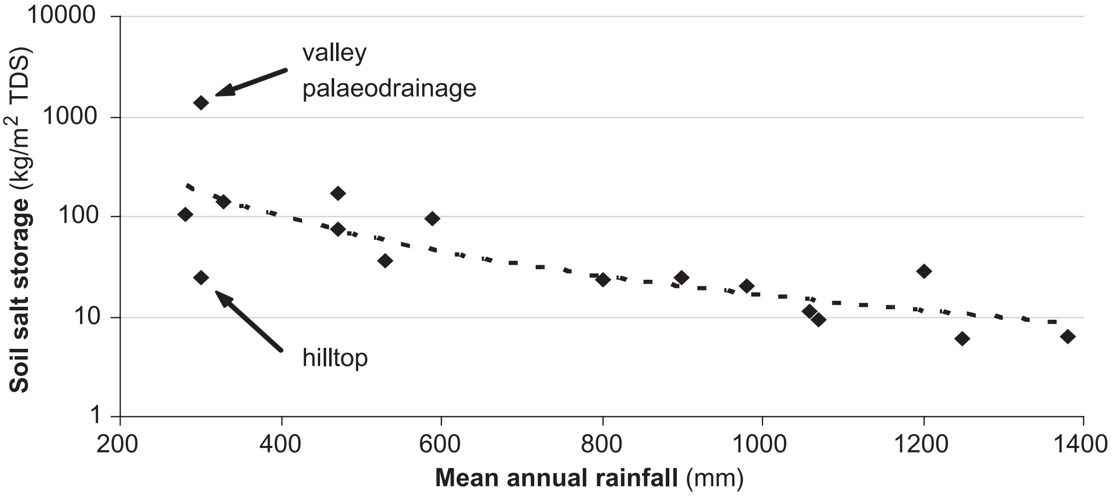


Figure 1.2 Increasing salt storage with decreasing annual rainfall

Catchment clearing in areas with mean annual rainfall greater than 1100 mm only marginally increased stream salinities and the water remained within the fresh range (Bari & Boyd 1993; Robinson et al. 1997; Schofield et al. 1988). In areas with mean annual rainfall between 900–1100 mm, clearing caused stream salinities to rise to marginal or brackish, and even higher in areas where the mean annual rainfall was below 900 mm (Schofield et al. 1988). Based on this and for the purposes of this report, areas with high rainfall (above 900 mm of mean annual rainfall) were considered to have low salinity risk and areas with mean annual rainfall less than 900 mm to have high salinity risk.

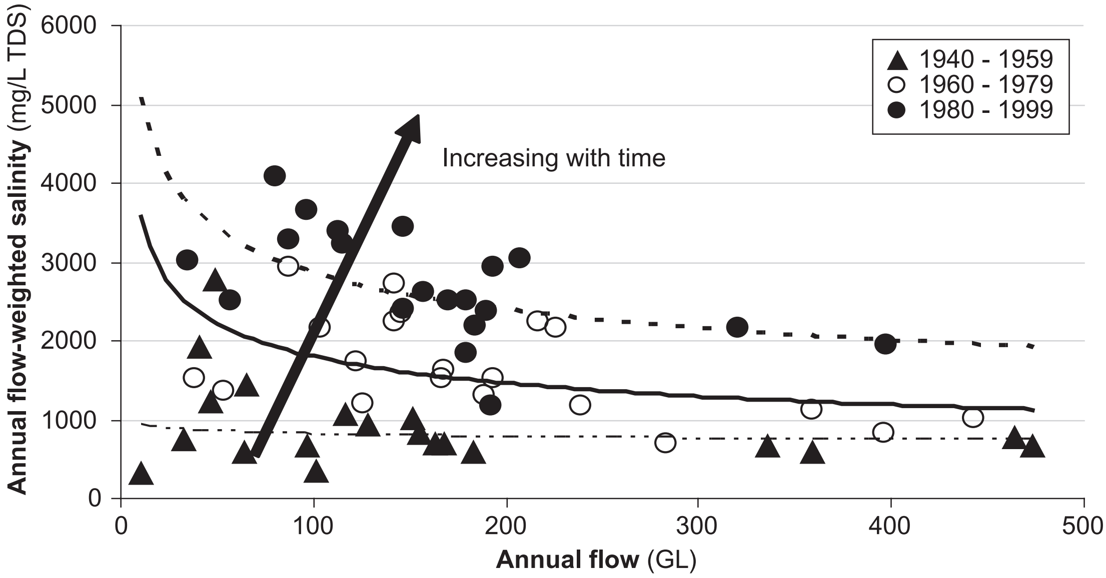


Figure 1.3 Relationship between the annual stream salinity and flow of the Frankland River

The volume of flow also greatly affects stream salinity. The relationship between annual streamflow and stream salinity is typically non-linear, particularly for more disturbed catchments (Fig. 1.3). The annual salinity range of the Frankland River in the 1940s was 500 to about 1000 mg/L TDS depending on streamflow and catchment conditions. There can be significant delays between the clearing of vegetation and the full increase in stream salinity (Fig. 1.3). The relationship between salt load and streamflow also changes because of clearing (Fig. 1.4).

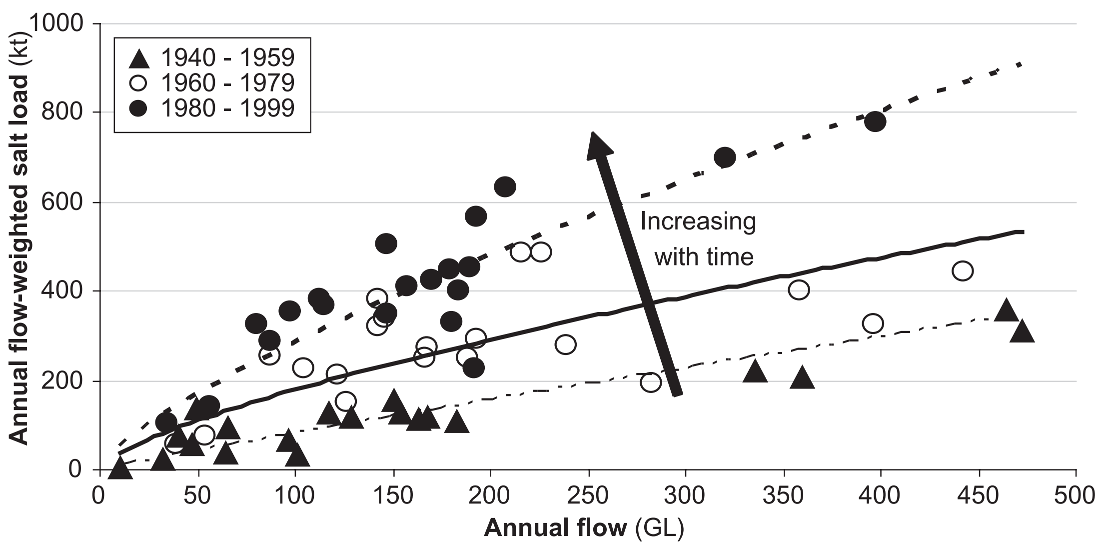


Figure 1.4 Relationship between the annual salt load and flow of the Frankland River

1.7 Chemical composition of river water

The chemistry of river/stream water is similar across the south-west and closely matches that of seawater (Table 1.1). Chloride and sodium are the dominant major ions accounting for about 80% of the ions by weight. This confirms the theory that the salts originated in the ocean (Schofield et al. 1988).

Table 1.1 Percentages of major ions by weight (adapted from Loh et al. 1983)

Major ion	Esperance to Albany Coast (601-602)*	Denmark to Blackwood (603-609)*	Busselton to Swan Coast (610-616)*	Seawater
Chloride	52.9	50.8	53	55
Bicarbonate	2.7	6.7	6	0
Sulfate	6	4.8	5	8
Nitrate	0.2	0.5	1	-
Sodium	28.6	26.7	27	31
Potassium	0.7	0.7	1	1
Magnesium	3.9	4.5	5	4
Calcium	1.6	2	2	1
Silica	3.5	3.2	2	-

*River basin numbers

There are small differences between some regional values and seawater in terms of the other ions, most notably bicarbonate (HCO_3), sulfate (SO_4) and calcium (Ca). Mazor and George (1992) and Salama et al. (1993b) showed, through geochemical analyses and modelling, that most of the constituents of groundwater can be accounted for by considering the constituents of rainfall, with minor additions from the weathering process. Dogramaci and Yesertener (2001) suggested that sulfate in the Blackwood River Basin may be removed from the soil solution by reduction before mixing with rainfall. This occurs where there is seasonal inundation and extensive waterlogging (De Silva et al. 2001). Waterlogging and seasonal inundation are features of many south-west catchments.

2 Methodology

This report's objective is to provide salinity information for rivers and some other watercourses across the south-west of Western Australia — the whole of Land Division 6, a small part of Land Division 7 and the whole Wheatbelt region (Fig. 3.1). The area was divided into four study areas — roughly corresponding to Natural Resource Management (NRM) regions — and the report and appendices group the analyses according to these areas. Some of the study areas, particularly the Northern Agricultural Study Area, have quite different boundaries from their corresponding Natural Resource Management region boundaries because this report includes the entire catchment areas contributing water to the river basins.

All data from suitably gauged rivers (except for small, research catchments which were not representative on a regional scale) were analysed. Suitably gauged rivers were defined as those with continuous conductivity measurements or more than 30 samples of salinity per year. Some important gauging stations with less data were included. Data codes were used to mark such sparse data and to separate adequate data from frequently collected data (Table 2.1). Data reliability was reported as the mean reliability for the years included in whichever calculation was being reported. Some means consisted of only a few years of data — in such cases, a more appropriate, lower code was assigned to that mean.

Table 2.1 Data reliability codes

Code	Annual data collection frequency
1	Mostly continuous measurements
2	Mostly continuous measurements with small estimated gaps (< 2 days) or more than 100 discrete samples per year
3	Mostly continuous measurements with small estimated gaps (< 10 days) or more than 30 discrete samples per year
4	Mostly continuous measurements with large estimated gaps (> 1 month) or fewer than 30 discrete samples per year
5	Mostly continuous measurements with very large estimated gaps (> 3 months) or fewer than 6 discrete samples per year or data estimated from flow

The data were used to calculate annual salinity, salt load and streamflow means for two distinct periods, 1983–1992 and 1993–2002. The more recent 10-year mean (1993–2002) was used to define the salinity status of the sites using the classifications in Table 2.2. Mean data reliability was also reported for each calculation and was the mean of the data reliability codes for each year included in the calculation.

The annual data were also used to provide linear decadal trends for salinity at mean flow, salt load at mean flow and streamflow. 'Salinity at mean flow' is a method of calculating what the salinity of a river would be in a year of average flow. The calculation is used to remove the influence of climatic variability. Variability in climate leads to variability in rainfall and, in turn, variability in flow. For example, salinity values will often be lower in years of high flow but not because salinity has decreased permanently (Section 1.6 and Appendix A). Calculating salinity at mean flow removes the effects of these flow variations in order to estimate the changes in salinity due to land use changes only. See Appendix A for more detail on this method.

Table 2.2 Classification of water salinity (adapted from Hillel 2000)

Salinity (mg/L TDS)	**Salinity status**	**Category**
<500	Fresh	Drinking and irrigation
500 – 1 000	Marginal	Irrigation
1 000 – 2 000	Brackish	Irrigation with caution
2 000 – 5 000	Moderately saline	Primary drainage
5 000 – 10 000	Saline	Secondary drainage and saline groundwater
10 000 – 35 000	Highly saline	Very saline groundwater
> 35 000	Brine	Seawater

Seasonal analyses — finding the arithmetic monthly means for flow-weighted salinity, salt load and streamflow — were performed on data from gauging stations with continuous data for 1993–2002. The results are presented in Appendices B, E, H and K.

For some sites with long records of measurements, long-term trends of salinity at mean flow, salt load at mean flow and streamflow were calculated and are presented graphically in Appendices C, F, I and L.

Salt output/input ratios (the mass of salt exported from catchments via streams compared with the mass entering the catchments from rainfall) indicate whether, overall, salt is being exported from catchments or is accumulating. If salt is being lost from a catchment the ratio will be more than one, and if salt is accumulating it will be less than one. The salt output was taken as the mean salt load at each gauging station for the period 1993–2002. The input was calculated by multiplying the catchment area contributing to the gauging station by the salt fall (based on the relationship found by Hingston and Gailitis (1976) between salt fall and the distance to the coast from the centroid of a catchment). The ratios for each basin are presented in table form in the Appendices D, G, J and M, with brief descriptions of the results in the text as well.

Appendix N shows relationships between the conductivity and salinity for five regions.

An overview of stream salinity around south-west Western Australia is shown in the Map. This map uses a more extensive dataset than the rigorous dataset used in the rest of this report. The Map also shows results of salinity modelling (REG6S) and some estimations for a more complete overview of stream salinity in the south-west of Western Australia. These data were analysed and classified separately and the map is coded with a slightly different classification scheme from that shown in Table 2.2 (see Appendix A).

3 Regional salinity status

3.1 Introduction

This section presents an overview of each river basin within the four study areas — South Coast, South West, Swan-Avon and Northern Agricultural — which cover the whole of Division 6 and the southern part of Division 7 and the entire Wheatbelt (Fig. 3.1). The study areas roughly correspond with the four Natural Resource Management (NRM) regions but also include areas of other NRM regions. For example, the Swan-Avon Study Area encompasses both the Swan and the Avon Catchment Council areas, and the Northern Agricultural Study Area encompasses part of the Rangelands NRM region. These Rangelands areas are included in the Northern Agricultural Study Area because they contribute water to the rivers in the Northern Agricultural NRM Region.

The south-west region experiences a temperate climate with cool to cold wet winters and warm to hot dry summers although some of the more inland portions in the north of the Swan-Avon and the Northern Agricultural study areas are better described as having a semi-arid climate. This climate is characterised by mild winters, hot summers and unreliable rainfall. In general, mean annual rainfall decreases and mean annual evaporation increases inland and to the north.

The south-west region, especially some of the inland parts, has been extensively cleared for agriculture (Map at the back) and this has caused the widespread stream salinisation problems which are the reason for this report.

3.2 South Coast Study Area

The salinity trends and seasonal variations of salinity in the basins are presented in Figures 3.2–3.11 and the salinity status (classification) of the selected sites is shown in the map of the area in Figure 3.12.

Climate

This area extends from the Frankland River Basin in the west to the Esperance Coast Basin in the east (Fig. 3.12) and experiences a temperate climate with cool wet winters and warm dry summers. The mean annual rainfall varies from 1400 mm in the south-western parts to less than 300 mm in the north-eastern parts (Fig. 3.12). About 70% of this rain falls between May and October. Mean annual evaporation increases from 1200 mm in the south to more than 2000 mm in the north (Luke et al. 1988).

Clearing

Much of this area has been extensively cleared, although large areas of deep-rooted vegetation remain, particularly in the three western basins, over the Stirling Range, and between Bremer Bay and Ravensthorpe (Fig. 3.12). Most of the clearing in the Esperance, Albany and Denmark basins was done since the 1950s. In the Kent River Basin, a significant proportion was cleared prior to 1950 and clearing was mostly completed by 1965. In the Frankland, most of the clearing occurred before 1930 with the establishment of the Wheatbelt (Public Works Department 1984a). There has been significant revegetation recently in the Denmark, Frankland and Kent basins.

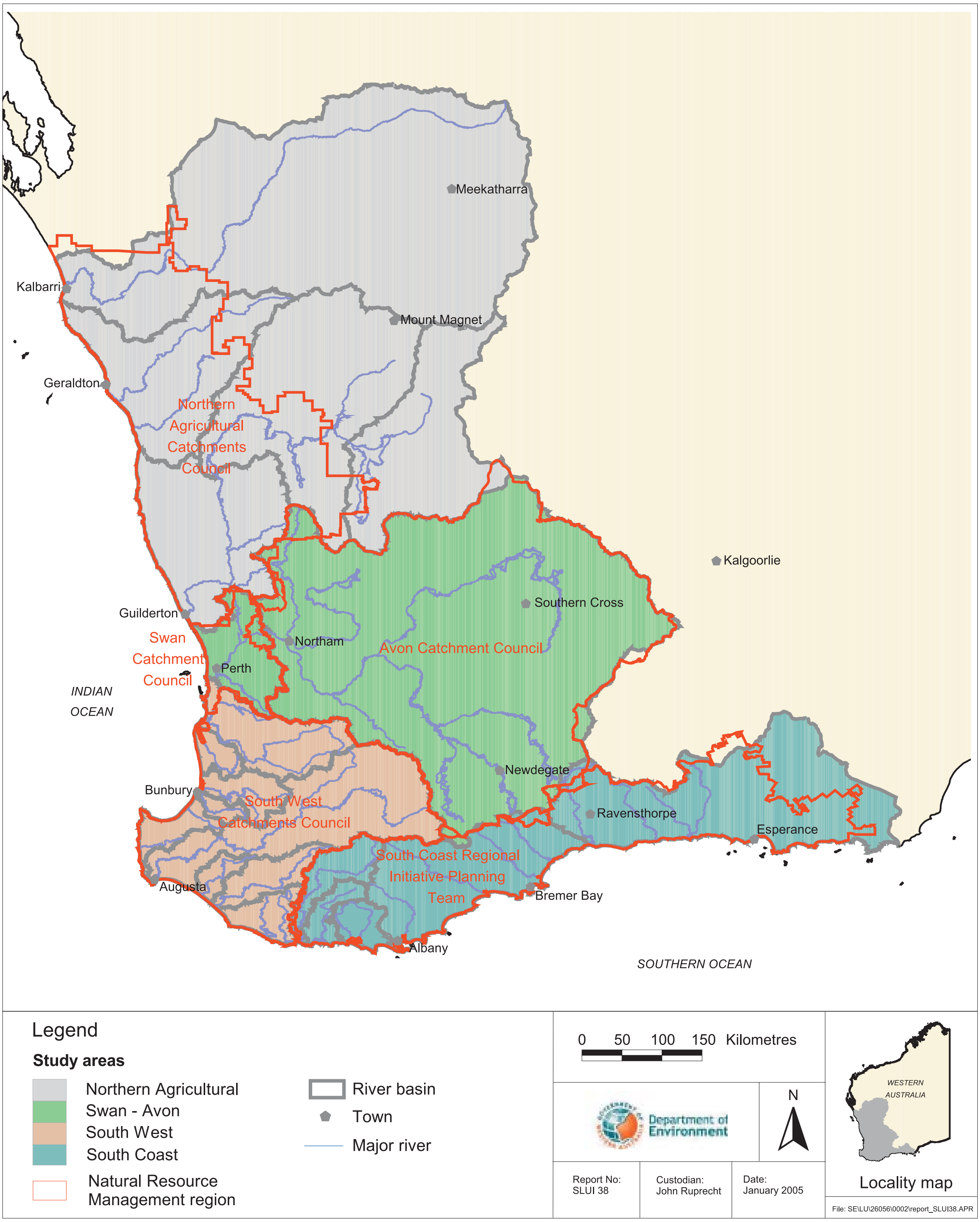


Figure 3.1 Location map of the four study areas

Salinity

Stream water was fresh in the smaller, coastal streams and marginal to highly saline in the larger or more inland streams (Fig. 3.12). Salt output/input ratios showed that most of the catchments were, overall, exporting salt. High output/input ratios (> 1) can be a symptom of secondary salinisation and in these cases the salinisation was due to clearing the deep-rooted vegetation.

Mean salinities were generally higher in more eastern locations than in the west (Fig. 3.12). This trend in salinities was attributed to lower rainfall and significantly more clearing in these eastern catchments than those in the far west.

In the western part of the study area, stream salinities increased to the north and with increased extents of clearing. Longer rivers tended to be more saline since their catchments extended further into areas with lower rainfall where the topography was also flatter with poorer drainage.

It is difficult to say whether salinity was rising or falling recently in the Esperance and Albany basins as the data were too sparse to draw any definite conclusions. In the three western basins, salinity appeared to have been levelling off in recent times (Section 4.2).

3.2.1 Esperance Coast Basin (601)

The Esperance Coast Basin covers an area of about 35 000 km^2 and stretches from just west of Ravensthorpe to about 150 km east of Esperance. Mean annual rainfall ranges from 600 mm at the coast to less than 300 mm inland to the north. Mean annual evaporation ranges from 1800 mm per year near the coast to 2200 mm inland to the north (Luke et al. 1988).

The main river systems west of Esperance are the Oldfield, Young, Lort, Phillips and Jerdacuttup. The rivers all begin 50–100 km inland and drain gently undulating farmland, flow through shallow valleys and then deeper dissections before moving across the coastal plain (Pen 1999). Most of the rivers discharge into intermittent estuaries which are barred from the sea unless there is sufficient rain to cause a breach which

The lower reaches of the Young River (L Pen) usually lasts only a few weeks. The bars are also sometimes artificially breached. The Jerdacuttup River discharges to the Jerdacuttup Lakes, now permanently separated from the ocean by a high dune (Pen 1999). Near Esperance, a number of significant watercourses, such as Coramup Creek and the Dalyup River, flow mostly to lakes and wetlands — some of which overflow to the sea while others such as Thomas River are usually blocked from the sea by a sand bar (Pen 1999).

The basin is largely cleared of its native vegetation and used predominantly for agricultural crops (Beeston et al. 2002). Most of the clearing happened since 1950. In the Young River catchment, clearing took place mostly since the early 1960s and was carried out as part of the agricultural development of the Esperance area. Most of the Lort River's catchment was cleared from the mid 1950s onwards as part of post-war settlement schemes (Public Works Department 1984a).

Due to infrequent sampling in this basin and inadequate data, only two rivers were assessed. They both had highly saline water and extensively cleared catchments (Table 3.1). These salinities are probably elevated above their natural levels. These rivers are in an area with naturally saline groundwater, low annual rainfall, flat topography and relatively impermeable Tertiary sediments. With these characteristics and extensive clearing, the rivers produced very saline water. High salt output/input ratios indicated that there was a net salt export from these catchments, and were another indication that salinities are raised above the natural level (Table 3.1).

Table 3.1 Key sites in the Esperance Coast Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km²)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
601-001	Young River	55	405	1893	Highly saline	12 100[a]	5	3.2
601-004	Lort River	64	370	2901	Highly saline	26 900[a]	4	6.0

[a] Data record incomplete. See Appendix D.

Salinity in the Lort River seemed to be stable during the 1980s but in the 1990s appeared to be rising sharply (Fig. 3.2). However, data collection at this site had been very sparse and irregular with fewer than 30 samples taken per year during most of the 1990s and as few as 2 samples in some years while, in the 1980s, data collection was much more frequent with 30–100 samples collected each year. The record was also short and so the trend must be treated with caution.

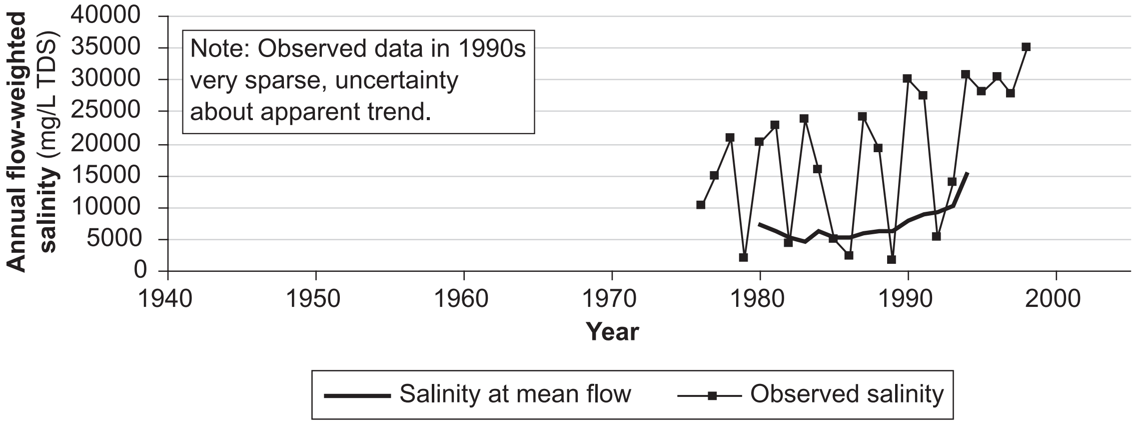


Figure 3.2 Salinity trend at Fairfield (601-004) on the Lort River

3.2.2 Albany Coast Basin (602)

This basin has an area of about 19 500 km^2 and stretches from Albany almost as far west as Ravensthorpe. Some recent investigations indicate that the basin is actually larger and includes an extra 3500 km^2 (18% of the total catchment area). It would then include Lakes Stubbs, Burkett, Buchan, Lockhart, Cobham and Magenta, which in the past (and in this report) were considered as part of the Avon River catchment. These lakes are mostly internally draining but may contribute to the Fitzgerald River in very wet years.

Mean annual evaporation in the basin varies from less than 1400 mm in the south-west to 1800 mm in the north-east (Luke et al. 1988). Annual rainfall near the far west coast reaches 1000 mm, while most of the eastern parts receive little and erratic rainfall — only 500 mm near most of the coast and 400 mm inland.

The Pallinup River (L Pen)

All the major rivers draining this basin (Bremer, Fitzgerald, Gairdner, Hamersley, Kalgan and Pallinup) extend 50–100 km inland. All lie east of the Stirling Range except the Kalgan which originates south of the Stirling Range and drains into Oyster Harbour at Albany. The others drain coastal plains or rugged ranges in the north and then flow south or south-east through deep gorge-like valleys before discharging into coastal lagoons which occasionally connect to the sea (Pen 1999).

Some short river or creek systems, including the Hunter, Kelly, Boondalup, St Mary and the tributaries of the Dempster, to the east of the Stirling Range give rise to coastal lagoons (Pen 1999). These systems only flow strongly after the heavy or prolonged rainfall that occurs during winter. Occasionally the rain results in the rivers bursting their ocean bars and discharging to the sea, but in most years the flow is extremely low (Pen 1999).

Table 3.2 Key sites in the Albany Coast Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km^2)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
602-001	Pallinup River	81	390	3327[a]	Highly saline	16 800[b]	5	19
602-004	Kalgan River	62	600	2384	Moderately saline	4 700	4	9.6
602-009	Robinson Drain	51	960	12[a]	Marginal	530[b]	4	2.4
602-031	Waychinicup River	47	760	238	Marginal	880[b]	5	1.6
602-199	Goodga River	51	870	49	Marginal	560[b]	5	2.2

[a] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[b] Data record incomplete. See Appendix D.

There are also many smaller river and creek systems. Yakamia Creek and the King River both drain heavily cleared farmland and discharge into Oyster Harbour near Albany (Pen 1999). North-east of Albany along the coast there are 30 minor drainage lines most of which do not extend more than 20 km inland. These mostly discharge to inland lakes, small seasonally closed or intermittent estuaries or coastal dune lagoons, and, very rarely, directly to the sea. Most drain farmland although there are a few large patches of remnant vegetation, mostly near the coast (Pen 1999). These streams flow only during winter and spring or after unseasonably heavy rain. Within this basin there are also some near-pristine ephemeral drainage lines of the Stirling Range which drain to peripheral lakes or dissipate on the lower slopes (Pen 1999).

The Albany Coast Basin is extensively cleared (Fig. 3.12) and land is mostly used for cropping, with a little plantation forestry and some national parks (Beeston et al. 2002). Most of the land has been cleared since the 1950s (Public Works Department 1984a).

The analysed watercourses varied in quality from marginal to highly saline (Table 3.2). The marginal rivers received higher rainfall and had less clearing in their catchments than the other two rivers.

The Pallinup River recorded the highest salinity but this was expected since the river extends more than 100 km inland where annual rainfall is less than 400 mm. Its catchment is also extensively cleared, which generates a significant saline groundwater contribution to the river. The salt output/input ratio suggested that 19 times more salt was exported from the catchment than it received from rainfall and dry fallout.

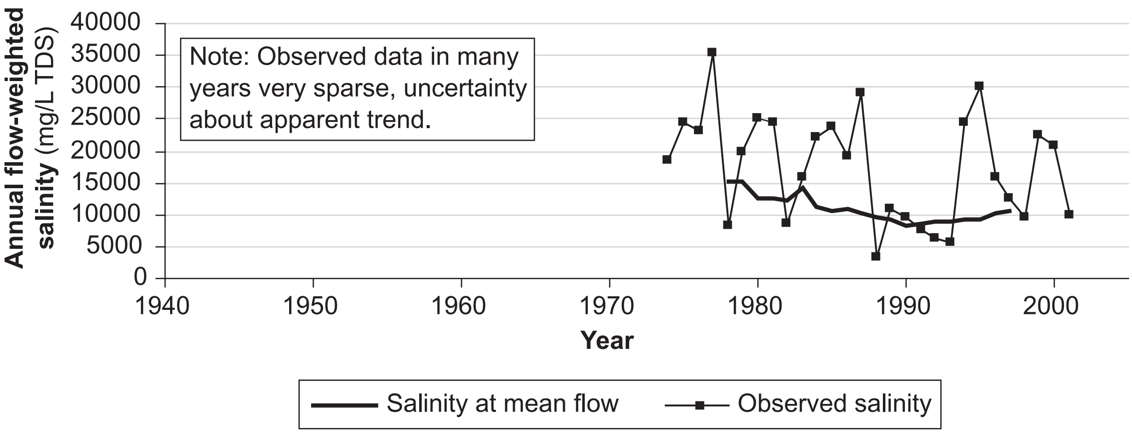


Figure 3.3 Salinity trend at Bull Crossing (602-001) on the Pallinup River

The long-term trend for the Pallinup further indicated that in recent times salinity had been rising, although it reached a low during the early 1990s (Fig. 3.3). The trend in salinity levels may be the result of climatic trends but further investigation is required. There is some uncertainty about the trend since data collection was infrequent, with fewer than 6 samples per year during the 1990s and fewer than 10 samples per year in most years during the 1970s and 1980s.

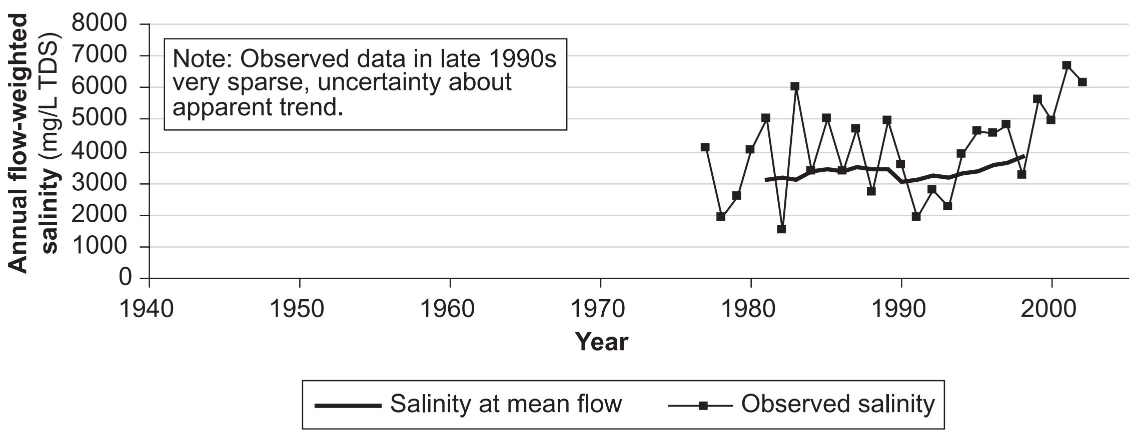


Figure 3.4 Salinity trend at Stevens Farm (602-004) on the Kalgan River

The Kalgan River had lower salinity than the Pallinup although it was still moderately saline and the output/input ratio still indicated that salt was being lost from the catchment. The Kalgan River lies considerably further west than the Pallinup, is in a higher rainfall area and does not extend as far inland (Table 3.2). There was also much less clearing (62% compared with 81%) in this catchment. The long-term trend for salinity in the Kalgan River had been downward but, since 1990, had been upward (Fig. 3.4). Sparse data collection during the late 1990s (fewer than 6 samples per year) casts doubt on the trend during that time. Prior to that, the data collection was quite frequent with more than 30 samples taken per year in most years.

The salinity on the Goodga River had risen steadily since the late 1960s (Fig. 3.5) and the salt output/input ratio indicated a net export of salt (Table 3.2). The Goodga River also had a higher mean salinity for the period 1993–2002 than for 1983–1992 (Appendix D). Thus, although much fresher than some other rivers in the basin, the Goodga was still experiencing rising stream salinity.

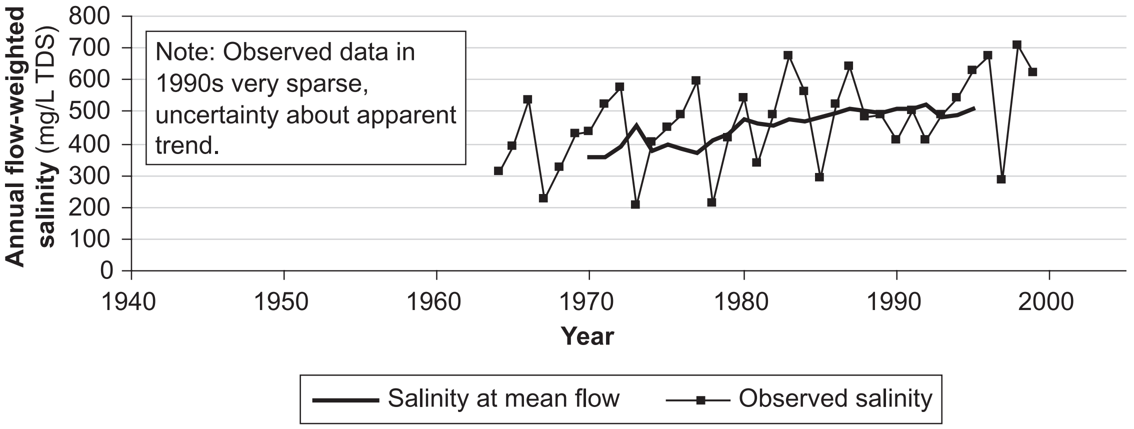


Figure 3.5 Salinity trend at Black Cat (602-199) on the Goodga River

The Denmark River at Mt Lindesay (T Sparks)

3.2.3 Denmark River Basin (603)

This basin, with a catchment area of about 2650 km^2, lies on the south coast of Western Australia and includes the towns of Denmark in the south and Mount Barker in the north. Annual rainfall decreases quickly from about 1100 mm at the coast to about 700 mm inland to the north-east. Mean annual evaporation in the basin is around 1400 mm (Luke et al. 1988).

This basin includes two major rivers — the Denmark and the Hay — which drain from about 50 km inland. This basin also has some small river and creek systems, including the Kordabup, Little and Sleeman Rivers, Lake Saide Drain, Torbay Drain and Marbelup Brook, which drain high to medium rainfall areas within 40 km of the coast.

Much of the land in the basin is in conservation estates or used for forestry although a significant portion has been cleared and is used for agriculture (Beeston et al. 2002). Most of the clearing took place since the 1950s. By 1965 clearing was at 10% for the main gauging station on the Denmark River (603-136) and 17% by 1982 (Public Works Department 1984a). Significant revegetation since 1991 lowered the figure to 11% by 2002 (Bari et al. 2004).

The analysed watercourses in the Denmark River Basin ranged from fresh to moderately saline. The Denmark River was brackish in its upper reaches and major tributaries (Yate Flat Creek) but marginal closer to its mouth (Table 3.3). This is because the upper reaches have more catchment clearing and lower rainfall (Section 1.6) than the lower reaches.

Table 3.3 Key sites in the Denmark River Basin

Site number	**Water-course**	**1996 Clearing** (%)	**Mean annual rainfall** (mm)	**Area** (km^2)	**Salinity status**	**1993–2002 Mean salinity** (mg/L TDS)	**Reliability**	**Salt output/ input ratio**
603-001	Marbelup Brook	63	890	122	Fresh	490[a]	4	3.0
603-003	Denmark River Kompup	31	760	241	Brackish	1800[a]	1	5.9
603-004	Hay River	52	760	1209	Moderately saline	2300	4	8.0
603-005	Mitchell River	0	855	51	Fresh	350[a]	4	1.5
603-006	Quickup River	6	895	38	Fresh	350[a]	5	1.0
603-007	Sleeman River	72	890	76	Fresh	480[a]	4	3.9
603-013	Cuppup River	73	1005	61	Fresh	470[a]	4	2.5
603-136	Denmark River Mt. Lindesay	18	800	505	Marginal	750	1	3.0
603-190	Yate Flat Creek	57	780	57	Brackish	1400[a]	1	8.3

[a] Data record incomplete. See Appendix D.

The Hay River had the highest salinity river water in the basin. The largest portion of its catchment lies in areas of lower rainfall and is extensively cleared (52%). The Marbelup Brook was fresh, but only just, and its salinity rose to brackish (above 800 mg/L TDS) during the first major flows of the year but dropped below 150 mg/L TDS in the winter. The Cuppup River was also marginal and a very high proportion of its catchment had been cleared. These results agree with studies by Schofield et al. (1988) which found that the salinity of rivers in catchments with mean annual rainfall between 900 and 1100 mm rose to marginal or brackish after clearing. All the smaller creeks analysed were fresh and had just less than 900 mm of mean annual rainfall (Table 3.3). They had different extents of clearing, which resulted in a difference of about 100 mg/L in their salinities.

For all the catchments, except the Quickup, salt output exceeded input and salt was being lost from the catchments. In general, the more saline catchments had higher ratios. The salt output/input ratio for the Quickup indicated that the mass of salt leaving the catchment was not much more than the mass entering from rainfall and dry fallout, probably because there is very little clearing in the catchment.

The arithmetic mean for monthly flow-weighted salinity was calculated for Mt Lindesay on the Denmark River (Appendix A). Salinity here (Fig. 3.6) varied from around 700 mg/L TDS during summer, peaked at more than 1000 mg/L during July and fell to about 600 mg/L in September.

Salinity in the Denmark River appeared to be falling (Fig. 3.7). Trend analysis showed that there had been a steady rise in salinity since at least the 1960s, a peak during the late 1980s and then a distinct fall. On further analysis, salinity at mean flow was found to have decreased significantly (statistically) by 7 mg/L per year during the 1990s whereas it had been increasing by 15 mg/L TDS per year during the 1980s (Appendix D).

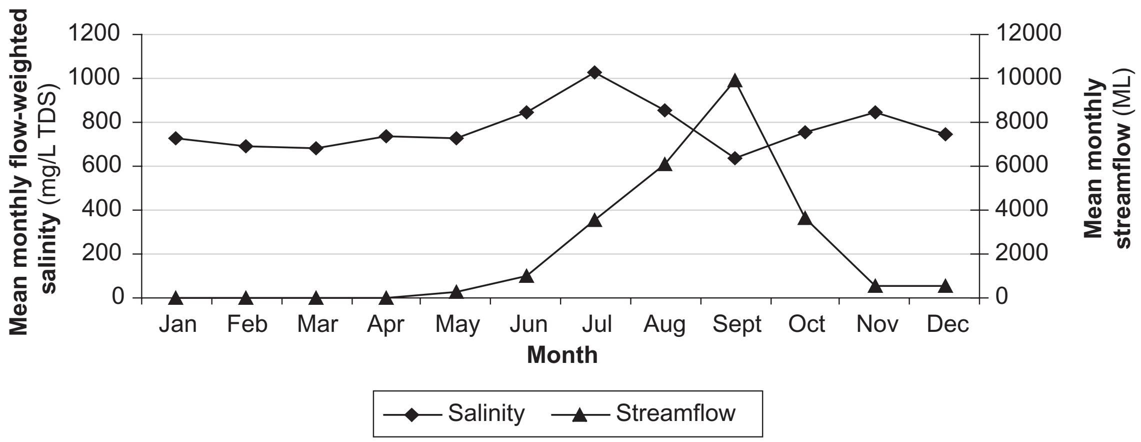


Figure 3.6 Seasonal variation in salinity at Mt Lindesay (603-136) on the Denmark River

The decrease in salinity in the Denmark River was probably the result of clearing controls imposed in 1978 and recent revegetation within the catchment (Bari et al. 2004). These actions were taken because the Denmark River is an important water resource, and is why its catchment was established as one of the five Water Resource Recovery Catchments in 1996. It has also been the subject of much research, and recently the report — *Salinity Situation Statement: Denmark River* (Bari et al. 2004) was published on the salinity of the river and management options to reduce it. The report also described a decreasing trend. Figure 3.7 combines data from two gauges (603-014 and 603-136) to show the salinity for the lower Denmark River.

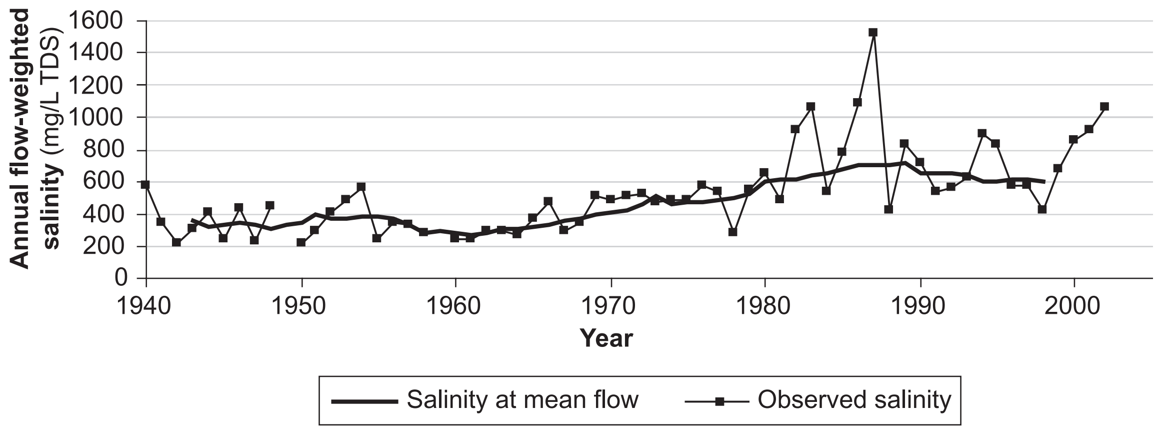


Figure 3.7 Salinity trend for the lower Denmark River

The fall in salinity in the Denmark is a first in a major river system in the south-west of the state. Although there are falling trends in other catchments, and salinity in the Mundaring Reservoir fell after ring-barking stopped (Reynoldson 1909), the Denmark is the first river where the water became too salty for drinking (non-potable) and is now becoming fresher due to human intervention.

The salinity of the Hay River had an upward trend between the mid 1980s and the mid 1990s and its salinity at mean flow seemed to be levelling off towards the end of the period (Fig. 3.8).

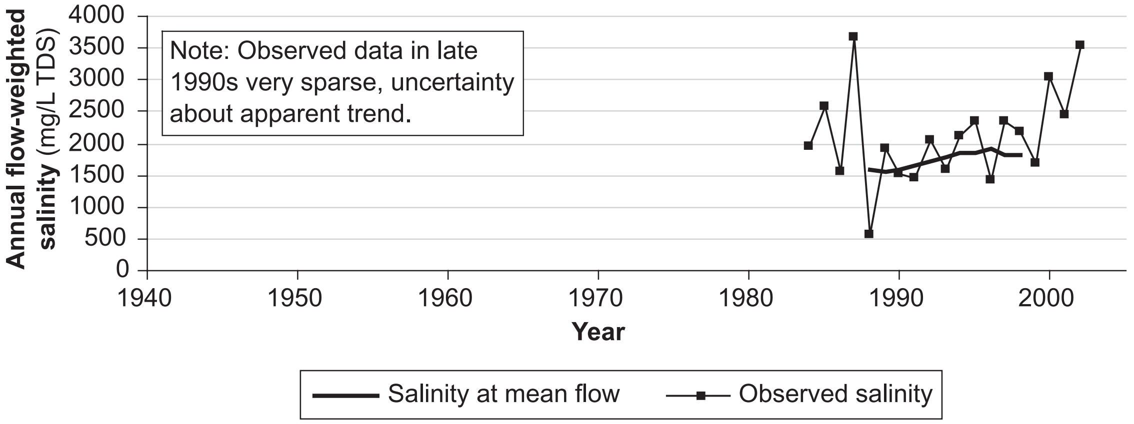


Figure 3.8 Salinity trend at Sunny Glen (603-004) on the Hay River

3.2.4 Kent River Basin (604)

This basin stretches about 80 km inland and has an area of about 2500 km^2. It lies between the towns of Walpole, Cranbrook and Denmark but includes none of these. Rainfall in the basin ranges from 1400 mm near the coast to 500 mm inland to the north. Mean annual evaporation ranges from 1200 mm in the south to more that 1400 mm in the north (Luke et al. 1988).

One tree remains alive in a valley of the upper Kent catchment (T Sparks)

A fair proportion of the land in the basin was cleared prior to 1950 (Public Works Department 1984a). In 1965, 46% of the Rocky Glen catchment and 27% of the Styx Junction catchment were cleared. Clearing was mostly completed by 1978 by which time the figures had risen to 65% and 39% respectively. The extent of clearing then remained stable until after 1996 when revegetation began, and by 2002 the extent of clearing was back to the 1965 level (De Silva et al. in prep).

At the headwaters of the basin, the land is used mostly for agricultural cropping with some plantations and some conservation estates. In the middle of the catchment, there is little clearing and this part is largely

The lower Kent River (T Sparks)

reserved for conservation. Land use in the coastal areas is a mixture of conservation, cropping and grazing (Beeston et al. 2002).

The only major river is the Kent which drains high rainfall areas near the coast and the inland areas with less than 600 mm of rain per year. The upper catchment is relatively flat with ill-defined drainage and watercourses that terminate internally in numerous salt lakes. These lakes only overflow in years of high rainfall. Thus, most of the flow is generated south of Muirs Highway where the land is still forested and the rainfall is high (Hodgkin & Clark 1988). The Kent finally discharges into Owingup Swamp, which in turn overflows into the Irwin Inlet and then the Southern Ocean (Pen 1999).

The Kent River was moderately saline in its middle to upper portions but its salinity dropped to brackish closer to the mouth (Table 3.4). The mean annual salinity for Rocky Glen, the upper gauging station, was considerably higher than the mean for Styx Junction so it is not surprising that the catchment above Rocky Glen contributed 80% of the salt load at Styx Junction. The Rocky Glen catchment is more extensively cleared and has lower rainfall than the rest of the catchment contributing to Styx Junction, and has a higher salt output/input ratio indicating that there was a higher rate of salt export from the upper catchment than from the catchment as a whole.

Table 3.4 Key sites in the Kent River Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km^2)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
604-001	Kent River Rocky Glen	64	650	1129	Moderately saline	4000	1	12
604-053	Kent River Styx Junction	40	800	1862	Brackish	1700	1	5.7

For most of the year the Kent River (at Styx Junction) was brackish, although salinity rose as high as 3000 mg/L TDS (moderately saline) in June (Fig. 3.9). This high salinity was probably due to the salt concentrated in riverine pools or collected in dry river reaches over summer being washed down the river with the first flows. In the winter months July and August, the river salinity was elevated by larger flows from the lower rainfall, more saline upper parts of the catchment. The salinity did not increase much over summer. During summer, fresh runoff in the mostly forested catchment in the high rainfall area contributed much more to the flow than the lower rainfall, saline areas above Rocky Glen (604-001).

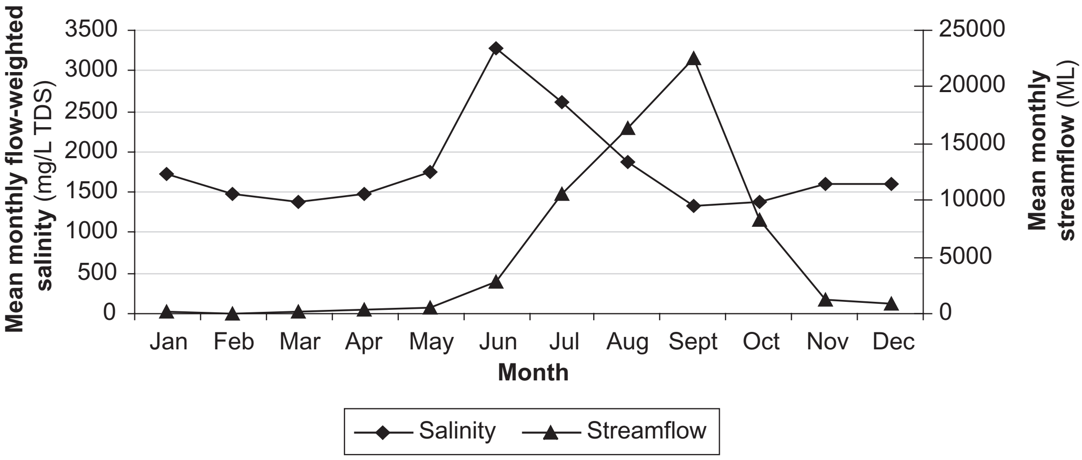


Figure 3.9 Seasonal variation in salinity at Styx Junction (604-053) on the Kent River

Salinity in the lower Kent River (Styx Junction) rose steadily until the 1990s, after which it appeared to stabilise (Fig. 3.10, a combination of gauges 604-010 and 604-053). Further analysis found an upward trend of 14 mg/L/yr in the 1990s. Although still statistically significantly increasing, this was much less than the upward trend of 42 mg/L/yr in the 1980s (Appendix D). This slowing was probably because the water balance of catchment was beginning to stabilise after the clearing controls imposed in the 1970s. Revegetation after the upper Kent River catchment was identified as a Water Resource Recovery Catchment (WRRC) may also have affected the salinity despite only beginning in the late 1990s. De Silva et al. are currently preparing the detailed report on the catchment — *Salinity Situation Statement: Kent River* (De Silva et al. in prep.).

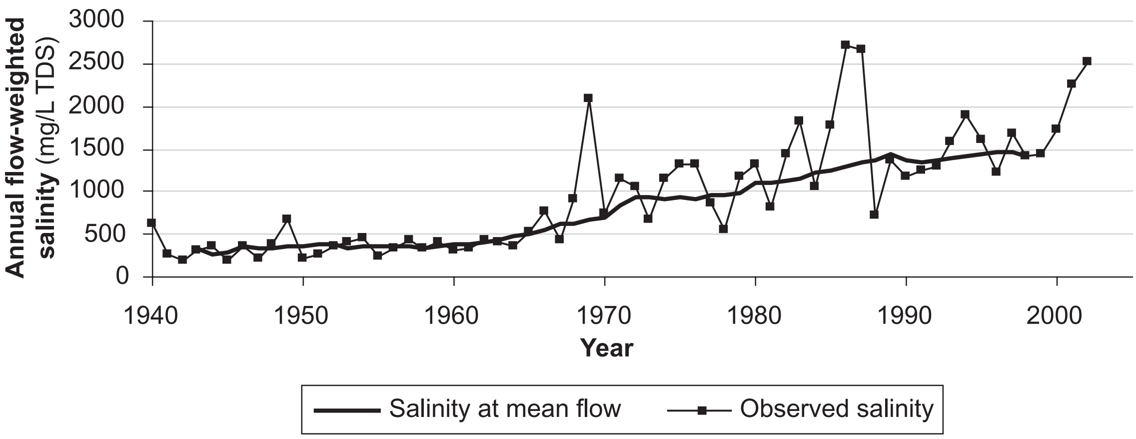


Figure 3.10 Salinity trend for the lower Kent River

3.2.5 Frankland River Basin (605)

This basin stretches from just east of the town of Walpole on the south coast to about 130 km inland. It has a catchment area of about 4630 km^2 and only one major river — the Frankland. The Frankland is called the Gordon in its upper reaches because the two parts of the river were discovered by different people and given different names. Mean annual rainfall ranges from 1300 mm near the coast to 500 mm inland to the north. Mean annual evaporation ranges from 1200 mm in the south to more that 1400 mm in the north (Luke et al. 1988).

There is a mix of land uses in the basin. The upper part of the basin is heavily cleared and the land mainly used for cropping. Moving downstream, more of the land is used for plantations and then for conservation.

Land use in the coastal areas includes grazing, forestry and conservation (Beeston et al. 2002). Much of the clearing was done before 1930 as part of the establishment of the Wheatbelt (Public Works Department 1984a). There has been some recent revegetation.

The upper reaches of the Gordon River (X Mayer)

The Frankland/Gordon River flows south and then westward through fairly flat, slightly undulating farming country with some significant tributaries joining from the north. The watercourse then turns south, becomes the Frankland and flows through incised, forested valleys until it empties into the ocean via the Nornalup Inlet.

The water quality in the Frankland River changes from saline to moderately saline along the course of the river (Table 3.5). The upper part of the catchment is more extensively cleared and has lower rainfall so unsurprisingly the salinity of the river was significantly higher than the wetter, less cleared lower part. The salt output/input ratio was higher in the upper catchment, further indicating that most of the salt load at the downstream gauging station was from the upper catchment.

Table 3.5 Key sites in the Frankland River Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km²)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
605-012	Frankland River Mount Frankland	69	600	4508	Moderately saline	3000	4	16
605-013	Frankland River Trappers Road	82	520	3763	Saline	5900[a]	4	28

[a] Data record incomplete. See Appendix D.

The stream salinity in the Frankland River had risen since the 1950s, but appeared to plateau over the 1990s (Fig. 3.11) with a reasonable amount of data to support the finding. However, the reliability of the salinity levels in the 1990s was less certain as data collection during this time was quite sparse (fewer than 5 samples per year).

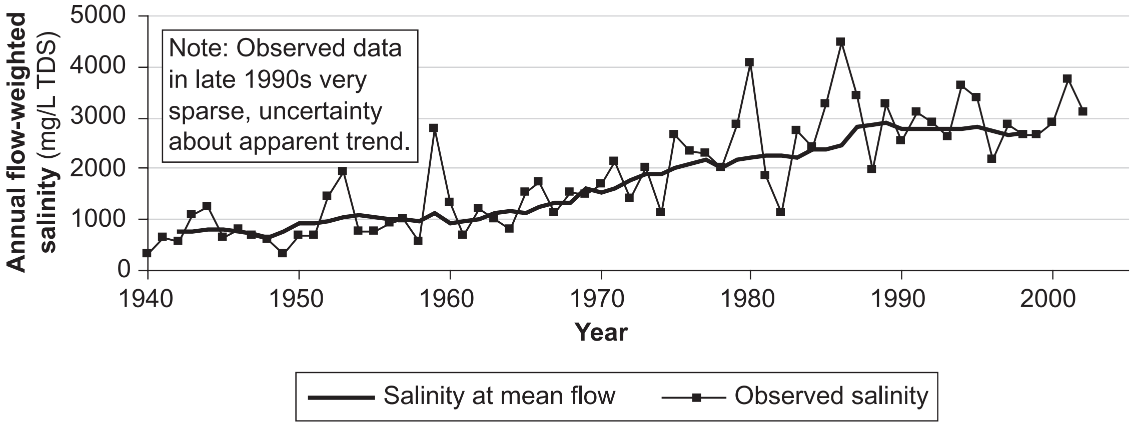


Figure 3.11 Salinity trend at Mount Frankland (605-012) on the Frankland River

3.3 South West Study Area

The salinity trends and seasonal variations of salinity in the basin are presented in Figures 3.13–3.26, and the salinity status, rainfall and clearing of the whole area are shown in the map in Figure 3.27.

Climate

The South West Study Area encompasses the south-west corner of the state and stretches from the Shannon Basin in the south-east to the Murray Basin in the north (Fig. 3.27). The area has a temperate climate with warm, dry summers and cool, wet winters. It receives about 80% of its rainfall between May and October although this percentage decreases in the more inland parts of the basin. Mean annual rainfall varies from 1400 mm in the south to about 400 mm in the north-east. Mean annual evaporation ranges from less than 1000 mm in the south-western corner of the area to more than 1800 mm in the north-eastern corner (Luke et al. 1988).

Clearing

The area has been extensively cleared particularly inland and along the coast. Most of the clearing was done either around 1925–30 or after 1950 when broadacre clearing became much easier.

Salinity

Salinity around the South West Study Area showed a clear relationship between clearing and mean annual rainfall (Fig. 3.27). All the analysed rivers with very little catchment clearing were fresh, whereas those with significant clearing had higher salinities, unless they were in very high rainfall areas. Streams with mean annual rainfall between 900–1100 mm were all fresh or of marginal quality. East of the 800 mm isohyet, all gauging stations recorded streamwater that was moderately saline to saline from catchments that are largely cleared. Those with catchments extending into the low rainfall areas had the highest salinities (e.g. Hotham River site 614-224).

In areas with more than 1100 mm of mean annual rainfall, the rivers were fresh, except major rivers such as the Blackwood (609-019) and the Warren (607-220), which have catchments extending inland into the lower rainfall areas (Fig. 3.27). The major rivers also had their highest salinities at their upstream gauging stations but the salinities dropped progressively to reach their lowest at the most downstream gauging station.

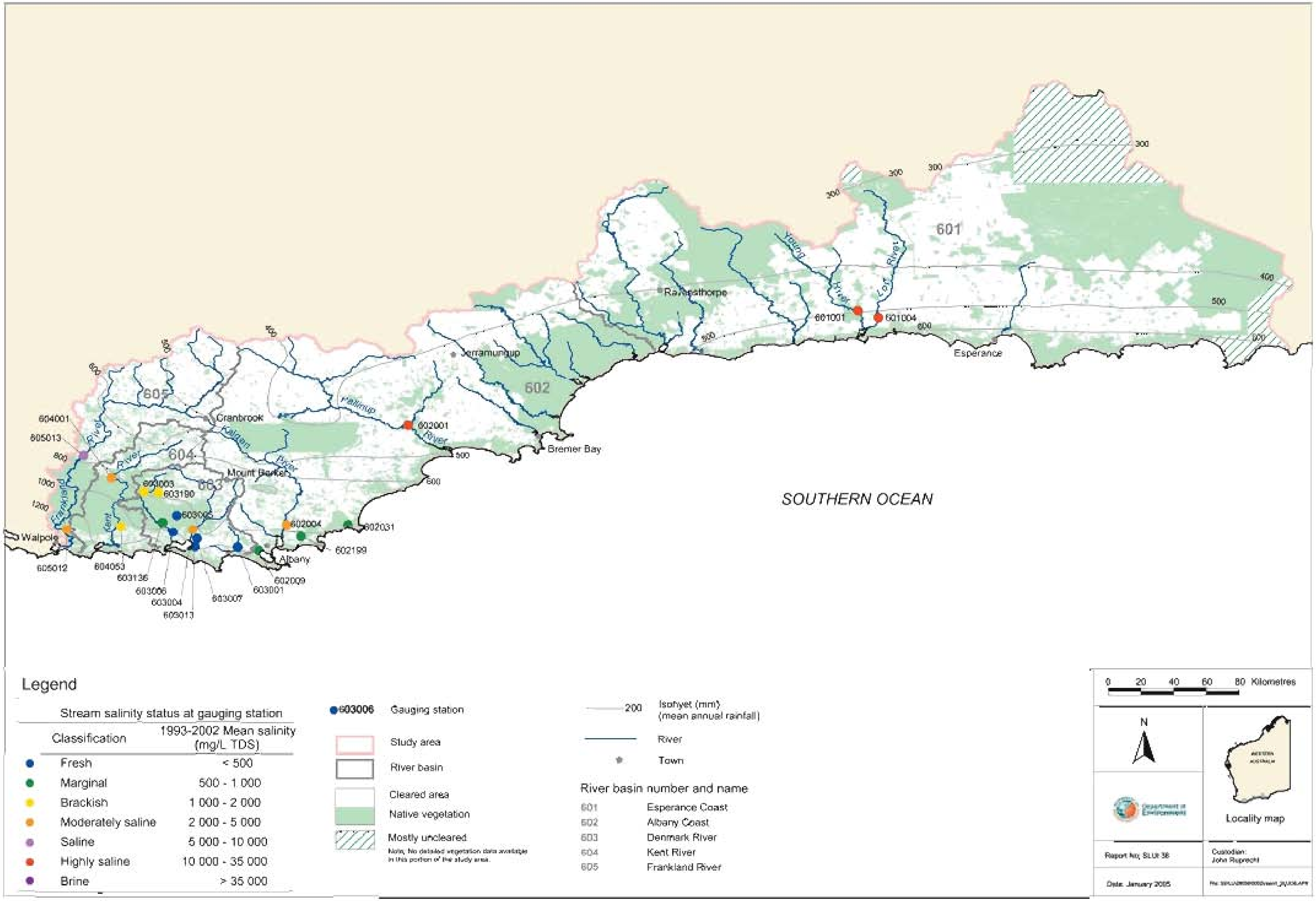


Figure 3.12 Stream salinity status, rainfall and clearing in the South Coast Study Area

These decreases in salinity along the rivers were caused by fresher inflows from higher rainfall areas and tributaries with little clearing in their catchments, such as the Bingham River (612-014) for the Collie and Lefroy Brook (607-022) for the Warren.

3.3.1 Shannon River Basin (606)

This basin lies near the south-west corner of the state (Fig. 3.27). It has an area of 3367 km^2 and the town of Walpole lies in its south-east corner. Although the north-eastern corner receives on average less than 700 mm of rain per year, most of the basin receives more than 1200 mm. Mean annual evaporation ranges from less than 1200 mm in the south to more than 1400 mm in the north-east (Luke et al. 1988).

The basin includes twelve small and three large rivers — the Gardner, Shannon and Deep (Pen 1999). An interesting feature is the large Muir wetland system located near the headwaters of the Deep River. There appears to be no surface connection between this system and the Deep River, except in times of extreme flood (Pen 1999). There are indications that, in the rare event of an overflow, this system may discharge to both the Deep and the Frankland rivers.

The basin is almost entirely covered in dense native forests and wetland vegetation (Pen 1999) with less than 6% of the area cleared (Collins & Barrett 1980). The only catchments with appreciable clearing included in this study are the catchments of the Gardner River and Noobijup Brook. Most of the clearing in these two catchments occurred since post-war settlement schemes around 1925 and the same is true for the clearing in the Shannon catchment (Public Works Department 1984a). The cleared areas in the Noobijup catchment are used for cropping (Beeston et al. 2002) and those further south for dairy farming and cattle grazing with some fruit and vegetable production (Collins & Barret 1980). Some of the forested areas are used for silviculture.

These watercourses were classified as fresh, except for Noobijup Brook which lies north of Lake Muir (Table 3.6) and has a catchment with lower rainfall than the rest of the basin and most of the land cleared for agriculture (Beeston et al. 2002).

Table 3.6 Key sites in the Shannon River Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km^2)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
606-001	Deep River	1	990	467[a]	Fresh	220	5	1.3
606-004	Noobijup Brook	71	740	17	Saline	5400[b]	5	21
606-185	Shannon River	2	1230	407	Fresh	140[b]	5	1.1
606-195	Weld River	1	1275	250	Fresh	210	5	1.6
606-218	Gardner River	19	1410	393	Fresh	160[b]	4	1.7

[a] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[b] Data record incomplete. See Appendix G.

Most of the fresh rivers drained completely forested catchments with mean annual rainfall above 1100 mm, except for the Deep River, which has rainfall less than 1100 mm. The catchment of the Gardner River has significant clearing (19%) but receives such high rainfall that the river remained fresh (Section 1.6).

The salt output/input ratios were greater than one for all the fresh-water-producing catchments. There is some uncertainty about these ratios since the input calculations are based on a number of assumptions and estimations (Appendix A). However, the consistency of the output/input ratios suggests that there is a small export of salt compared with the input from rainfall and dry fallout for the period analysed, and implies that there was some disturbance of the water balance within these catchments.

The mouth of the Deep River (L Pen)

Data in this basin are sparse — most sites have many fewer than 30 samples per year in most years and there have been as few as 6 samples in most of the recent years for the Deep, Shannon and Weld rivers. Noobijup Brook (606-004) is the only site with frequent data collection but the period of record is very short — only 3 years.

Long-term salinity trends for sites on the three large rivers (the Gardner, the Shannon and the Deep) were analysed. The Shannon River showed a continuous downward trend, but only dropped from around 170 to about 140 mg/L TDS over more than 20 years (Fig. 3.13). The Gardner and the Deep also showed little change in their salinity levels over the years (Appendix F).

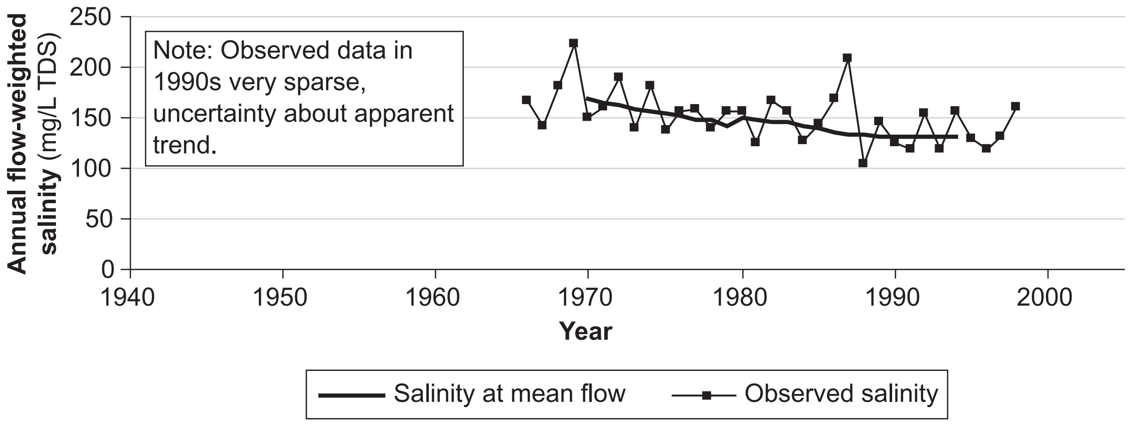


Figure 3.13 Salinity trend at Dog Pool (606-185) on the Shannon River

3.3.2 Warren River Basin (607)

This basin extends from near Kojonup down to the south coast of the state and includes the towns of Pemberton and Manjimup (Fig. 3.27). The basin has an area of 4350 km^2. Average annual rainfall is 865 mm with a range 1400 mm near the coast to 500 mm at the inland divide. Mean annual evaporation is about 1275 mm and ranges from less than 1200 mm in the south to about 1600 mm in the north (Luke et al. 1988).

The main river in the area is the Warren, which is one of the biggest rivers by flow volume in the south-west. It begins as the Tone River in the east and is later joined by important tributaries such as the Perup, the Wilgarup and the Lefroy. The basin consists of a deeply weathered, dissected plateau, which slopes gently from an elevation of about 300 m in the north down to the ocean (Collins & Barrett 1980). The north is a gently undulating plateau which gives way to more rounded hills further south and eventually sand dunes interspersed with swampy flats near the coast (Collins & Barrett 1980). The streams begin in broad, flat, swampy headwaters, then pass through various stages of dissected landscape until they flow through deeply incised V-shaped valleys, and finally flow onto the coastal plain (Collins & Barrett 1980).

Land use includes forestry and agriculture. About 50% of the area is state forest dominated by jarrah–marri and karri forest (Collins & Barrett 1980). The rest of the land is privately owned and generally cleared for agriculture or forest operations (Collins & Barrett 1980). Agricultural production in the study area includes fruit, vegetables, dairy, beef and crops (Collins & Barrett 1980).

Clearing in the Wilgarup, Dombakup and Lefroy catchments began in about 1925 as part of settlement schemes for the area. The main Warren River catchment (the catchment of 607-220) was mostly cleared

The Warren River at Barker Road Crossing (X Mayer)

since the 1950s. Twenty-three percent of this catchment was cleared by 1965 and 36% by 1982 (Public Works Department 1984a). Clearing controls were established in 1978 because salinity levels were rising and the river was considered to be an important water resource. Later, revegetation of the Warren catchment began in the effort to control salinity rise and the catchment was selected as one of the five Water Resource Recovery Catchments in 1996. By 1996, the cleared area was only 31% and by 2002 down to 24% (Smith et al. in prep.).

Table 3.7 Key sites in the Warren River Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km^2)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
607-003	Warren River Wheatley Farm	35	720	2931	Moderately saline	2600	1	9.7
607-004	Perup River	16	750	666	Moderately saline	2600	1	6.4
607-007	Tone River	65	630	983	Moderately saline	4400	1	28
607-022	Lefroy Brook	30	1200	348	Fresh	220[a]	4	1.8
607-144	Wilgarup River	30	950	460	Marginal	850	1	6.4
607-155	Dombakup Brook	16	1430	117	Fresh	140[a]	3	1.8
607-220	Warren River Barker Road Crossing	31	800	4043	Marginal	990	2	6.4

[a] Data record incomplete. See Appendix G.

The effects of salinisation in the upper Warren catchment

The rivers were classified as fresh to moderately saline (Table 3.7). The major watercourse, the Warren, was moderately saline upstream where it is called the Tone River. The Tone catchment (607-007) has the highest percentage cleared area (65%) and lowest rainfall in the basin. The salinity of the river decreases significantly by the time it becomes the Warren River and reaches the Wheatley Farm gauging station (607-003) which receives runoff from the Tone and the more forested, higher rainfall areas. The salinity decreases further to less than 1000 mg/L TDS by the most downstream gauging station — Barker Road Crossing (607-220).

The salt output/input ratios also decreased downstream. The upper parts of the catchment exported the most salt and produced the highest salt load per square kilometre (Appendix G). The Tone, for example, contributed 54% of the salt load of the Barker Road Crossing gauging station (607-220) but accounted for only about 25% of the contributing catchment area. The Warren River, at the Barker Road Crossing, exported, on average, more than 240 000 tonnes of salt from its catchment each year.

The Lefroy and Dombakup brooks, despite some clearing in their catchments, were the only two gauged streams that were fresh: the brooks flowed through very high rainfall areas where the groundwater was not as saline as in the rest of the basin. The output/input ratio for the Dombakup Brook was low indicating little net salt export despite 16% clearing in its catchment. The Wilgarup River had much higher salinity than the Dombakup, probably because its catchment is more extensively cleared and the river flowed through lower rainfall areas — factors that make river water more prone to salinity increases after clearing (Section 1.6).

Stream salinity could vary widely within the year. Salinity in the Tone, for example, rose to 9000 mg/L TDS during June, more than twice the annual average (Fig. 3.14). This peak was due to salts accumulated in riverine pools and dry river reaches during summer being washed down the river by the first flows. Over summer, the salinity stayed high due to high evaporation, very low flow and increased groundwater contributions (Appendix E), and the water would be classified as saline rather than moderately saline. The largest flows occurred in the high-rainfall months (July, August and September) when the water was fresher.

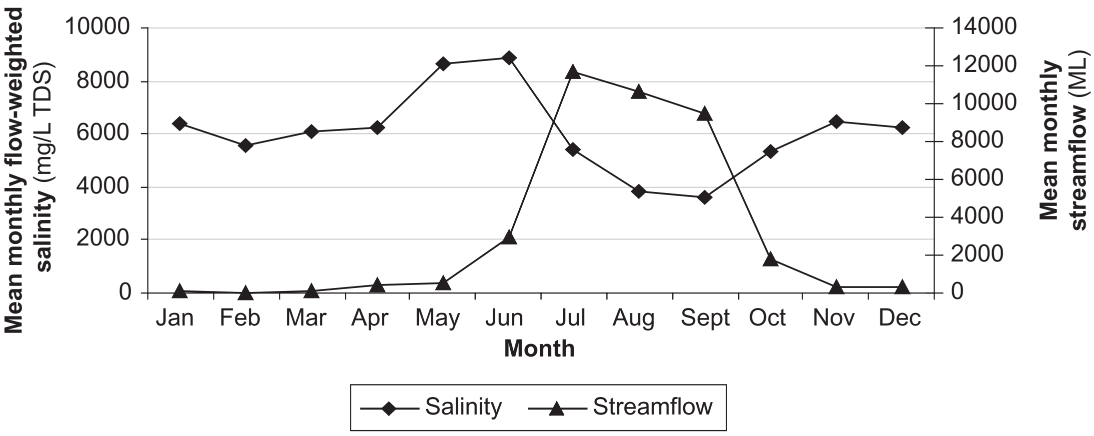


Figure 3.14 Seasonal variation in salinity at Bullilup (607-007) on the Tone River

The salinity at mean flow on the Warren River rose from fresh (500 mg/L) to marginal (990 mg/L TDS), but steadied during the 1990s (Fig. 3.15, a combination of gauges 607-008 and 607-220). Statistical tests showed a significant increase of 15 mg/L TDS per year during the 1980s but no significant trend during the 1990s.

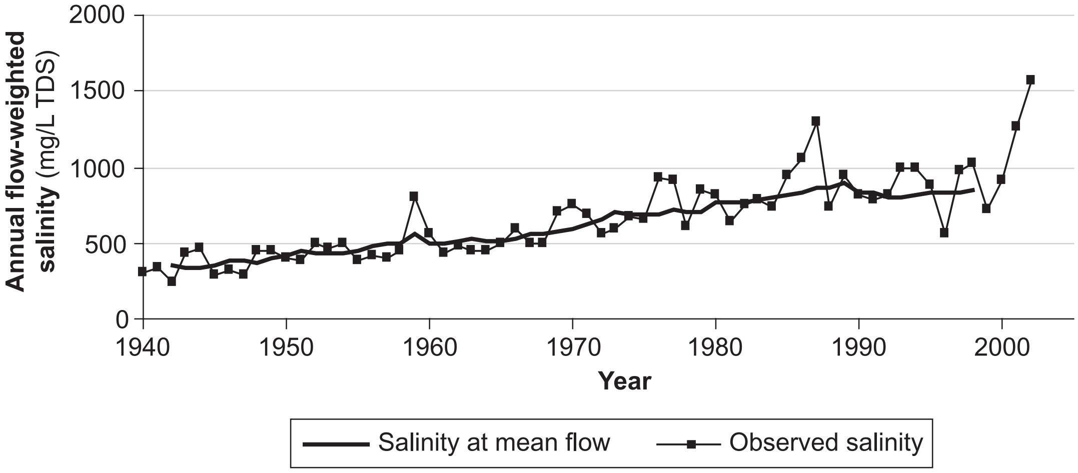


Figure 3.15 Salinity trend for the lower Warren River

Large-scale clearing in this catchment was identified as the primary cause of the rising salinity in the river. Clearing controls were imposed in the late 1970s and there has been significant revegetation recently. Given the Warren River's status as a Water Resource Recovery catchment (Government of Western Australia 1996) a detailed study — *Salinity Situation Statement: Warren River* (Smith et al. in prep) — is being finalised. It presents management options to return the river water quality to potable levels.

3.3.3 Donnelly River Basin (608)

This basin near the south-west corner of the South West Study Area has the town of Manjimup on its eastern border. The basin covers an area of 1670 km^2 and generally receives rainfall of over 1000 mm per year. Mean annual evaporation is around 1200 mm throughout the basin (Luke et al. 1988).

The main river is the Donnelly, with Barlee, Carey and Fly brooks as significant tributaries. Some of the upper parts of the catchment are cleared and flat. The river system then runs through forested, hilly country, through the densely vegetated, sandy and swampy Scott Coastal Plain. Finally it meanders through coastal dunes and into the ocean over a sand bar which blocks the river during summer (Pen 1999).

Barlee Brook (L Pen)

State forest covers about 70% of this basin and less than 15% of the area is cleared (Collins & Barrett 1980). Most of the clearing in the Donnelly River catchment occurred since the 1950s but, in other parts, such as the Fly Brook catchment, most of it dated from settlement schemes around 1925 or 1930 (Public Works Department 1984a). Dairy and beef production are the main economic land uses but logging, cropping and fruit and vegetable growing also occur (Collins & Barrett 1980).

The Donnelly River and all its monitored tributaries were fresh (Table 3.8). Most of the basin receives high rainfall and consequently even those rivers and tributaries with significant clearing within their catchments remained fresh (Section 1.6). The salt output/input ratios for the predominantly forested catchments were 1.1–1.8 indicating a small net loss of salt from the catchments.

Table 3.8 Key sites in the Donnelly River Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km^2)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
608-001	Barlee Brook	1	1170	159	Fresh	150[a]	5	1.8
608-002	Carey Brook	0	1415	30	Fresh	110	2	1.1
608-151	Donnelly River	20	1110	782	Fresh	220	3	2.1
608-171	Fly Brook	18	1420	63	Fresh	150[a]	5	1.7

[a] Data record incomplete. See Appendix G.

Data for Barlee and Fly brooks were very sparse with fewer than six samples of salinity taken per year for a large portion of the record. However, there was little variation in the results and it can be concluded that the watercourses were fresh.

Carey Brook showed very little seasonal variation of salinity (Fig. 3.16) and this was the case for all these watercourses. The salinity rose slightly over summer (probably due to the higher mean annual evaporation and lower flow conditions). These variations were very small compared with more saline catchments.

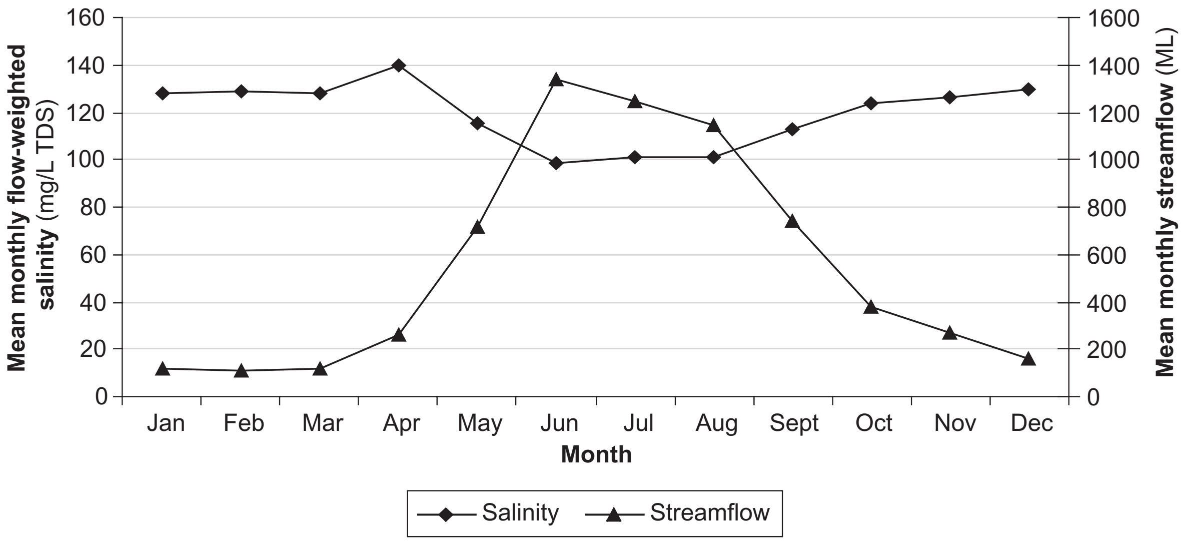


Figure 3.16 Seasonal salinity at Staircase Road (608-002) on Carey Brook

The annual flow-weighted salinity of the Donnelly River varied from less than 150 to more than 250 mg/L TDS with no clear trend (Fig. 3.17).

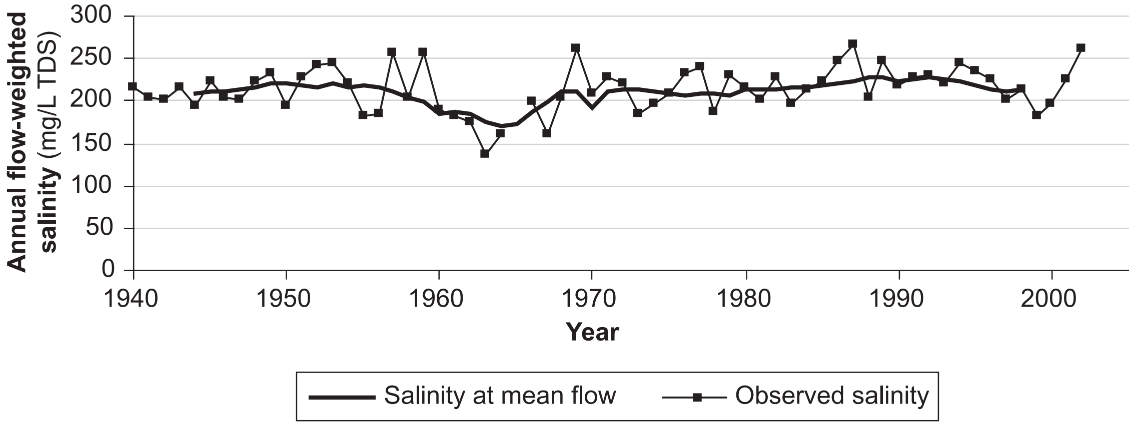


Figure 3.17 Salinity trend at Strickland (608-151) on the Donnelly River

3.3.4 Blackwood River Basin (609)

This basin has an area of about 23 000 km^2. Towns within the Blackwood River catchment include Narrogin, Wagin, Katanning and Dumbleyung in the north-east; Kojonup and Boyup Brook in the central region; and Bridgetown, Nannup and Augusta in the south-west (De Silva et al. 2001). Annual average rainfall varies from about 1200 mm in the south-west to 400 mm in the north-east of the basin. Mean annual evaporation ranges from about 1000 mm to 2000 mm (Luke et al. 1988).

The basin stretches 330 km inland and falls 380 m to the ocean over that distance (Pen 1999). Far inland, the land is flat and in the past rarely received enough rain to cause the broad, almost indiscernible streamlines to flow. These days, the watercourses flow almost every winter because of agricultural drains that flow into them. The rain, and the drains, usually only fill parts of the large lake and floodplain systems in the area (Beard 1981).

Lake Dumbleyung

The main river is the Blackwood and it is the largest river, by flow volume, in the south-west of the state. The upper catchment has many lakes, the largest being Lake Dumbleyung which overflowed into the lower Blackwood River only three times during the twentieth century (Pen 1999). This lake was considered to be 'almost fresh' prior to European settlement but was now usually saline to highly saline (Bari & Ruprecht 2003). The catchment contributing to this lake has an area of 7790 km^2, which means that about 33% of the total Blackwood catchment almost never contributed flow to the river downstream of Lake Dumbleyung. Below the lake systems, the Blackwood River drops 150 m through the Darling Range and along the deep Blackwood Valley (Pen 1999). The river in this section was seasonal but, below Nannup, driven by groundwater discharge, became more or less permanent (Pen 1999). Near the town of Augusta the river discharges into the Hardy Inlet which links to the ocean.

This basin also includes the Scott River, a lower tributary of the Blackwood River's estuary, the Hardy Inlet. This river drains the western portion of the extensively cleared, low-lying, sandy and swampy Scott Coastal Plain (Pen 1999).

Most of the basin, especially the upper parts, has been cleared for agriculture (Pen 1999). Most of the broadacre clearing occurred since the 1950s (Public Works Department 1984a). Broadacre cereal cropping and sheep grazing predominate in the east whereas in the western areas agriculture is more intensive, and includes cropping, viticulture, dairy and beef farming with horticulture on the Scott Coastal Plain. Milling for timber and forest preservation for tourism and ecological purposes (De Silva et al. 2001) take place in the large areas of forest in the south, between Boyup Brook and Augusta.

Four of the seven rivers in the Blackwood River Basin were classified as moderately saline but with a salinity range from 2100 mg/L to 5000 mg/L TDS (Table 3.9). The Coblinine River was highly saline with mean salinity an order of magnitude higher than the other monitored rivers. It lies in a very low rainfall area that is extensively cleared and has broad, flat valley floors that drain very slowly, allowing evaporation and evapotranspiration to concentrate the salt. Fortunately, this saline water rarely reached the lower Blackwood River since Lake Dumbleyung almost never overflowed (Pen 1999).

Table 3.9 Key sites in the Blackwood River Basin

Site number	**Water-course**	**1996 Clearing** (%)	**Mean annual rainfall** (mm)	**Area** (km^2)	**Salinity status**	**1993–2002 Mean salinity** (mg/L TDS)	**Reliability**	**Salt output/ input ratio**
609-005	Balgarup River	87	530	82	Moderately saline	5 000	1	38
609-010	Northern Arthur River	90	415	438	Moderately saline	2 200	1	0.8
609-012	Blackwood River Winnejup	84	500	9 725[a]	Moderately saline	4 700	2	28
609-014	Arthur River	88	460	2 116[a]	Saline	7 100[b]	3	20
609-015	Beaufort River	89	480	1 565[a]	Saline	6 900[b]	4	20
609-019	Blackwood River Hut Pool	64	600	13 368[a]	Moderately saline	2 100	1	14
609-021	Coblinine River	89	400	3 915[a]	Highly saline	21 600[b]	1	4.8

[a] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[b] Data record incomplete. See Appendix G.

The main Blackwood River exported about a million tonnes of salt from its catchment annually. The river water decreased in salinity as it flowed from some of the upper tributaries (609-014, 609-015) to the upper Blackwood gauging station (609-012) and then decreased still further as it flowed to the lower Blackwood gauging station (609-019). The decrease was due to fresher tributaries, high rainfall in the downstream area and fresher groundwater contributions from forested areas in the lower catchment.


The Beaufort River in summer (left) and winter (right) (L Pen)

The salt output/input ratios were interesting. The most saline river, the Coblinine, had quite a low ratio (4.8) and the Northern Arthur River, although moderately saline, had a higher input than output (0.8). The Northern Arthur River (the Lake Toolibin Inflow) is the only catchment with such a low rainfall and extensively cleared area to have an output/input ratio less than one. The reasons for this are not clearly understood. The salt output/input ratio for the Coblinine was much lower than that for most of the other sites in the Blackwood River Basin. While the Coblinine catchment was exporting salt, salt may also be collecting in the broad valleys which drain very slowly. The other rivers showed the high output/input ratios expected where clearing has resulted in increasing masses of salt being exported from the catchments.

The mean monthly salinity on the lower Blackwood River for the period 1993–2002 rose to more than 2500 mg/L in July but also dropped as low as 1000 mg/L TDS in April (Fig. 3.18). This seasonal variation did not follow the usual pattern of rising salinity over summer, a peak after the first heavy rains and a fall as the large winter flows set in. Instead, the salinity fell as the summer progressed to a low in April as an increased proportion of the flow was fresh groundwater discharge and then, as the major rains began, the salinity rose as the upper, more saline portions of the catchment began to contribute flow.

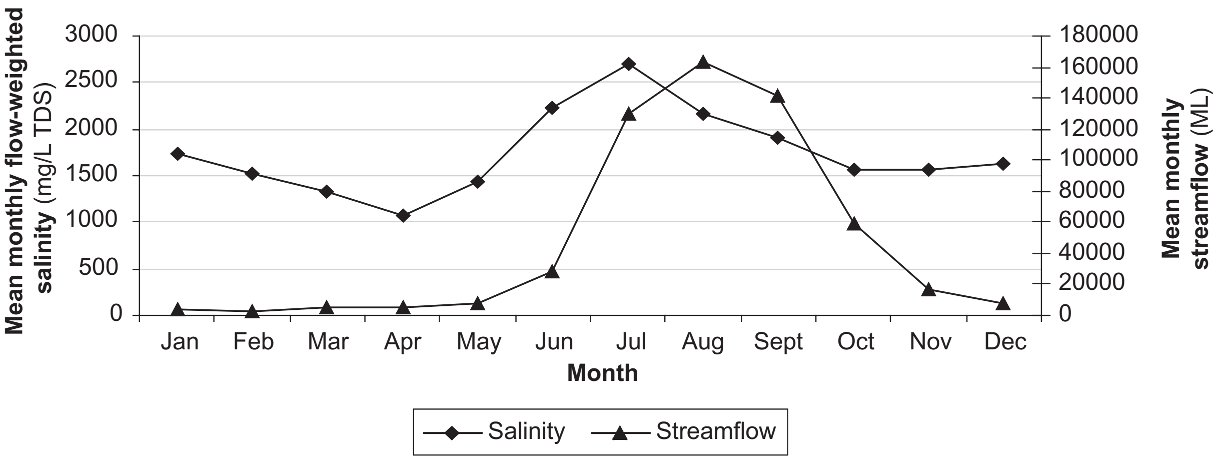


Figure 3.18 Seasonal variation in stream salinity at Hut Pool (609-019) on the Blackwood River

At Winnejup (the upper gauging station) on the Blackwood River, salinity at mean flow rose from around 3000 mg/L in the early 1980s to nearly 4000 mg/L TDS in the early 1990s (Fig. 3.19). In the 1990s salinity was more or less stable and analysis showed no statistically significant trend. (Appendix G). The rising salinity was probably the result of increasing contributions from the upper parts of the catchment which are more extensively cleared and have low rainfall. The levelling out during the 1990s may have been because the catchment was beginning to reach equilibrium since the extent of clearing has been relatively unchanged since the early 1980s. However, significant areas of the Blackwood River catchment are predicted to be at risk of salinisation in the future (Department of Environment 2003), and there was lower rainfall in the 1990s (Section 4.2) so further investigation is necessary.

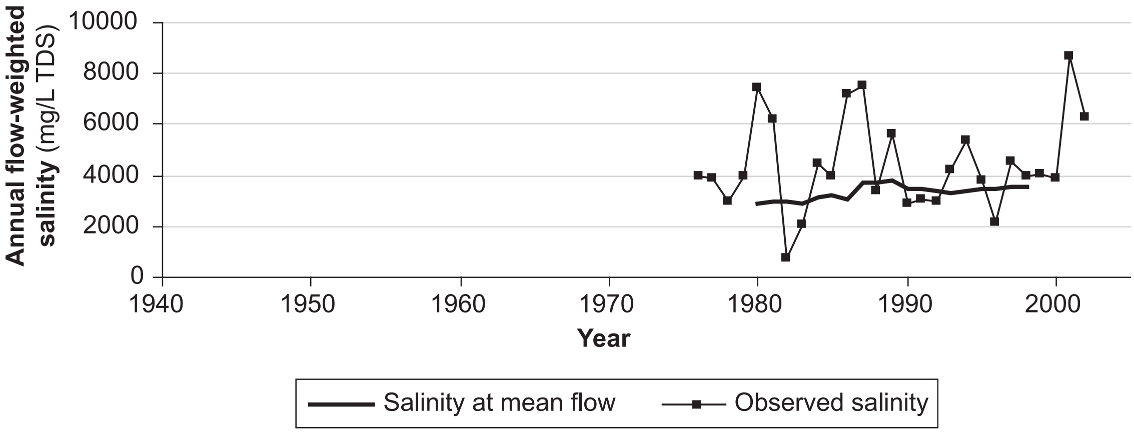


Figure 3.19 Salinity trend at Winnejup (609-012) on the Blackwood River

Figure 3.20 shows that the lower Blackwood River was once fresh (< 500 mg/L TDS) but over the years became progressively more saline. This graph used data from three gauging stations on the lower Blackwood River (609-007, 609-019 and 609-025). These gauging stations were not used in the analysis because their salinity data collection ended in the 1940s and the early 1990s respectively.

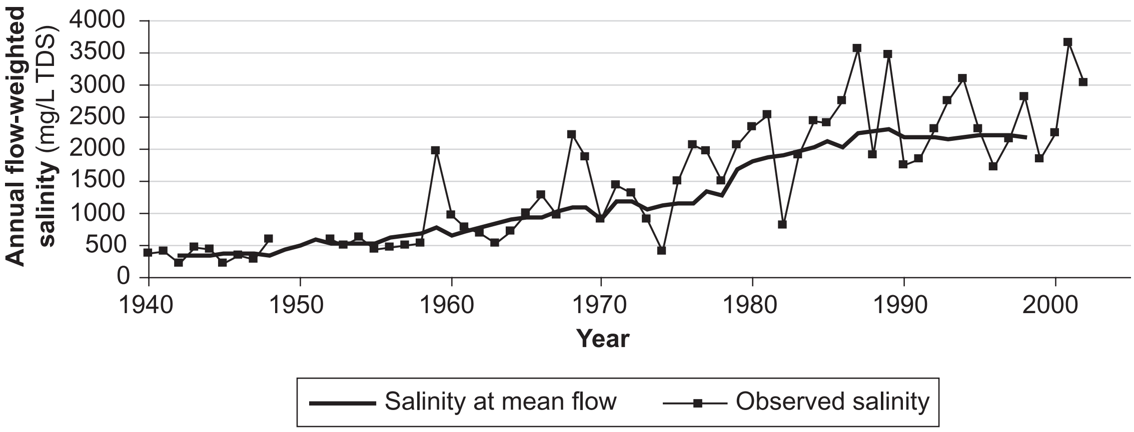


Figure 3.20 Salinity of the lower Blackwood River from the 1940s

3.3.5 Busselton Coast Basin (610)

This is the southernmost river basin on the west coast of Western Australia and includes the towns of Capel, Busselton, Dunsborough and Margaret River. It has an area of 2650 km^2. The annual average rainfall within the catchment is between 800 and 1200 mm and mean annual evaporation ranges from 1000 mm in the west to more than 1200 mm in the east (Luke et al. 1988).

The basin includes 26 short river and creek systems that drain into the ocean between Bunbury and Augusta (Pen 1999) (Fig. 3.27). These watercourses can be divided into two main groups that drain two distinct landforms: those draining the edge of the Darling/Whicher Range and the Swan Coastal Plain, and those draining the Leeuwin–Naturaliste Ridge.

The edge of the Darling/Whicher Range and the Swan Coastal Plain are drained by nine short rivers and major creeks which discharge into Geographe Bay between Bunbury and Cape Naturaliste (Pen 1999). The headwaters of the more substantial rivers (Capel, Ludlow, Abba and Sabina) lie in the forested Whicher


The Margaret River (L Pen)

Range while most of their lower reaches have been partly or entirely modified as parts of artificial drainage systems to drain the very low-lying coastal plain that has been cleared for dairy farming and other forms of agriculture (Pen 1999).

Seventeen major creeks drain the Leeuwin–Naturaliste Ridge. Many of these systems are either partially or wholly contained within remnant coastal vegetation. The Margaret River, which is the only true river system to pass through the ridge, drains the north-western corner of the Blackwood Plateau. The upper part of this catchment is heavily forested and has numerous swamps (Pen 1999).

There is significant clearing in much of the catchment although some large areas are still well vegetated. This clearing mostly dates from the settlement schemes between 1925 and 1930 (Public Works Department 1984a).

The gauged creeks and rivers of the Busselton Basin were all fresh (Table 3.10). Although many had significantly cleared catchments, the rivers drain through the Swan Coastal Plain which has generally fresh groundwater. The Margaret River North, in an area with mean annual rainfall of 940 mm, was fresh. Clearing in catchments with between 900 and 1100 mm of mean annual rainfall often results in stream salinity rising to marginal or brackish quality (Section 1.6). However, there was very little clearing in the Margaret River North catchment so the river remained fresh. The salt output/input ratio was very close to one, as expected of an undisturbed catchment. The other catchments showed higher salt exports than imports indicating that the accumulated salt in the catchments was being exported.

Table 3.10 Key sites in the Busselton Coast Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km²)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
610-001	Margaret River	23	1070	443	Fresh	210[b]	4	2.2
610-003	Vasse River	65	1005	47	Fresh	200[b]	5	2.6
610-006	Wilyabrup Brook	72[a]	1105	82	Fresh	370[b]	4	2.3
610-008	Margaret River North	2	940	15	Fresh	160[b]	5	0.9
610-010	Capel River	35	1000	394	Fresh	330[b]	4	2.9

[a] Clearing figures not consistent with the other catchments. See Appendix A.

[b] Data record incomplete. See Appendix G.

Data for all the rivers in this basin, except the Capel River, were sparse with fewer than 30 samples in most years. The data for the Vasse and Margaret River North were even more sporadic with fewer than 6 samples of salinity collected most years.

3.3.6 Preston River Basin (611)

This basin has an area of 1134 km² and includes the towns of Bunbury and Donnybrook. Mean annual evaporation in the basin is around 1400 mm (Luke et al. 1988). The mean annual rainfall is 900 mm at the eastern border, rises to 1100 mm in the middle of the catchment and then drops again to 900 mm near the coast in the west (Fig. 3.27).

The main watercourse, the Preston River, flows 80 km from the Darling Range, through the Blackwood Plateau and onto the Swan Coastal Plain (Pen 1999). It drains mostly farmland although forest remains on the headwaters of many of its tributaries. One of the tributaries supplies the Glen Mervyn Dam which is used for reticulated horticulture near Donnybrook and Boyanup (Pen 1999). Near these towns the river is incised deeply into the land, and the sandy riverbanks are prone to serious erosion. Near Bunbury the river has been straightened and leveed to prevent flooding (Pen 1999).

There is significant clearing in the basin, although there are still large areas of native vegetated land. Most of the clearing in the valleys of the Preston River Basin occurred before 1930. Since the 1950s, some of the upslope areas have also been cleared (Public Works Department 1984a).

The watercourses analysed were fresh (Table 3.11). All the catchments were extensively cleared, but the waters stayed fresh probably because groundwater in the area was fresh to marginal in quality. Salinities were high within the fresh range. Salt output/input ratios were higher than one indicating net exports of salt, so these watercourses were probably experiencing some secondary salinisation following clearing.

Table 3.11 Key sites in the Preston River Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km^2)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
611-004	Preston River	34	980	808	Fresh	310[a]	3	3.0
611-007	Ferguson River	48	1050	145	Fresh	450[a]	4	3.1
611-111	Thomson Brook	26	960	102	Fresh	400[a]	3	4.0

[a] Data record incomplete. See Appendix G.

The salinity of the Preston River showed a distinctly downward trend from its peak just above 350 mg/L TDS in the mid 1980s to about 300 mg/L by the 1990s (Fig. 3.21). Increased irrigation with groundwater over this period may have altered the water balance. This trend should be treated with caution. Data reliability was coded as an average of 3 in Table 3.11 which means that, on average, there were more than 30 salinity samples collected per year but this reliability value was influenced by a few years where sampling was very frequent while in many years there were fewer than 10 samples collected. The data period was also very short and the salinity value fell only about 50 mg/L TDS.

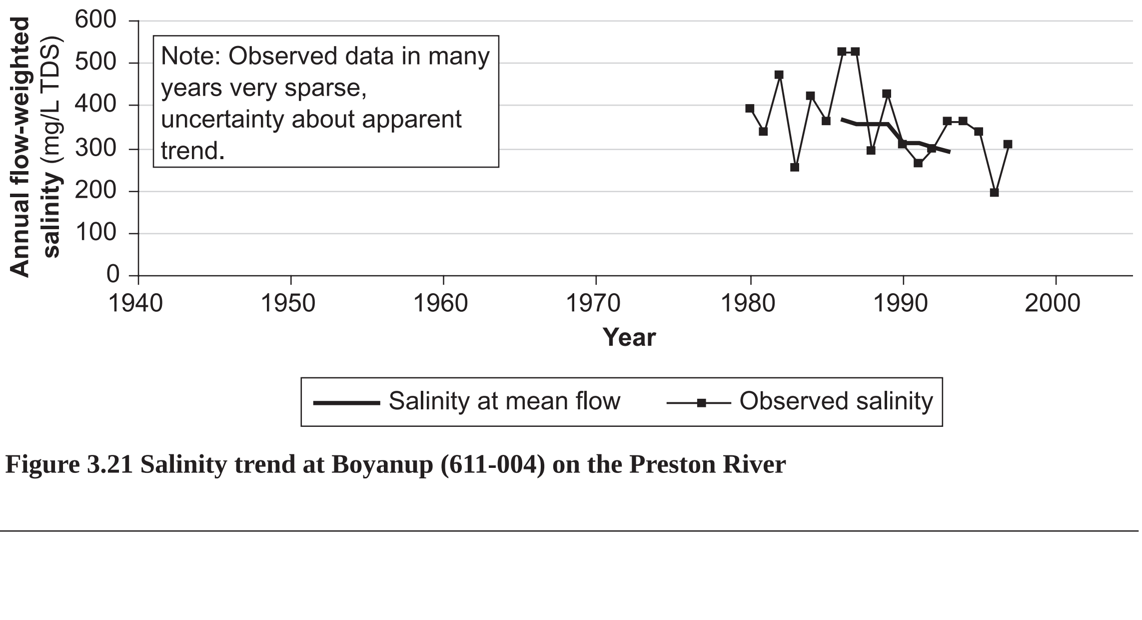


Figure 3.21 Salinity trend at Boyanup (611-004) on the Preston River

3.3.7 Collie River Basin (612)

This basin is situated south of Perth and has the town of Collie lying near its centre. It extends up to 100 km inland from the coast over the Darling Range and the edge of the Yilgarn Plateau (Pen 1999). Annual rainfall varies across the basin from 1200 mm over the escarpment of the Darling Range to 600 mm in the east (Fig. 3.27). Mean annual evaporation is about 1400 mm (Luke et al. 1988).

The Collie River South Branch (L Pen)

The Collie River is the main river system and flows approximately 110 km through the basin until it drains into the Leschenault Inlet north of Bunbury (Pen 1999). The river supports the large Wellington Reservoir. The main tributaries of the Collie River include the Brunswick, Collie River South Branch, Collie River East, Harris and Bingham rivers. Parts of the basin are still forested but a large portion has been cleared and is mostly used for cropping (Pen 1999).

The effects of stream salinity at Batalling Creek on Maxon Farm

The catchment above Mungalup Tower (612-002) on the Collie River is a Water Resource Recovery Catchment where clearing controls and revegetation have been implemented to limit rising salinity. All the gauging stations investigated in this basin, except for the Brunswick River (612-022), contribute to the Collie River at the Mungalup Tower gauging station (612-002). In the 1940s, 8% of the Mungalup Tower catchment (612-002) had been cleared and, by the 1950s, 12% had been cleared. By 1976, the year clearing controls were introduced, 24% of the catchment had been cleared (Public Works Department 1984b). Replanting began in 1980 and by the late 1990s only 17% was still cleared (Mauger et al. 2001).

The rivers of the basin had mean flow-weighted salinities ranging from fresh to saline with a range of 150 to

6800 mg/L TDS (Table 3.12). Stream salinity was higher in the drier eastern portions of the basin (Fig. 3.27). Clearing was also more extensive in these areas than in most of the rest of the basin, except for a strip close to the coast, and the rainfall was lower — factors which usually suggest areas at higher risk of salinity (Section 1.6).

Table 3.12 Key sites in the Collie River Basin

Site number	**Water-course**	**1996 Clearing** (%)	**Mean annual rainfall** (mm)	**Area** (km^2)	**Salinity status**	**1993–2002 Mean salinity** (mg/L TDS)	**Reliability**	**Salt output/ input ratio**
612-001	Collie River East Tributary	24	710	1345	Moderately saline	2700	1	8.7
612-002	Collie River Mungalup Tower	22	790	2546	Brackish	1500	1	5.2
612-014	Bingham River	5	750	366	Fresh	320	1	0.5
612-016	Batalling Creek	38	650	17	Saline	6800	1	28
612-022	Brunswick River	11	1220	116	Fresh	150[a]	3	2.1
612-025	Camballan Creek	40	660	170	Moderately saline	3600	1	14
612-034	Collie River South Branch	30	780	661	Brackish	1100	1	5.0
612-230	Collie River East Tributary	52	640	170	Saline	6700	1	49

[a] Data record incomplete. See Appendix G.

The output/input ratios in the basin varied from 0.5 to 49, with the freshest river having the lowest value and the more saline rivers having higher values. Salt was being lost from the catchments except from the Bingham River catchment. The Bingham River catchment had been extensively cleared and has now been mostly revegetated. The low output/input ratio (0.5) may indicate that the streamflow from the catchment was returning to its preclearing salinity levels.

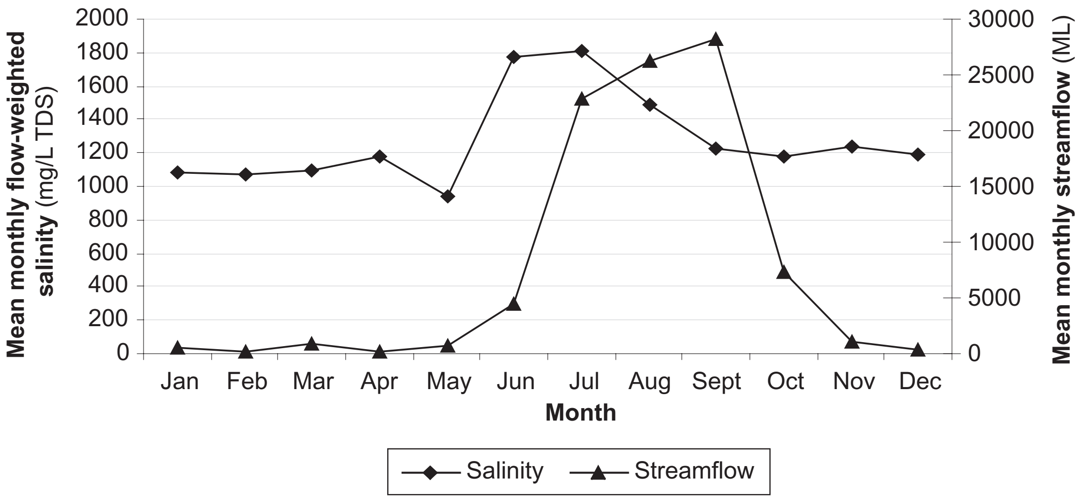


Figure 3.22 Seasonal variation in stream salinity at Mungalup Tower (612-002) on the Collie River

The Collie River East (612-230) was a good example of a watercourse strongly affected by secondary salinisation. It was saline and exported 49 times more salt than its catchment received via rain and dry fallout.

For this river, statistically significantly increasing trends of 110 mg/L TDS per year were found in the 1980s and 200 mg/L TDS per year in the 1990s (Appendices F and G).

Although Table 3.12 shows mean annual salinity values, it does not indicate seasonal variations — which can be substantial. The Collie River at Mungalup Tower (612-002), for instance, peaked at 1800 mg/L in June and July and dropped below 1000 mg/L TDS in May (Fig. 3.22). The salinity peaked in June and July because the seasonal increase in rainfall resulted in the saltier, lower-rainfall tributaries starting to flow and contribute to the main Collie River. The salinity then dropped again over summer when these higher salinity tributaries stopped contributing.

At the most downstream gauging station (612-002) on the Collie River, salinity rose from the 1970s to the late 1980s after which it appeared to level off (Fig. 3.23). Further calculations showed that there was a statistically significant trend of – 6 mg/L TDS per year during the 1990s although salinity had been increasing by 33 mg/L TDS per year during the 1980s.

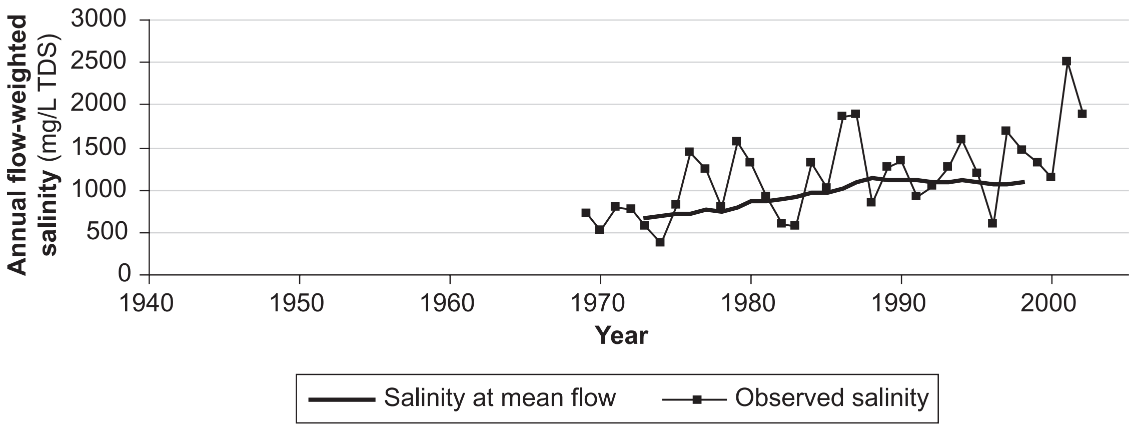


Figure 3.23 Salinity trend at Mungalup Tower (612-002) on the Collie River

Irrigation water being released from the Wellington Reservoir (T Sparks)

Large-scale clearing in this catchment was identified as the cause of the rising salinity in the river. The catchment was made a 'Clearing Control catchment' in the late 1970s and was later classified as a Water Resource Recovery catchment (Government of Western Australia 1996). There have also been revegetation initiatives to lower the salinity. The detailed study — *Salinity Situation Statement: Collie River* (Mauger et al. 2001) — set out management options to return the river water to potable quality state. A similar analysis to that shown in Figure 3.23 was done as part of that report but the results looks slightly different because a different period was used.

The detailed modelling and trend analysis (Mauger et al. 2001) suggested that the management actions (clearing control and revegetation among others) were effective in halting the rise of salinity. The analysis for this report also found a stable salinity at mean flow during the 1990s which could be the result of these management actions (Fig. 3.23).

3.3.8 Harvey River Basin (613)

This basin is on the west coast of Western Australia (Fig. 3.27). The mean annual rainfall is around 1100 mm in the east of the catchment, increases over the Darling Range but decreases again to about 900 mm at the coast. Mean annual evaporation is about 1500 mm (Luke et al. 1988).

The Harvey River (L Pen)

The basin drains the coastal plain and the forested Darling Scarp and Darling Range between the towns of Harvey and Waroona. The largest watercourse, the Harvey River, lies to the south and originates 20 km into the Darling Range and then flows to the Indian Ocean. Two dams lie on the Harvey River and there are smaller dams on some of the northern tributaries including Logue, Samson and Drakes brooks. Originally the Harvey River, after leaving the scarp, meandered through a long area of seasonal wetlands as it gathered water from the smaller northern scarp tributaries before discharging into the southern end of the Harvey Estuary. Today, this coastal plain has been greatly modified by drainage for farming and flood prevention (Pen 1999). Bauxite mining is another activity in this catchment (Pen 1999).

All the watercourses were fresh (Table 3.13). Although some catchments are extensively cleared, most have mean annual rainfall above 1100 mm (Section 1.6). Such high rainfall indicates low salinity risk though clearing might be expected to raise stream salinity slightly, but not out of the fresh category. The salt output/input ratios suggest some net salt export indicating that salinity levels may be slightly raised above the natural level. The elevation of salinity is probably the result of irrigation plus clearing causing the rising groundwater levels, which in some areas, are evident as salt scalds (pers comm. Richard Pickett). As the calculations of ratios required many assumptions and estimations the values should be treated with caution.

Table 3.13 Key sites in the Harvey River Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km^2)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
613-002	Harvey River Dingo Road	0	1195	147	Fresh	120[a]	5	1.3
613-007	Bancell Brook	10	1220	13	Fresh	100[a]	5	1.5
613-018	Mcknoes Brook	13	1200	24	Fresh	100[a]	5	1.6
613-052	Harvey River Clifton Park	39	1100	727	Fresh	290[a]	5	3.3
613-054	Mayfield Sub G drain	95	1025	10	Fresh	-	-	1.6
613-146	Clarke Brook	10	1150	17	Fresh	-	-	1.9

[a] Data record incomplete. See Appendix G.

For the purposes of this study the frequency and regularity of data collection at all the sites in this basin were low. Fewer than 6 samples per year were collected at all sites in almost every year. This throws significant doubts on the results although it is still probably safe to say that the rivers were fresh (based on the more frequently collected data for the 1980s).

3.3.9 Murray River Basin (614)

This basin, on the western coast of south-west Western Australia, includes the major towns of Boddington, Dwellingup, Mandurah and Williams and parts of the suburb of Fremantle (Fig. 3.27). Mean annual rainfall varies from 450 mm in the eastern Wheatbelt area, peaks at 1300 mm on the western approach to the Darling Range near Dwellingup and drops away again to 900 mm just inland from the west coast. The mean annual evaporation ranges from above 1800 mm in the north–east corner of the basin to about 1600 mm towards the south-west (Luke et al. 1988).

There are two river systems — the small shorter Serpentine and the longer Murray — both of which drain into the Indian Ocean via the Peel Inlet near Mandurah. The Serpentine River drains forest east of the Darling Scarp, then falls steeply down the scarp and meanders across the coastal plain where it enters a long drain before discharging into the Goegrup Lakes and finally into the Peel Inlet (Pen 1999).

Tree death from salinity along the Williams River (L Pen)

The Murray River is one of the largest rivers (by flow volume) in the south-west. It begins as the Hotham and Williams River systems. At their headwaters, annual rainfall is about 500 mm and the catchments are heavily cleared. The rivers deepen as they pass through the hilly country and unite south of Boddington to form the Murray (Pen 1999). The river then passes through the Darling Range and onto the coastal plain, where it is joined by the North and South Dandalup rivers, both of which drain state forest and are regulated by reservoirs on their tributaries (Pen 1999).

About 60% of the basin above the Baden Powell Water Spout (614-006) on the Murray River has been cleared. The valleys of this catchment were cleared from the 1890s onwards but broadacre clearing only began in the 1950s (Public Works Department 1984b). State forest covers most of the rest of the land except for cleared areas closer to the coast (Public Works Department 1984b). The cleared areas are used for sheep and cattle grazing with some cereal production (Beeston et al. 2002).

The streamflow of the analysed rivers ranged from fresh to moderately saline (Table 3.14). The fresh rivers received water from catchments with very high rainfall and little or no clearing. These rivers had output/input ratios below one, indicating that salt was accumulating in the catchments.

Table 3.14 Key sites in the Murray River Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km²)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
614-006	Murray River	60	750	6757	Moderately saline	2900	4	16
614-036	North Dandalup River	5	1250	80	Fresh	130[a]	4	0.8
614-037	Big Brook	0	1050	149	Fresh	120[a]	3	0.3
614-196	Williams River	79	560	1408	Moderately saline	2700[a]	5	22
614-224	Hotham River	69	600	3967	Moderately saline	3000[a]	4	15

[a] Data record incomplete. See Appendix G.

The Murray River was one of the biggest rivers (by flow volume) in the south-west and it moved on average more than 600 000 tonnes of salt each year. The Murray and its two tributaries (the Hotham and Williams) were moderately saline with about the same mean salinity value (Table 3.14). All three received water from extensively cleared catchments with much lower rainfall than the fresh rivers of the basin. As expected, their output/input ratios indicated that they were losing salt from their catchments whereas forested catchments with fresh watercourses were accumulating salt.

The salinity of the Murray River increased steadily over the decades (Fig. 3.24). In the 1950s, the river would have been classified as brackish rather than moderately saline although the salinity seemed to have reached a plateau in the last 10 years. On further analysis, salinity had increased at about 29 mg/L per year during the 1980s but at only 10 mg/L TDS per year during the 1990s.

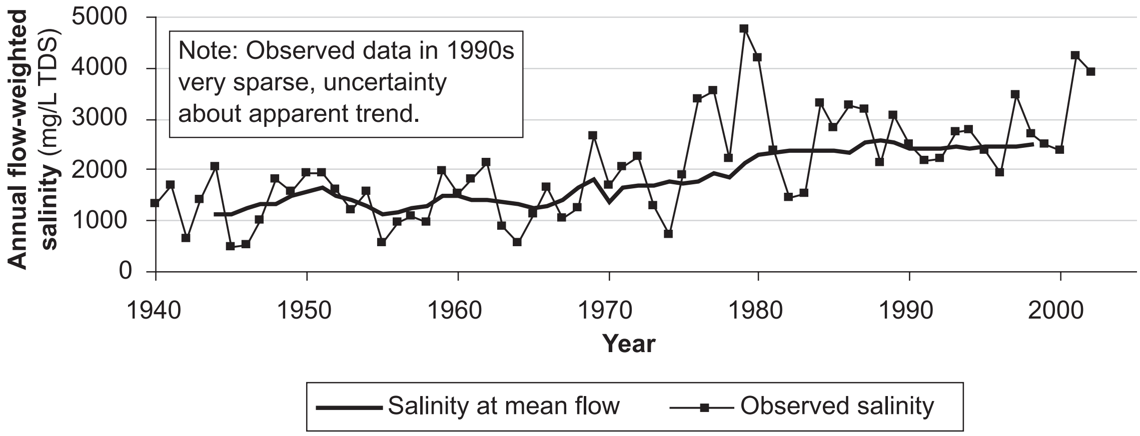


Figure 3.24 Salinity trend at the Baden Powell Water Spout (614-006) on the Murray River

The salinity of the Williams River had changed little over the last 20 years (Fig. 3.25).

The salinity of the Hotham River showed a definite upward trend until the late 1980s after which it began to fall (Fig. 3.26). This stabilisation and decrease may have been the result of a new equilibrium established in an area where the extent of clearing had not changed for many years.

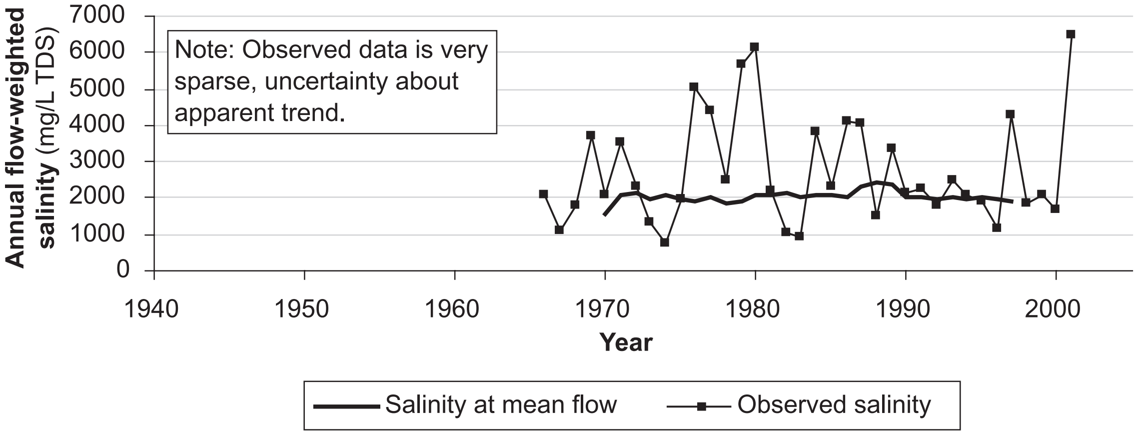


Figure 3.25 Salinity trend at Saddleback Road Bridge (614-196) on the Williams River

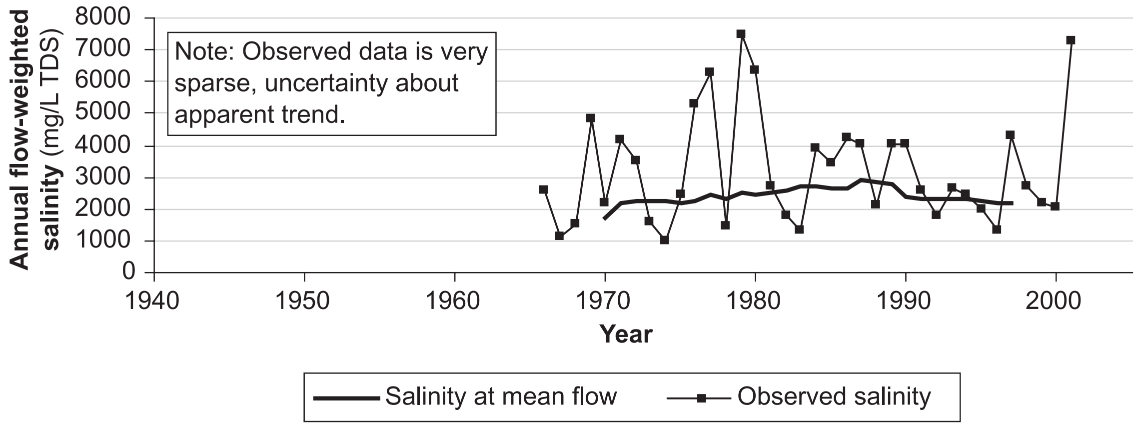


Figure 3.26 Salinity trend at Marradong Road Bridge (614-224) on the Hotham River

3.4 Swan–Avon Study Area (615, 616)

The salinity trends and seasonal variations of salinity are presented in Figures 3.28–3.31 and the salinity status status, rainfall and clearing of the whole area are shown in the map on Figure 3.32.

This study area, a large river basin of about 128 200 km^2, extends from the west coast at Perth to about 500 km inland and includes the city of Perth and the towns of Northam, York and Merredin (Fig. 3.32). The study area consists of only one river basin — the Swan-Avon River Basin but is sometimes referred to as two: the Swan Basin and the Avon Basin. For simplicity this report will refer to it as the Swan–Avon Study Area.

Most of the area has been cleared and is used predominantly for dryland agriculture although the area close to the coast includes some forested land and the large urban area of Perth (Pen 1999). In the Yilgarn catchment a lot of clearing was done around the 1920s but broadacre extensions occurred in 1950s and 1960s. Much of the clearing in the Mortlock River North, Mortlock River and Dale River South catchments also occurred in the 1950s. The rest of the catchments mostly were cleared since the 1950s (Public Works Department 1984b).

The major agricultural produce of the area includes wheat, other cereals and, recently, lupins and canola. Sheep are the major livestock but pigs and cattle are also significant (Seal 1991). The northern part of the coastal area was extensively cleared about 20–30 years ago. The watertable has risen significantly and there are localised areas of fresh and brackish seepage leading to secondary salinisation problems (pers. comm. Kim Griffin).

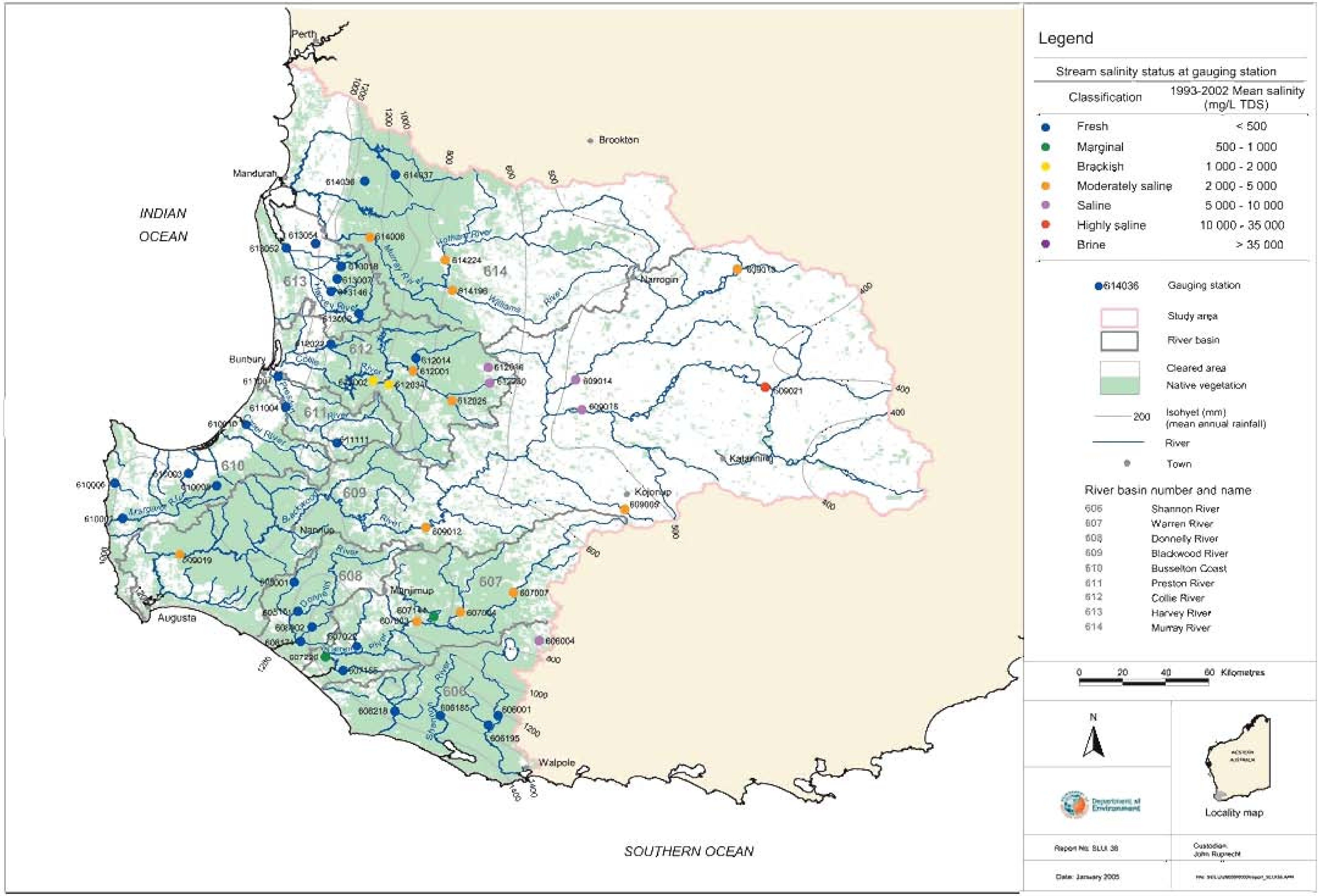


Figure 3.27 Stream salinity status, rainfall and clearing in the South West Study Area

The City of Perth near the mouth of the Swan River (L Pen)

The area experiences a temperate climate in the west changing to a semi-arid climate in the east (Seal 1991). Temperatures vary from warm to hot in summer to mild during the late autumn and spring with some frost in winter (Walker 1986). The mean annual rainfall is less that 300 mm in the eastern, semi-arid area and as much as 1300 mm over the escarpment close to the coast. Most of the basin lies far from the coast and receives about 70% of its annual rainfall between May and October. Near the coast this percentage climbs to about 85%. The mean annual evaporation also varies widely, from 1800 mm in the south to about 3000 mm in the north (Luke et al. 1988).

The main watercourse in the basin is the Avon River. It is known as the Swan further downstream below Wooroloo Brook and is the second largest river, by flow volume, in the south–west. About 65% of the Swan–Avon Basin lies in an Area of Ancient Drainage to the east where there are numerous salt lakes and systems of internal or irregular drainage (Pen 1999). The main river valleys are very broad and flat and watercourses only flow in periods of exceptionally intense and widespread rainfall (Pen 1999). The tributaries feeding these rivers are more incised into the landscape.

The Mortlock River East Branch (P Muirden)

About 19% of the basin lies in an area where there is a slightly more undulating landscape with discernible drainage lines and broad, flat but more continuous river valleys dotted with salt lakes (Pen 1999). This area only produces flow in years of above average rain (Pen 1999). The flow this portion generates enters the Avon via the Mortlock River at Northam and the Yenyening Lakes upstream of Beverley.

Qualandary crossing at the bottom of Yenyening Lakes (T Sparks)

Downstream of the Salt River confluence at Yenyening Lakes, the river is joined by the tributaries — Dale and Mackie rivers and Spencers, Wongamine and Toodyay brooks — which drain forest and farmland in the 400–600 mm rainfall areas. This portion of the Avon River was naturally braided but has been modified and 'trained' to mitigate flooding (Pen 1999). Below Toodyay, the river flows through a forested area and small tributaries from the 600–900 mm rainfall zone join. Two large tributaries, the Brockman River and Wooroloo Brook, drain mostly cleared catchments (Pen 1999).

The Avon River is officially renamed the Swan River below Wooroloo Brook — about five years after European settlement the settlers discovered that the Avon and the Swan were the same river, but the two names remained (Shaw 1984). Just past the Walyunga gauging station, the river is joined by the Ellen Brook, another major tributary, which drains farmland in the north-east. Downstream of the Ellen Brook the tributaries, Jane and Susannah brooks, join the main river. These drain forest, farmland and urban areas in the scarp. The largest tributary of the Swan River, the Helena River, supplies the Mundaring Weir and enters the Swan River at Guildford. The Swan River drains partially cleared forest in the Darling Range before meandering across urban areas and farmland. It then winds through farmland and vineyards in the Swan Valley and into the urban areas of Perth until it joins the Swan–Canning Estuary at Guildford.

Another notable watercourse in the study area is the Canning River, which, extending only as far inland as the escarpment, is very short compared with the Swan–Avon. The main Canning River drains forest with mean annual rainfall 700–1300 mm. The river flows through an increasingly urbanised valley until it discharges onto the Swan Coastal Plain at Kelmscott. It then meanders through urban areas where it collects water from a number of scarp tributaries, the largest of which is the Southern–Wungong River. Other tributaries include Bickley and Churchman brooks. All of these tributaries, as well as the upper Canning, support water supply dams.

The rivers in this area ranged from fresh to highly saline (Table 3.15, Fig. 3.32). All the fresh rivers were from catchments that were:

- cleared but with quite high mean annual rainfall (> 1100 mm)
- in lower rainfall areas but forested
- both forested and in higher rainfall areas.

Those rivers, such as the Helena, in catchments with only a little clearing but also low enough rainfall to suggest that they had a salinisation risk (Section 1.6) were in fact brackish. The salinity rose to moderately saline in catchments, such as that of the Brockman, where clearing was more extensive. In the very low rainfall areas, streamflows from substantially cleared catchments were highly saline.

Table 3.15 Key sites in the Swan–Avon Study Area

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km²)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
615-012	Lockhart River	90	350	6 050[a]	Highly saline	33 900	4	9.0
615-013	Mortlock River North	96	380	2 333[a]	Highly saline	15 000	4	37
615-014	Avon River Brouns Farm	86	380	26 856[a]	Saline	6 600[b]	1	14
615-015	Yilgarn River	82	310	11 540[a]	Highly saline	22 500	5	3.6
615-020	Mortlock River	97	360	5 040[a]	Highly saline	11 100	4	12
615-062	Avon River Northam Weir	86	390	28 485[a]	Saline	6 700	2	27
615-222	Dale River South	64	530	286	Moderately saline	3 700[b]	3	80
616-001	Wooroloo Brook	49	850	514	Moderately saline	2 200	2	19
616-002	Darkin River	4	730	665	Fresh	240	4	0.15
616-006	Brockman River Tanamerah	48	610	961	Moderately saline	3 400	1	12
616-011	Avon River Walyunga	85	400	40 401[a]	Moderately saline	4 900	3	14
616-013	Helena River Ngangagurin-guring	9	650	327	Brackish	2 000	4	1.5
616-019	Brockman River Yalliawirra	43	700	1 521	Moderately saline	2 500	1	11
616-039	Canning River Millars Road	0	820	146	Fresh	210[b]	5	0.26
616-040	Susannah Brook	58	1000	23	Fresh	350[b]	4	4.8
616-065	Canning River Glen Eagle	0	880	520	Fresh	210[b]	5	0.52
616-189	Ellen Brook	45	780	581	Marginal	620	4	2.7
616-216	Helena River Poison Lease	8	720	590	Brackish	1 300[b]	1	1.1

[a] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[b] Data record incomplete. See Appendix J.

The Swan–Avon River was the second largest river (by flow volume) in the south-west of the state and had the highest salt load. It exported, on average, more than 1.5 million tonnes of salt each year from its catchment (down to the Walyunga gauging station). Generally, the salinity of the river decreased downstream into higher rainfall and then more forested areas. At the most downstream gauging station assessed (Walyunga), the river was moderately saline but further upstream at the Northam Weir it was saline. The highest salinities were recorded in the Lockhart and Yilgarn rivers, the most eastern tributaries. Their entire catchments lie east of the 400 mm isohyet, and the parts of their catchments that regularly contribute to flows are extensively cleared.

The middle Brockman River (L Pen)

They are also dominated by chains of salt lakes which concentrate salt in the high evaporation climate. In average to low rainfall years, these salt lake systems contributed little or no flow to the Avon River.

Salt output/input ratios in most of the catchments were much greater than one indicating that the catchments had been disturbed by clearing and were exporting salt (Table 3.15). Salt outputs/inputs were less than one only in the uncleared catchments.

The seasonal variations in salinity, salt load and flow were calculated for those sites with continuous salinity measurements (Appendix H). At Brouns Farm on the Avon River, the salinity varied from less than 5000 mg/L TDS in December and January to about 12 000 mg/L in May (Fig. 3.28).

Figure 3.29 shows the relative contributions from around the Swan–Avon River Basin to the Avon River at Walyunga. The larger areas in the east contributed disproportionately high salt loads while the smaller, higher rainfall catchments contributed a much higher percentage of flow than salt. The percentage contributions around the Avon varied widely especially for the Lockhart and Yilgarn rivers.

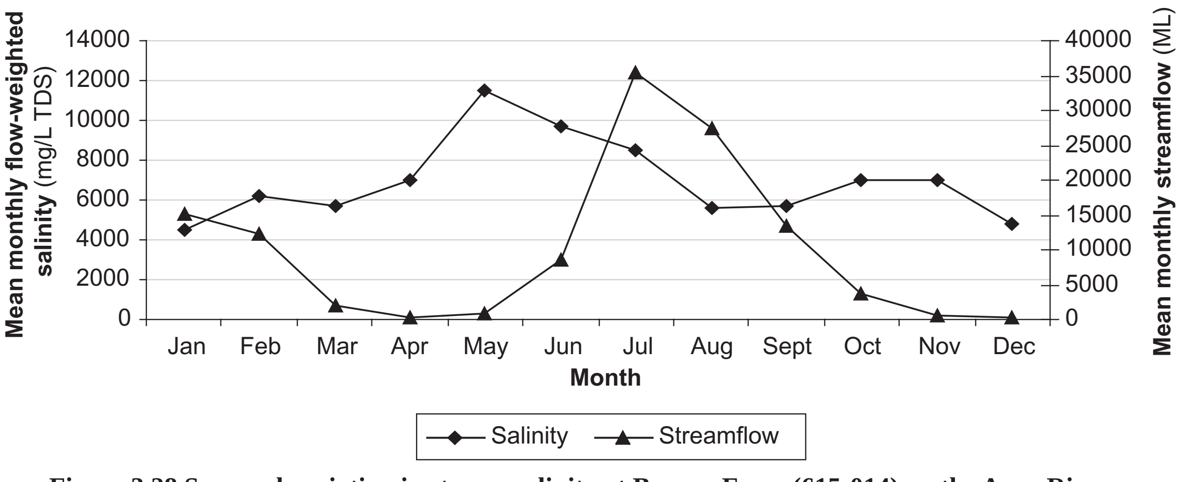


Figure 3.28 Seasonal variation in stream salinity at Brouns Farm (615-014) on the Avon River

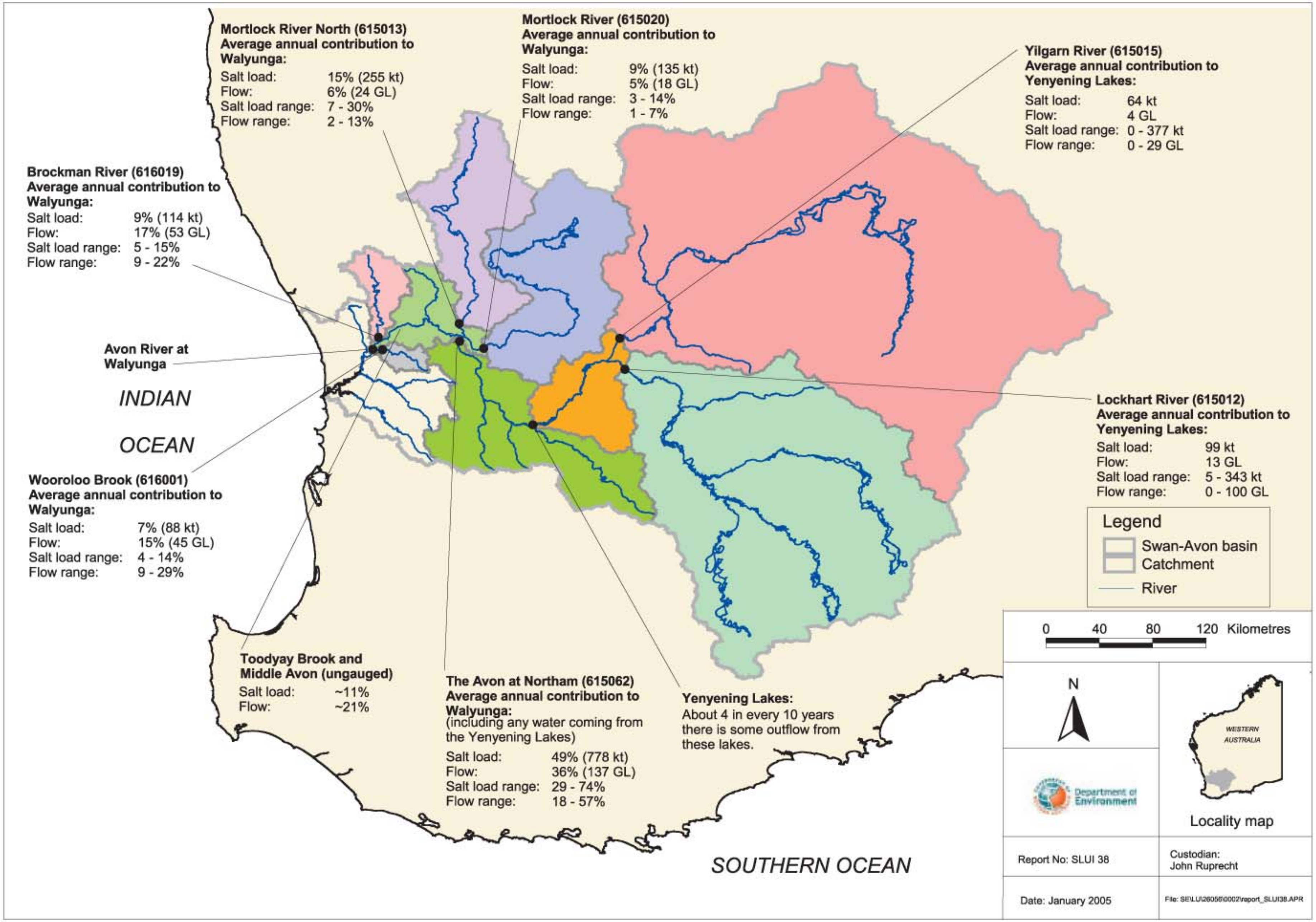


Figure 3.29 Relative contributions (1993-2002) to the Avon River at Walyunga

The salinity at mean flow in the Avon River varied little over most of the period of record until the increasing trend in the 1990s (Fig. 3.30). Extreme variability characterised the river with annual salinity ranging from more than 8000 mg/L TDS to less than 3000 mg/L TDS. This also made it difficult to identify a clear trend.

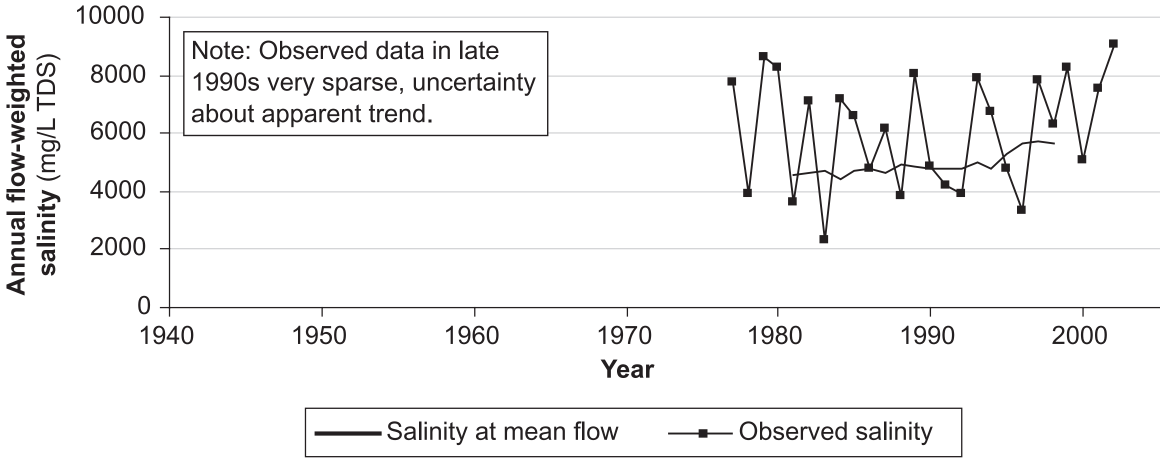


Figure 3.30 Salinity trend at the Northam Weir (615-062) on the Avon River

Further downstream at Walyunga the variability was much smaller, with salinity in most years between 4000–6000 mg/L TDS (Fig. 3.31). The variability was probably tempered by large fresh inputs from the higher rainfall catchments closer to the coast.

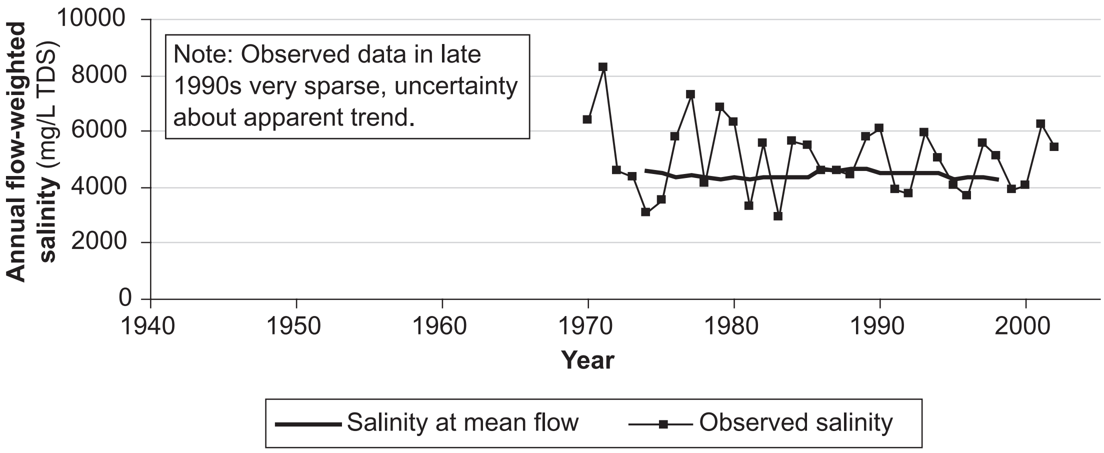


Figure 3.31 Salinity trend at Walyunga (616-011) on the Avon River

The apparent trend of decreasing salinity in the Avon River needs further investigation (Fig. 3.31). The Avon is a complex river system (Fig. 3.29) with contributions from a number of very different rivers such as Wooroloo, Brockman, Mortlock and Dale and a complex salt lake system upstream of the Yenyening Lakes. Consequently, the trend may be the result of different contributions from each of the tributaries or the result of inadequately incorporating climate variability into the trend analysis. Consistent climatic trends across the catchment are unlikely as it is such a large catchment that rainfall may be high in one part of the catchment in one year but normal in another part that same year. Further study is also required to assess the impacts of predicted large increases in areas with high watertables (Land Monitor 2003).

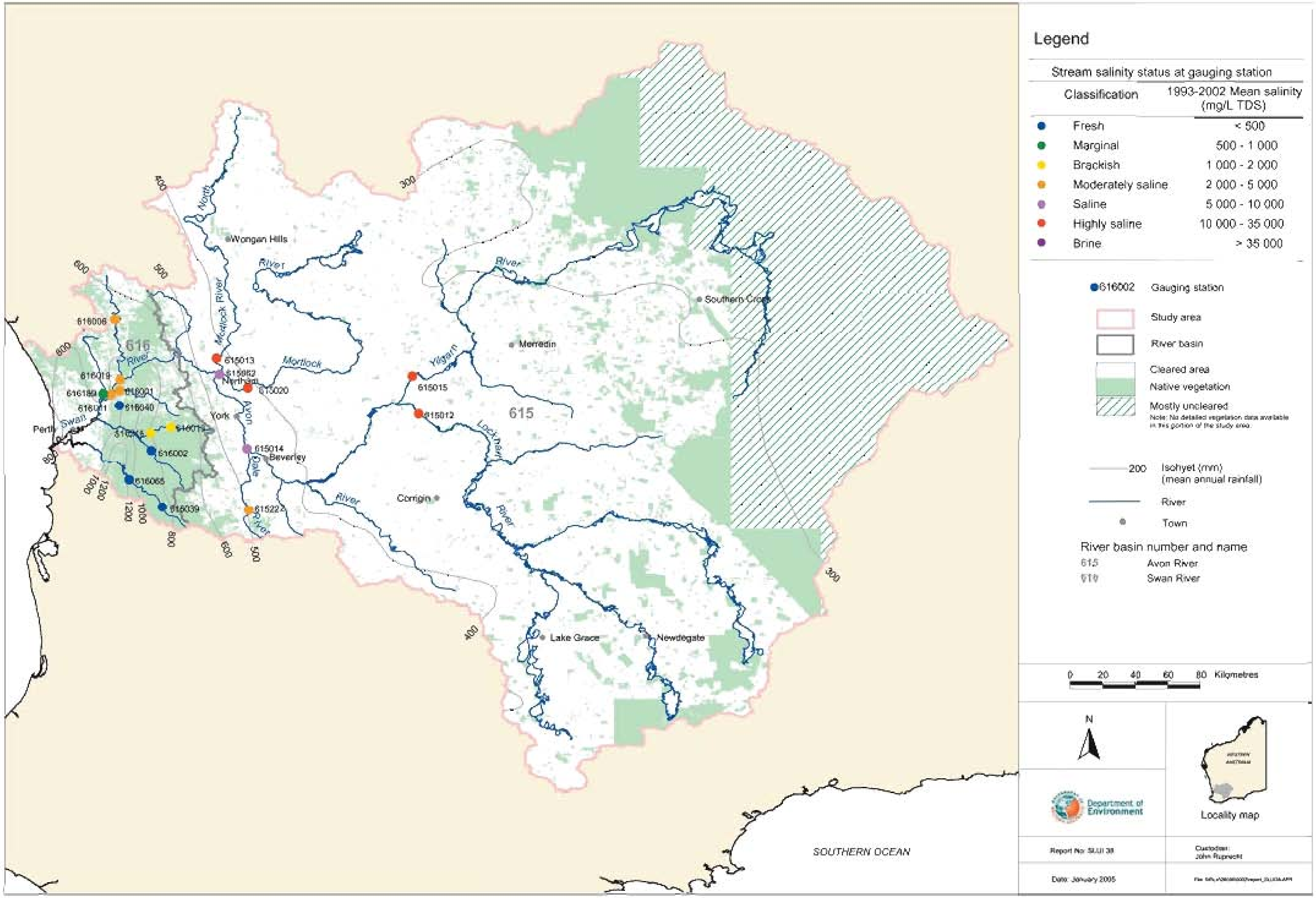


Figure 3.32 Stream salinity status, rainfall and clearing in the Swan-Avon Study Area

3.5 Northern Agricultural Study Area

Figures 3.33–3.36 show aspects of the salinity and flow on the Moore and Greenough rivers and Figure 3.37 shows the salinity status, rainfall and clearing information for the whole study area.

Climate

The coastal part of the Northern Agricultural Study Area has a temperate climate with winter rainfall dominating. Far inland, particularly in the Murchison Basin, the climate would be better described as semi-arid with mild winters, hot summers and unreliable rainfall (Water and Rivers Commission 2002a). Near the coast about 80% of the rain falls between May and October whereas far inland only 40% falls during this time. The mean annual evaporation varies from less than 2000 mm in the south and along the coast to more than 3800 in the north-east (Luke et al. 1988).

Clearing

Close to the coast this study area is extensively cleared but further inland, especially in the Murchison River Basin, there is little clearing. Some clearing dates as far back as the 1850s, although most broadacre clearing only began in the 1950s. A large portion of the Northern Agricultural Study Area's sandplain has been cleared in the past 30 to 40 years. The sandplain could not be cropped previously, but crop rotations of wheat and lupins, and better fertilisers have allowed it to be developed as viable farming land. As a result, there are now many sandplain seeps with the groundwater varying from fresh to brackish and causing salinisation of the watercourses (pers. comm. Kim Griffin).

Salinity

Analysis of gauging station records in this study area revealed no clear geographical pattern (Fig. 3.37) though watercourses closer to the coast, such as the Hill River and Gingin Brook, were fresher than those with tributaries further inland in extensively cleared Wheatbelt areas. The Murchison also extended far inland but this area is pastoral and, unlike the Wheatbelt, little of the natural vegetation has been cleared.

Almost all the salt output/input ratios were above one, indicating that most of the catchments were disturbed and losing salt. The more saline rivers exhibited high annual variability which made it difficult to discern trends.

As discussed in Section 1.6, watercourses in extensively cleared catchments with low rainfall usually had higher stream salinity. Many of the stream salinities in this study area were comparatively low considering the low mean annual rainfalls, probably because the catchments mostly lie on the coastal plain which has low soil salt storage (Section 4.1). For instance, Gingin Brook had mean annual rainfall of 720 mm, which is usually associated with a high stream salinity risk, and its catchment is extensively cleared (65%) but the water was fresh because fresh springs and relatively fresh groundwater seepage almost permanently fed the brook.

3.5.1 Moore–Hill Rivers Basin (617)

This basin lies along the west coast of the state and has an area of 24 900 km^2 (Fig. 3.37). It stretches from about 80 km south of Geraldton to just north of Two Rocks and about 150 km inland. It includes the towns of Jurien, Guilderton, Gingin, Moora and Dalwallinu.

The basin experiences a temperate climate, with hot dry summers and cool wet winters. Rainfall decreased inland and northwards with the most inland areas receiving only 350 mm of rainfall per year while the southernmost coastal areas received more than 700 mm. Mean annual evaporation was very high, ranging from about 2000 mm in the south-west to more than 2600 mm in the north-east (Luke et al. 1988).

The Hill River (P Howard)

The two major rivers in the area are the Hill and the Moore. The Hill River drains an area some 50 km inland. The northern tributaries of the Moore River begin in an area of mature and ancient drainage with numerous salt lakes in clay soils. These stretch across almost imperceptible valleys and join to flow in periods of unusually high rainfall. This part is the Marchagee River and it flows into the Coonderoo River. The Coonderoo flows along a sandplain full of lakes and finally into the Moore River North. The Moore River North drains flat valley floors east of Moora and moves 40 km south before it joins the Moore River East Branch to become the Moore River. The Moore River first flows through a well-defined valley with no tributaries until it descends the Gingin Scarp at Regans Ford. After descending the scarp, the river becomes braided across a broad swampy floodplain. In this part, numerous levees have been constructed for flood control. Finally the river discharges to the ocean at the town of Guilderton.

A notable tributary of the Moore is Gingin Brook, which enters the Moore about 10 km from the coast at the head of the estuary. The brook has year-round flow for most of its length since it is fed by springs as well as groundwater seepage. Many streams in the region that flow westward from the Gingin Scarp end in small fresh or saline lakes and swamps that have formed against the coastal strip of dunes and limestone or flow into caves (Beard 1976).

Most of the basin, except in coastal areas, is extensively cleared. The cleared areas are used mostly for agricultural cropping with some forestry in the southern tip of the basin (Beeston et al. 2002).

Tree death on Eganu Lake in the upper Moore River catchment. This is probably the result of waterlogging, a problem associated with salinity (P Muirden)

The analysed rivers ranged from fresh to saline (Table 3.16). The fresh streams — Gingin Brook and Lennard Brook — lie in the south of the catchment where rainfall is higher. Their catchments are almost 50% cleared with rainfall below 900 mm, which as discussed in Section 1.6, are factors indicating a high risk of salinity.

The streams were fresh because more than 50% of the Gingin Brook catchment is underlain by Bassendean Sandplain which has a low salt storage (Section 4.6). Further downstream Gingin Brook water became marginal in quality.

Table 3.16 Key sites in the Moore–Hill Rivers Basin

Site number	**Water-course**	**1996 Clearing** (%)	**Mean annual rainfall** (mm)	**Area** (km²)	**Salinity status**	**1993–2002 Mean salinity** (mg/L TDS)	**Reliability**	**Salt output/ input ratio**
617-001	Moore River	79	450	9608[a]	Saline	7200	1	18
617-002	Hill River	52	530	1141	Brackish	1100	4	0.2
617-003	Gingin Brook Bookine Bookine	44	700	1370	Marginal	840	5	2.3
617-058	Gingin Brook Gingin	59	720	106	Fresh	300	5	4.1
617-165	Lennard Brook	49	720	59	Fresh	390[b]	5	5.5

[a] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[b] Data record incomplete. See Appendix M.

The major rivers, the Moore and the Hill, were saline and brackish respectively. The catchments of both rivers were extensively cleared. The Moore's high salinity was because its large catchment area stretches north and inland into low-rainfall areas where rivers peter out into salt lake systems (Pen 1999). The Hill, on the other hand, is shorter and does not extend east of the 400 mm isohyet. It was much fresher than rivers in other basins with catchments of similar rainfall. This was probably because more than 85% of the catchment lies on sandplain landforms with lower soil salt storage and lower groundwater salinity than other catchments. The Hill River is a rarity in terms of its river classification, values and reasonable condition especially when compared with other rivers in the Mid West Gascoyne region. The Hill flows into a high value estuary — not many rivers in the area have estuaries, especially estuaries in reasonable condition.

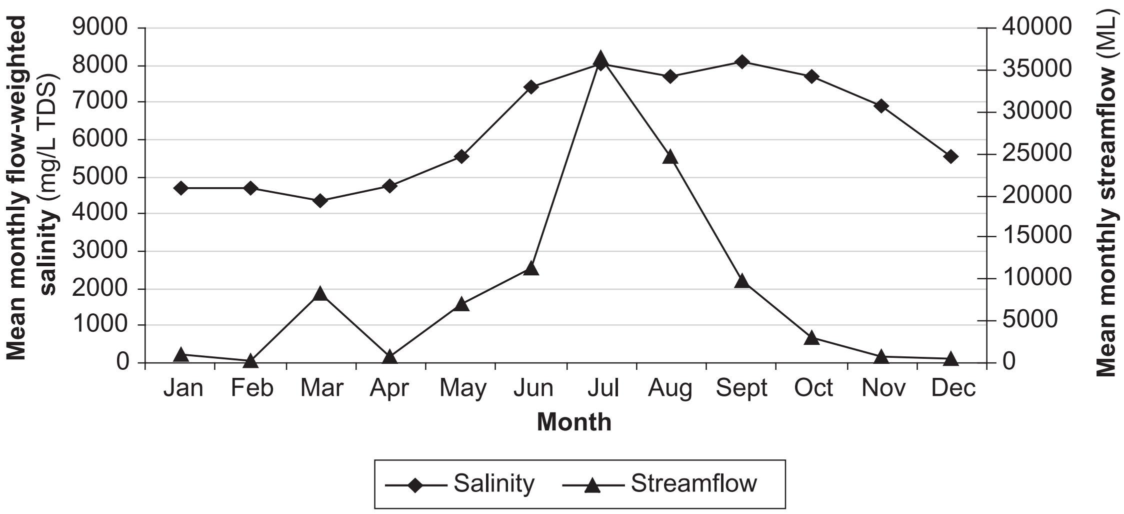


Figure 3.33 Seasonal variation in salinity at Quinns Ford (617-001) on the Moore River

Although the Moore River had a very high annual flow-weighted salinity, it became significantly fresher over summer when its salinity fell below 5000 mg/L (Fig. 3.33). This was because the lower rainfall areas of the catchment did not contribute to the lower Moore River during summer, and fresher groundwater discharge dominated the river flow in the lower reaches.

Flows in the Moore River have been measured since 1969 and showed a small summer baseflow which was driven by groundwater discharge, so the river did not dry up below Mogumber. Clearing in this vicinity occurred quite late (in the last 30–40 years), and in recent times there had been significant groundwater rise. Figure 3.34 shows the results of this groundwater rise as the increasing discharge into the river caused the exponential rise in minimum summer flows from the 20 ML/month during the 1970s to the present 400 ML/month.

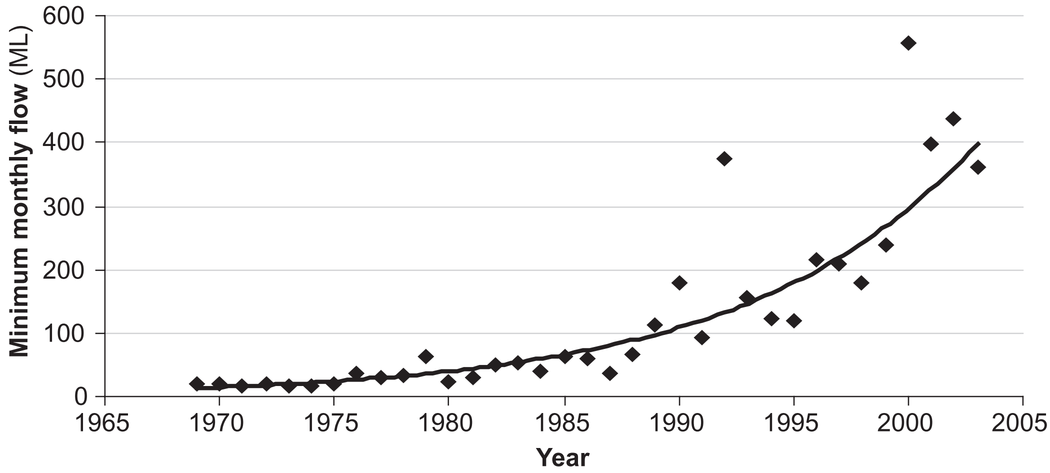


Figure 3.34 Minimum monthly flows for Quinns Ford on the Moore River over the last 30 years

There was no clear pattern in salinity at mean flow on the Moore River (Fig. 3.35) because the flow and salinity of the river were highly variable with different parts of the catchment contributing in wet years from those contributing in drier years. The annual salinity ranged from less than 4000 mg/L to more than 10 000 mg/L TDS.

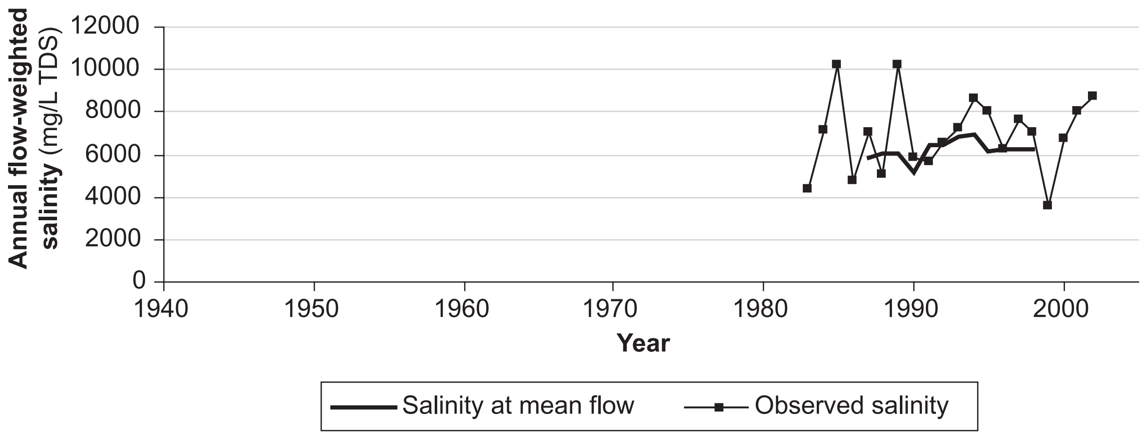


Figure 3.35 Salinity trend at Quinns Ford (617-001) on the Moore River

3.5.2 Yarra Yarra Basin (618) and Ninghan Basin (619)

These two basins are inland of the Greenough and the Moore–Hill Rivers Basins. No adequate data were available on the watercourses of these basins so no analyses were performed but they are still described.

A paleodrainage line flowing into the Yarra Yarra Lakes (P Muirden)

The Yarra Yarra Basin includes the towns of Carnamah, Morawa, Kalannie, Three Springs and Mount Magnet, and the Ninghan Basin includes Paynes Find. The highest mean annual rainfall in the Yarra Yarra Basin is 400 mm but most of the basin receives less than 300 mm. The whole of the Ninghan Basin receives less than 300 mm of mean annual rainfall. Both basins are dominated by chains of salt lakes and are internally drained (Fig. 3.37).

These two basins could be thought of as part of the 'Greater Moore' catchment as, in a wetter age, they probably contributed to the Moore River in the Moore–Hill River Basin. There is no known occasion of these basins contributing to the Moore River via a surface connection although, during the high rainfall year 1999, the level of the Yarra Yarra Lakes rose to within 300 mm of overflowing into the Coonderoo River. There was heavier rainfall in the 1917–18 period and it is possible that overflow occurred then. There is some evidence that the groundwater beneath the Yarra Yarra Lake system is leaking to aquifers along the Darling Scarp (Water and Rivers Commission 2002b). Consequently there may be some groundwater connection between the areas but only very rare, if any, surface connection.

3.5.3 Greenough River Basin (701)

This basin lies along the west coast of the state and has an area of just over 24 900 km^2. The city of Geraldton lies on the basin's coast and the basin stretches over 200 km inland from there (Fig. 3.37). The basin also includes the towns of Dongara, Northampton, Mingenew and Mullewa.

The basin experiences hot, dry summers and cool, wet winters. The mean annual rainfall at the coast is about 500 mm and it gradually drops off to less than 250 mm inland. The lowest mean annual evaporation is about 2600 mm at the coast and increases to about 3200 mm in the north-eastern corner (Luke et al. 1988).

The main rivers of the region from north to south are the Hutt, Chapman, Greenough, Irwin and Arrowsmith. The Hutt River, north of Geraldton, is about 50 km long and drains farming areas north of Northampton. The Chapman River is about 80 km long and drains the farming areas around the Waterloo Range as well as the Chapman Valley. The Greenough River is the longest of these, about 320 km, and it rises inland in the Zone of Ancient Drainage where the mean annual rainfall is less than 250 mm and the native vegetation is largely intact. It then flows through the farming areas east of the town of Eradu before passing through the Kojarena Range to the Greenough flats and finally discharging near the town of Greenough 10 km south of Geraldton. The Irwin River rises east of Mullewa at the eastern edge of the Wheatbelt before flowing 170 km to the coast at Port Denison. It starts in the Zone of Ancient Drainage, then flows through a wide valley into a hilly area and then onto the coastal plain. The southernmost waterway analysed in the basin is the Arrowsmith River which also drains farmland and is 80 km long.

Broadacre clearing for agriculture around the Greenough River (L Pen)

Except for its north-eastern corner and the southern portion, this basin is largely cleared. The cleared areas are used mostly for agricultural crops (Beeston et al. 2002). Clearing in the catchment of the Greenough River began in the 1850s but there has been substantial broadacre clearing since the 1950s. Clearing in the Arrowsmith catchment was also mostly since the 1950s (Public Works Department 1984b).

The gauged rivers of the basin were all moderately saline with mean salinities 2900–3700 mg/L TDS (Table 3.17). All these catchments are extensively cleared and the rainfall is low.

Table 3.17 Key sites in the Greenough River Basin

Site number	**Water-course**	**1996 Clearing** (%)	**Mean annual rainfall** (mm)	**Area** (km^2)	**Salinity status**	**1993–2002 Mean salinity** (mg/L TDS)	**Reliability**	**Salt output/ input ratio**
701-002	Greenough River	50[a]	330	11 736	Moderately saline	3700[b]	5	2.5
701-005	Arrowsmith River	83	510	809	Moderately saline	2900[b]	5	3.3
701-007	Chapman River	90	470	1 578	Moderately saline	2900[b]	3	6.1
701-009	Irwin River	84	415	5 264	Moderately saline	2300[b]	5	3.3

[a] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[b] Data record incomplete. See Appendix M.

There were not enough measurements to be sure whether salinity in the Greenough River was increasing or decreasing (Fig. 3.36). The data record was too short and sparse and the data too variable. However, the variability was itself an important feature of this river. Figure 3.36 illustrates that the salinity varied from nearly 10 000 mg/L TDS (saline) down to 1000 mg/L TDS (brackish), a range of 9000 mg/L TDS.

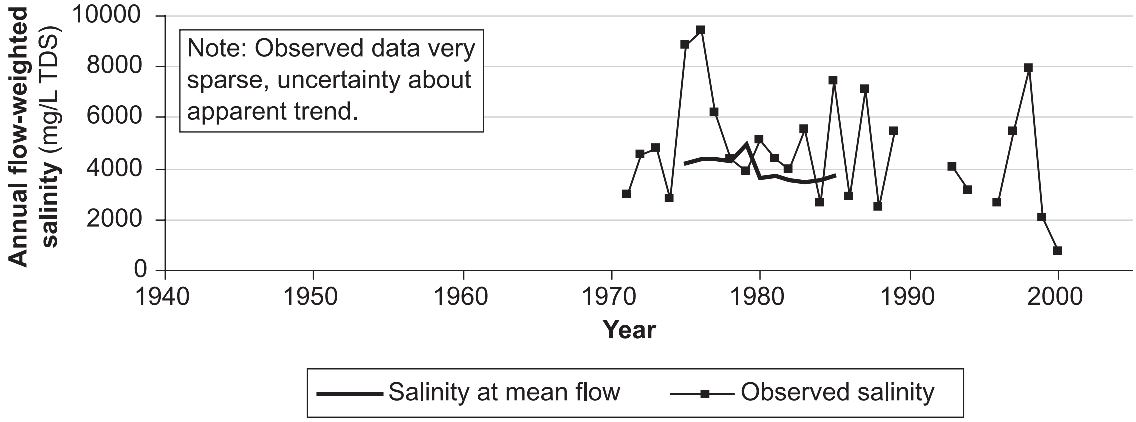


Figure 3.36 Salinity trend at Karlanew Peak (701-002) on the Greenough River

3.5.4 Murchison River Basin (702)

This is the northernmost river basin of this study. It has an area of 105 000 km^2 and stretches 450 km inland from the west coast at Kalbarri to beyond Meekatharra.

The coastal part of this basin has a temperate climate with winter rainfall dominating. Inland the climate would be better described as arid with mild winters, hot summers and unreliable rainfall (Water and Rivers Commission 2002a). On average in these inland areas there is more rainfall during summer than over winter (Water and Rivers Commission 2002a). Mean annual rainfall varies from a maximum 400 mm at the coast to less than 300 mm within 80 km and most of the basin receives only 200 mm. The mean annual evaporation ranges from about 2600 mm at the coast to about 3800 mm inland (Luke et al. 1988).

The drainage of the Murchison River is considered to be dendritic as the river and its two main tributaries have numerous smaller tributaries which sprawl out over the basin like the branches and twigs of a tree. Very little of the Murchison Basin is cleared; rather, most of the basin is used for grazing and there is an issue with overgrazing (Public Works Department 1984b). Closer to the coast there is some grain production and a few large tracts of conserved land, in particular the Kalbarri National Park (Beeston et al. 2002).

The Murchison River at the Emu Springs gauging station (702-001) was brackish with a mean salinity of 2000 mg/L TDS (Table 3.18). It was one of the five biggest rivers by flow but exported only about 149 000 tonnes of salt each year — less than smaller rivers such as the Frankland, Pallinup and Moore and quite small in comparison with the largest river, the Blackwood, which exported 1 million tonnes. The rainfall is extremely low but there is also very little clearing. It is not surprising that the salt output/input ratio was quite low (Section 1.6) although it still indicated some net loss of salt. This salt was probably coming from the cleared agricultural land south-east of the town of Ajana in the Croton Creek catchment. The output/input ratio should be treated with caution since it was calculated with limited site data (Appendix A).

Table 3.18 Key sites in the Murchison River Basin

Site number	Water-course	1996 Clearing (%)	Mean annual rainfall (mm)	Area (km^2)	Salinity status	1993–2002 Mean salinity (mg/L TDS)	Reliability	Salt output/ input ratio
702-001	Murchison River	5[a]	220	86 800[b]	Brackish	2000[c]	4	1.6

[a] Clearing figures not consistent with the other catchments. See Appendix A.

[b] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[c] Data record incomplete. See Appendix M.

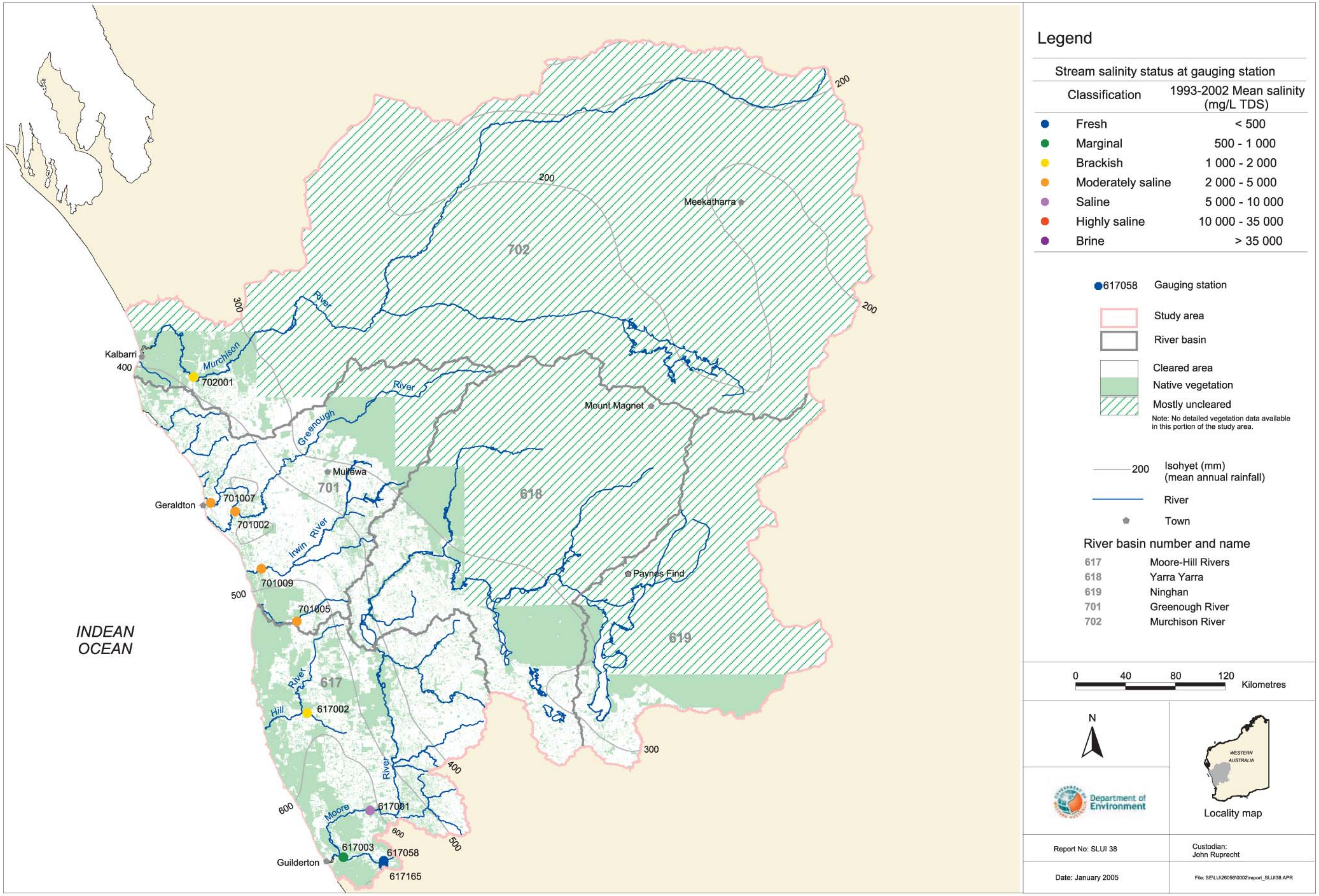


Figure 3.37 Stream salinity status, rainfall and clearing in the Northern Agricultural Study Area

4 Overview of salinity in the south-west

4.1 Patterns of salinity

Calculations of the average annual flows (by volume) from the analysed rivers of the south-west to the ocean showed that only 44% of the flow was fresh, 10% marginal in quality, 21% brackish and 25% moderately to highly saline. More than half of the major rivers of the south-west (the largest 30 by mean annual flow) were brackish to saline (Fig. 4.1).

It was estimated that, in the period 1960–2002, the rivers of the south-west discharged 4700 GL of water and exported about 7.5 million tonnes of salt to the ocean each year. The Avon River alone, as recorded up to the Walyunga gauging station, exported 1.5 million tonnes of salt each year (mean 1993–2002) (Fig. 4.2). This was the highest salt load in a south-west river although the Avon is only the second largest river by volume of flow. The largest river by flow, the Blackwood, which was once fresh near its mouth, now exports 1 million tonnes (mean 1993–2002 at the Hut Pool gauging station) of salt each year (Fig. 4.2).

Stream salinity around the south-west showed the expected, distinct pattern described in Section 3 (see Map). Watercourses originating in the higher rainfall (> 900 mm) uncleared areas near the coast between Mundaring and Albany were generally fresh. To the east of this band, the salinities increased progressively as rainfall decreased. The band of fresh tributaries was pierced by large saline rivers, which originate in low rainfall, extensively cleared catchments of the Wheatbelt and were fresher downstream than at their headwaters.

The factors controlling this salinity pattern include clearing, rainfall, groundwater salinity, geology and topography and are discussed below.

Stream salinity was lowest along the coast of the south-west corner, where there was higher rainfall and little catchment clearing. Most of the rivers with catchments not extending east of the 1000 mm isohyet were fresh, even those with clearing in their catchments (Map). This was in keeping with the findings of Schofield et al. (1988) that clearing in high rainfall areas (> 1100 mm of mean annual rainfall) only slightly increased stream salinities and on an annual basis kept water quality well within the fresh range.

Higher stream salinities were observed in the lower rainfall areas (see Map). Between the 1000 and 800 mm isohyets most sites were marginal to marginal-brackish (500–1500 mg/L TDS) and between about the 800 and 500 mm isohyets high-brackish (1500–3000 mg/L TDS). Between about 400–700 mm of mean annual rainfall, most sites were classified as low-saline (3000–7000 mg/L TDS) and with less that 500 mm salinities were more than 7000 mg/L TDS (saline) (see Appendix A and Map). Exceptions to these patterns included the Gingin and Lennard brooks (Map) with catchments underlain mostly by sandy sediments, which typically have low groundwater salinity and low soil salt storage.

The most saline rivers or river sections were inland, had tributaries originating inland or are east of Albany along the south coast (Map 1). These areas generally had low rainfall, extensive catchment clearing and were underlain by higher salinity groundwater than the western coastal areas (Fig. 4.5). They were also in flat poorly-drained topography where the evaporation of water pooling in lakes and wet areas concentrated salt even further.

In the low-rainfall areas (< 500 mm of mean annual rainfall) of the eastern Wheatbelt were found the highest stream salinities for flowing water in the state. There was very little flow or salinity data available but from correlating gauging station data with data from snapshot sampling it is evident that average annual stream salinities were higher than seawater (35 000 mg/L TDS) in areas with annual rainfall below 300 mm.

Generally, the greater the extent of clearing in the catchment the higher the stream salinity, but the effect was difficult to separate from rainfall since clearing was often more extensive in the lower rainfall areas (Map).

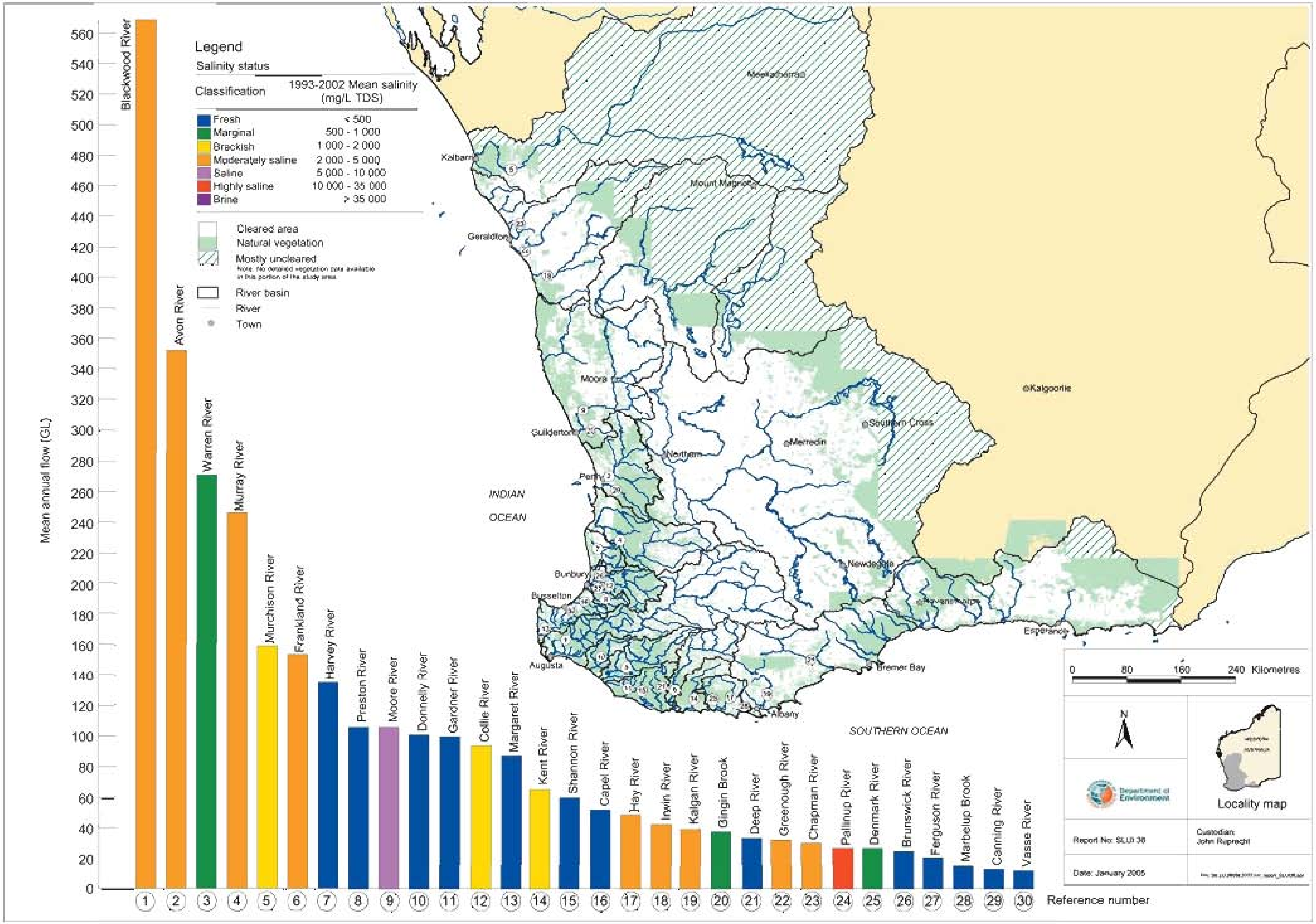


Figure 4.1 Salinity of major gauged rivers ranked by streamflow (mean 1993–2002)

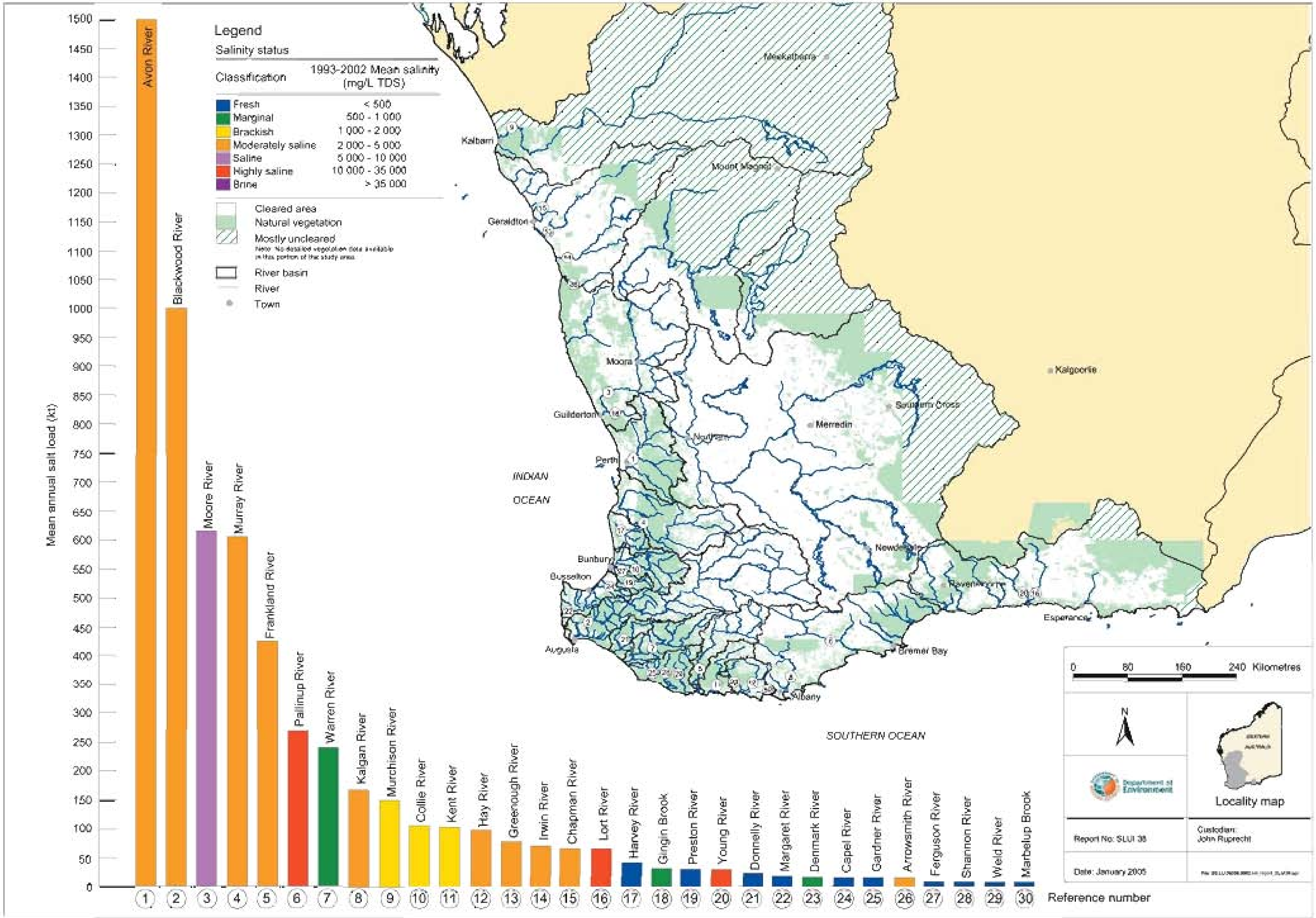


Figure 4.2 Salinity of major gauged rivers ranked by salt load (mean 1993–2002)

It was especially difficult to gauge the effect of clearing in low-rainfall areas since these areas were almost entirely cleared. The fresh streams near Bremer Bay illustrate the protective value of forested catchments even where the mean annual rainfall was less than 600 mm. This provides some evidence that, where there was good drainage, rivers in the low-rainfall areas were fresh before clearing. There is also anecdotal evidence of streams with less than 600 mm of mean annual rainfall being used as fresh supplies for steam engines but subsequently becoming too salty for use (Bleazby 1917).

The effects of clearing were most apparent in the areas between the 600 and 800 mm isohyets. The rivers in areas with almost no clearing remained fresh or marginal, but those with even small percentages of catchment clearing became saline. Schofield et al. (1988) found that, after clearing in areas with 500–700 mm of mean annual rainfall, river salinities rose from fresh to marginal or brackish (1500–5000 mg/L TDS).

Between the 800 and 1000 mm isohyets, streams in forested catchments remained fresh whereas those with significant catchment clearing were more often marginal to marginal-brackish. Schofield et al. (1988) similarly found that clearing raised stream salinities from fresh to marginal in areas of 900–1100 mm of mean annual rainfall.

Some rivers close to the coast in high rainfall zones were marginal to low-saline, but their catchments extended quite far inland to areas of low rainfall and significant clearing. These rivers showed the familiar pattern observed in major rivers of the south-west: their headwaters in poorly drained and lower rainfall catchment areas were more saline than the downstream sections with fresh inputs from high rainfall areas and fresh groundwater.

4.2 Changes in salinity

The percentage change of average annual salinity from the 1980s to the 1990s for the analysed gauging stations in the four study areas was calculated (Fig. 4.3). At most sites the observed mean annual salinity increased. The biggest increases were recorded in the South Coast and Northern Agricultural Study Areas, and the smallest in the South West and Swan–Avon Study Areas.

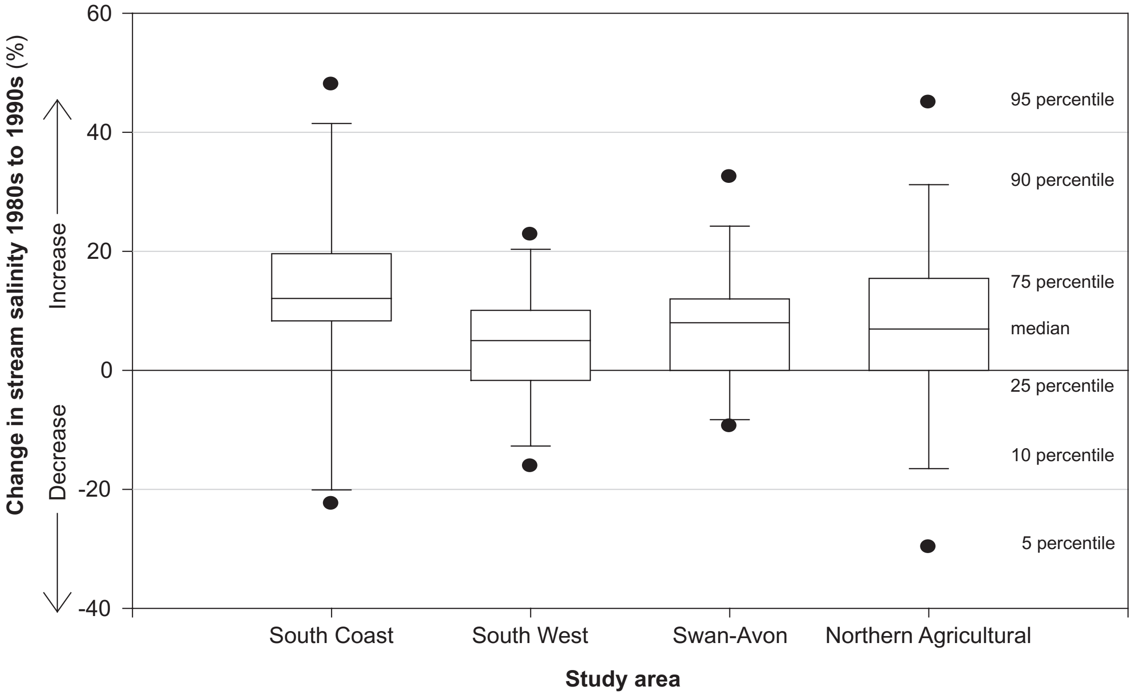


Figure 4.3 Changes in salinity from 1983–1992 to 1993–2002

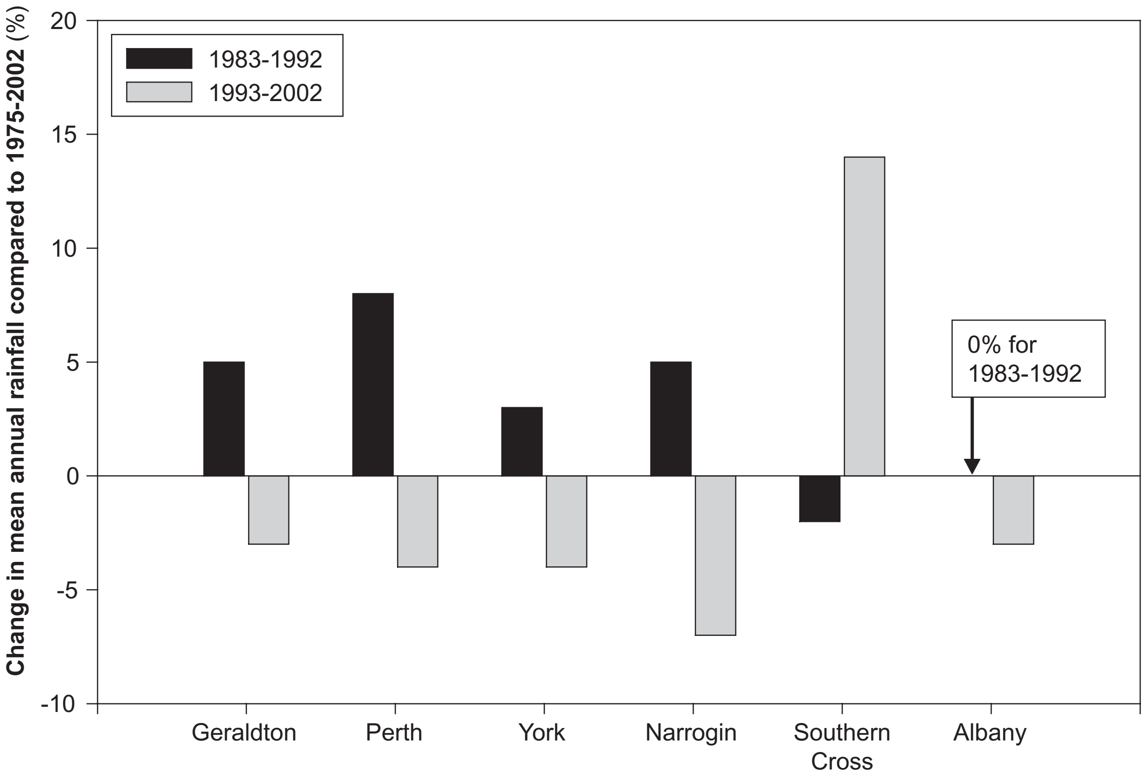


Figure 4.4 Changes in mean annual rainfall 1983–1992 and 1993–2002 compared to 1975–2002

During the 1990s rainfall and streamflow were also lower meaning that the higher salinities were the result (at least in part) of climate variations rather than land use changes (Fig. 4.4). The 1993–2002 mean average rainfall for the area from Geraldton to Narrogin was consistently below the 1975–2002 values (Fig. 4.4). The area near Southern Cross went against this trend, with an almost 15% increase in the average annual rainfall in the 1990s.

Table 4.1 Summary of rivers with statistically significant trends in salinity

Site number	Watercourse	Site	Clearing 1996 (%)	Mean annual rainfall (mm)	1993-2002 Mean annual salinity (mg/L TDS)	Annual salinity trend[a] (mg/L TDS) 1980–1989	1990–1998
603-136	Denmark River	Mt Lindesay	18	800	750	14s	-7.5s
604-053	Kent River	Styx Junction	40	800	1700	42s	14s
607-220	Warren River	Barker Road Crossing	31	800	990	15s	2.0ns
608-002	Carey Brook	Staircase Road	0	1415	110	-0.54s	-0.54s
608-151	Donnelly River	Strickland	20	1110	220	1.8s	-1.9s
609-005	Balgarup River	Mandelup Pool	87	530	5000	-30ns	17s
612-002	Collie River	Mungalup Tower	22	790	1500	33s	-5.9s
614-006	Murray River	Baden Powell Water Spout	60	750	2900	29s	10s
615-062	Avon River	Northam Weir	86	390	6700	-	140s
616-019	Brockman River	Yalliawirra	43	700	2500	51s	22s
616-216	Helena River	Poison Lease	8	720	1300	15s	-19s
617-001	Moore River	Quinns Ford	79	450	7200	-	50ns

[a] s denotes statistically significant trend at the 95% confidence limit, ns means not statistically significant

The statistical analyses of trends showed that, when climate variability was removed, stream salinity increases in the 1990s were smaller than in the 1980s, and salinities in some catchments were possibly even levelling off (Table 4.1). The rivers with frequent enough sampling and long enough records to produce these trends were mostly in the South West Study Area. Few trends could be calculated for rivers far east along the south coast (in the Albany and Esperance regions) or north on the west coast. Further work is needed at specific sites to confirm these slowing and levelling salinity trends. Some of the uncertainty with these trends relates to isolating decadal climate variability from annual variability.

4.3 Major rivers

Water at the gauging stations of the major rivers (the seven largest catchment areas) in these study areas varied from brackish (1000–2000 mg/L TDS) to saline (5000–10 000 mg/L TDS) but none were fresh (Table 4.2). There is historical evidence that the water at some of these gauging stations, such as the one on the Blackwood River, was once fresh. All of these catchments include large areas with low rainfall and, except for the Murchison, have been extensively cleared.

Table 4.2 Mean salinities and trends of major rivers (ranked by catchment size)

Site number	Watercourse	Mean annual salinity (mg/L TDS)				Annual salinity trend (mg/L TDS)[b]	
		1983–1992	Reliability	1993–2002	Reliability	1980–1989	1990–1998
609-019	Blackwood River	2000	2	2100	1	-	-0.64ns
614-006	Murray River	2600	2	2900	4	29s	10s
616-011	Swan River	5000	2	4900	3	95s	-
617-001	Moore River	6700	2	7200	1	-	50ns
701-002	Greenough River	4800[a]	4	3700[a]	5	-	-
701-009	Irwin River	1900[a]	4	2300[a]	5	-	-
702-001	Murchison River	1100[a]	3	2000[a]	4	-	-

[a] Data record incomplete. See Appendix M.

[b] s denotes statistically significant trend at the 95% confidence limit, ns means not statistically significant

The sparse record of data for most of the major rivers precluded calculating trends. Rivers with adequate data showed significantly rising trends in the 1980s but smaller rises or statistically insignificant trends in the 1990s.

4.4 Forested catchments

Forested catchments are the best indicators of what stream salinity may have been before extensive clearing. They also provide a 'control' since they should not be influenced by land use change. However, most forested catchments in the south-west have had some level of disturbance such as timber harvesting.

Forested catchments were defined, for the purposes of this section, as those with less than 4% of their area cleared of native vegetation. Streamflows in such catchments were fresh although there was significant variation within the fresh range (Table 4.3). Most of these catchments were in high-rainfall areas (> 900 mm of mean annual rainfall) where there is a low risk of large rises in stream salinity after clearing (Section 1.6). Water from forested catchments with less than 900 mm of mean annual rainfall may also have been fresh since the Canning and Mitchell rivers, despite less than 900 mm of mean annual rainfall, were still fresh.

The mostly forested (4% clearing) Darkin River catchment with even lower rainfall (730 mm) remained fresh. Although there were no analyses in this report of gauging stations in fully forested catchments with less than 700 mm rainfall there is some data on such rivers. For instance, sampling of some fully forested catchments in the Stirling Range (~ 450 mm of mean annual rainfall) indicates marginal water quality and historical evidence notes that streams near Cranbrook (~ 550 mm of mean annual rainfall) and Yornaning (~ 500 mm of mean annual rainfall) were fresh before native vegetation was cleared (Bleazby 1917).

Table 4.3 Mean salinities and trends of selected forested catchments

Site number	Watercourse	Mean annual salinity (mg/L TDS)						Annual salinity trend (mg/L TDS)[b]	
		Mean annual rainfall (mm)	1983–1992	Reliability	1993–2002	Reliability	Salt output/ input ratio	1980–1989	1990–1998
603-005	Mitchell River	855	280[a]	3	350[a]	4	1.5	-	-
606-001	Deep River	990	200	3	220	5	1.3	-	-
606-185	Shannon River	1230	140	3	140[a]	5	1.1	-2.1s	-
606-195	Weld River	1275	160	3	210	5	1.6	-0.32ns	-
608-001	Barlee Brook	1170	150	3	150[a]	5	1.8	-	-
608-002	Carey Brook	1415	120	2	110	2	1.1	-	-0.5s
610-008	Margaret River North	940	160	4	160[a]	5	0.94	-	-
613-002	Harvey River	1195	110	4	120[a]	5	1.3	-	-
614-037	Big Brook	1050	-	-	120[a]	3	0.27	-	-
616-002	Darkin River	730	180[a]	4	240	4	0.15	-	-
616-039	Canning River	820	200[a]	4	210[a]	5	0.26	-	-
616-065	Canning River	880	210[a]	3	210[a]	5	0.52	-	-

[a] Data record incomplete. See relevant Appendix.

[b] s denotes statistically significant trend at the 95% confidence limit, ns means not statistically significant

Forested catchments are known to export little salt and often accumulate it (depending on catchment characteristics, predominantly rainfall). In a forested catchment in a high rainfall area (> 1100 mm of mean annual rainfall) the salt output/input ratio would be expected to be close to one since the catchment is hydrologically undisturbed and the high rainfall enables the throughflow of salt. In low rainfall areas where groundwater is not discharging to the stream the salt output/input ratio is likely to be much lower than one. For example, in very small forested catchments with mean annual rainfall less than 700 mm, the ratio could be less than 0.25 or even as low as 0.01 (Williamson et al. 1987). The inference (Table 4.3) is that there was a small net loss rather than the expected value of one for forested catchments in the high rainfall areas. However, as expected and similar to Williamson et al. (1987), the data in Table 4.3 suggest that, for most of the lower rainfall areas, forested catchments were still accumulating salt.

The output/input ratios presented in Table 4.3 should be viewed in light of the methodology used to calculate them. Calculating inputs was based on a salt fall relationship developed before 1976 (Hingston & Gailitis 1976) and many estimations, such as the distance to the coast and the mean annual rainfall for each catchment. Consequently, there is uncertainty about these figures, which makes interpretation difficult. Further work is needed to better understand catchment water and salt balance changes.

The salinites of streamflow from forested catchments changed little. The data for the forested catchments were sparse so few trends could be calculated. Where calculations were possible, the trends were very small (most less than 4 mg/L per year) and either statistically insignificant or decreasing.

Some forested experimental control catchments considered too small to be regionally significant were not included in this study. Much research, such as by Bari and Boyd (1993), found that their groundwater levels and stream salinities were more or less stable.

4.5 Water Resource Recovery Catchments

The 1996 *Salinity Action Plan* (Government of Western Australia 1996) identified the Helena catchment, and parts of the Collie, Warren, Denmark and Kent River basins as Water Resource Recovery Catchments (WRRCs). These areas were existing or potential water supply sources expected to deteriorate beyond recovery without further management. A target — drinking water quality (500 mg/L TDS) — and dates were set: by 2015 for the Collie River at the Wellington Reservoir (closest gauging station: 612-002); by 2020 for the Denmark River (603-136); and by 2030 for the Warren (607-220) and Kent (604-053) rivers. Mundaring Weir in the Helena River catchment still has water of drinking quality but is at risk of salinisation and therefore was included as a WRRC.

These five catchments have, for decades, been a major part of the state's water resource salinity management strategies. Clearing controls were placed on the catchments in the late 1970s, and they have subsequently been partly revegetated to control salinity. Revegetation in the Collie catchment began in 1980 (Mauger et al. 2001), and there has been significant revegetation in the Denmark, Warren, and Kent catchments during the 1990s (Bari et al. 2004; Smith et al. in prep.; De Silva et al. in prep.). There has been relatively little clearing and some revegetation in the Helena catchment (Dixon 1999).

The rivers of the Water Resource Recovery Catchments showed a distinct pattern of rising salinity during the 1980s, but the pattern had changed by the 1990s. Mauger et al. (2001) found that salinity in the Collie River was levelling off, Bari et al. (2004) found that salinity in the Denmark River was decreasing, the salinity of the Kent River was still rising but at a lower rate than in the 1980s, and salinity in the Warren River was also still rising but the rise was statistically insignificant (Table 4.4).

A salinity situation statement has been prepared or is being prepared for each catchment. These are modelling studies which review the salinity situation and model the effects of past clearing, planting, and relevant land use, and assess additional plant or engineering based activities (management options) for their potential to reach the salinity target by the set date. Mauger et al. (2001) and Bari et al. (2004) showed the effectiveness of options such as the diversion of saline water, plantations or groundwater pumping in lowering the salinity of the river. Mauger et al. (2001) showed that, without clearing controls or revegetation, the mean annual salinity of the Collie River would have risen above 1500 mg/L TDS at the Wellington Reservoir while, with current and planned plantations, it is expected to level off at around 750 mg/L TDS.

Bari et al. (2004) showed that stream salinity in the Denmark River would have reached about 680 mg/L TDS if no replanting or tree regeneration had occurred, but with current plantations (to 2001) would only reach about 630 mg/L TDS, and presented management options — tree planting, deep rooted perennials, diversion of saline water and groundwater pumping — for reducing the salinity to 370–500 mg/L TDS (Bari et al. 2004). Similar studies on the Warren, Kent and Helena catchments are being finalised (Smith et al. in prep.; De Silva et al. in prep; Smith in prep.).

Table 4.4 Mean salinities and trends at gauging stations downstream of the Water Resource Recovery Catchments

Site number	Watercourse	Mean annual salinity (mg/L TDS)				Annual salinity trend (mg/L TDS)[b]	
		1983–1992	Reliability	1993–2002	Reliability	1980–1989	1990–1998
603-136	Denmark River	810	2	750	1	14s	-7.5s
604-053	Kent River	1600	1	1700	1	42s	14s
607-220	Warren River	890	2	990	2	15s	2.0ns
612-002	Collie River	1200	1	1500	1	33s	-5.9s
616-216	Helena River	1400	2	1300	1	15s	-19s

[a]s denotes statistically significant trend at the 95% confidence limit, ns means not statistically significant

4.6 Groundwater salinity

Regional groundwater salinity is generally lowest in the coastal areas and highest inland within the broad flat river valleys (Fig. 4.5).

Rainfall, geology and topography are considered three of the most important factors that influence groundwater salinity (Fig. 4.5).

Salinity is generally low in the (mostly) sandy sediments of the Perth Basin, and higher in the areas of crystalline rock, which lie east of the Darling Fault because the sandy sediments are much more permeable and better drained than the areas of crystalline rock.

Drainage, and hence salinity of groundwater, is also controlled by the topography. Flatter landscapes, such as those found in inland parts of the south-west, are poorly drained. So most rainfall is either lost by evapotranspiration, infiltrates to groundwater or collects in salt lakes or wet areas where salt concentrates by evaporation.

An example of geological and topographical control can also be seen along the coast, east of Albany, where groundwater salinity is relatively high, reflecting the flat poorly-drained topography and relatively impermeable sediments. By comparison, groundwater in the Swan Coastal Plain, with similar rainfall, has lower salinity because of underlying mostly sandy sediments.

High groundwater salinity has important implications for stream salinity, especially in cleared areas where the major cause of stream salinity is groundwater rising and discharging to streams. In the Darling Plateau, forest clearing has been shown to increase recharge to groundwater, raising the watertable and leading to dissolution of salts stored in the unsaturated zone. Where this occurs, the salt can leach into the streamline increasing stream salinity. In the agricultural areas to the east, clearing native vegetation has raised the level of the naturally saline groundwater, leading to soil salinisation and, consequently, a higher salinity of runoff. In the dissected topography of the western agricultural areas, where the watertable is closer to the surface, saline seeps can occur relatively high in the landscape, while in the eastern areas the discharge is typically in the broad valley floors.

Structural features and geological variability can influence groundwater flow and salinity (George et al. 1997), particularly at the local scale.

4.7 Salinity relationships

The stream salinity of rivers east of the Darling Scarp rose as the mean annual rainfall decreased, particularly from less than 1000 mm to 400 mm (Fig. 4.6), and, as the percentage of catchment clearing rose, with the highest rises where more than 5% of the catchment had been cleared and mean annual rainfall was less than 900 mm. There was also a greater range of salinities in areas of lower mean annual rainfall, such as for the 400 to 600 mm rainfall band where the mean annual salinity range was from 2050 to 7000 mg/L TDS.

Since after clearing there is a strong relationship between salinity and rainfall, the mean annual rainfall (combined with information on geology and soil type) is a more convenient and practical indicator of the salinity risk than the more accurate, but difficult and expensive to measure, soil salt storage in the catchment. The rainfall–salinity relationship held less well on the coastal plain where the sandy sediments allow quicker flow through of water resulting in lower salt storage in the soil.

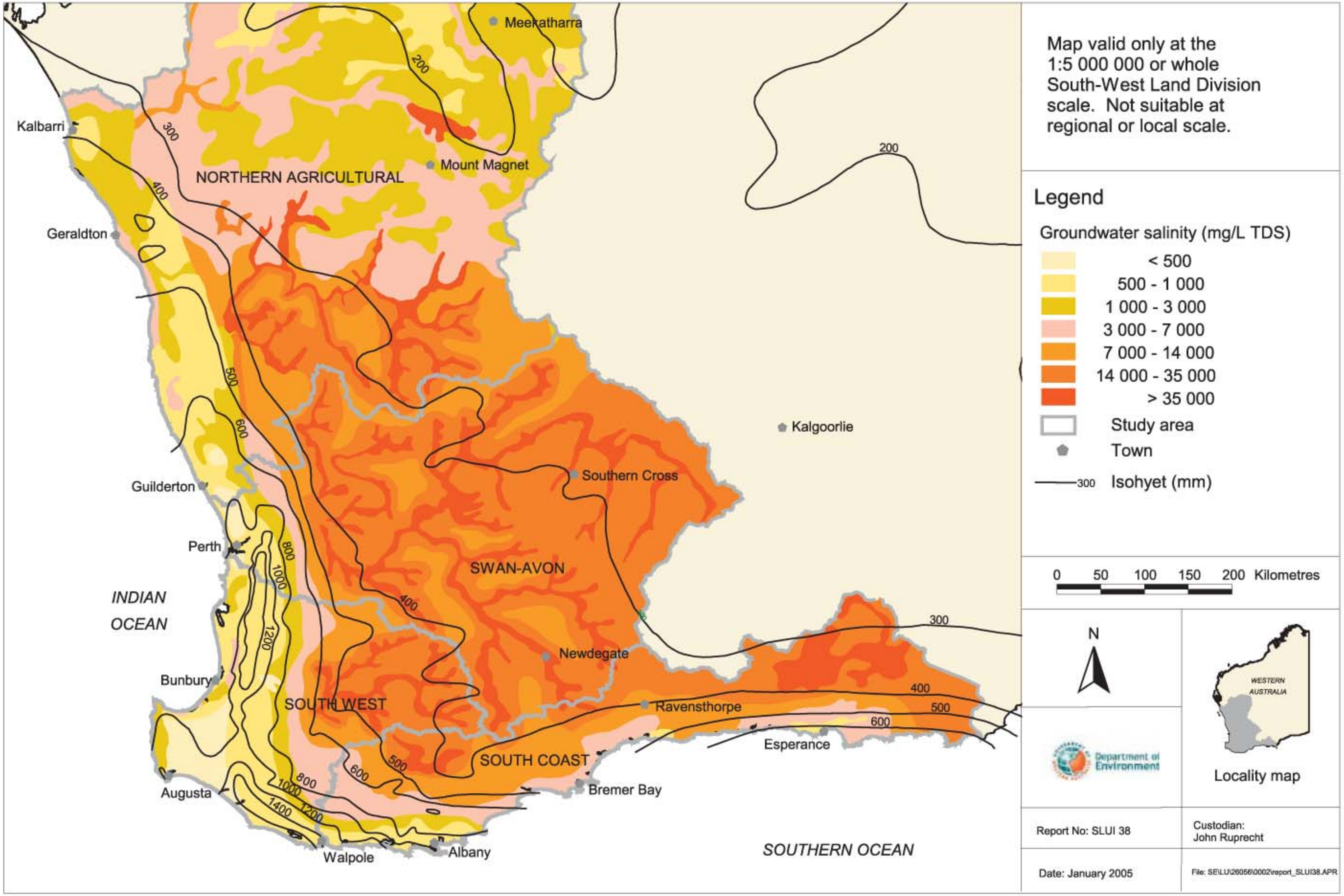


Figure 4.5 Groundwater salinity across the south-west

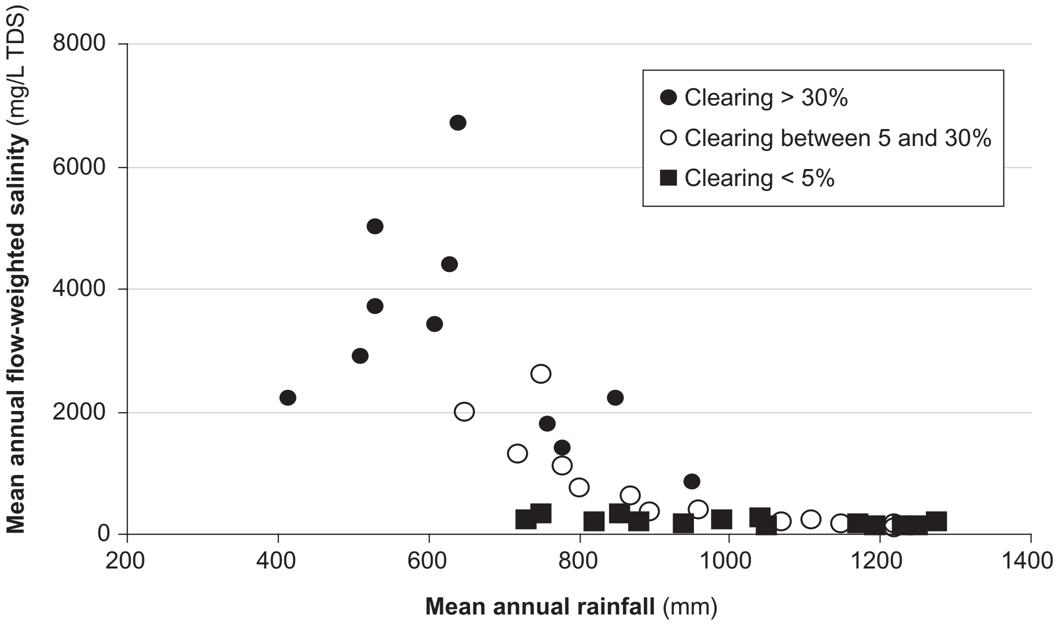


Figure 4.6 Relationship between salinity, rainfall and clearing

Three distinct groupings were apparent when salinity was plotted against climatic dryness (Fig. 4.7). The mean annual rainfall minus streamflow as a percentage of rainfall was used as the indicator of climatic dryness:

- Catchments with little clearing (< 5%): Streamflows were in the fresh range, but with a trend of higher salinity with higher climatic dryness.
- Catchments with 5–30% clearing: Most stream salinity increased with increasing climatic dryness. These catchments exhibited bigger increases in stream salinity for the same increase in climatic dryness than the first group.
- Catchments where clearing is greater than 30%: Most stream salinities were higher than 1000 mg/L TDS but the trend was less clear.

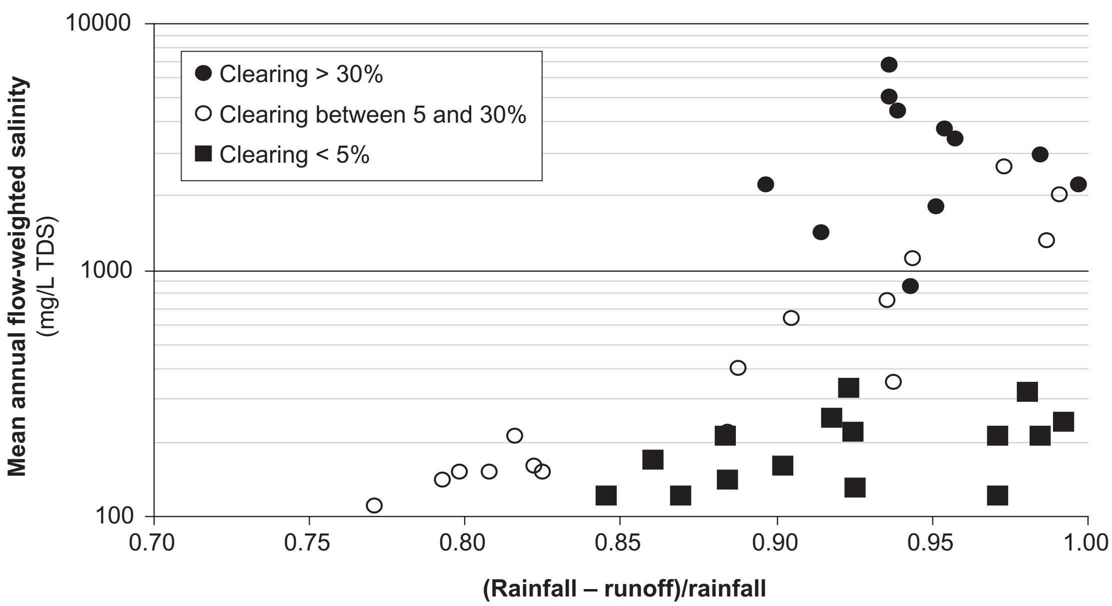


Figure 4.7 Relationship of salinity to a measure of climatic dryness

4.8 Salt balance

Salt output/input ratios were used to calculate whether salt was accumulating in or being lost from a catchment. The results showed that cleared catchments exported salt but forested catchments were either accumulating salt or losing only a little.

For forested catchments, salt output/input ratios ranged from 2.1 (mean annual rainfall of 1300 mm) to 0.17 (mean annual rainfall of 740 mm) (Table 4.3). Loh et al. (1984) also found that output/input ratios of forested catchments decreased with decreasing mean annual rainfall. This indicated that forested catchments in high rainfall areas had a small net loss of salt, while lower rainfall forested catchments were accumulating salt (Schofield et al. 1988). However, there was some uncertainty in the ratios since outputs were often based on sparse salinity data and inputs based on assumptions, such as the relationship between salt fall and distance to the coast, and estimations, such as the mean annual rainfall.

Clearing for agriculture typically changed the salt balance of a catchment from a state of equilibrium or accumulation to a state of net salt export (Fig. 1.1). After clearing, output/input ratios exceeded one when mean annual rainfall was lower than 1000 mm (Fig. 4.8). The high rate of salt exported from cleared catchments means that eventually stream salinity will drop to levels equivalent to the salt input from rain and dry fallout, except in river systems with large salt lakes which do not overflow even in extreme events where the salt will remain in the receiving salt lakes.

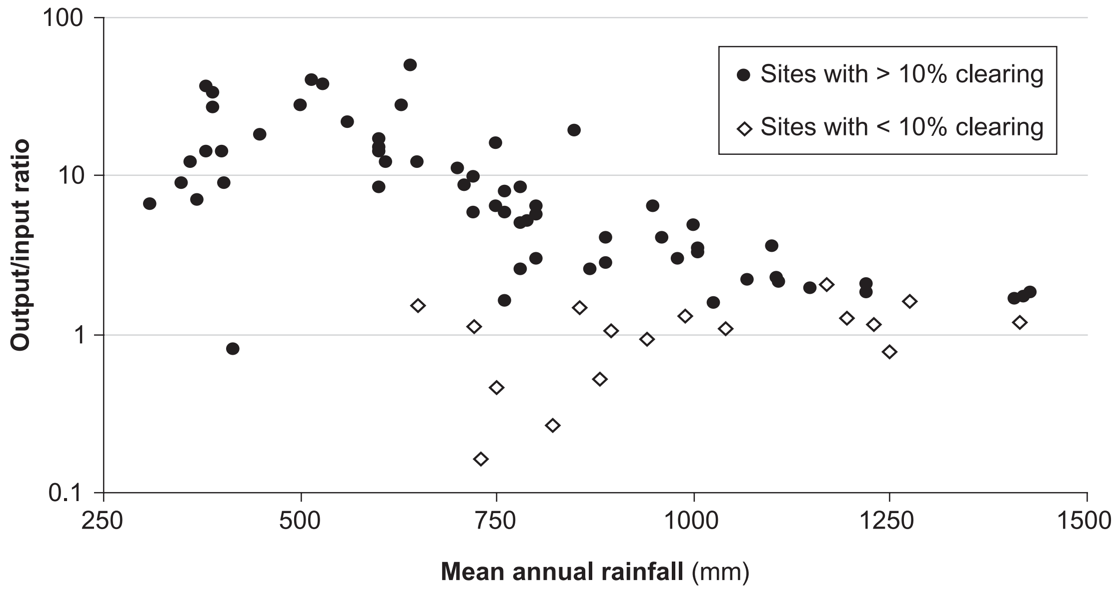


Figure 4.8 Output/input ratios for rivers of the South-West Drainage Division

Two conceptual approaches were used to calculate the time for the salt outputs of cleared catchments to once again equal inputs: characteristic time (Peck & Hurle 1973) and salt storage export (Table 4.5). Another method is exponential decay, which Hatton et al. (2002) applied to salt storage to highlight the longer times that would be required to return catchments to a new equilibrium where salt outputs equalled inputs. However Hatton et al. (2002) also showed that if the target is freshwater then the time required may be significantly shorter — decades rather than centuries for streams in higher rainfall areas to become fresh (< 500 mg/L TDS) again.

Table 4.5 Estimated times to reach a new salt equilibrium

Watercourse	**Groundwater recharge** (mm)	**Groundwater salinity** (mg/L TDS)	**Streamflow** (mm)	**Stream salinity** (mg/L)	**Regolith depth** (m)	**Characteristic time**[(a)] (years)	**Salt export time**[(b)] (years)
Denmark River — Kompup	12.7	5 500	51.0	1 400	10–15	240	470
Collie River — James Crossing	4.0	25 000	40.2	6 100	20–30	610	920
Perup River	5.8	10 000	26.5	2 200	15–25	780	1 300
Weenup Creek	6.5	18 000	30.0	4 100	15–25	660	1 100
Wights Catchment	96.7	1 750	400.0	450	15–25	47	78
Collie River — South	16.7	2 500	45.1	1 100	15–25	230	380
Young River	0.6	30 000	1.2	15 800	20–25	9500	11 900
Pallinup River	2.2	35 000	4.9	15 600	20–25	2760	3 450
Denmark River — Mt Lindesay	21.2	1 800	61.7	640	20–25	280	360
Kent River	19.7	3 500	46.5	1 500	20–25	300	382
Wilgarup River	29.7	2 500	75.8	860	20–25	237	296
Yate Flat Creek	15.4	6 000	95.1	1 200	20–25	323	404

(a) Groundwater storage divided by recharge, based on Peck and Hurle (1973).

(b) Salt storage divided by net salt export.

It will probably take more than 1000 years for south-west catchments with mean annual rainfall less than 500 mm to return to pre-disturbance levels (Fig. 4.9). If instead the target is 500 mg/L TDS (drinking quality water rather than the lower predisturbance salinity) then the time required may be substantially shorter. In addition, the time to achieve a target of 500 mg/L TDS at downstream locations which receive significant fresh water contributions may be much shorter again than the figures presented in this section. For example, to achieve the target of 500 mg/L TDS for the Denmark River at Mt Lindesay (603-136) requires only 860 mg/L TDS upstream at the Kompup gauging station (603-003) because substantial volumes of water with salinity below 500 mg/L TDS are contributed by forest streams downstream of the Kompup gauging station.

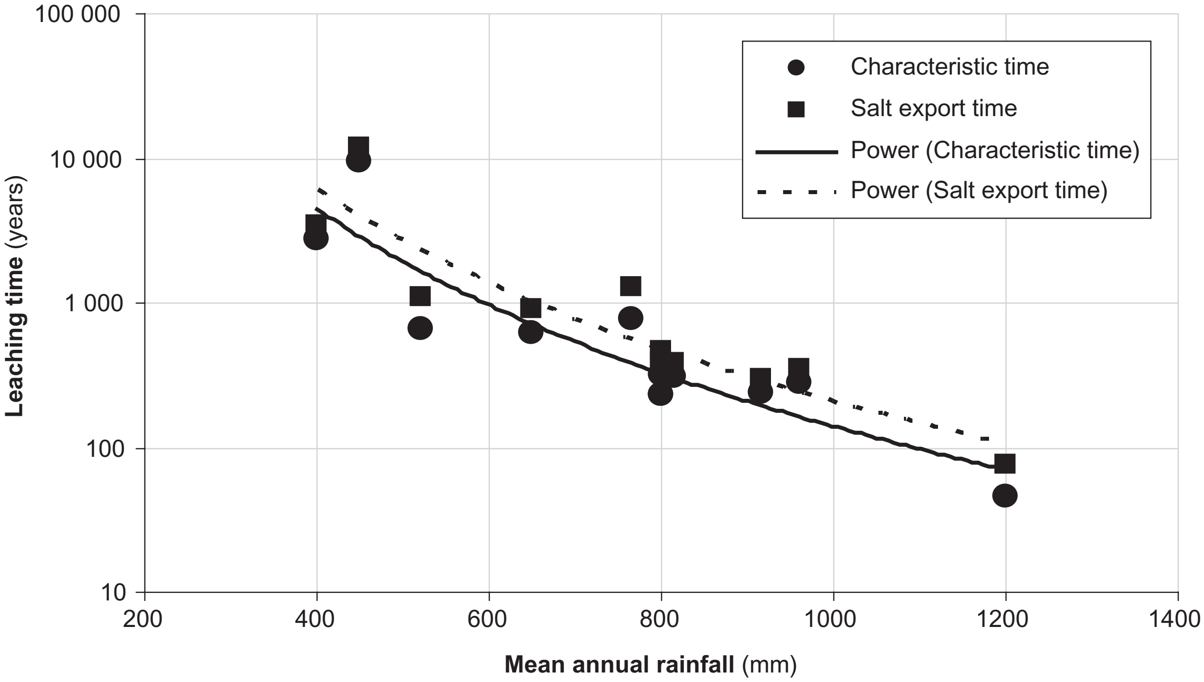


Figure 4.9 Estimated time to reach a new salt equilibrium

4.9 Salinity and biodiversity

Brackish to saline water was common in the Wheatbelt areas of the south-west river systems prior to land clearing because most rivers and wetlands were ephemeral and salt concentrated as they dried out. Since clearing, the rivers have shown 20-fold increases in salinity, with these levels sustained and still rising in some areas.

South-west Western Australia is recognised as a global 'hot spot' for biodiversity on the basis of endemic plant species, as well as for the extent of land clearing (Myers et al. 2000). Elevated salinities have already caused substantial changes to the biological communities of aquatic ecosystems (Halse et al. 2003). Up to one-third of wetland and river invertebrate species, many plant species and a substantial proportion of waterbird fauna are predicted to disappear from the Wheatbelt (Halse et al. 2003). Biodiversity is also threatened by associated problems such as increased water volumes and acidity.

4.10 Longer term prognosis

In many areas where groundwater levels keep rising the results may not be increased stream salinity but rather increased salt loads and flows causing permanent and transient flooding. Recent estimates from the Land Monitor project that approximately 1 040 000 ha (5.5% of the South West Agricultural Zone) are currently affected by salinity (Department of Environment 2003) and that the area at risk of high watertables (< 2 m from the surface) will increase to 5 428 000 ha (29% of South West Agricultural Zone). These predictions are based on the premise that large-scale vegetation or engineering solutions have not been implemented. The magnitude of the treatments required were explored by George et al. (2001), and the modelling studies showed that the watertable in relatively flat catchments in low rainfall areas would only respond to large reductions in recharge.

What river salinities in the areas predicted to have high watertables in the future will be is unclear since many of these areas already have very saline rivers. For example, salinity in the Lockhart River averages 33 900 mg/L TDS and in the Yilgarn River 22 500 mg/L TDS. The increasing volumes of saline groundwater discharged may be counteracted by increased volumes of surface flow. Thus, the main outcome of these increases might be increased flows. This may lead to longer hydroperiods (the length of time the river flows) further downstream than currently experienced. Further work is needed to understand the likely impacts on salinity and aspects such as flow volumes and flooding of the increased saturated areas predicted for the Wheatbelt.

5 Conclusions

Each year, on average, the combined flow of south-west rivers to the ocean was estimated to be 4700 GL and the salt carried by them to be about 7.5 million tonnes. It would require 625 000 12-tonne farm trucks a year or more than 1700 per day to carry this mass of salt. Each year rainfall and dry fallout deposited only about a million tonnes of salt on the catchments of the south-west.

Each year, on average, the Avon River, up to the Walyunga gauging station, exported 1.5 million tonnes of salt (mean 1993–2002) and the Blackwood River, up to the Hut Pool gauging station, one million tonnes (mean 1993–2002). By comparison, the entire Murray-Darling system, with an average flow ten times that of the Avon River, discharges about the same amount of salt as the Avon.

5.1 Salinity status

- The risk of stream salinisation after clearing depended primarily on the amount of salt stored in the soil of the catchment. For most areas outside the coastal plain there was a close relationship between soil salt storage and mean annual rainfall. For areas with more than 1100 mm of mean annual rainfall, clearing was unlikely to cause stream salinities to increase beyond 500 mg/L TDS. However, for areas with mean annual rainfall below 1100 mm, there was a risk of significant stream salinity rises after permanent land use changes such as clearing. Other risk factors for higher stream salinities were topography (flat poorly-drained landscapes) and underlying geology (less permeable sediments).
- The pattern of salinity around the south-west was a band of generally fresh watercourses originating in the higher rainfall (> 900 mm) uncleared areas near the coast between Mundaring and Albany pierced by large saline rivers with their headwaters in low rainfall, extensively cleared catchments of the Wheatbelt and fresher downstream than at their headwaters. Watercourses east of the band had salinities that increased progressively as rainfall decreased.
- Approximately 44% of the flow out to sea each year was fresh, 10% marginal, 21% brackish, about 20% moderately saline, 3% saline and 2% highly saline.

5.2 Salinity trends

- A much richer data record, and hence significantly greater levels of monitoring, is required to calculate trends than to calculate averages. More focused monitoring programs are required to determine at what sites more detailed trend analyses are needed. Currently there are very few sites outside the WRRCs (Collie, Denmark, Warren, Kent and Helena) with appropriate monitoring programs.
- Salt output/input ratios indicated that forested catchments were either accumulating salt or only losing small amounts. Following clearing, output/input ratios exceeded one when mean annual rainfall was lower than 1000 mm. In river systems with large salt lakes which rarely overflow, outputs were unlikely to exceed inputs even if the catchments had been cleared.
- The high rate of salt exported from cleared catchments will eventually result in stream salinities dropping to levels where salt outputs equal salt inputs from rain and dry fallout. The time required is probably centuries for higher rainfall areas but thousands of years for lower rainfall areas (< 500 mm of mean annual rainfall). If the target is fresh water (drinking quality water rather than predisturbance salinities which were often lower) then it may take only decades rather than centuries for streams in higher rainfall areas to become fresh again.

5.3 Salt balance

- Salt output/input ratios indicated that forested catchments were either accumulating salt or only losing small amounts. Following clearing, output/input ratios exceeded one when mean annual rainfall was lower than 1000 mm. In river systems with large salt lakes which rarely overflow, outputs were unlikely to exceed inputs even if the catchments had been cleared.
- The high rate of salt exported from cleared catchments will eventually result in stream salinities dropping to levels where salt outputs equal salt inputs from rain and dry fallout. The time required is probably centuries for higher rainfall areas but thousands of years for lower rainfall areas (< 500 mm of mean annual rainfall). If the target is fresh water (drinking quality water rather than predisturbance salinities which were often lower) then it may take only decades rather than centuries for streams in higher rainfall areas to become fresh again.

5.4 Forested catchments, major rivers and Water Resource Recovery Catchments

- Over the last 20 years, stream salinities of forested catchments were either unchanged or decreasing.
- Targeted salinity control programs, such as the Water Resource Recovery Catchments (WRRCs) program, have been successful in slowing the rise of salinity in the Kent River, stabilising salinity in the Warren River and decreasing salinity in the Denmark and Collie rivers.

6 Recommendations

6.1 Assessment

- Repeat this study on a 10-year cycle to maintain up-to-date knowledge of stream salinity across the south-west of Western Australia.
- Assess the stream salinity implications, particularly for rivers such as the Avon, of Land Monitor predictions that the area with shallow watertables will increase by 400%.
- Investigate further the interactions between decadal climate variability, climate change and land use change, and assess their relative impacts on stream salinity trends.
- Develop a better understanding of the variations of salinity along the major rivers. The processes involved are complex with influences such as stratification and storage in lakes, infiltration and groundwater contributions. Considering the prediction of hugely increased areas of shallow watertables, the influence of salt lakes on stream salinity should, in particular, be evaluated.
- Update data for, and check the relationship between, salt fall and distance from the coast. This report used a regional relationship developed in the 1970s, but with the recent shift in climate this relationship may have changed.

6.2 Monitoring and evaluation

- Establish focused monitoring programs to assess the status and trend of stream salinity that meet local needs for data and the broader goals of water resource assessment. Priority areas are considered to include the lower rainfall areas of the Swan-Avon, Northern Agricultural and South Coast study areas.

Glossary

Clearing controls	The legal and administrative procedures associated with the Country Areas Water Supply Act (1947–76) to control clearing of native vegetation through licensing.
Climatic dryness	Ratio of evaporation to precipitation.
Dry fallout	Airborne salt falling on the landscape other than in rainfall.
Electrical conductivity (EC)	The ability of a soil mass or a water sample to conduct electricity. It is strongly correlated to the salinity and/or quantity of ions.
Evapotranspiration	The collective term for evaporation and transpiration. The amount and process by which the soil surface and plants lose water to the atmosphere as water vapour.
Grains per gallon	Imperial measure of salinity (equivalent to 14.2 mg/L).
Groundwater	Subsurface water that occurs beneath the watertable in soils and geologic formations that are fully saturated.
Interception	Water retained by vegetation for some period, however short, after rain has struck the vegetation above the soil surface.
Ion	An electrically charged atom or group of atoms.
Isohyet	A line on a map joining places of equal rainfall.
Percolation	The passage of water under hydrostatic pressure through the interstices of soil or rock, excluding the movement through large openings.
Potable water	Water suitable for human consumption.
Reforestation	Planting trees as a forest on land previously cleared of native forest overstorey.
Ring-barking	Killing trees by cutting through all active pathways for sap movement.
Salinity	The concentration of total dissolved salts in water.
Salinity (general)	The effects on land and in water of the build up of salts near the surface as a result of rising or discharging groundwater.
Salinity at mean flow	The stream salinity expected in a year of average annual flow. This is calculated because salinity has a strong inverse relationship with flow. In a low-flow year, salinity will be high. In a high-flow year, salinity will be low because of the increased contributions from surface runoff and rainfall. In a run of below average rainfall years, stream salinity may appear to have risen permanently. Salinity at mean flow accounts for the variations in flow, making it easier to discern any trends due to the long-term effects of land use changes such as clearing and revegetation.
Salinity status	Based on the salinity at a gauging station, sites in this report are classified as fresh, marginal, saline, highly saline or brine. See Section 2 for classifications.
Salt input	The salt entering a catchment in rain or dry fallout, typically measured in kilotonnes per year.
Salt output	The salt exported from a catchment in surface water, typically measured in kilotonnes per year.

Salt output/input ratio	Calculated by dividing the kilotonnes of salt exported annually from a catchment by the kilotonnes of salt a year falling annually on that catchment. A ratio > 1 indicates a net export of salt from the catchment. A ratio < 1 indicates salt is accumulating in the catchment.
Saturated zone	That part of the subsurface in which all voids, large and small, are filled with water under pressure equal to or greater than atmospheric.
Stream salinity	Concentration of dissolved salts in stream water.
	It can also be defined as the concentration of the major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, CO_3^{2-} and SO_4^{2-}) in a solution.
Surface flow	The portion of the rainfall that runs over the surface of the land to rivers or lakes rather than being trapped in the soil or by vegetation.
Throughflow	Downslope flow of water occurring within the soil profile, under saturated or unsaturated conditions.
Transpiration	The amount and process by which plants transfer water to the atmosphere as water vapour.
Unsaturated zone	That part of the soil profile between the land surface and the watertable. It includes the capillary fringe. In this zone, liquid water is under less than atmospheric pressure while water in the gas phase is at atmospheric pressure.
Wetland	Area of seasonally, intermittently or permanently waterlogged soils or inundated land, whether natural or otherwise, fresh or saline, e.g. waterlogged soils, ponds, billabongs, lakes, swamps, tidal flats, estuaries, rivers and their tributaries.

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Appendix A
Methodology

Definitions and measurement of stream salinity

Stream salinity is a general term that usually refers to the concentrations of dissolved salts in stream water (Schofield et al. 1988). Sometimes a simpler definition such as the concentration of specific major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, CO_3^{2-} and SO_4^{2-}) in a solution is used (Peck et al. 1983).

There are various methods of measuring stream salinity. The most accurate involves summing the measured masses of all individual ions in a sample and is expressed as Total Dissolved Salts (TDS) in mg/L (Schofield et al. 1988). Mostly, only the major ions are measured and summed. In addition to the major ions given by Peck et al. (1983) above, the Department of Environment also includes dissolved silica and fluoride (Schofield et al. 1988).

Another common method of measuring stream salinity is to measure the Total Dissolved Solids (TDSolids). This involves filtering a water sample to remove sediment and then weighing the residue after evaporation (Schofield et al. 1988). TDS and TDSolids usually differ only slightly because of minor ions and are likely to vary much only when there are large concentrations of carbon-based ions (Schofield et al. 1988).

Stream salinity expressed as TDS can also be estimated from measurements of the electrical conductivity (EC) of water, which is very useful as a cheap periodic measurement as well as for continuous measurements (Schofield et al. 1988). The EC can be converted to TDS using an EC–TDS relationship (Appendix N), which is usually calculated for areas with similar relationships and, if possible, for each stream (Schofield et al. 1988). There is a generic relationship for the south-west (Appendix N).

In the south-west of Western Australia, the dominant anion is the chloride ion (Schofield et al. 1988). It can be used to indicate the salinity in a stream or converted to TDS using a chloride–TDS relationship (Schofield et al. 1988). Historically this ion was often the only one measured when samples were taken.

In this report the analyses have used mg/L TDS. Over the years many of the methods described above have been used and, in order to include all the data possible, data not measured as TDS were converted using relationships between TDS and the other methods of measurement.

Project method

Division of catchments

The objective of the study was to provide an overview of salinity in the south-west of Western Australia. The south-west was divided into four study areas roughly corresponding to the NRM (Natural Resource Management) regions and the results are reported by study area. The NRM regions were then divided into drainage basins which represent the catchments draining into the major river systems. The basins and their gauging stations are described briefly.

Selection of gauging stations

Gauging stations were selected on their length of record and frequency of data collection. Good data frequency was defined as more than 30 samples of salinity (in mg/L TDS) per year or a continuous conductivity record at the site. Some basins had no such gauging stations. For these, gauging stations with sporadic but recent data were selected. See the data reliability classification section for further details (p. 95).

Some gauging stations with large quantities of frequently collected data but very small catchment areas (< 10 km^2) were not selected for analysis. Most of these were research catchments and not representative on a regional scale.

The Map (in the back) illustrates relative salinities across the south-west rather than specific annual means. Many extra sites were used for spatial analysis of stream salinity. These even included sites with very short record lengths, with only discrete samples, with only one-off snapshot samples or where salinity was estimated using regional estimates of flow and their relationship to stream salinity (pers. comm. Peter Muirden). More details on the calculations for this map are given in the section 'Computing data for Map' (p. 93). Please note that this map also uses a different classification system from the rest of the report. See the Salinity Status Classification section for more details (p. 94).

Data analysis

Clearing and rainfall figures

The extent of clearing and the average rainfall were estimated for the catchment area contributing to each gauging site. The average rainfall of a catchment was taken as the rainfall at its centroid — estimated using digital maps.

The catchment contributing to each gauging site was assumed to be the normal catchment area, that is, the area that would contribute to that gauging station in a normal rainfall year. In most catchments there is no difference between the normal catchment area and the whole catchment area since the whole catchment contributes to the gauging station almost yearly. However, in places such as the Avon River Basin, there are large lake systems which may only overflow in very large storm events which happen so infrequently that the lake systems rarely contribute to the total flow of the catchment. Such areas are excluded from the definition of the normal catchment area. In other basins, such as the Harvey River Basin, there are dams and numerous interconnected drains. The dams do not normally overflow and the drains can be used to divert water to one stream in some cases and to another in others. In such catchments the normal catchment area was defined as the area that usually contributed to the gauging site based on the usual flow of the drain.

Catchment clearing percentages were estimated using Land Monitor (2003). The extent of clearing in 1996 was used since this was roughly in the middle of the current mean value calculated for the salinity data (1993–2002). The Land Monitor data was divided into pixels 25 by 25 metres. Each pixel was classified as either 'not perennial vegetation' (includes cleared land, rocks, roads, wet areas) or 'perennial vegetation' or 'not processed'. The information was analysed to find the percentage of the area cleared of deep-rooted perennial vegetation contributing to each gauging station.

There are some limitations to the methods used to classify each pixel (Land Monitor 2003). The classification of pixels depends on differences in reflectance signals between vegetation and other cover types (e.g. soil, crops, bare rocks) detected by Landsat TM. The thresholds for the classification were defined from comparison with earlier maps where detailed air photography was used. A certain density of vegetation was required for an area to be classified as vegetated based on its reflectance. Consequently, bare areas or very thin areas of bush may have been classified as cleared. Other examples are bush containing tracks, rocks and fire scars. It also takes some time for revegetated areas to reach a density that is recognisable as vegetated. Errors may also occur where other land covers have a similar reflectance to deep-rooted perennial vegetation. Techniques to remove these errors were used but some errors such as cleared areas with persistent dark soil may remain. Lake fringes where changes in water level have a dramatic effect on cover and reflectance are another source of error (Land Monitor 2003).

There are also errors associated with calculating the percentages from the Land Monitor (2003) data. The data is in the form of 25 by 25 metre pixels but catchment boundaries are smooth lines. Consequently some pixels may be half in and half out of a catchment leading to small boundary errors.

Some catchments, such as those in the Murchison, were not covered by the Land Monitor data. In these, clearing was estimated from topographical maps from the Department of Land Administration. The maps were for the year 1980 or thereabouts. Little clearing has occurred in the south-west of Western Australia since then but there has been some reforestation.

Computing annual data

Annual flow, salinity and salt load were calculated at each gauging station. Continuous monthly flows were summed to produce the annual flow volumes. The flow for a particular year was not used if there were any gaps in the data unless the flow in these gaps had been adequately estimated.

Annual salinity and salt load were calculated in two ways depending on whether the salinity data was continuous or discrete. If it was continuous data, then the instantaneous salinity was multiplied by the instantaneous flow to get the salt load at that time. These salt loads were summed to create an annual salt load value. If there were gaps in the data, it was treated in the same way as the flow data, as described above. The salinity was then calculated for each year using the annual flow and salt load figures. Calculating salinity in this way gives flow-weighted salinity. Equation 1 below describes this calculation.

$$\text{Flow weighted salinity} = \frac{\sum Q_i S_i}{\sum Q_i} \qquad \text{(Equation 1)}$$

$$\text{Where } Q_i = \text{Instantaneous Flow}$$

$$S_i = \text{Instantaneous Salinity}$$

Flow weighted (F-W) salinity was also calculated when discrete data was available. This was done once again by multiplying the salinity taken at a particular time by the instantaneous flow at this time, which gave the instantaneous load. The loads and the flows were then summed as before. The summed load was divided by the summed flow to give the salinity. This was taken as the annual flow-weighted salinity. The method thus far is the same as that for continuous F-W salinity as the same equation still applies. However, the salt load cannot be taken as the sum of the instantaneous loads (the numerator of Equation 1) since this did not add up to a whole year. Consequently, the salt load was estimated by multiplying the annual salinity by the annual flow.

If there was too little data to find the annual flow-weighted salinity for a particular year then that year was estimated. The estimation was based stream salinity being inversely proportional to streamflow. In other words, during periods of high streamflow the average stream salinity is usually low and during low flows the average stream salinity tends to be higher. The annual flow-weighted means from years where there was adequate data was used to create an equation for this relationship. This was done by taking a power regression of the form shown in Equation 2.

$$S = aQ^b \qquad \text{(Equation 2)}$$

The five Water Resource Recovery catchments — of the Collie, Denmark, Warren, Kent & Helena rivers — have been extensively studied and a lot of their data has already been analysed. For these catchments the annual datasets from their earlier analyses for their *Salinity situation statements* were used (Mauger et al. 2001; Bari et al. 2004; Smith et al. in prep.; de Silva et al. in prep.; Smith in prep.) and their discrete data were interpolated in a different way.

The relationship described by Equation 2 was used to describe the relationship between the discrete sample and its associated daily flow. The above parameters (a and b) were calculated using 5 discrete data points of salinity and the associated flow. Since the relationship between the salinity and the streamflow changes due to significant changes in land use, the values of these two parameters were different at different times hence only 5 points were used for each relationship. This relationship was then used to calculate the daily salinity from the known daily flow for the period from when the discrete sample central to the regression was taken until the next discrete sample was taken. This daily salinity (S_d) and the daily flow (Q_d) were then used to compute daily salt load (L_d) as shown in Equation 3.

$$L_d = Q_d \times S_d \qquad \text{(Equation 3)}$$

The salt loads for each day were summed into annual salt loads and the annual salinity was obtained by dividing this load by the annual flow (Equation 4). This method was only used for the Recovery Catchments.

$$S_a = \frac{L_a}{Q_a} \qquad \text{(Equation 4)}$$

Computing annual means and current values

Mean annual flow, salinity and salt load was calculated for the periods 1993–2002 and 1983–1992. The more recent ten-year period was used as the current annual mean and to classify the salinity status of the river at that gauging station.

At some sites a shorter period than the intended ten-year period was used because they were important sites but did not have all the necessary data. In these cases whatever data was available within the relevant 10-year period was used. For instance, a site that had data from 1983 to 1999 would contain means for 1983–1992 and 1993–1999. These sites are marked in their respective tables and their data period is noted. In all cases the same period of record is used for salinity, flow and salt load at a site.

Computing monthly means

Monthly salt loads and flows were calculated by summing the daily data for each gauge that recorded continuous conductivity. Dividing salt load by flow produced flow-weighted monthly salinity. The means for each month were then calculated using the years 1993–2002. Thus the monthly means presented are the arithmetic means for each month.

There was one problem with the computation of the means. Some rivers were ephemeral and mostly only flowed during the winter months. Uncharacteristically, they might flow in a summer month in one or two years after unusually heavy summer rains, but the mean for a month was only computed if there were at least four years in which there was flow in that month.

Computing annual trends

Annual trends for salinity, flow and salt load were calculated at all suitable gauging stations for 1990–98 and 1980–89. The reasons for using data until 1998 rather than 1999 related to the method used to calculate the trends. Salinity at mean flow was used to calculate the trend rather than observed salinity. This involved taking a nine-point regression around each year of interest, which meant that 4 years of data was necessary on each side of the year to be used. So the 1990–98 period actually used data from 1986–2002. The method is described in detail below.

Using salinity at mean flow aims to negate the influence of flow on salinity. In a high-flow year, salinity is low because an increased proportion of the streamflow comes from surface runoff and direct rainfall while in low-flow years the salinity is often higher. The salinity of a stream is highly variable and strongly correlated to flow. If the flow component can be removed, there can be a much better understanding of the status and trend in salinity of a stream. Thus, using the ‘salinity at mean flow’ provides an estimate of the true salinity in any year and a number of these years provides a trend that is more representative of the change due to long-term land use rather than the natural variability.

The salinity and salt load trends were calculated using the annual ‘salinity at mean flow’ and ‘salt load at mean flow’ data. First, a nine-year regression was done between the observed annual flows and the observed annual salinities with the relevant year at the centre of that regression. This provided the coefficients a and b for a power relationship of the form shown in Equation 5 between the flow in the relevant year (Q) and the salinity in the relevant year (S). This was done for each year using data from four years on either side of each year.

$$S = aQ^b \qquad \text{(Equation 5)}$$

The mean flow for the relevant decade (Q_m) was then used in this Equation 6 along with the coefficients for the year being calculated to get a new salinity value for that year — the salinity at mean flow (S_{mf}).

$$S_{mf} = aQ_m{}^b \qquad \text{(Equation 6)}$$

The annual salt load at mean flow (L_{mf}) for a particular year was worked out by multiplying the mean flow for the decade (Q_m) by the salinity at mean flow (S_{mf}) for that year as shown in Equation 7

$$L_{mf} = Q_m \times S_{mf} \qquad \text{(Equation 7)}$$

A linear trend for salinity at mean flow and salt load at mean flow over the periods 1980–99 and 1990–98 was then calculated. The trend could not be calculated past 1999 because the nine-year regression used to get the salinity-flow relationship required four years of data after each year of interest in order to calculate the salinity at mean flow of that year. The trend was calculated by using an equation of the form shown in Equation 8. For example, in the case of salinity at mean flow the equation is used to find the values of the coefficients c and d when time (t) and salinity at mean flow (S_{mf}) are known. The trend in mg/L/year is the calculated value of c. The equation was used in a similar way for calculating the trend in flow (Q) and salt load at mean flow (L_{mf})

$$S_{mf} = (\mathrm{c} \times \mathrm{t}) + \mathrm{d} \qquad \text{(Equation 8)}$$

For some gauging stations, the annual salinities, salt loads and flows were plotted for the whole period. Generally, chosen gauging stations were well distributed around the catchment, had long data records, or were important. The trend was plotted as the salinity at mean flow and the salt load at mean flow.

The significance of each linear trend for 1980–89 and 1990–98 was also tested using the following equation (Watts & Halliwell 1996).

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \qquad \text{(Equation 9)}$$

$$\text{where } r = \text{coefficient of correlation}$$

$$n = \text{no. of observations}$$

This t value was then compared with a table of t values (Watts & Halliwell 1996) with consideration that it was a two-tailed test and the significance level sought was 0.05. In other words, if the t value was significant there was a 95% certainty a trend was present in the data (Watts & Halliwell 1996). Finding the significance in a trend does not mean that it is 95% certain that the correlation coefficient is correct or that the exact trend is, for instance, 5 mg/L per year. It merely indicates 95% certainty that there is a trend that is not just the result of natural variability, and that the trend is either positive or negative (as shown by the correlation coefficient). This is because the t test is based on the normal distribution and the null hypothesis (or the first assumption) is that the data has a normal distribution and there is no trend in it.

Salt output/input ratios

The salt output used was the average annual salt load calculated in this report (i.e. the 1993–2002 mean). Salt input was calculated by multiplying annual salt fall by the area of each catchment.

Salt fall was estimated using the observed relationship of Hingston and Gailitis (1976) between salt concentration in rain and distance from the coast in Western Australia (Fig. A). The data given in Hingston and Gailitis for the curve was converted to TDS and used to provide an equation describing the relationship. The salt fall included dry fallout and salt precipitated in rainfall.

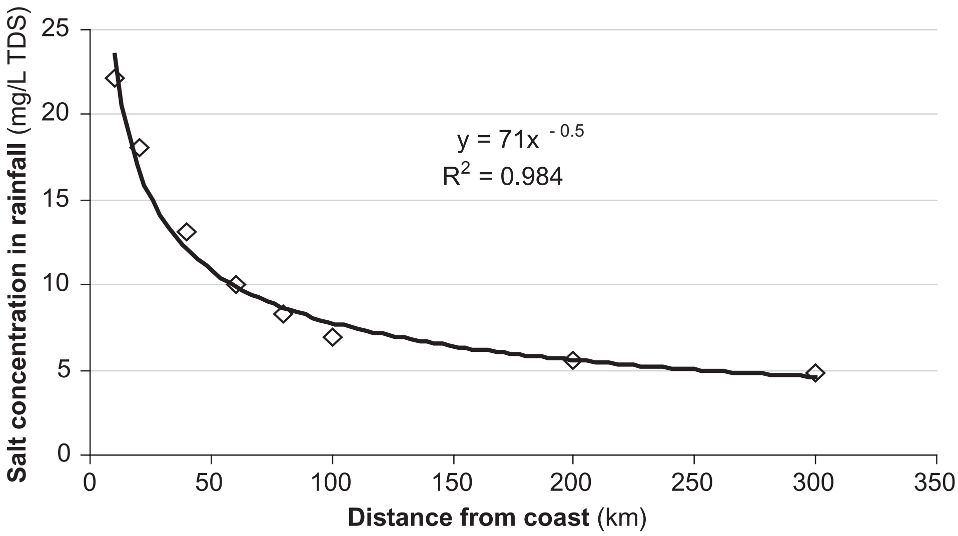


Figure A Salt concentration in rainfall with distance from the coast
(adapted from Hingston & Gailitis 1976)

The salt concentration was converted to salt input in tonnes per year using the catchment area and the average annual rainfall at the centroid of the catchment. The output/input ratio was then calculated by dividing the salt load by the salt input. If this ratio was less than 1, then input was larger than output and salt was accumulating within the catchment. If it was more than 1, then output was larger than input and, overall, salt was being lost from the catchment.

In some cases where the catchment contributing to the gauging station was very large it was divided into subcatchments. The salt input was calculated for each subcatchment and then summed to give the input for the whole catchment.

The catchment area contributing to each gauging site was assumed to be the normal catchment area, that is, the area that would normally contribute to that gauging station. In most catchments there is no difference between the normal catchment area and the whole catchment area since the whole catchment contributes to the gauge almost yearly. However, in some places, such as the Avon River Basin, there are large lake systems which may only overflow after very large storms. This happens so infrequently that the lakes rarely contribute to the total flow of the catchment. Such areas were excluded from the definition of the normal catchment area. In other basins, such as the Harvey River Basin, there are numerous interconnected drains. These drains can be used to divert water from one stream to another. For such catchments the normal catchment area was defined as the area that usually contributed to the gauging site based on the usual flow of the drain.

Computing data for the Map

The Map shows the current classification of stream salinity (1985–2002) for watercourses across the whole South-West Land Division. This dataset has been derived from a large array of data from many sources and provides the best current information of stream salinities along watercourses, with each stream classified by the possible uses of that water during the primary flow period.

Classification

While comprehensive monitoring of salinity is available at some sites, there is substantial salinity data which comprises only a few years and/or a small number of samples per year. In addition, it is possible to estimate the salinity between known points on a streamline, and so classify whole watercourses. Accurate values of flow-weighted stream salinity require large amounts of good quality data and extensive resources — a single gauging station collecting data for 10 years (the minimum period for good data) would cost $150 000. There is little real difference in use between water that is 3200 mg/L and water that is 3800 mg/L so the calculated or estimated flow-weighted stream salinities has been grouped into 8 classifications based on the water's potential use for drinking, irrigation, livestock or industry. The broad classifications used are given in Table A below.

Table A Salinity classifications used in the Map (note these are different from those in the rest of the report)

Water quality (status)	**Salinity** (mg/L TDS) **and EC** (mS/m)	**Code**	**Comment**
Fresh	Less than 500 [< 100 mS/m]	1	Good quality drinking water Suitable for highly salt sensitive plants (e.g. most fruit and vegetables: apples, citrus, carrots, peas)
Marginal	500 to 1000 [100–200 mS/m]	2	Acceptable for most uses Direct adverse biological effects become more apparent in river, stream and wetland ecosystems as salinity increases to 1000 mg/L
Brackish	1000 to 3000 [200–550 mS/m]		Acceptable for most stock and some irrigation
Marginal-Brackish	1000 to 1500 [200–290 mS/m]	3	Acceptable as drinking water based on taste. The acceptable level for irrigation will range with type of crop, soil type, and level of drainage.
High-Brackish	1500 to 3000 [290–550 mS/m]	4	Acceptable for limited irrigation and all livestock
Saline	3000 to 35 000 [550–5000 mS/m]		Restricted farm and industrial use
Low-Saline	3000 to 7000 [550–1200 mS/m]	5	Acceptable for most livestock (not pigs or horses)
Mid-Saline	7000 to 14 000 [1200–2200 mS/m]	6	Acceptable for some livestock (beef cattle and adult sheep)
High-Saline	14 000 to 35 000 [2200–5000 mS/m]	7	Acceptable for industrial and other limited uses
Brine	> 35 000 [> 5000 mS/m]	8	Acceptable for industrial and mining use
	35 000		Seawater

NOTE: 100 mS/m = 1 mS/cm = 1 000 μS/cm = 520 mg/L = 40 gr/gal

Source data

Five key sources of information were used to classify the streamlines shown on the Map:

- Long-term gauging station sites with continuously recorded flow and salinity

- Gauging station sites with short-term data (these may be current sites or those that have stopped recording)
- Gauging station sites with little salinity data (either continuous or discrete)
- Sampling sites with discrete flow and salinity
- Sampling sites with snapshot data collected over a broad area on a specific date

To get a consistent classification between all basins, the last four datasets were correlated with the good long-term datasets.

Modelling

Even using all available data, there were still many stream reaches where there was little data or where the appropriate classification was not obvious. In these cases, the REG6S model — ideal where there are nearby gauging station data to correlate the model to — was used to estimate the salinity.

Mapping

Based on its salinity each streamline was assigned a classification code from 1 to 8 where 1 was ‘Fresh’ and 8 was ‘Brine’ (Table A). There were still many streamlines and especially lakes where the salinity was not known and the major ones were coded and shown as grey.

Classification systems

Salinity status classification

The mean annual salinity for each gauging station was calculated based on 10 years of data from 1993–2002. The gauging station and its corresponding catchment were then classified according to Table B — a World Bank classification scheme.

The salinity on the Map in the back cover was classified using different salinity intervals (Table A) from Table B because the data came from another source where it had been previously classified based on use in Western Australia.

Table B Salinity status classified by total salt concentration (Hillel 2000)

Salinity status	Salinity (mg/L TDS)	Description
Fresh	< 500	Drinking and irrigation
Marginal	500 – 1 000	Irrigation
Brackish	1 000 – 2 000	Irrigation with caution
Moderately saline	2 000 – 5 000	Primary drainage
Saline	5 000 – 10 000	Secondary drainage and saline groundwater
Highly saline	10 000 – 35 000	Very saline groundwater
Brine	> 35 000	Seawater

Data reliability classification

Flow data for each year was assigned a reliability classification. It was assigned a classification of 1 if it was continuous and a lower classification if it contained a large amount of estimated data. If there were only a few gaps of a few days (< 2) in the continuous data then a code of 2 was assigned. If there were larger gaps of less than 10 days then a code of 3 was assigned. If a season of data was missing (more than 3 months) and was estimated then a code of 5 was assigned. This was also assigned if the flow was based on a relationship with flow at another gauge (Table C).

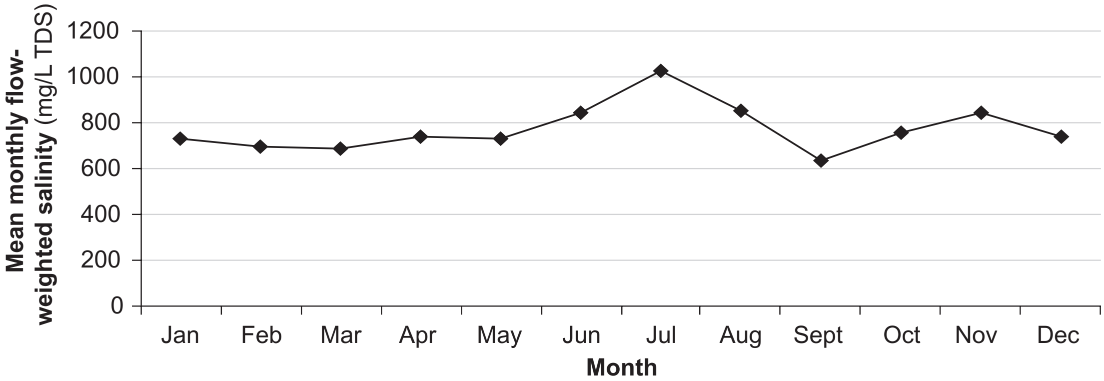
Table C Data reliability codes used in analysis

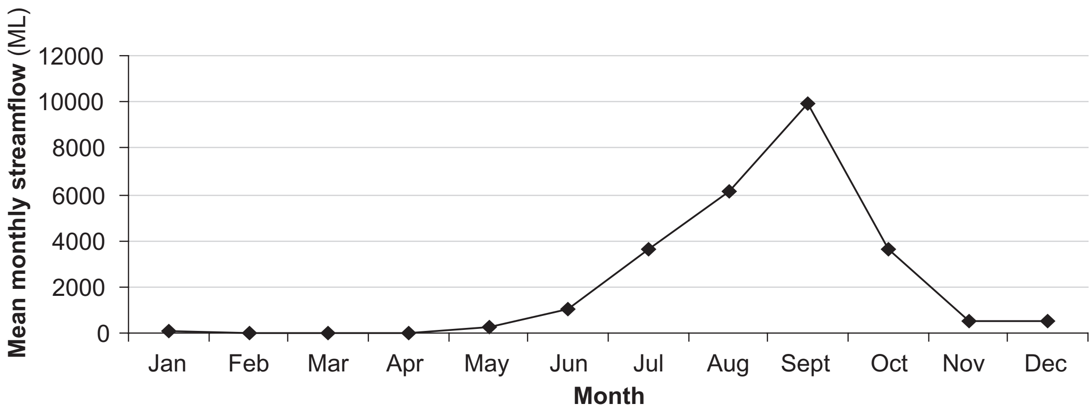
Code	Data collection frequency for a particular year
1	Mostly continuous measurement
2	Mostly continuous measurement with small estimated gaps (< 2 days) or more than 100 discrete samples per year
3	Mostly continuous measurement with small estimated gaps (< 10 days) or more than 30 discrete samples per year
4	Mostly continuous measurement with large estimated gaps (> 1 month) or less than 30 discrete samples per year
5	Mostly continuous measurement with very large estimated gaps (> 3 months) or less than 6 discrete samples per year or data estimated from flow

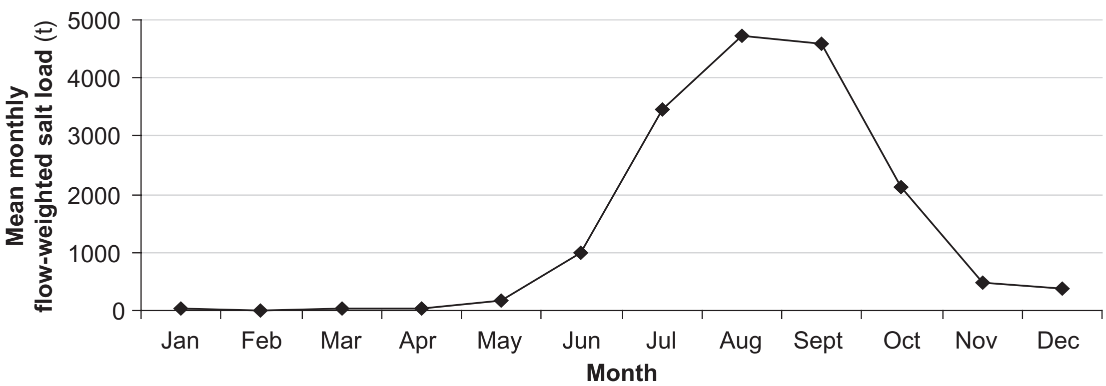
Salinity data was assigned a classification 1 if it was continuous, 2 if it was calculated from more than 100 discrete points, 3 if it was calculated from more than 30 discrete points and 4 if it was calculated from more than 6 points (Table C). If there were fewer than 6 samples taken during the year (with each sample being on a different day), then a code 5 was assigned. Code 5 data was only included where there was a good spread of the data throughout the year with at least a few points over the winter months when most of the flow occurred. It was also only included if it fell on the flow–salinity curve (similar to Equation 2) for that site and if the site had a clear salinity curve without many outliers. If it did not and the flow–salinity curve was a good, clear curve then the flow–salinity relationship (Equation 2) was used to estimate the data and the code 5 was still assigned. Code 4 and 5 data were not used unless the site was important. If continuous data was available but there were gaps in it then the classification system was the same as that for flow.

The data reliabilities reported are not for single years but rather for ten-year means. The values reported are actually the mean reliability of the data. In other words, the data reliability codes were averaged for the years for which the salinity, salt load and flow means were calculated and reported as mean reliability. In some cases, gauging stations had not been operating for many years decreasing the accuracy of the mean value. In cases like this data reliability was already reported as ‘low’ because of sparse data collection so these values were left. In other cases, gauging stations had continuous data or very frequently sampled data for that short period of record and in such a case the reliability code did not reflect the reliability of the data. So, if there were more than two years of data missing for a site then the mean was worked out a little differently: the years of missing data were assigned a quality code 6 and the average of all the quality codes was then taken.

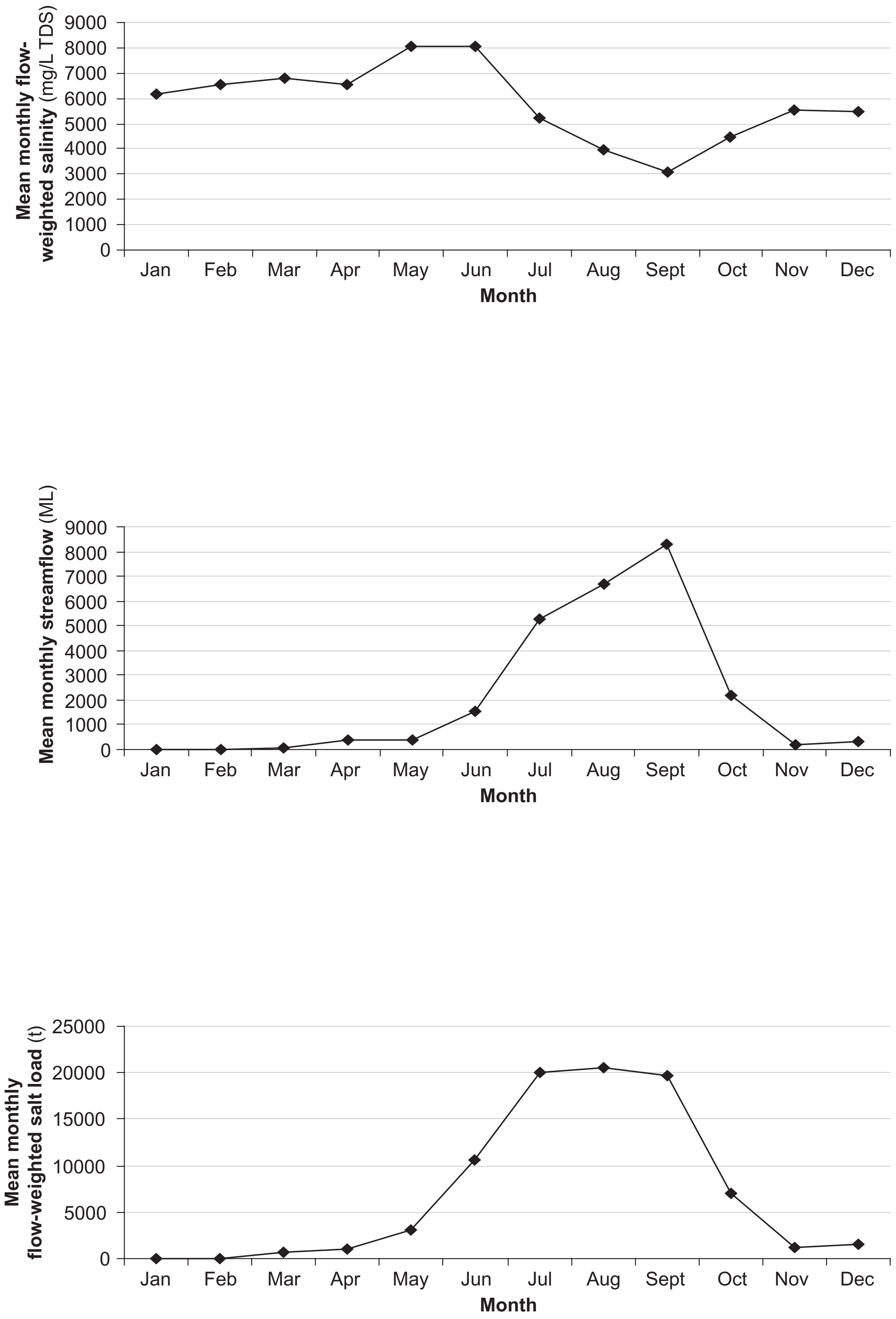
Appendix B
South Coast Study Area: mean monthly flow, salinity and salt loads



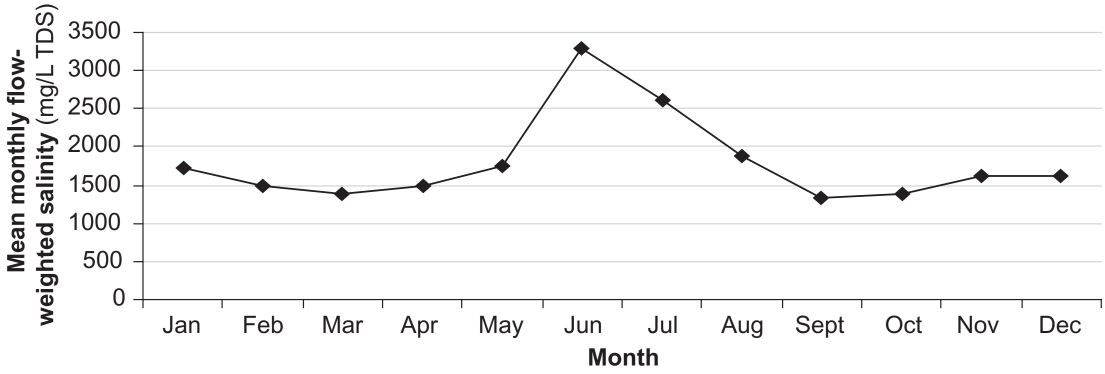


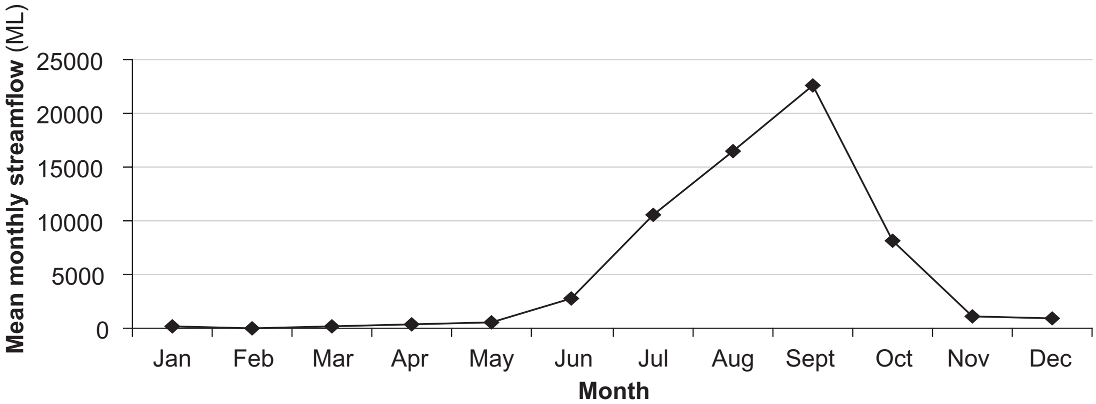


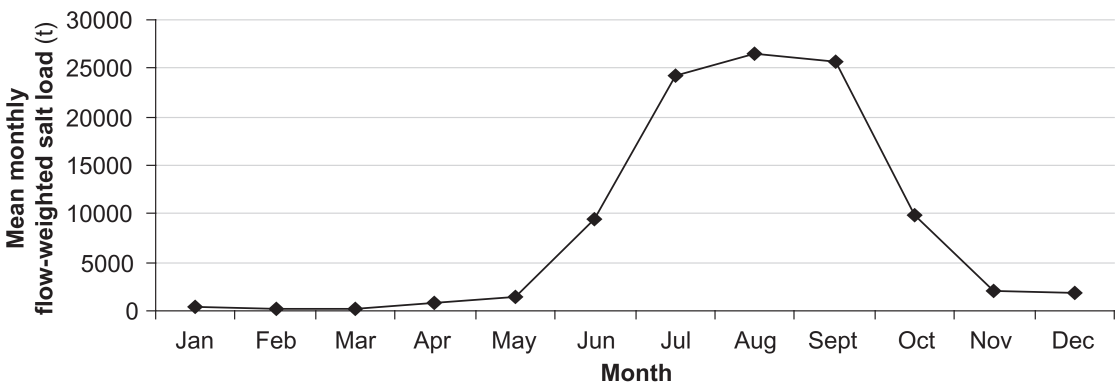
Monthly means (1993–2002) for site 603-136, Denmark River, Mt Lindesay



Monthly means (1993–2002) for site 604-001, Kent River, Rocky Glen

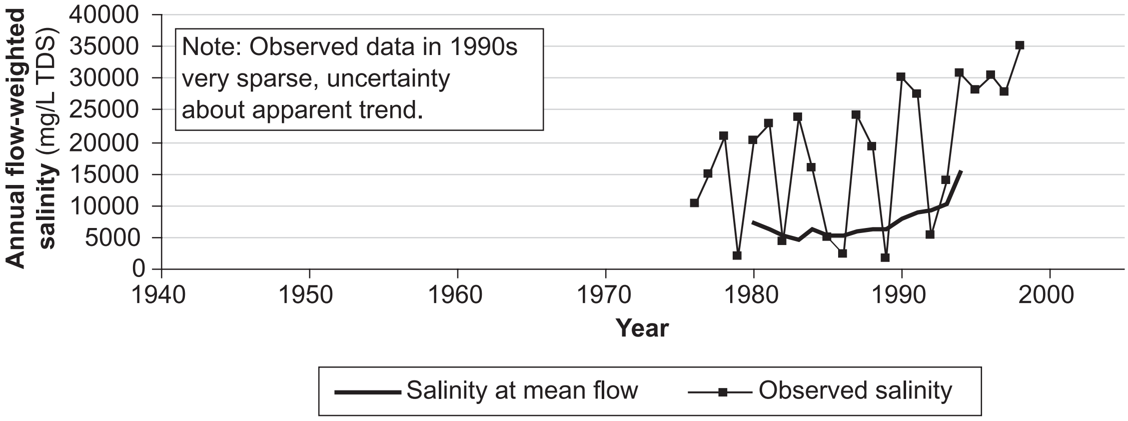


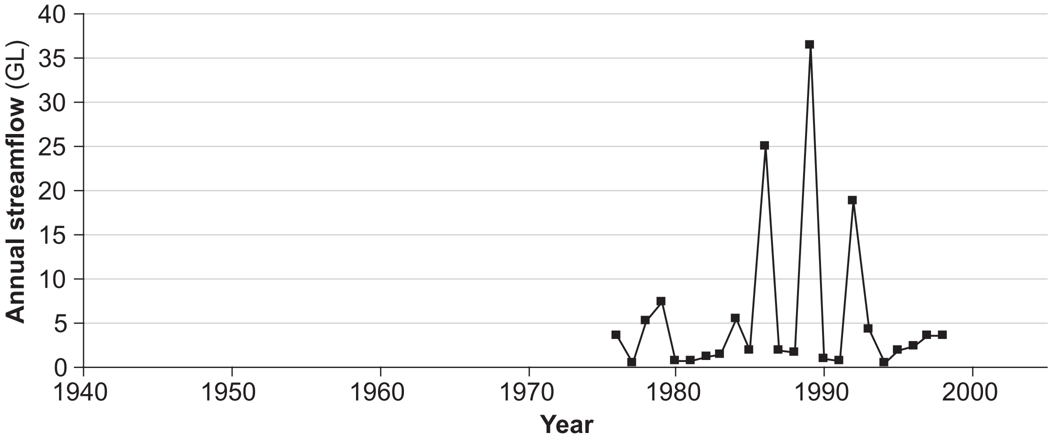


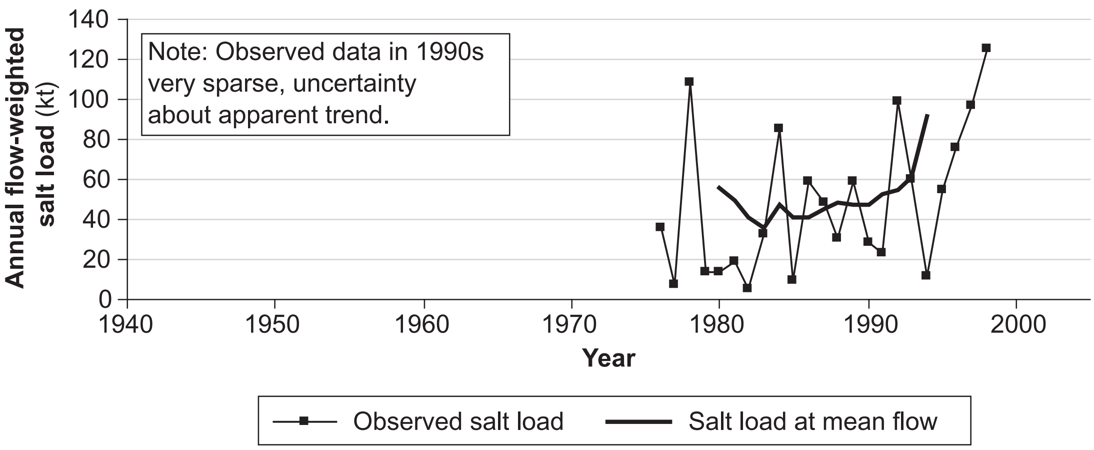


Monthly means (1993–2002) for site 604-053, Kent River, Styx Junction

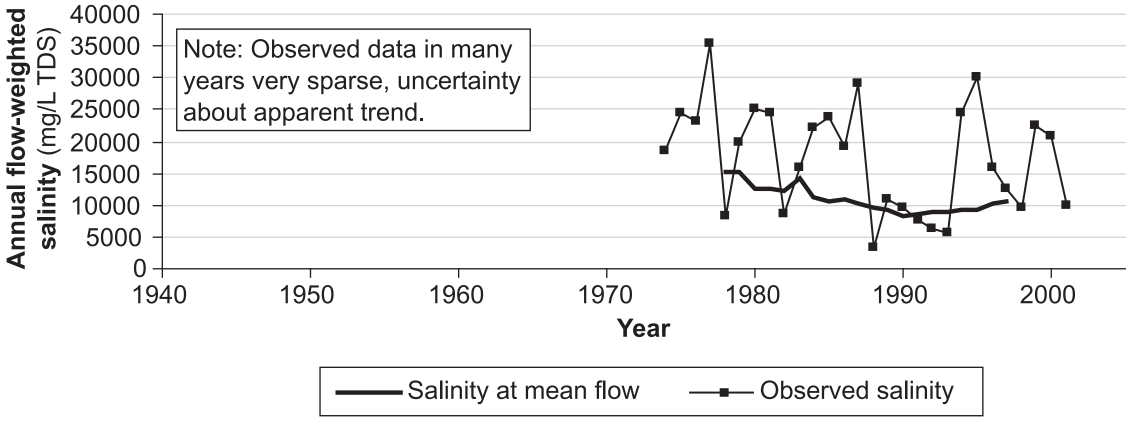
Appendix C
South Coast Study Area: long-term salinity, salt load and flow trends

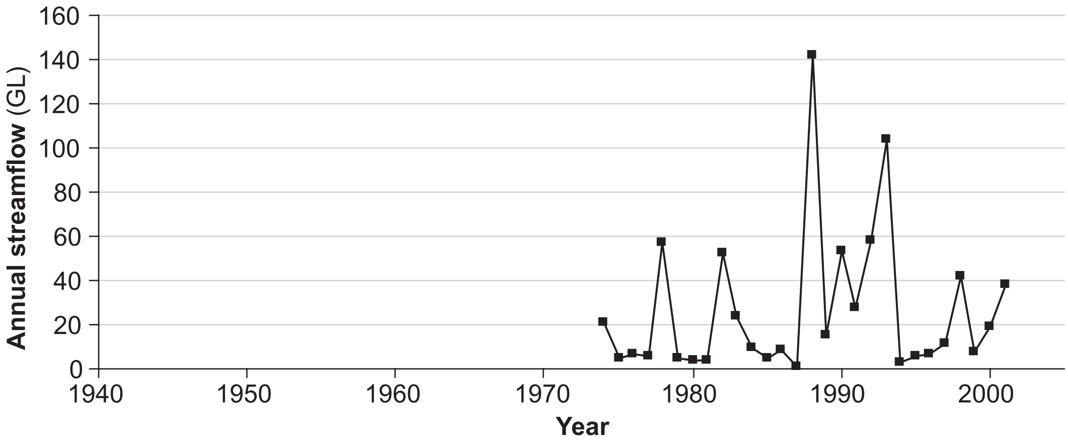


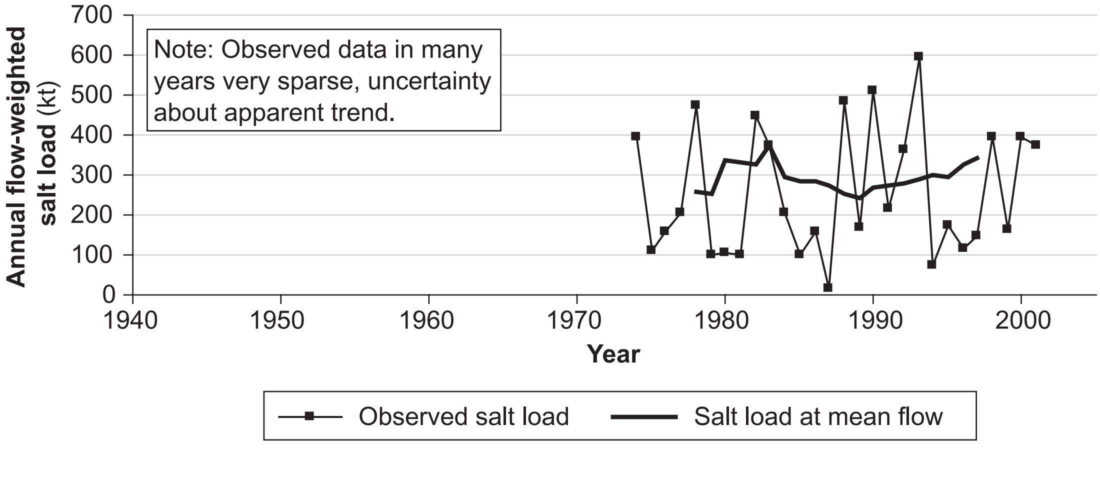




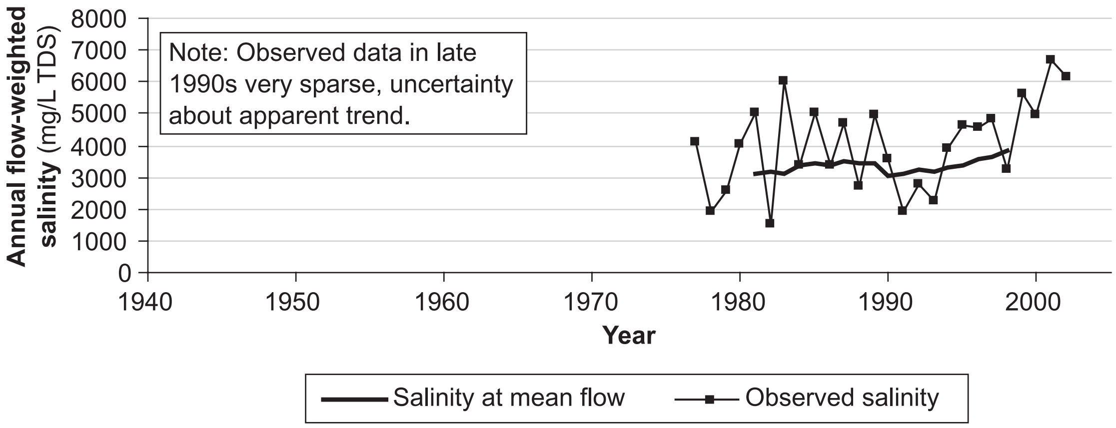
Long-term trends for site 601-004, Lort River, Fairfield

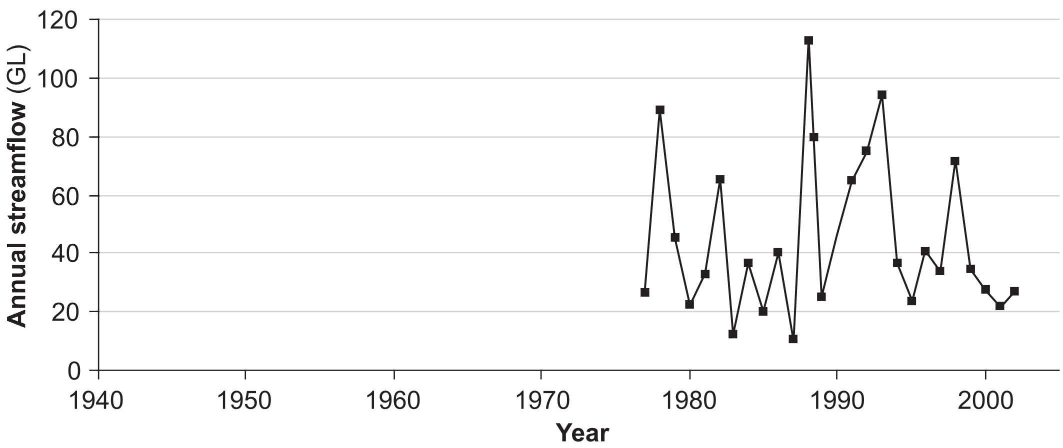


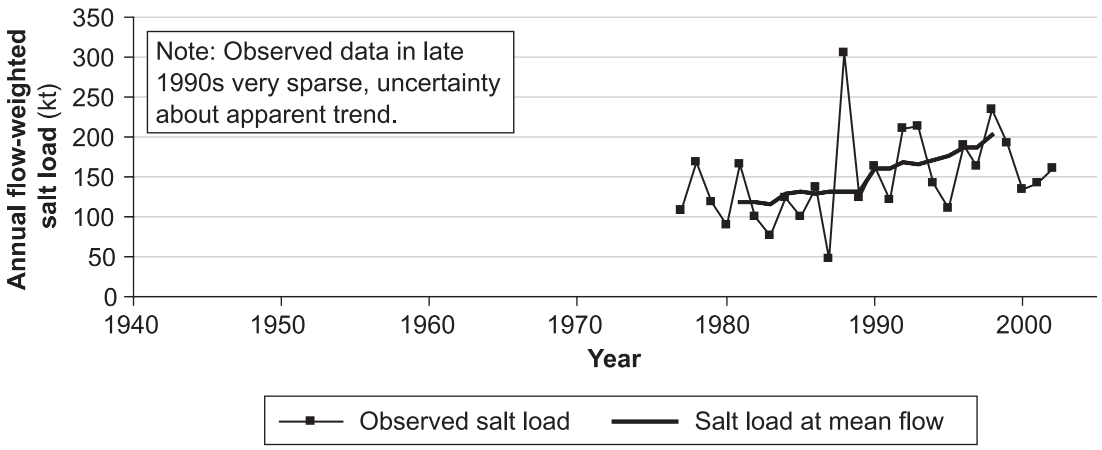




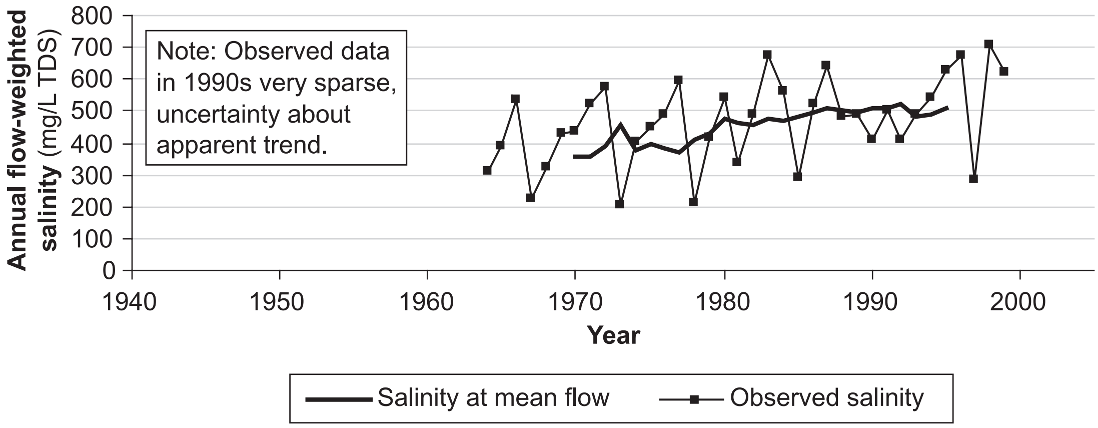
Long-term trends for site 602-001, Pallinup River, Bull Crossing

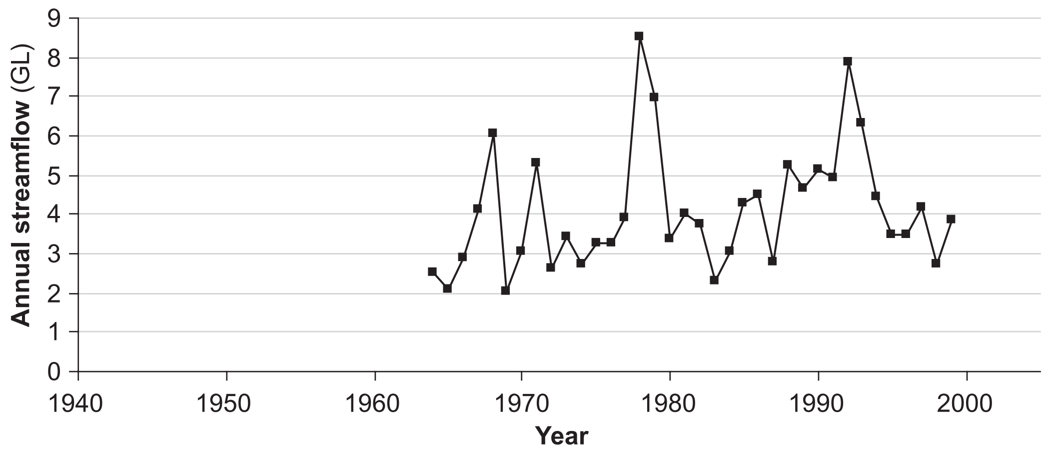


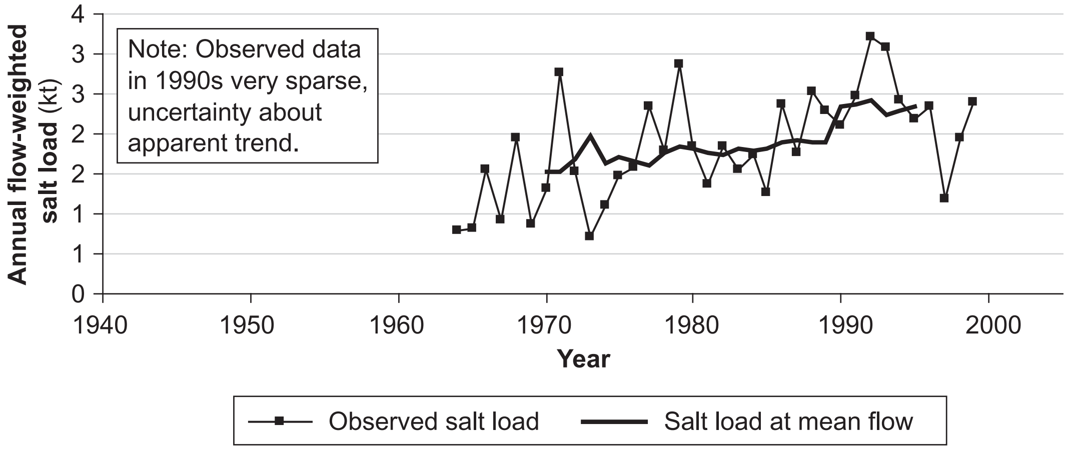




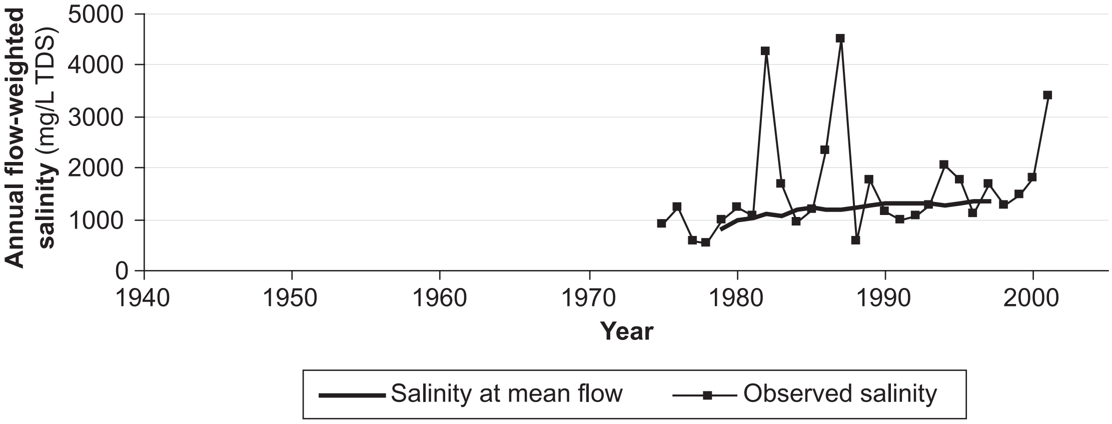
Long-term trends for site 602-004, Kalgan River, Stevens Farm

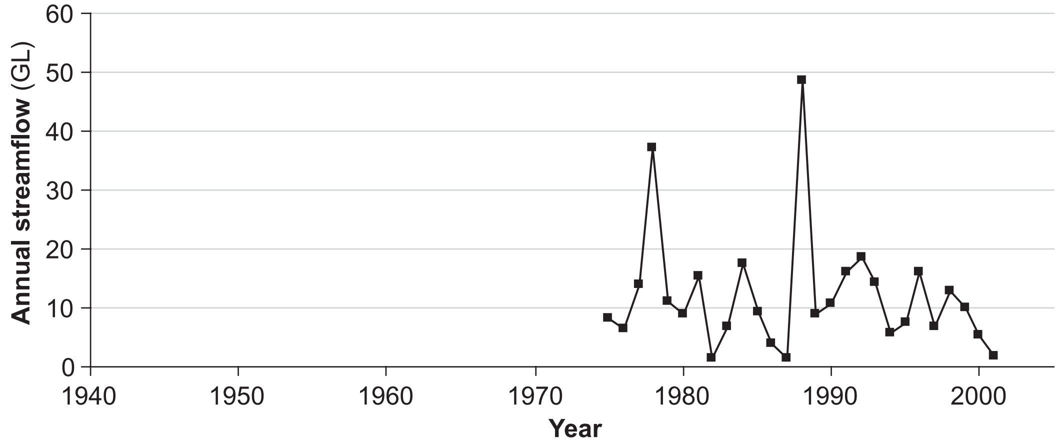


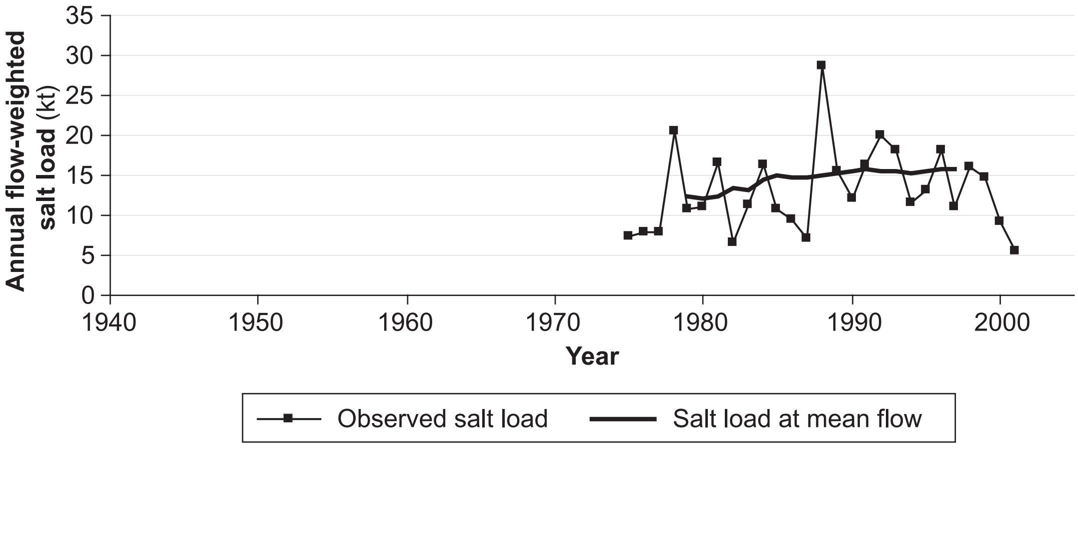




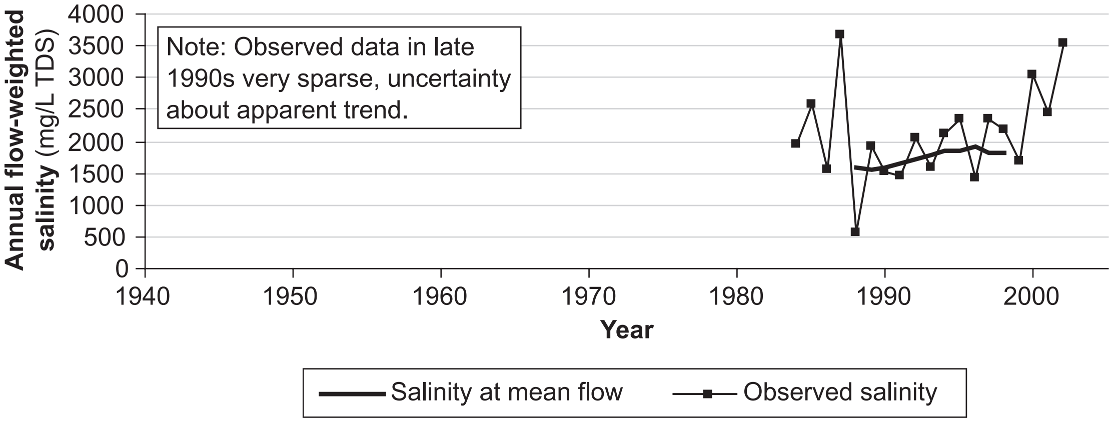
Long-term trends for site 602-199, Goodga River, Black Cat

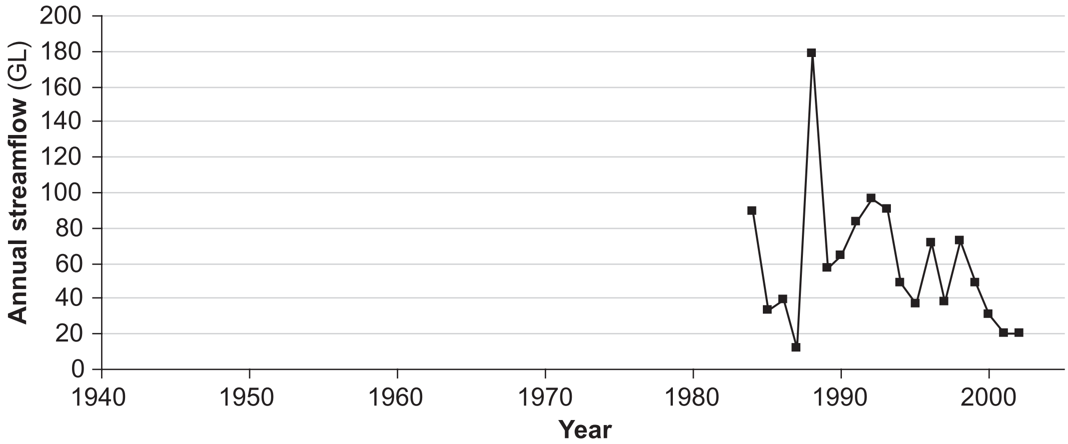


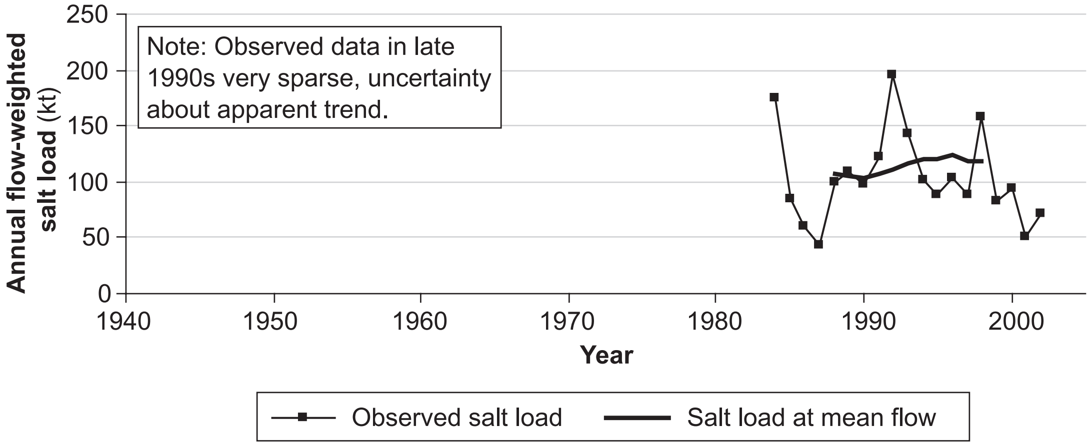




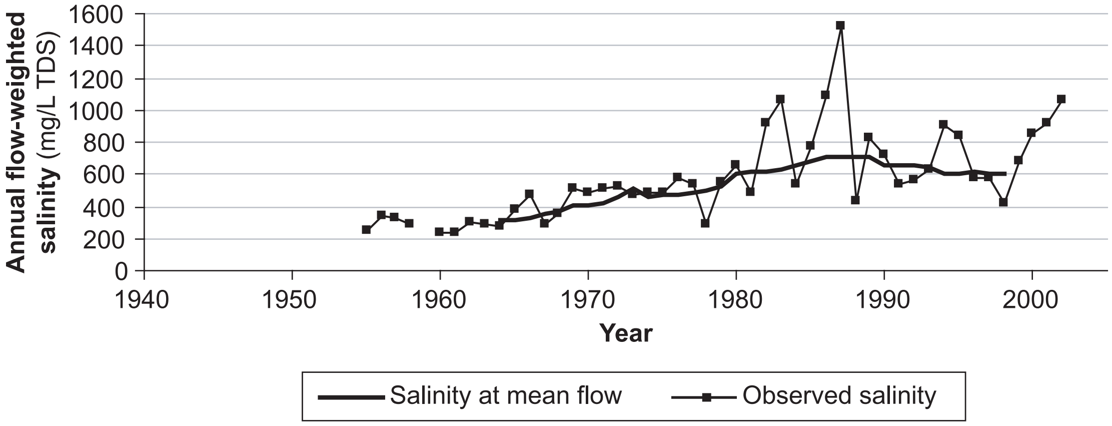
Long-term trends for site 603-003, Denmark River, Kompup

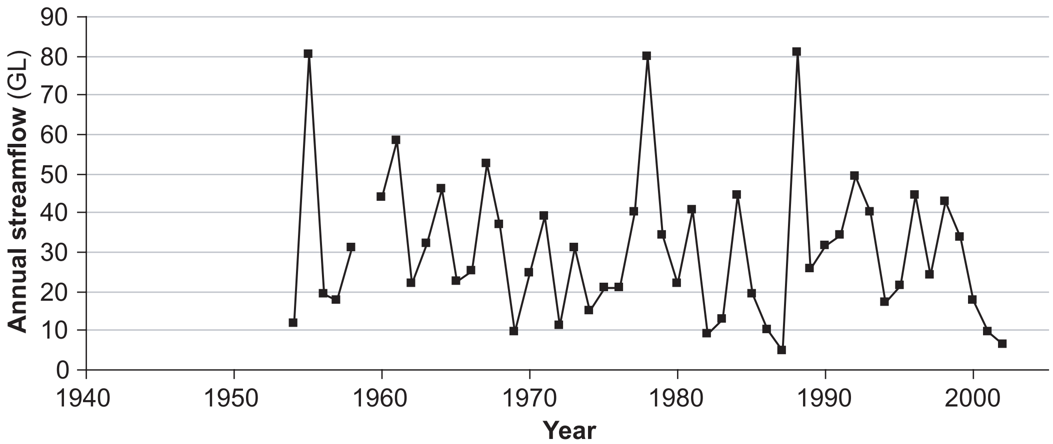


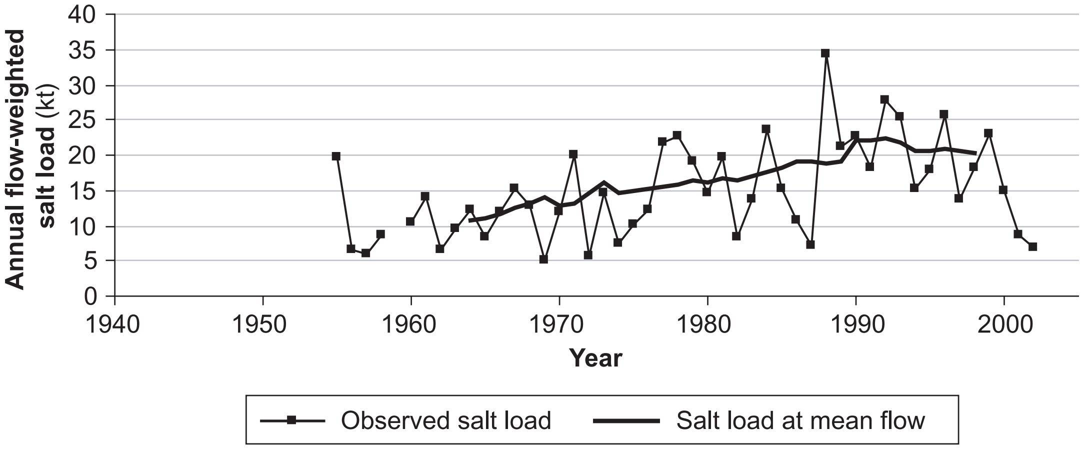




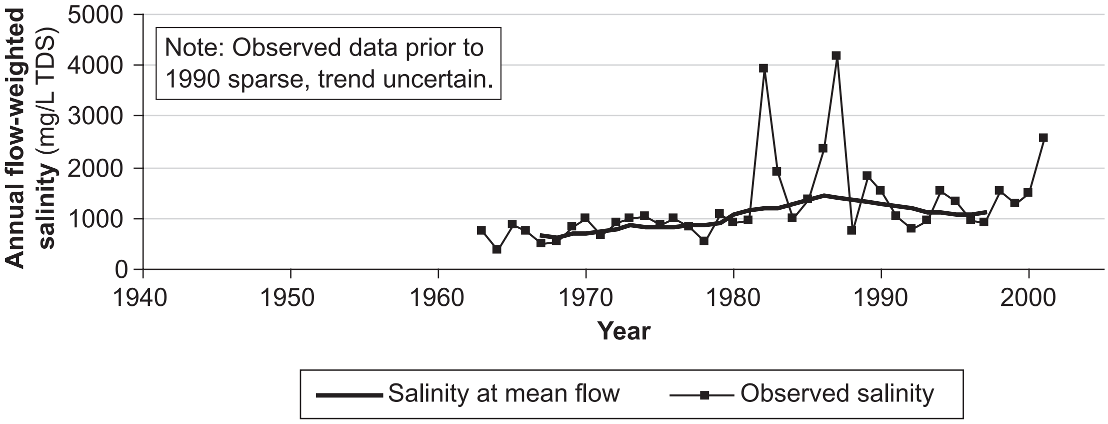
Long-term trends for site 603-004, Hay River, Sunny Glen

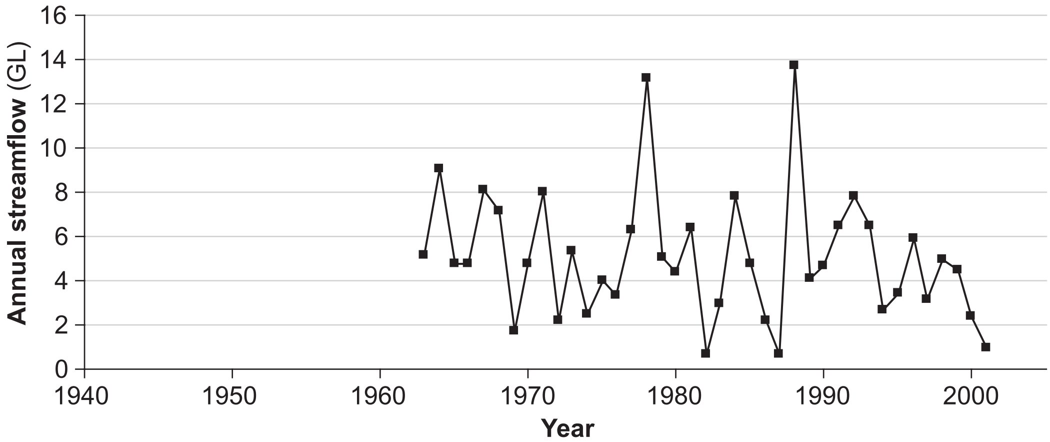


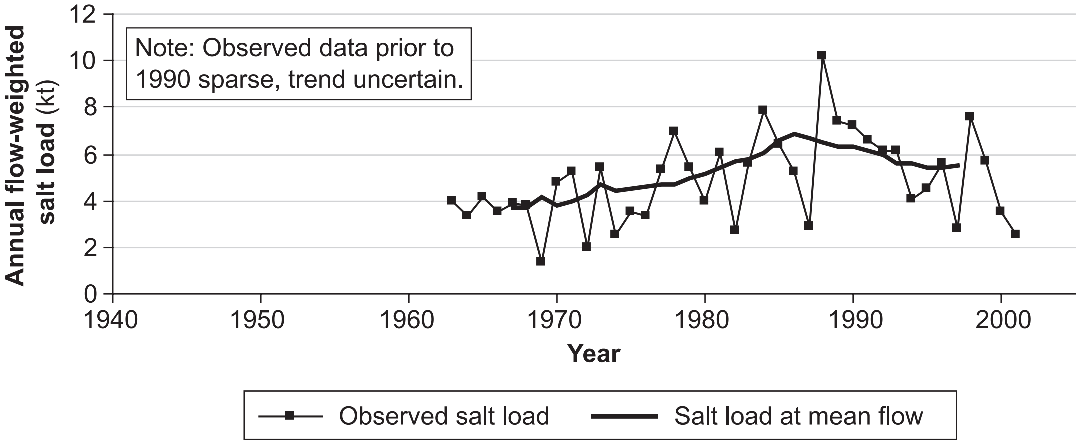




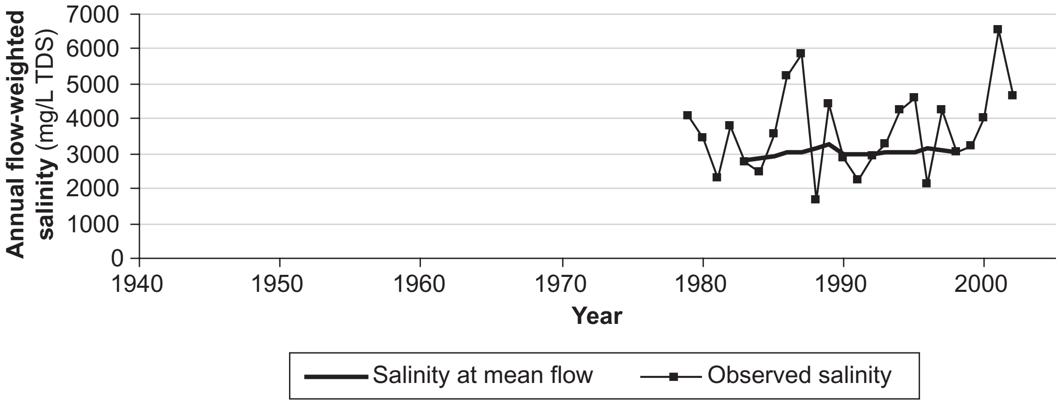
Long-term trends for site 603-136, Denmark River, Mt Lindesay

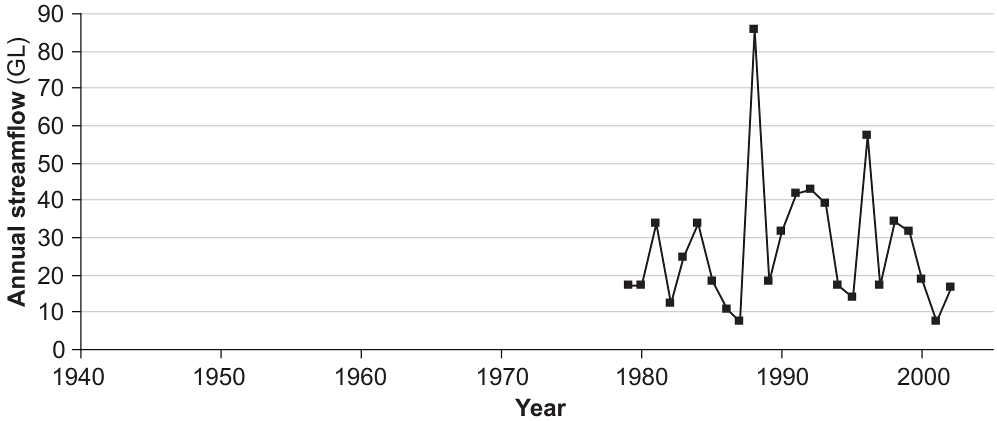


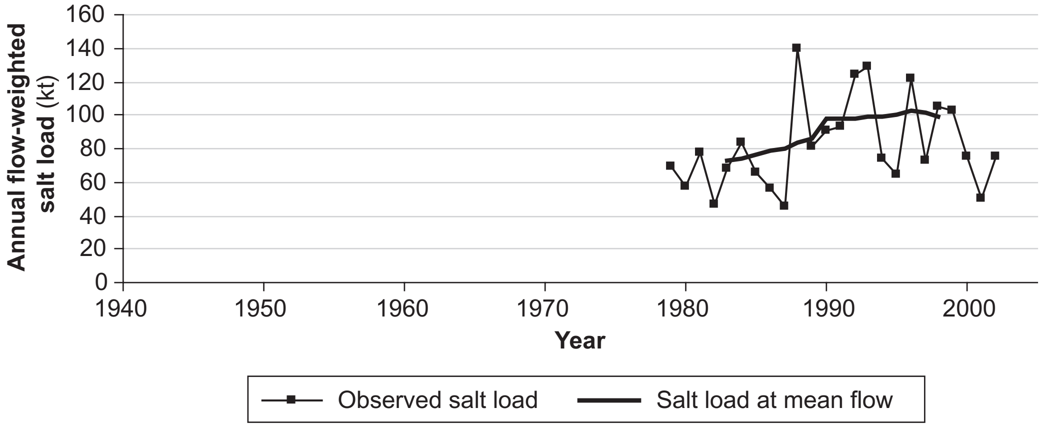




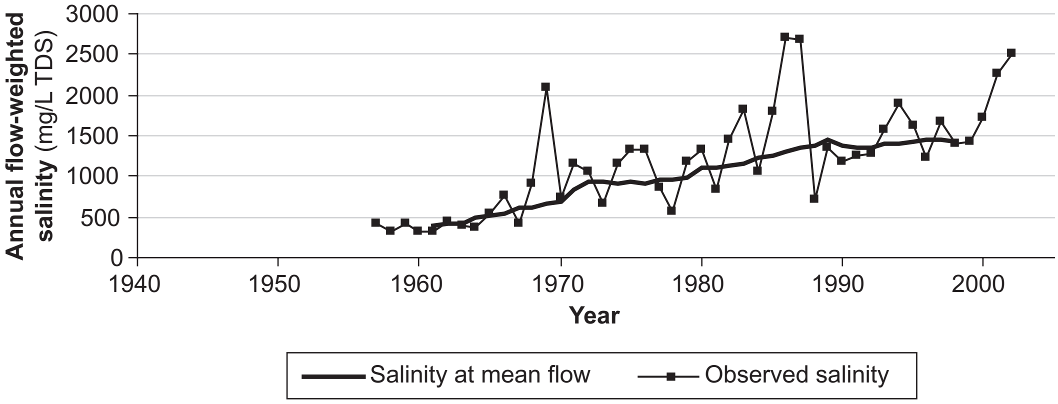
Long-term trends for site 603-190, Yate Flat Creek, Woonanup

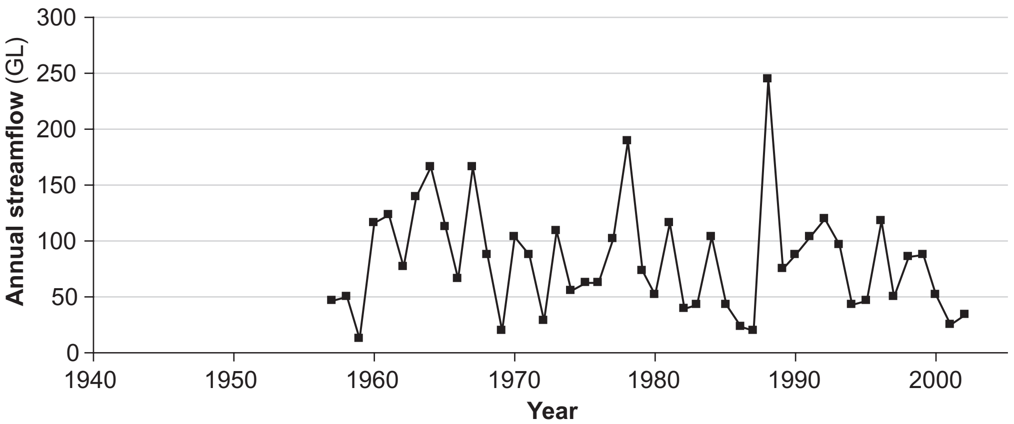


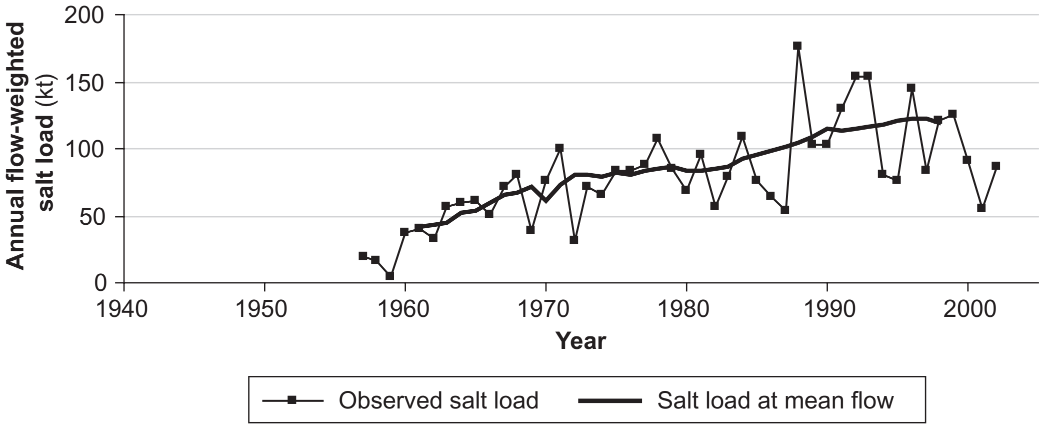




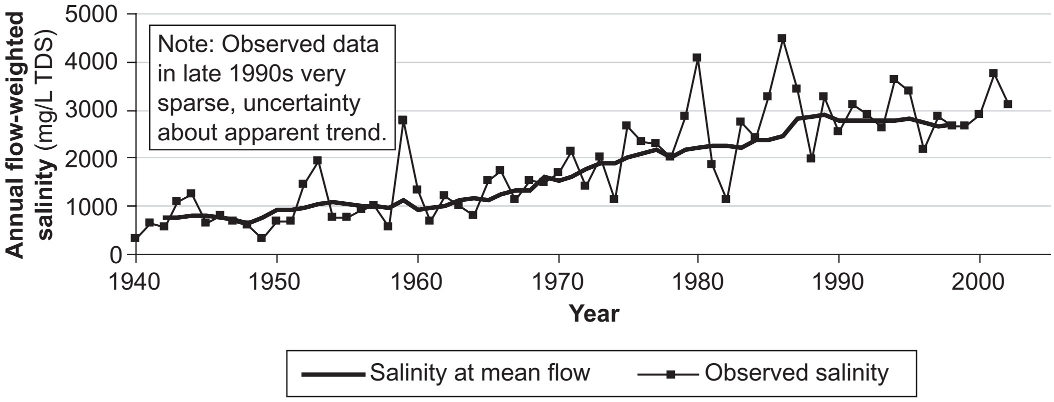
Long-term trends for site 604-001, Kent River, Rocky Glen

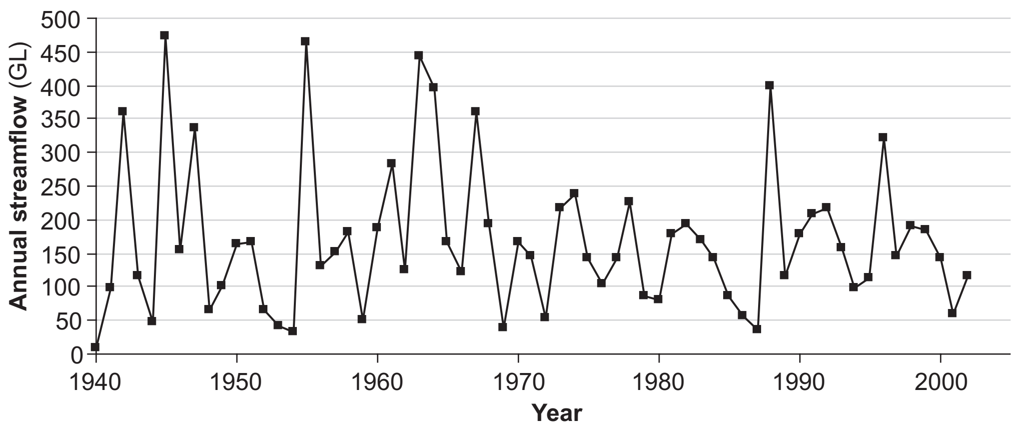


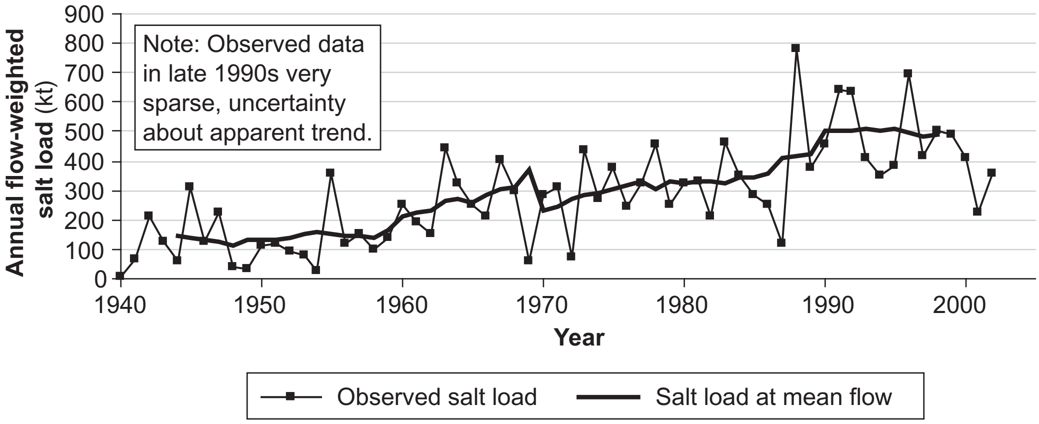




Long-term trends for site 604-053, Kent River, Styx Junction







Long-term trends for site 605-012, Frankland River, Mount Frankland

Appendix D
South Coast Study Area: catchment characteristics, salinity status, mean and current values, salt output/input ratios and annual trends

South Coast Study Area:
Catchment characteristics, salinity status, mean and current salinities, salt loads and streamflow

				Characteristics				Mean annuals 1983–1992					Current annuals (mean 1993–2002)				
Site number	Watercourse	Site	Data period[a]	Clearing 1996 (%)	Mean annual rainfall (mm)	Area (km²)[b]	Salinity status	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability
ESPERANCE COAST BASIN																	
601-001	Young River	Neds Corner	–89, 92, 93, 95–02	55	405	1893	Highly saline	6000	5	16	14	1	12100	5	29	8.0	1
601-004	Lort River	Fairfield	–99, 01, 02	64	370	2901	Highly saline	15500	3	47	9.4	1	26900	4	66	4.6	2
ALBANY COAST BASIN																	
602-001	Pallinup River	Bull Crossing	–01	81	390	3327	Highly saline	14800	5	260	34	1	16800	5	270	26	1
602-004	Kalgan River	Stevens Farm		62	600	2384	Moderately saline	3800	3	141	44	1	4700	4	168	41	1
602-009	Robinson Drain	Drop Structure	94–02	51	960	12	Marginal	-	-	-	-	-	530	4	0.86	1.7	1
602-031	Waychinicup River	Cheynes Beach Road	–98, 01	47	760	238	Marginal	780	4	6.4	8.7	1	880	5	6.2	7.9	1
602-199	Goodga River	Black Cat	–99	51	870	49	Marginal	500	3	2.1	4.5	1	560	5	2.2	4.1	1
DENMARK RIVER BASIN																	
603-001	Marbelup Brook	Elleker	–99, 02	63	890	122	Fresh	430	3	6.8	16	1	490	4	7.3	15	1
603-003	Denmark River	Kompup	–01	31	760	241	Brackish	1600	2	15	14	1	1800	1	13	8.8	1
603-004	Hay River	Sunny Glen	84–02	52	760	1209	Moderately saline	1900	3	110	73	1	2300	4	98	48	1
603-005	Mitchell River	Beigpiegup	86–97, 99–02	0	855	51	Fresh	280	3	1.0	3.9	1	350	4	1.0	3.2	1
603-006	Quickup River	Mount Leay	86–98	6	895	38	Fresh	430	4	0.72	2.0	1	350	5	0.68	2.1	1
603-007	Sleeman River	Sleeman Road Bridge	86–97, 99–02	72	890	76	Fresh	320	3	4.4	14	1	480	4	5.1	11	1
603-013	Cuppup River	Eden Road	93–97, 99–02	73	1005	61	Fresh	-	-	-	-	-	470	4	4.3	9.3	1
603-136	Denmark River	Mt Lindesay		18	800	505	Marginal	810	2	20	31	1	750	1	17	26	1
603-190	Yate Flat Creek	Woonanup	–81, 83–86, 88–00	57	780	57	Brackish	1700	4	6.6	5.5	1	1400	1	4.7	3.8	1
KENT RIVER BASIN																	
604-001	Kent River	Rocky Glen	80–02	64	650	1129	Moderately saline	3400	1	85	31	1	4000	1	87	25	1
604-053	Kent River	Styx Junction		40	800	1862	Brackish	1600	1	105	86	1	1700	1	102	64	1
FRANKLAND RIVER BASIN																	
605-012	Frankland River	Mount Frankland		69	600	4508	Moderately saline	3000	3	436	161	1	3000	4	425	153	1
605-013	Frankland River	Trappers Road	97–01	82	520	3763	Saline	-	-	-	-	-	5900	4	471[c]	93	1

Note:

Dividing the mean salt load by the mean flow will not give the reported mean salinity because mean salinity was calculated by taking the average of the 10 annual salinity figures.

[a] If the whole period for the 10-year means was not available then whatever data was available within that period was used.

[b] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[c] Salt load at the upstream gauging station of the Frankland River (605-013) is higher than at the downstream gauging station (605-012) due to the different periods of record and sparse data at the 605-012 gauging station.

South Coast Study Area:
Salt output/input ratios and annual trends

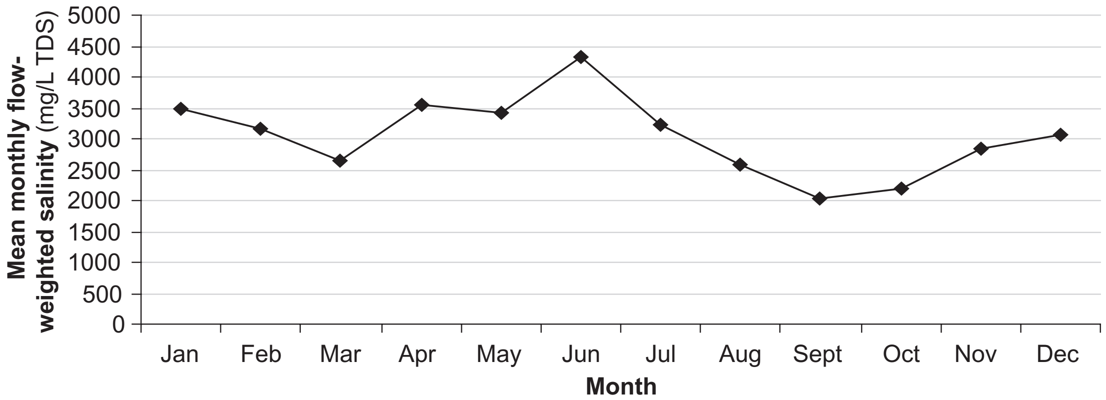
Site number	Watercourse	Site	Characteristics: Clearing 1996 (%)	Characteristics: Mean annual rainfall (mm)	Characteristics: Area (km²)[a]	Salinity status	Salt balance: Salt input (t/yr/km²)	Salt balance: Salt output (t/yr/km²)	Salt balance: Salt output/input ratio	Annual salinity trend (mg/L TDS)[b] 1980–1989	Annual salinity trend (mg/L TDS)[b] 1990–1998	Annual salt load trend (kt)[b] 1980–1989	Annual salt load trend (kt)[b] 1990–1998	Annual flow trend (GL)[b] 1980–1989	Annual flow trend (GL)[b] 1990–1998
ESPERANCE BASIN															
601-001	Young River	Neds Corner	55	405	1893	Highly saline	4.7	15	3.2	-	-	-	-	3.3ns	-
601-004	Lort River	Fairfield	64	370	2901	Highly saline	3.8	23	6.0	-	-	-	-	2.4ns	-0.27ns
ALBANY COAST BASIN															
602-001	Pallinup River	Bull Crossing	81	390	3327	Highly saline	4.1	76	19	-	-	-	-	4.6ns	-5.0ns
602-004	Kalgan River	Stevens Farm	62	600	2383	Moderately saline	7.4	71	9.6	-	-	-	-	2.3ns	-
602-009	Robinson Drain	Drop Structure	51	960	12	Marginal	29	70	2.4	-	-	-	-	-	-
602-031	Waychinicup River	Cheynes Beach Road	47	760	238	Marginal	17	26	1.6	-	-	-	-	-	-0.80ns
602-199	Goodga River	Black Cat	51	870	49	Marginal	20	45	2.2	-	-	-	-	0.14ns	-0.39s
DENMARK RIVER BASIN															
603-001	Marbelup Brook	Elleker	63	890	122	Fresh	20	59	3.0	5s	-	0.075s	-	0.36ns	-0.92s
603-003	Denmark River	Kompup	31	760	241	Brackish	9.3	54	5.9	29s	-	0.35s	-	1.3ns	-0.55ns
603-004	Hay River	Sunny Glen	52	760	1209	Moderately saline	10	81	8.0	-	-	-	-	-	-3.5ns
603-005	Mitchell River	Beigpiegup	0	855	51	Fresh	13	20	1.5	-	-	-	-	-	-
603-006	Quickup River	Mount Leay	6	895	38	Fresh	17	18	1.0	-	-	-	-	-	-
603-007	Sleeman River	Sleeman Road Bridge	72	890	76	Fresh	17	67	3.9	-	-	-	-	-	-
603-013	Cuppup River	Eden Road	73	1005	61	Fresh	28	71	2.5	-	-	-	-	-	-
603-136	Denmark River	Mt Lindesay	18	800	525	Marginal	11	34	3.0	14s	-7.5s	0.38s	-0.25s	1.6ns	-0.23ns
603-190	Yate Flat Creek	Woonanup	57	780	57	Brackish	9.9	83	8.3	6.5ns	-	0.031ns	-	0.26ns	-0.26ns
KENT RIVER BASIN															
604-001	Kent River	Rocky Glen	64	650	1129	Moderately saline	6.6	77	12	-	15s	-	0.49s	1.8ns	-1.0ns
604-053	Kent River	Styx Junction	40	800	1862	Brackish	9.6	55	5.7	42s	14s	3.2s	1.2s	5.5ns	-3.7ns
FRANKLAND RIVER BASIN															
605-012	Frankland River	Mount Frankland	69	600	4508	Moderately saline	5.9	94	16	-	-	-	-	-	-
605-013	Frankland River	Trappers Road	82	520	3763	Saline	4.5	125	28	-	-	-	-	-	-

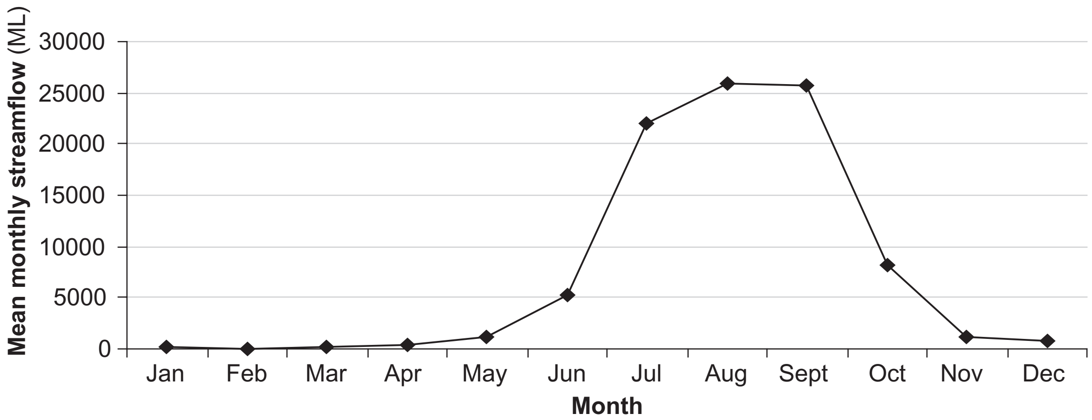
Note:

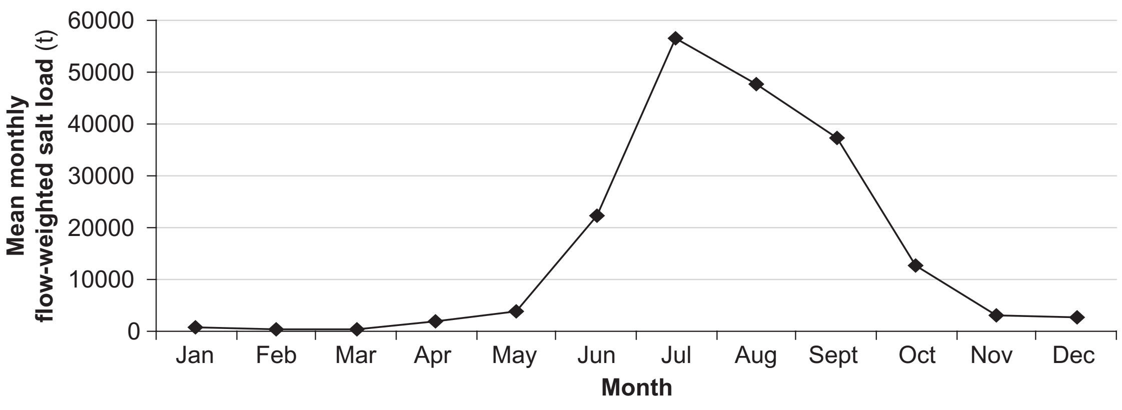
[a] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[b] s denotes statistically significant trend at the 95% confidence limit, ns means not statistically significant.

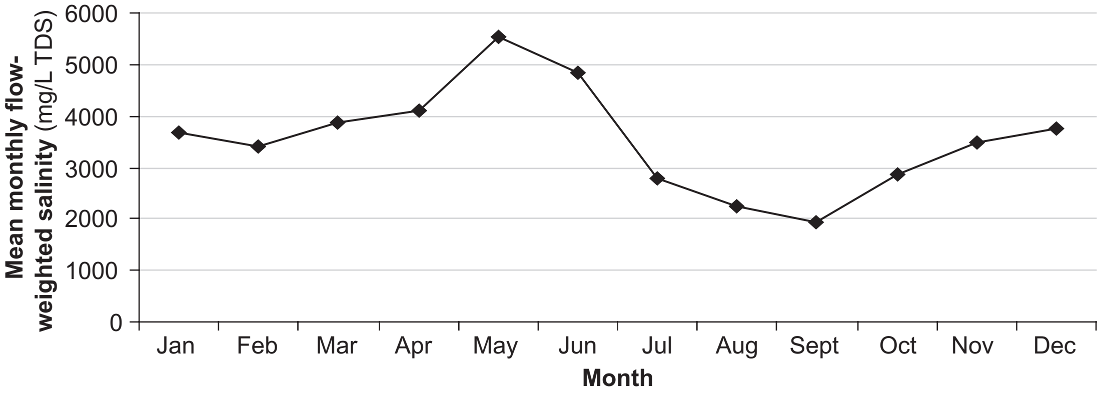
Appendix E
South West Study Area:
mean monthly flow, salinity and salt loads

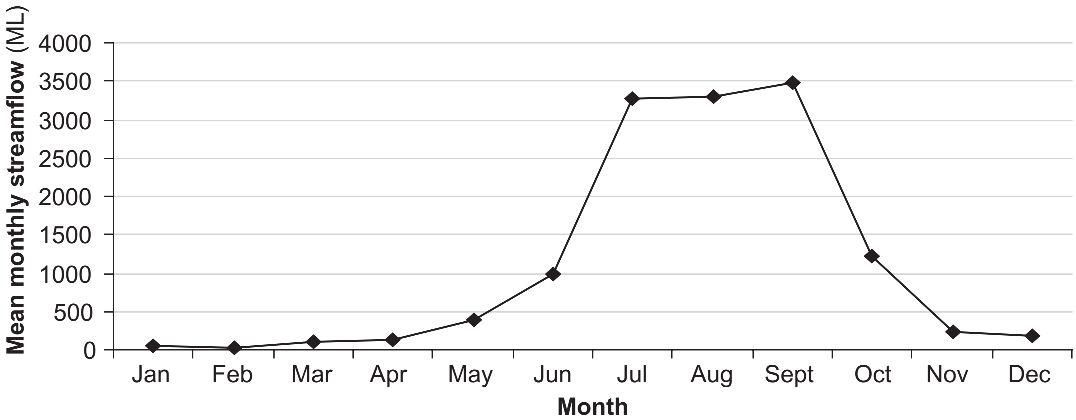


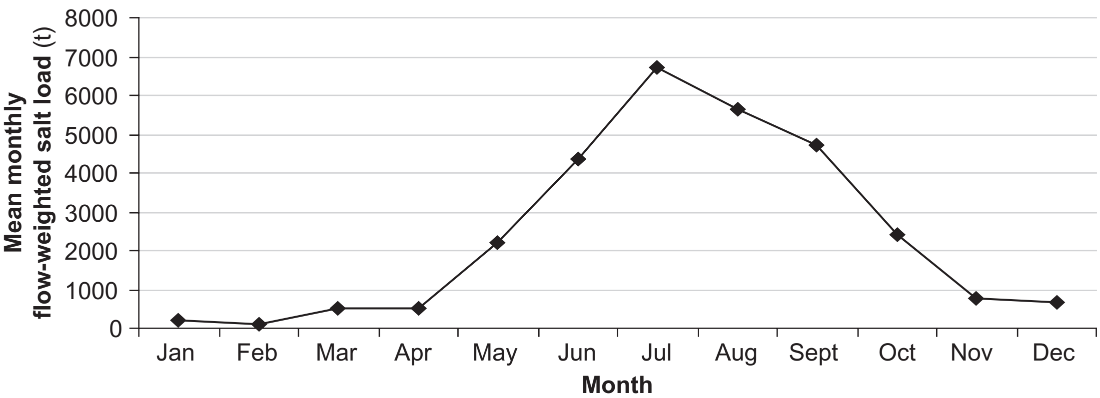




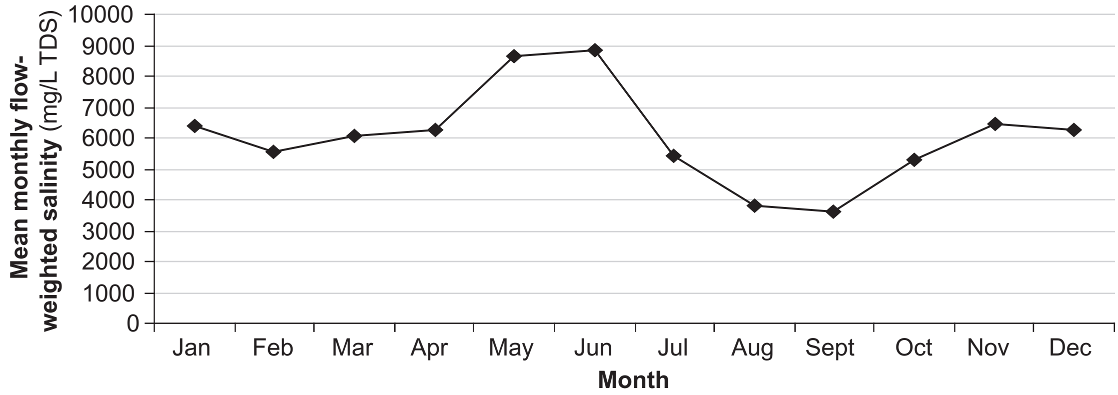
Monthly means (1993–2002) for site 607-003, Warren River, Wheatley Farm

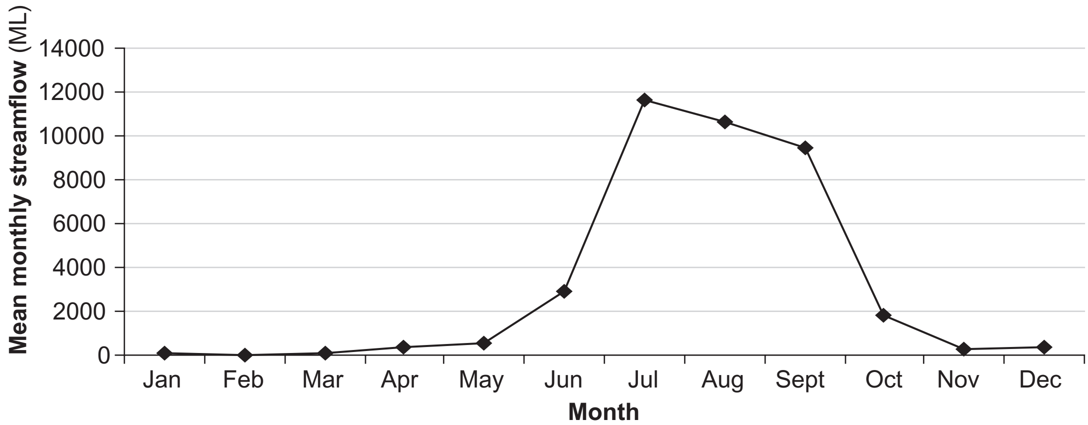


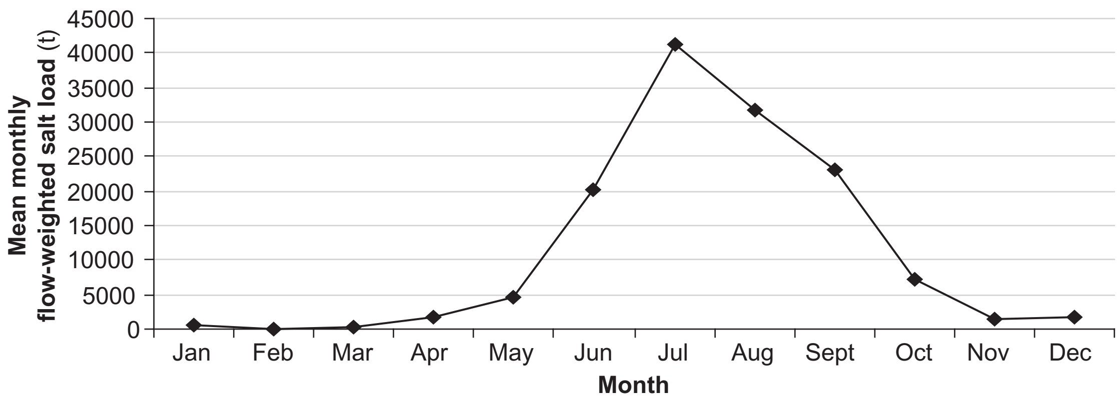




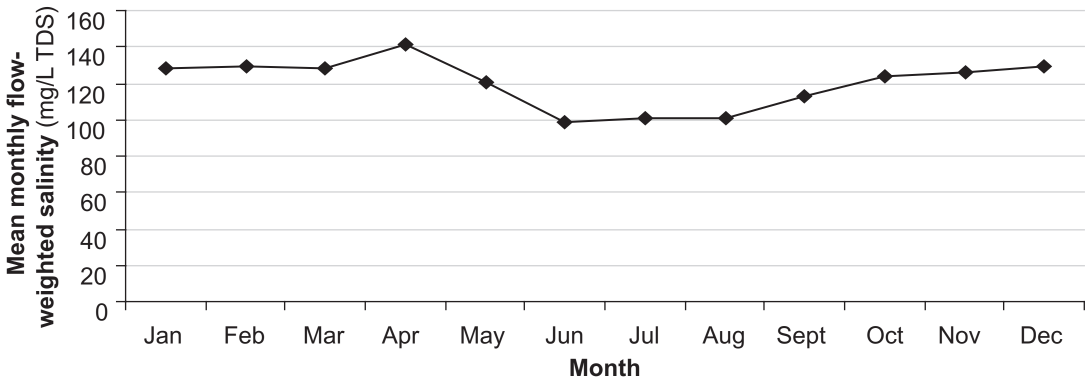
Monthly means (1993–2002) for site 607-004, Perup River, Quabicup Hill

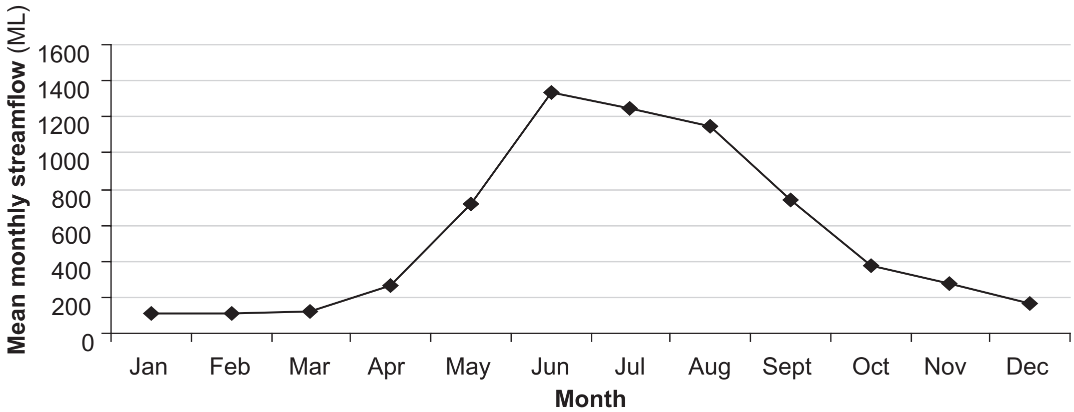


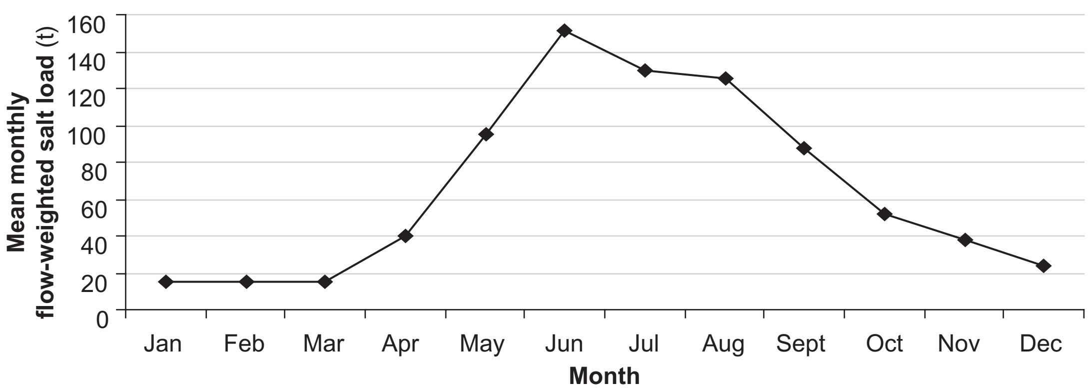




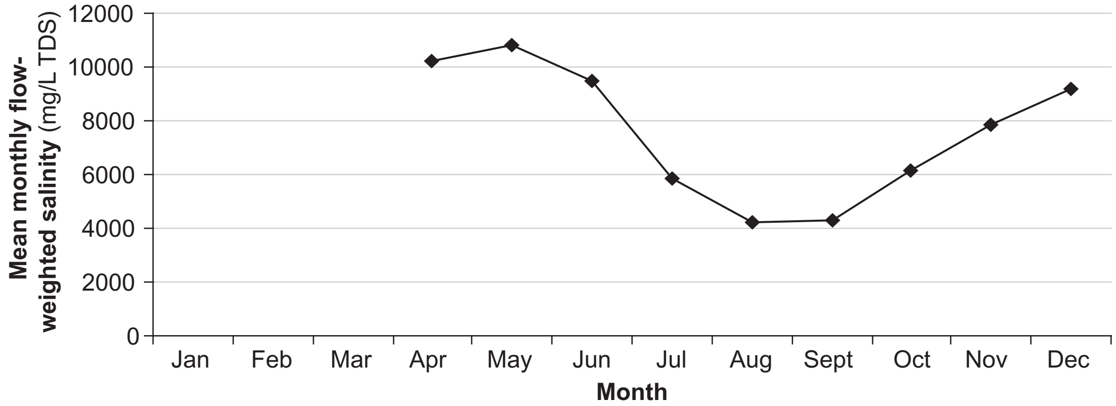
Monthly means (1993–2002) for site 607-007, Tone River, Bullilup

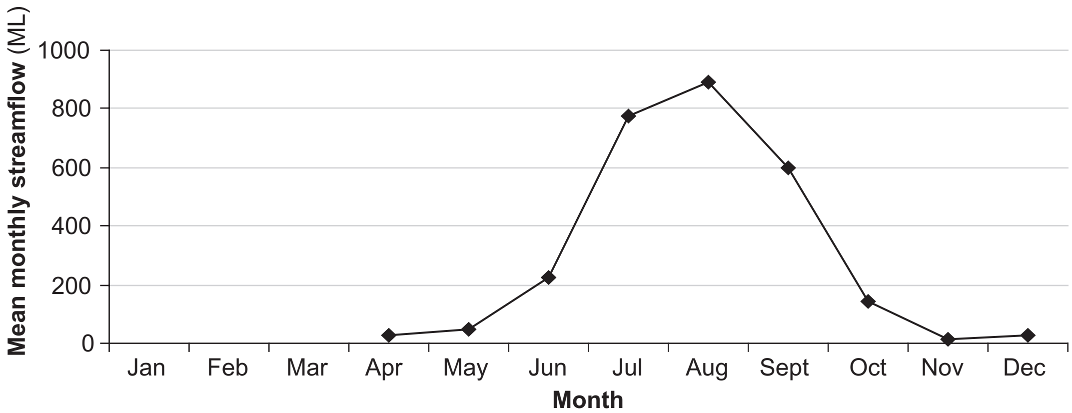


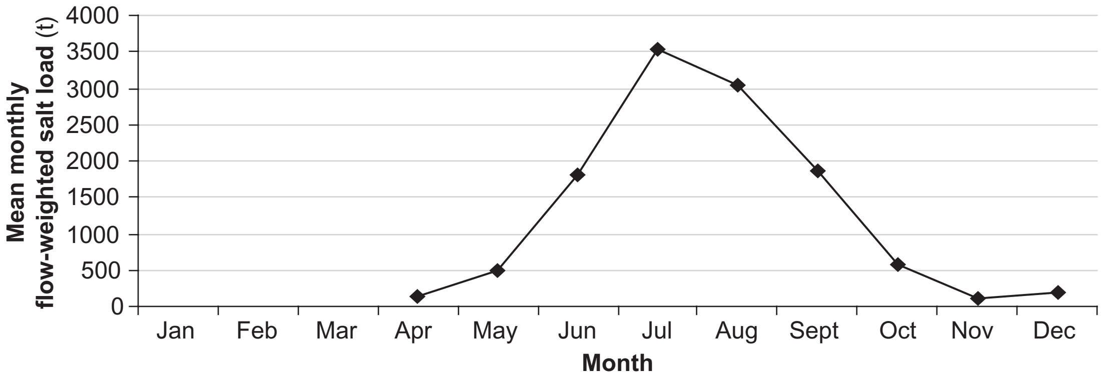




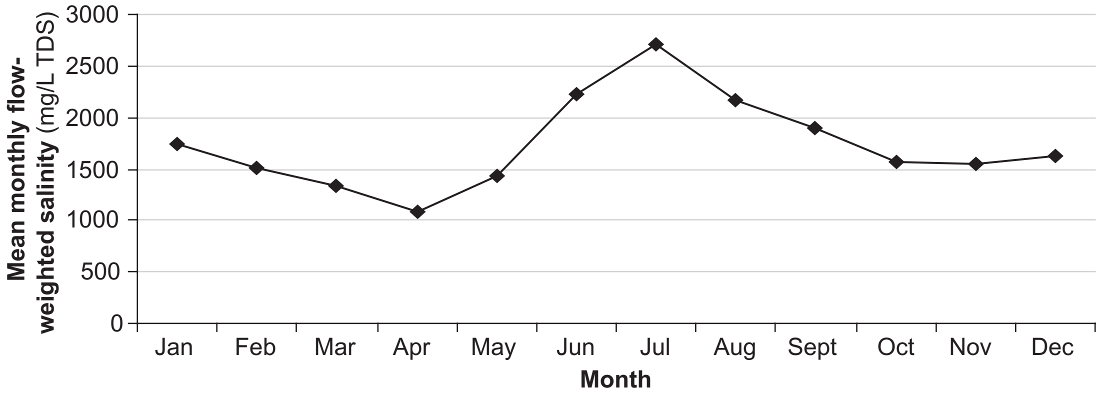
Monthly means (1993–2002) for site 608-002, Carey Brook, Staircase Road

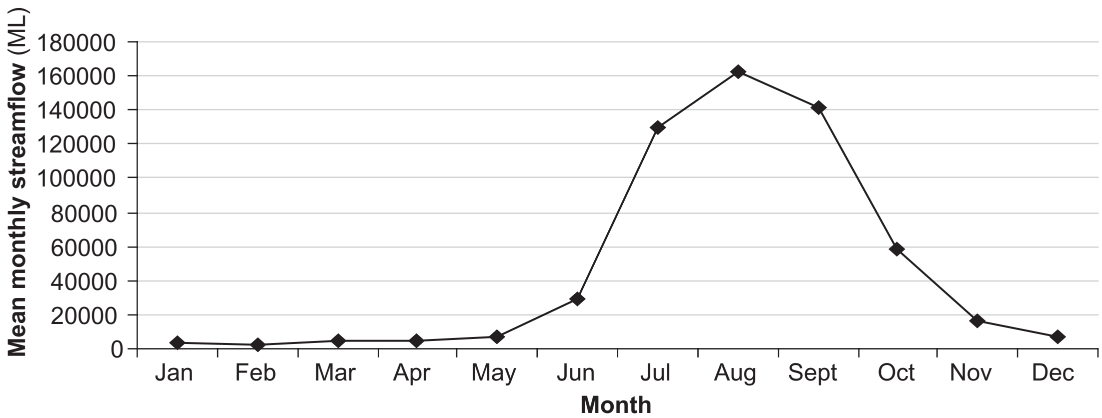


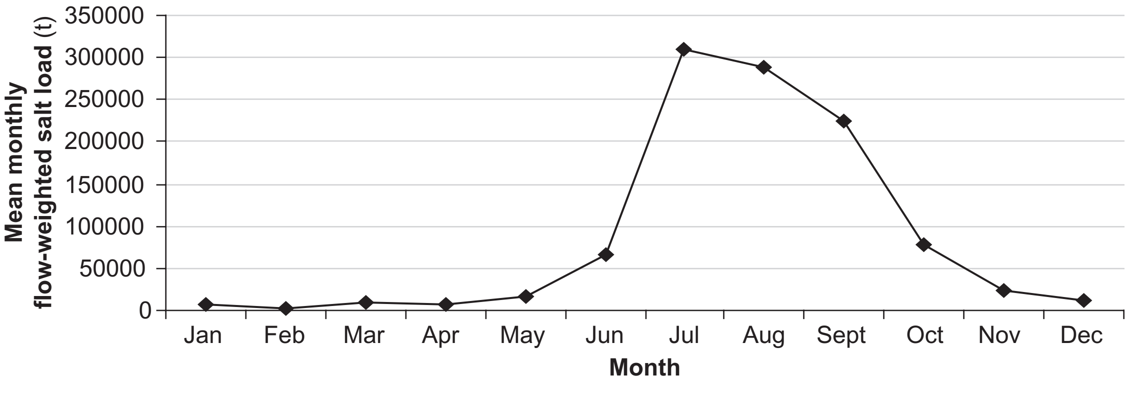




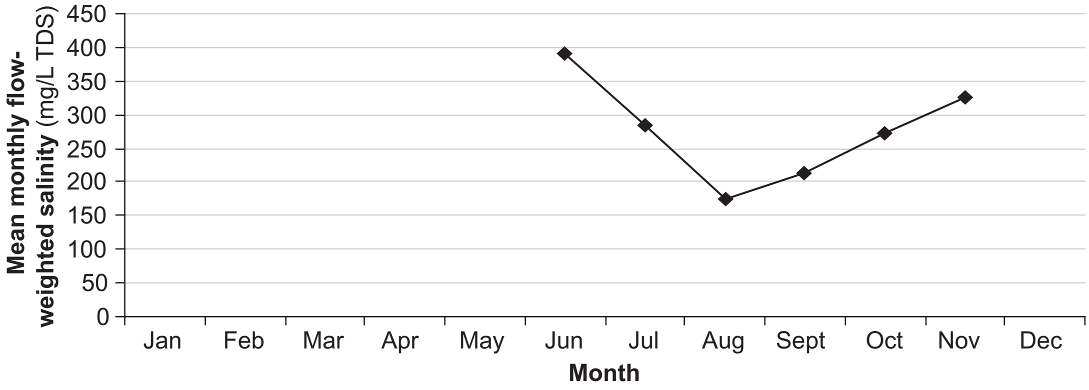
Monthly means (1993–2002) for site 609-005, Balgarup River, Mandelup Pool

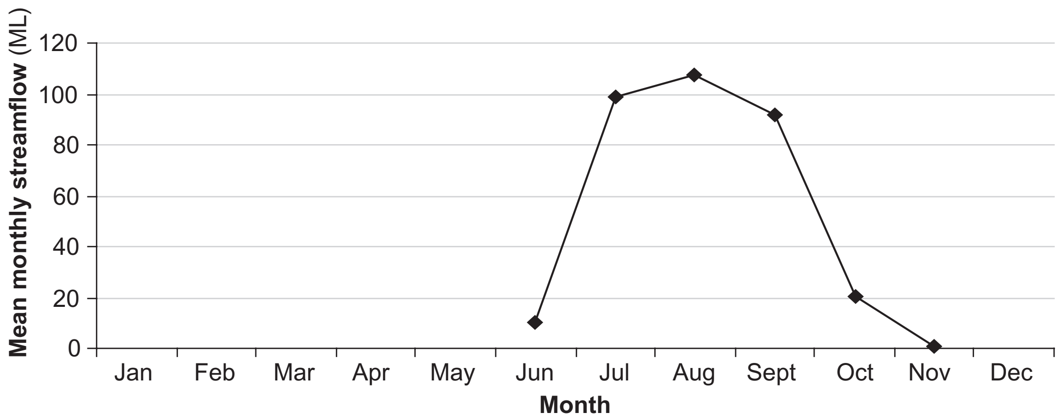


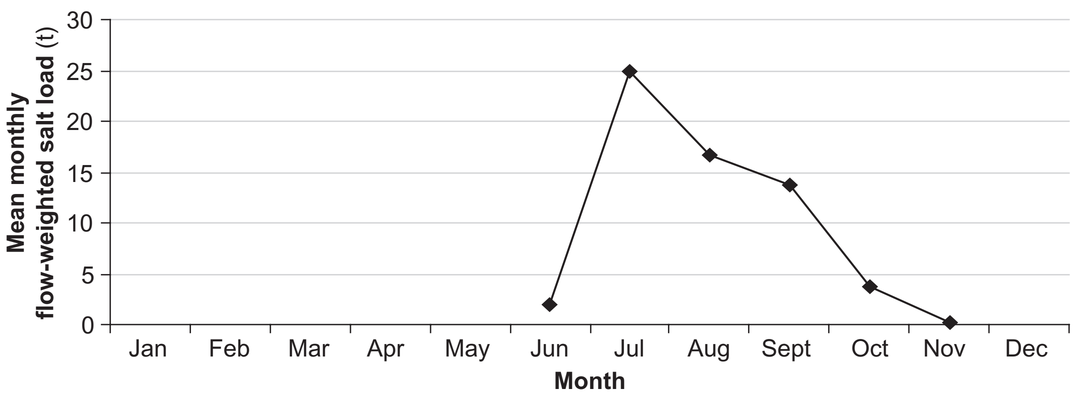




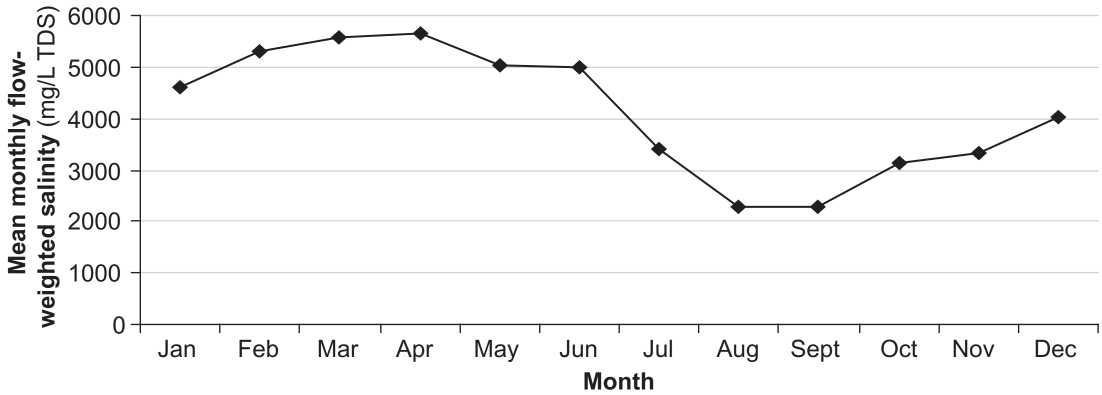
Monthly means (1993–2002) for site 609-019, Blackwood River, Hut Pool

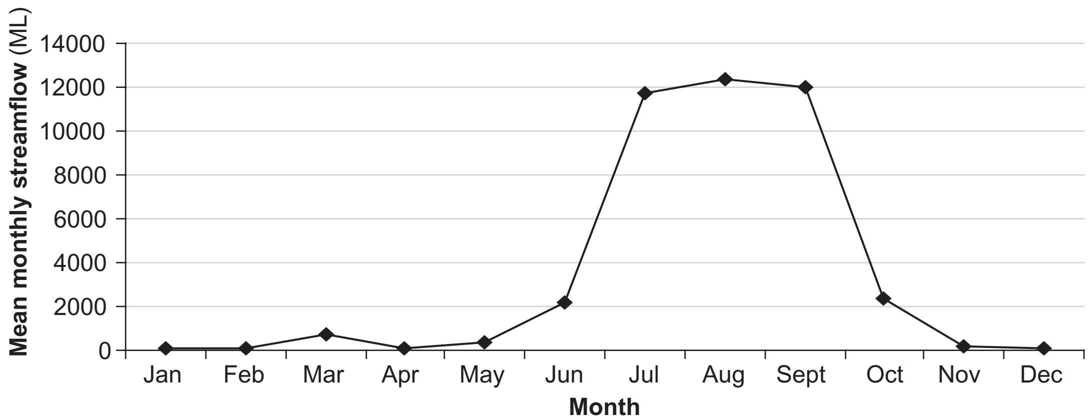


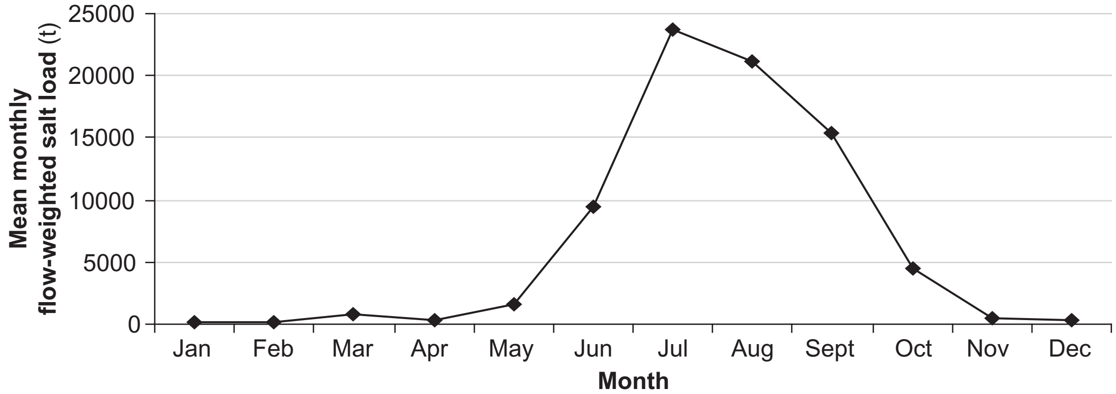




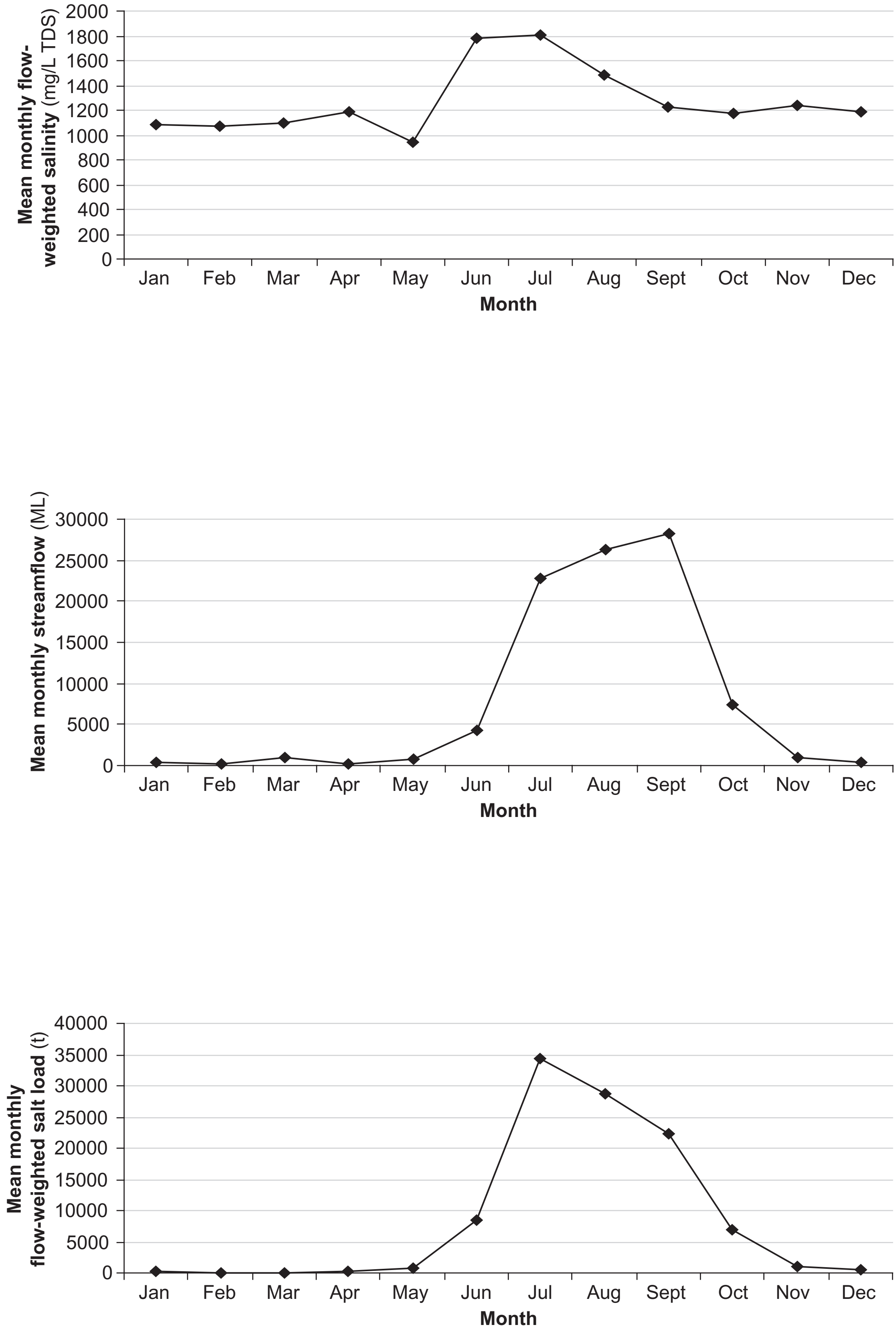
Monthly means (1993–2002) for site 611-211, Coolingutup Brook, Pesconeris Farm



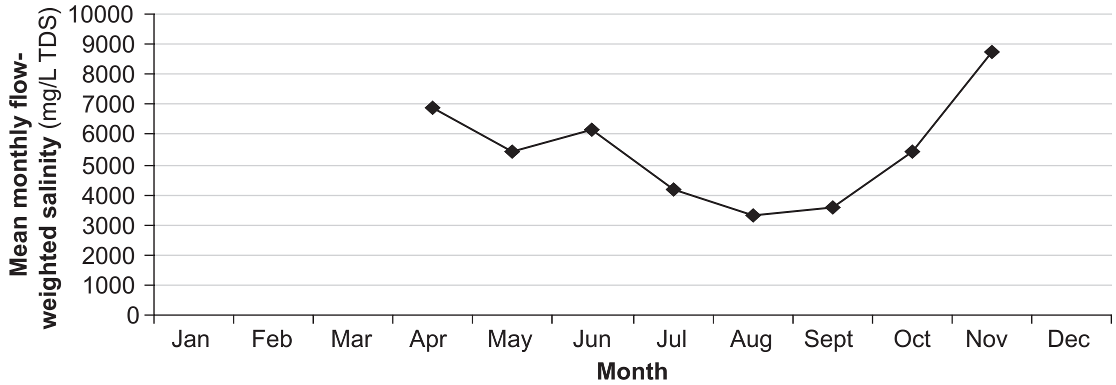


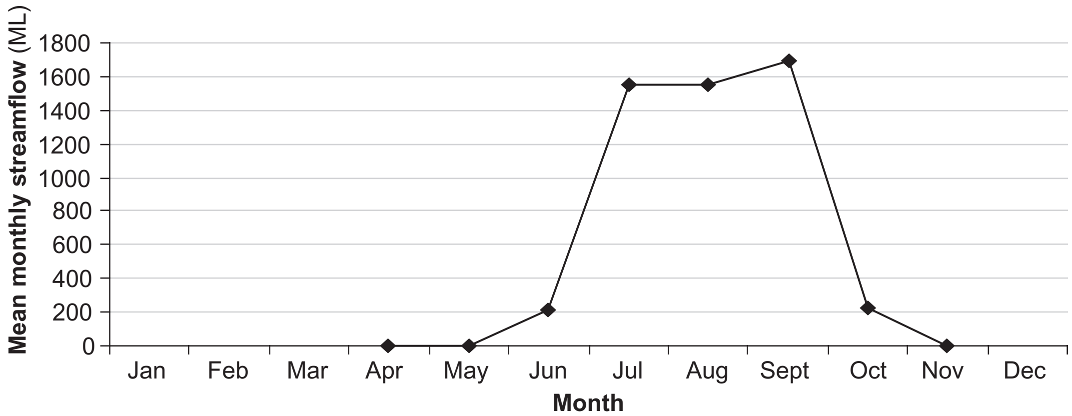


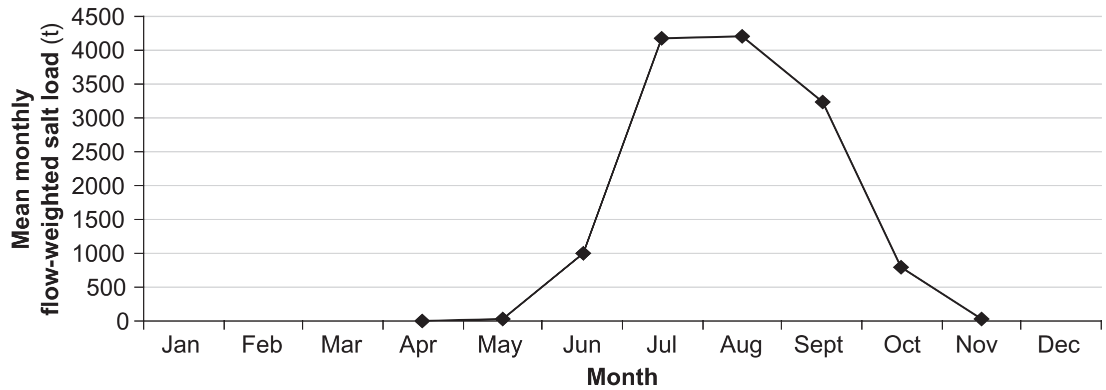
Monthly means (1993–2002) for site 612-001, Collie River East Tributary, Coolangatta Farm



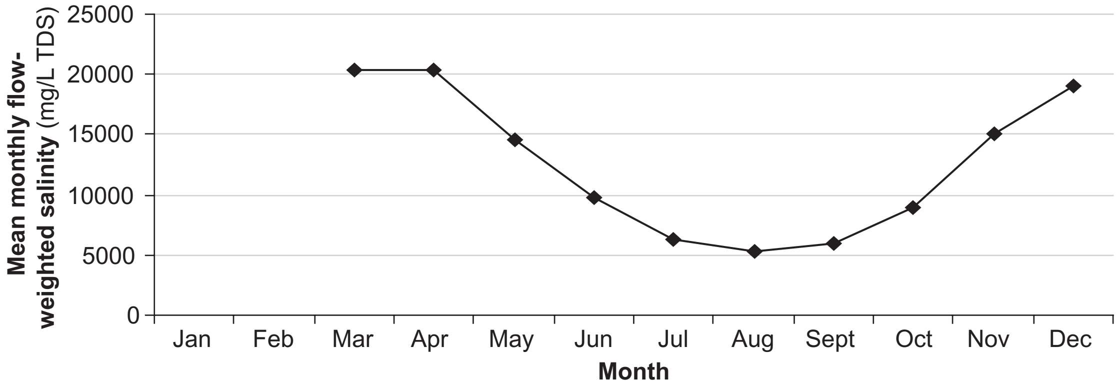
Monthly means (1993–2002) for site 612-002, Collie River, Mungalup Tower

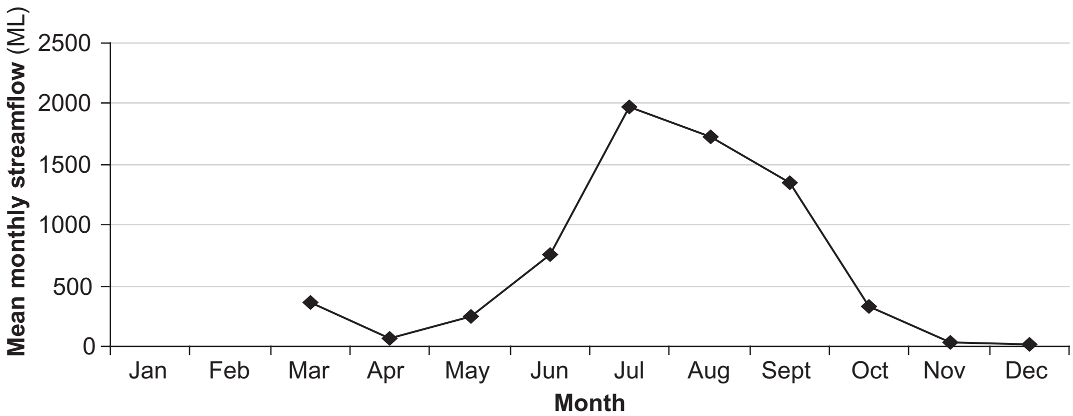


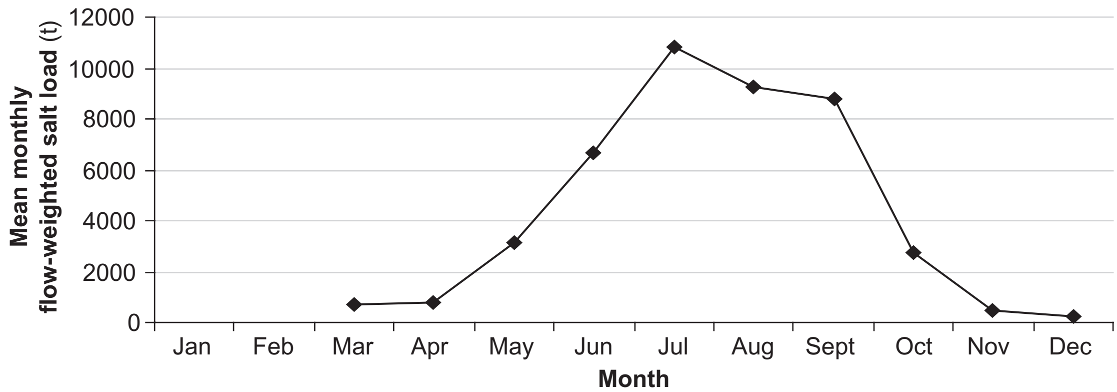




Monthly means (1993–2002) for site 612-025, Camballan Creek, James Well

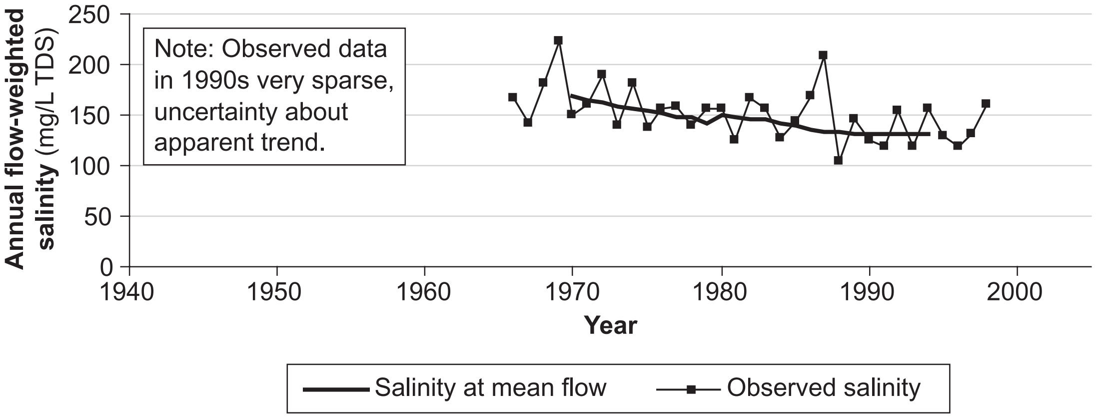


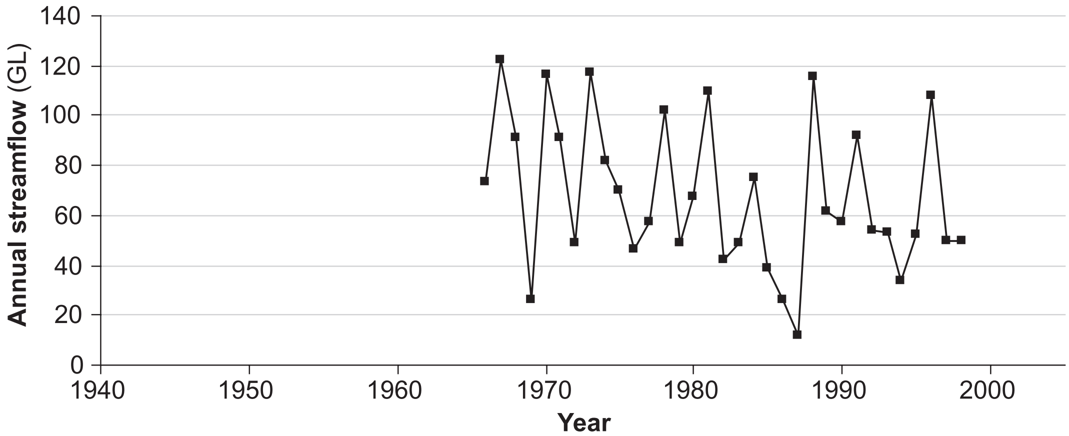


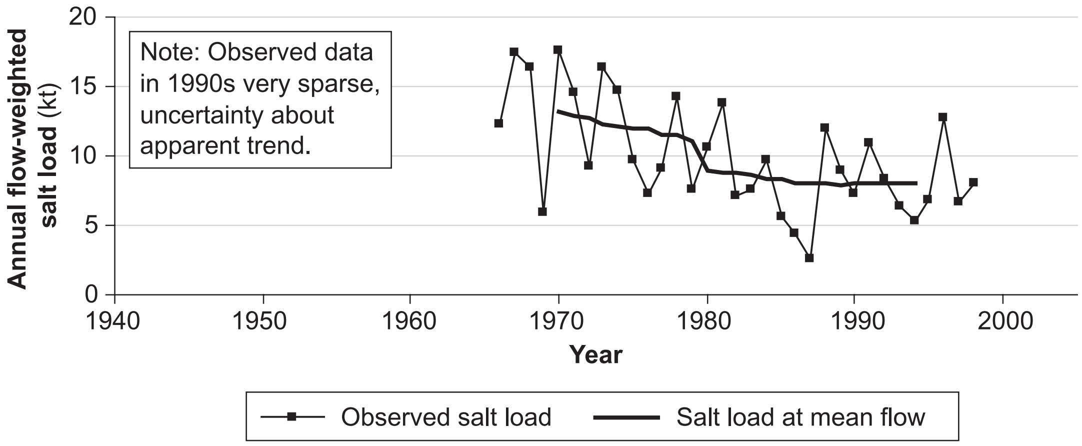


Monthly means (1993–2002) for site 612-230, Collie River East Tributary, James Crossing

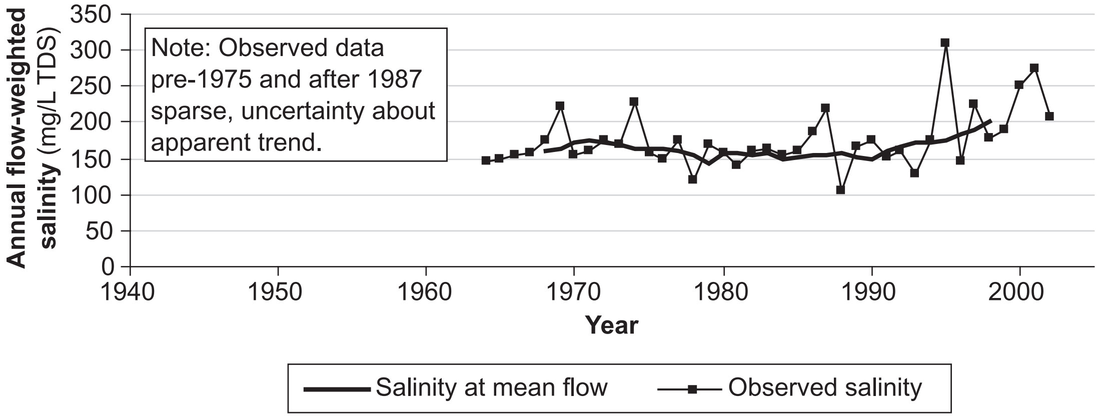
Appendix F
South West Study Area: long-term salinity, salt load and flow trends

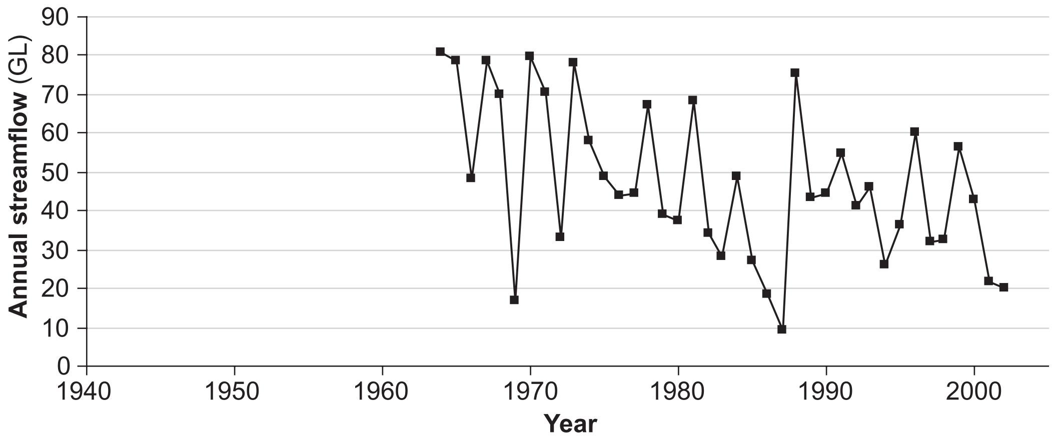


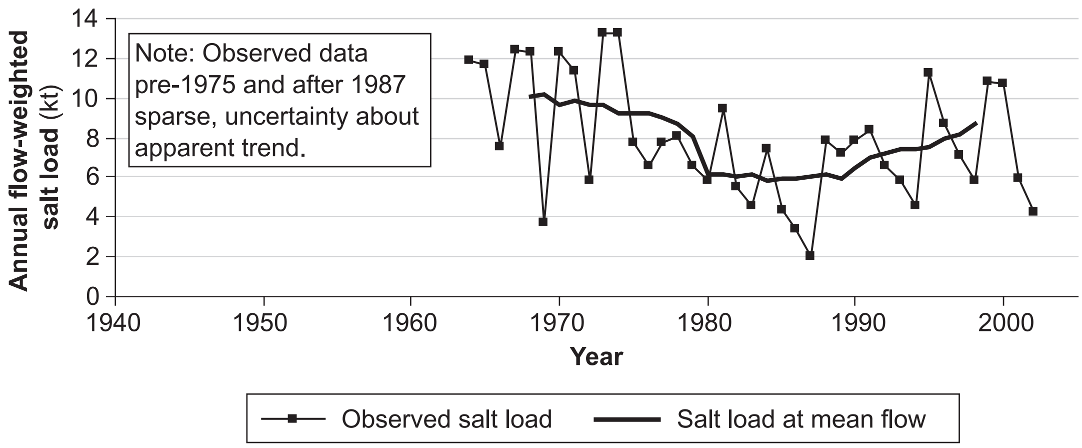




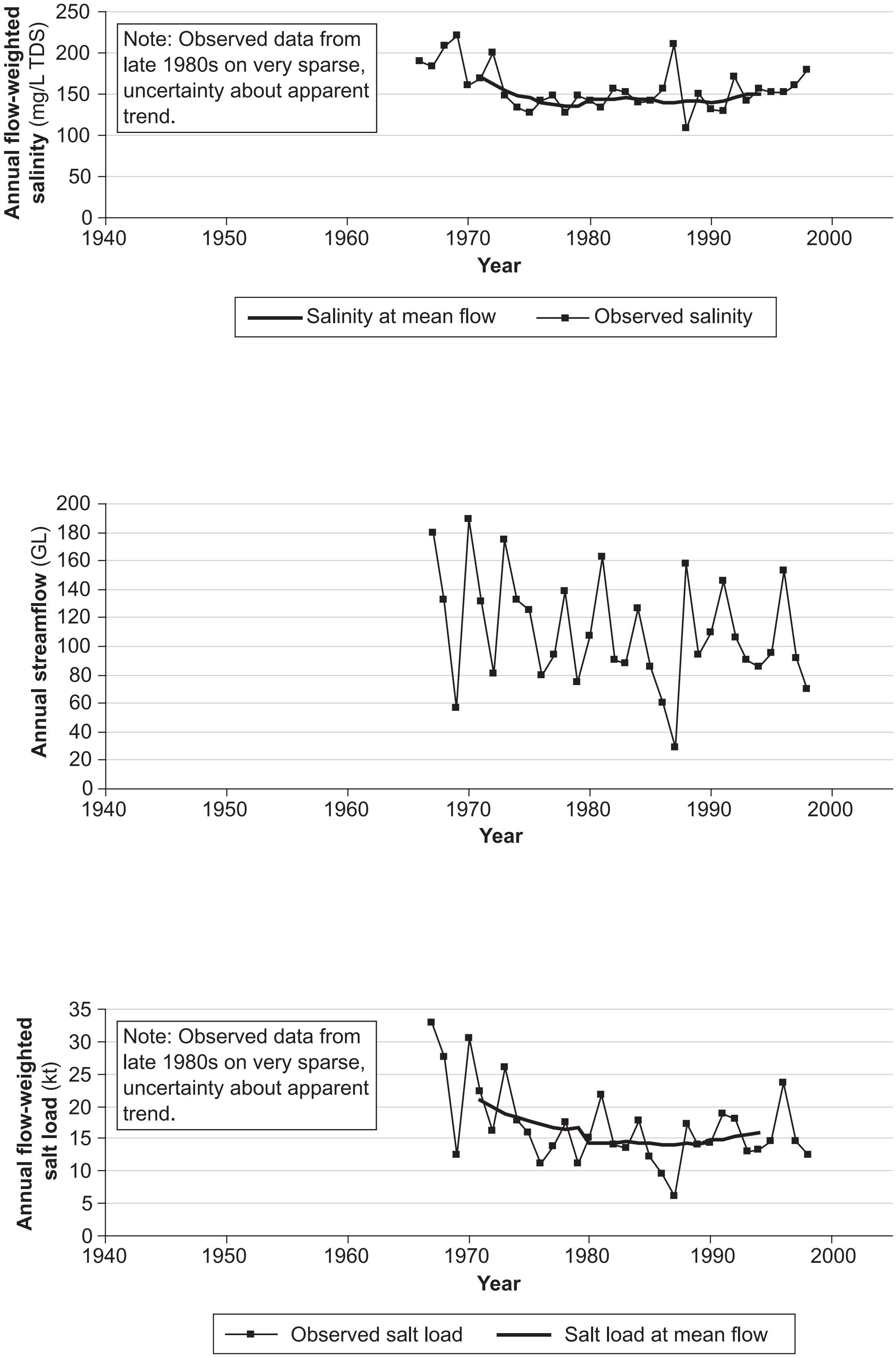
Long-term trends for site 606-185, Shannon River, Dog Pool



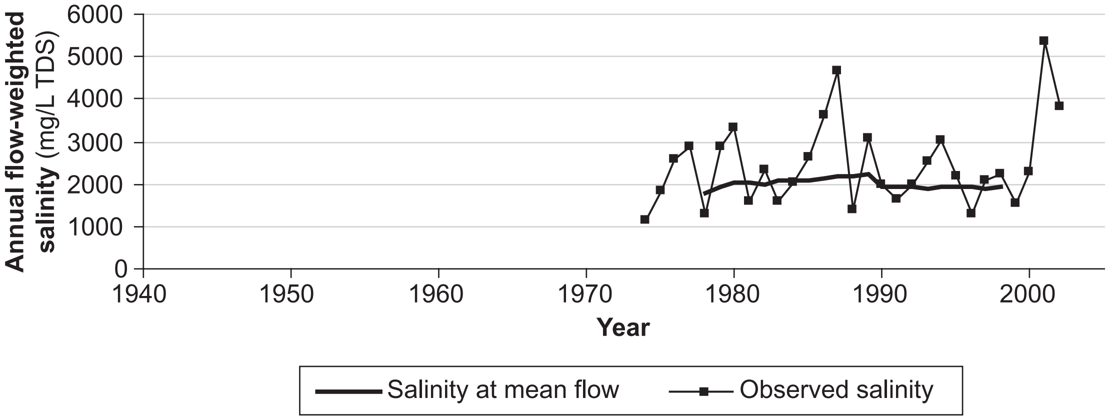


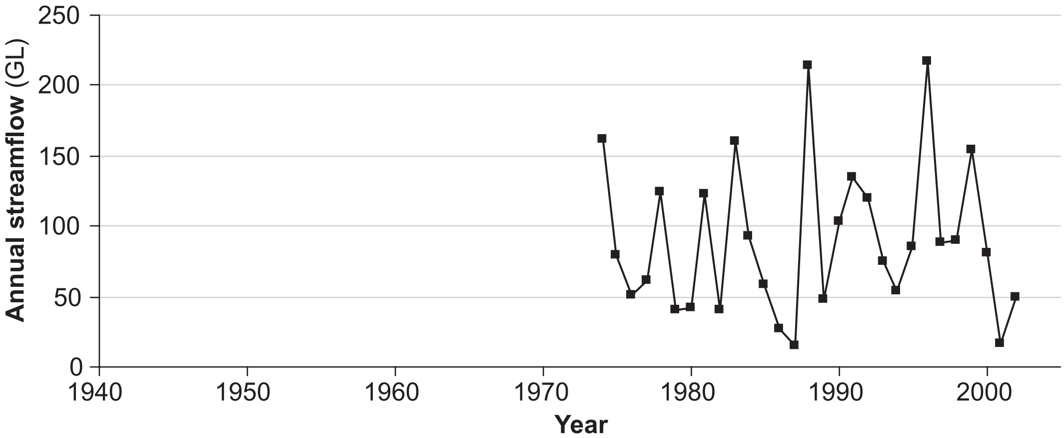


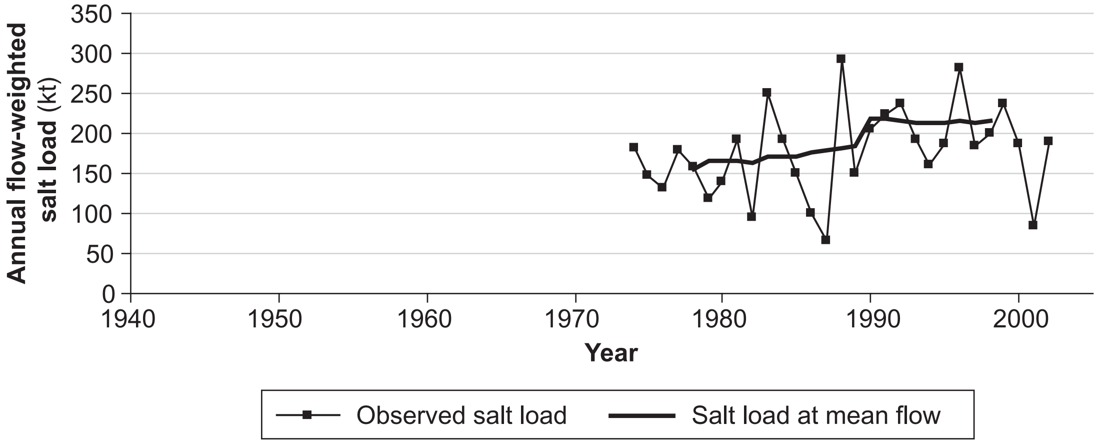
Long-term trends for site 606-195, Weld River, Ordnance Road Crossing



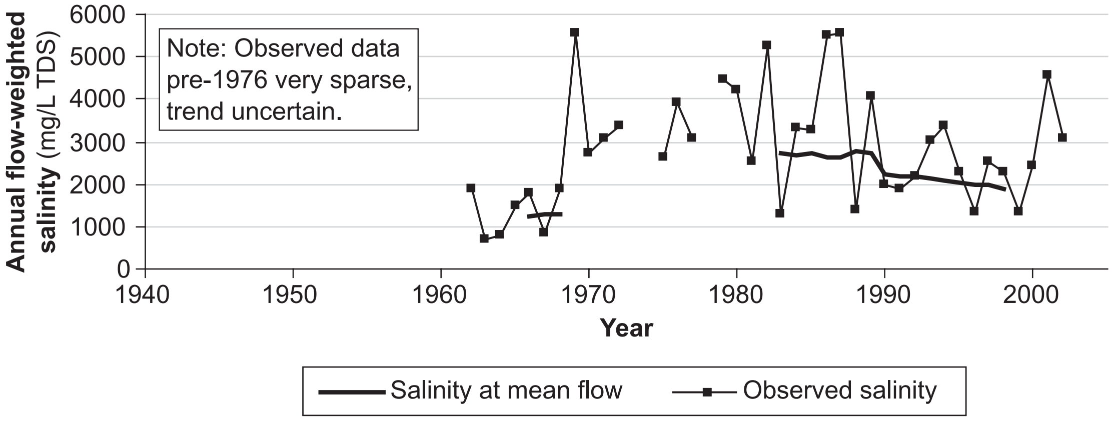
Long-term trends for site 606-218, Gardner River, Baldania Creek Confluence

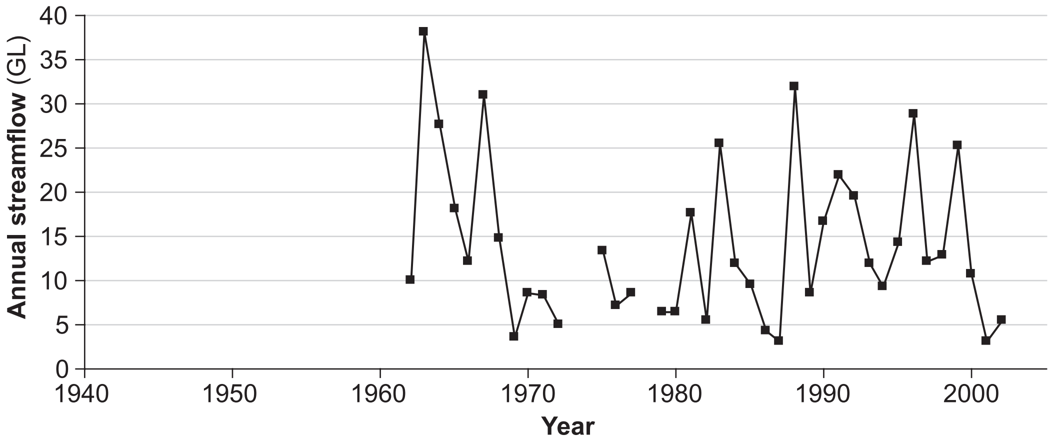


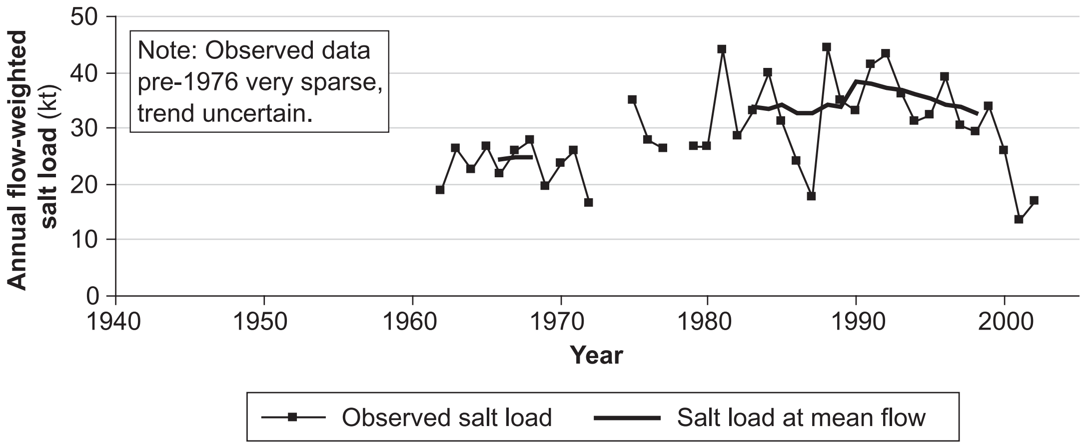




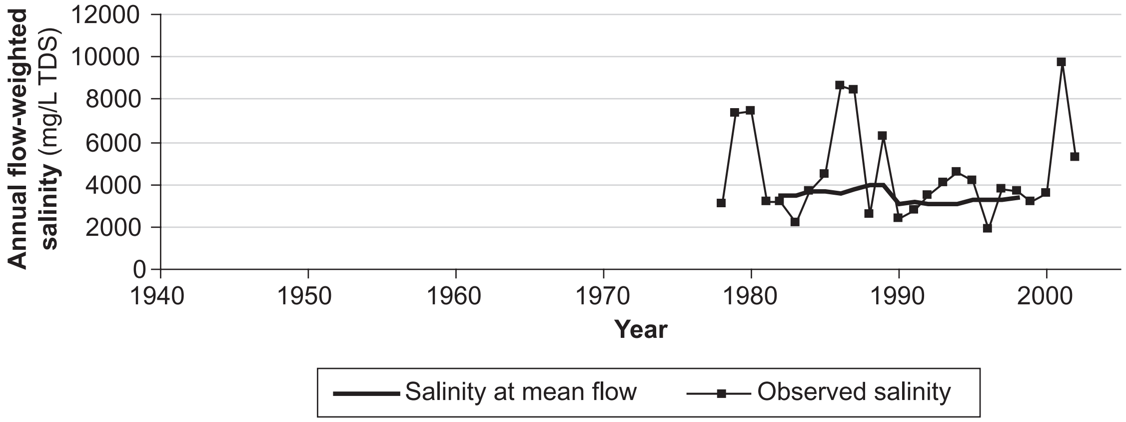
Long-term trends for site 607-003, Warren River, Wheatley Farm

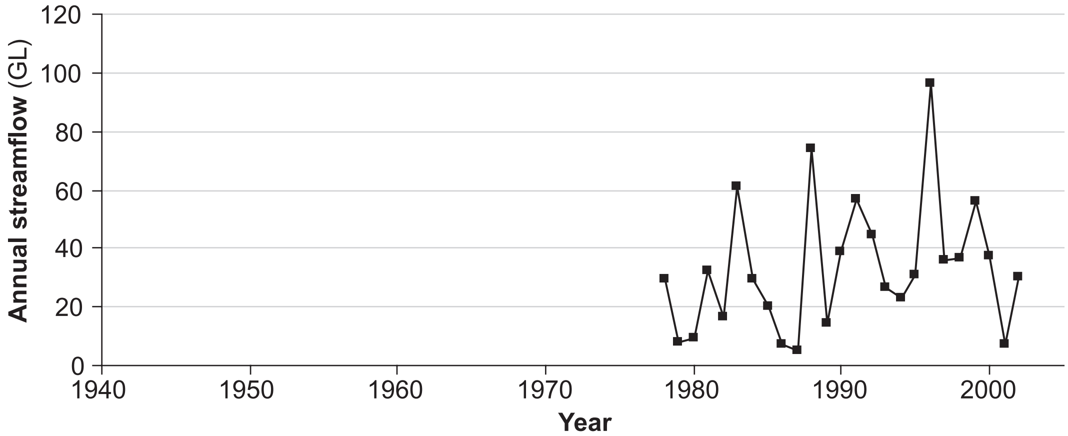


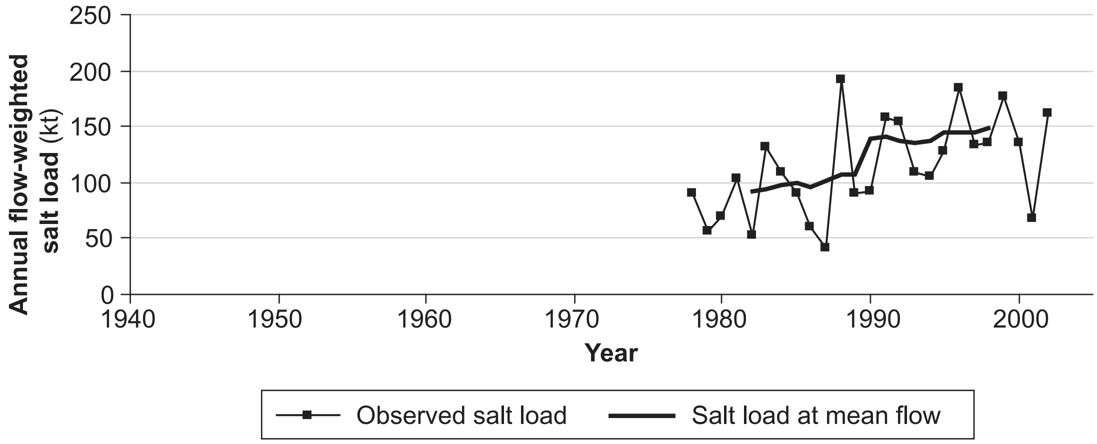




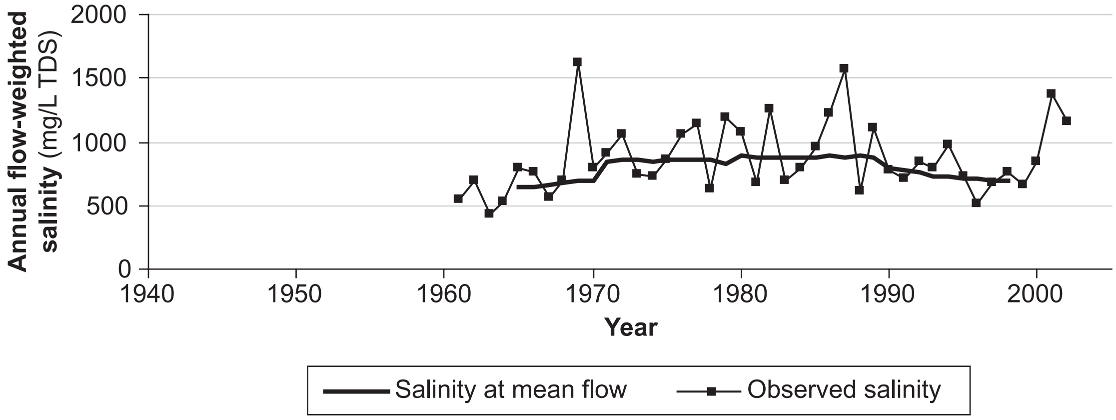
Long-term trends for site 607-004, Perup River, Quabicup Hill

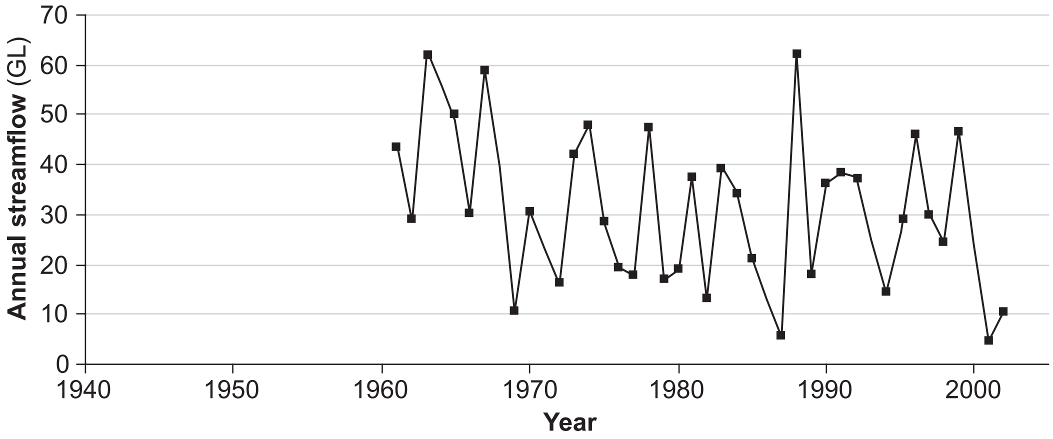


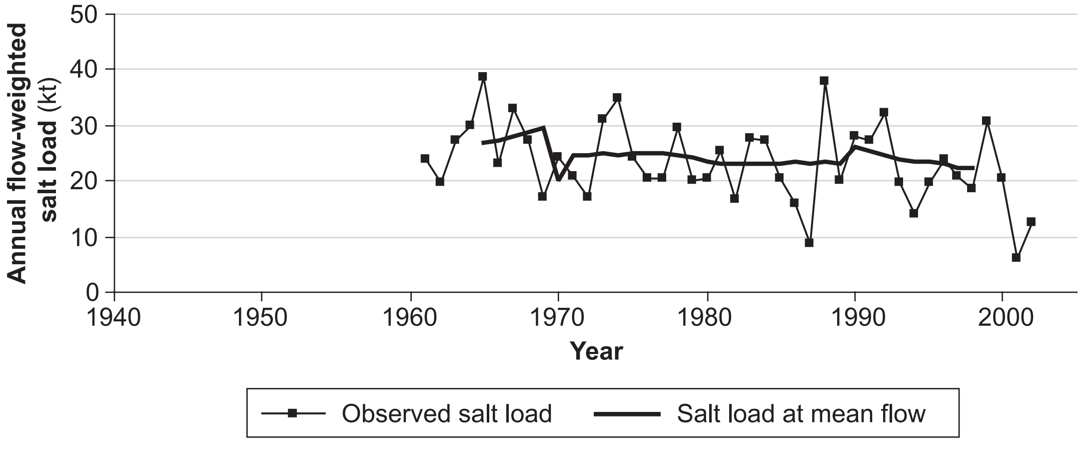




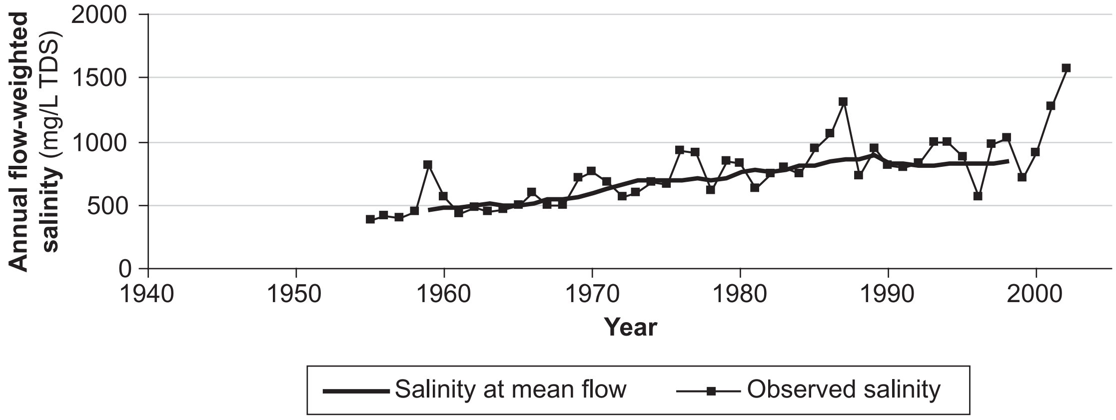
Long-term trends for site 607-007, Tone River, Bullilup

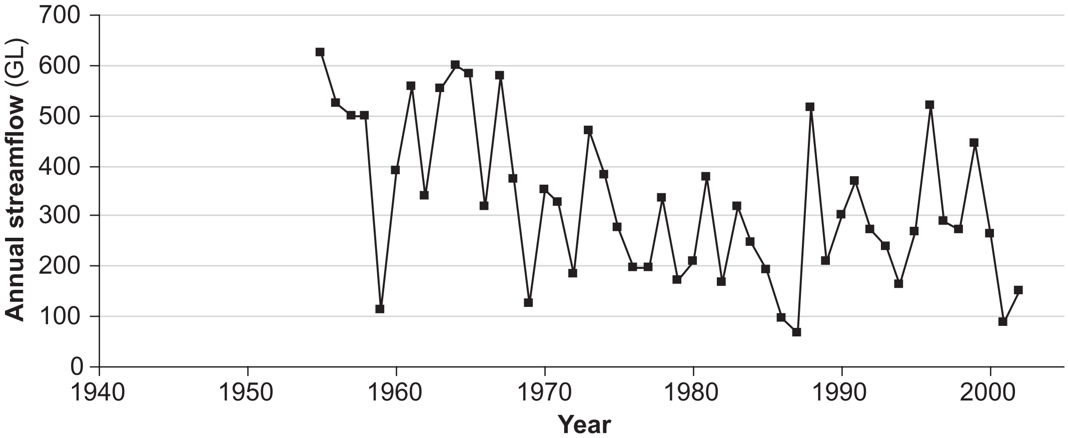


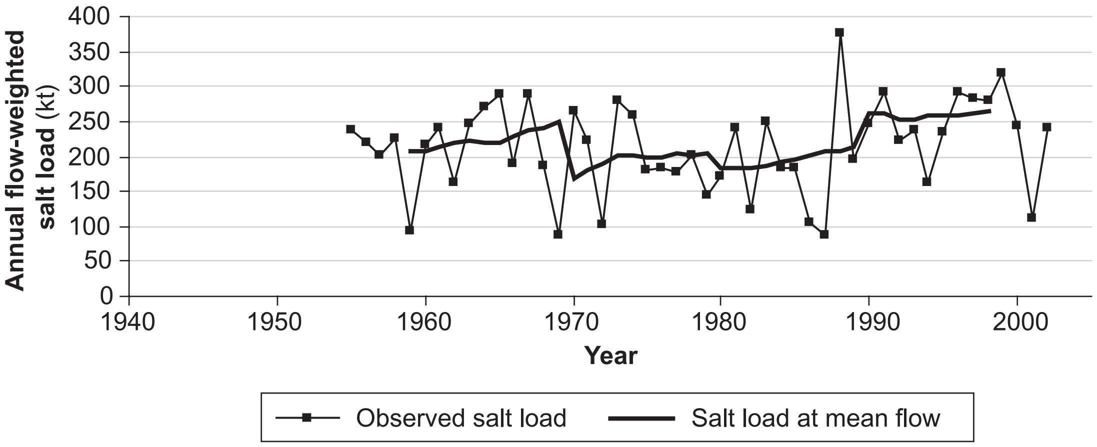




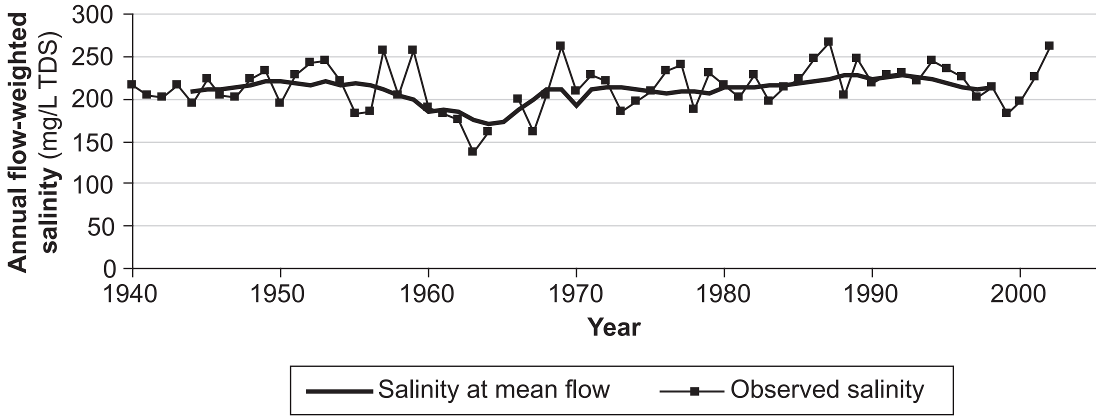
Long-term trends for site 607-144, Wilgarup River, Quintarrup

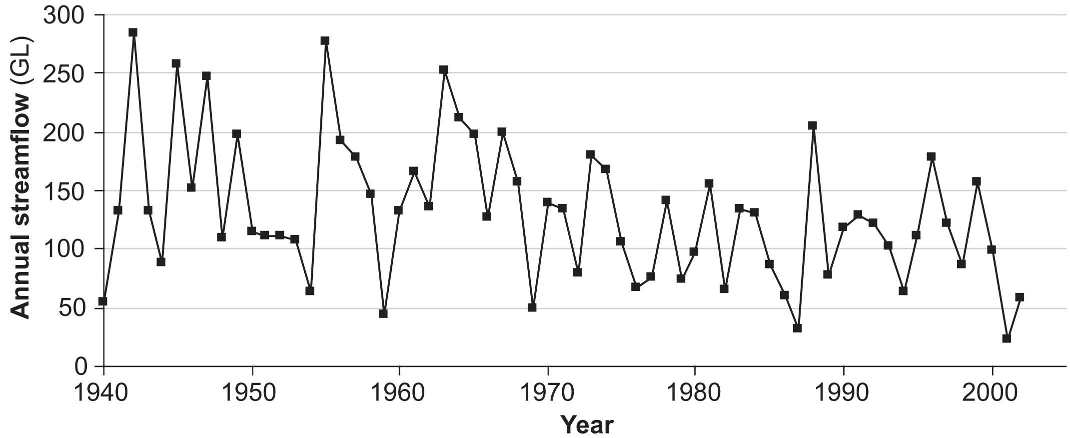


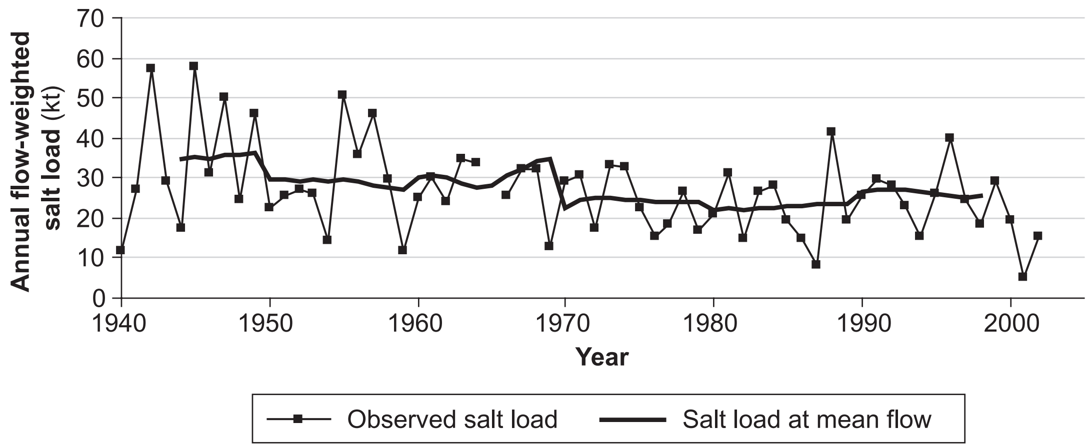




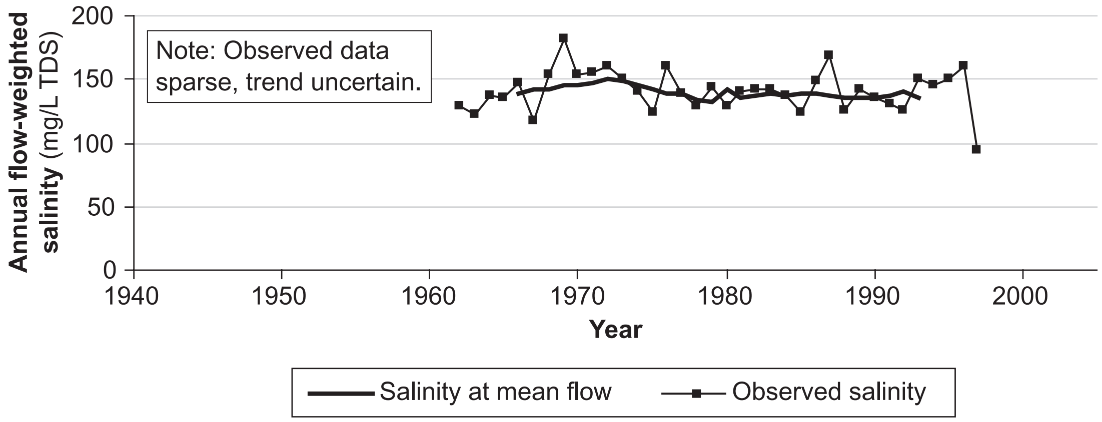
Long-term trends for site 607-220, Warren River, Barker Road Crossing

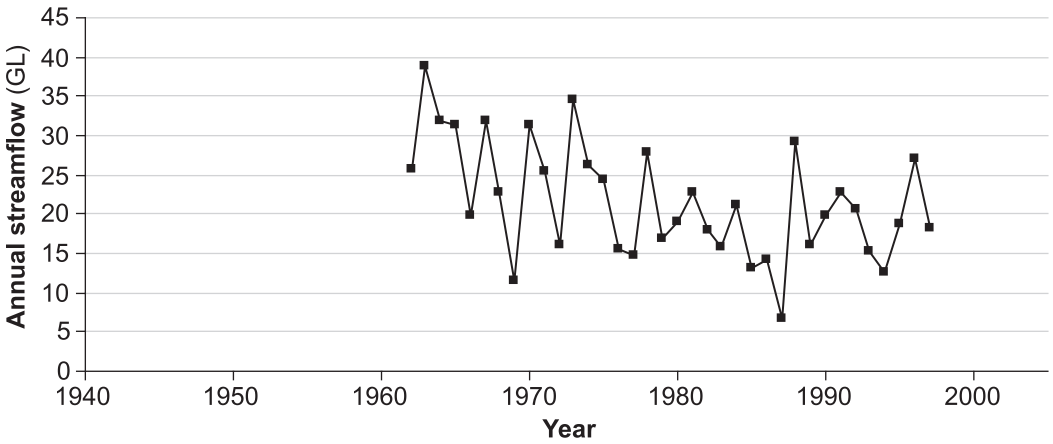


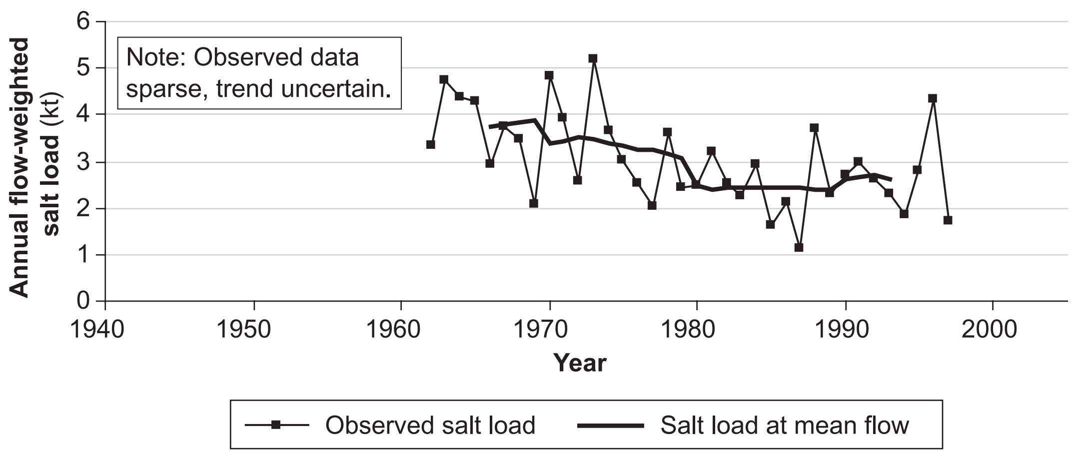




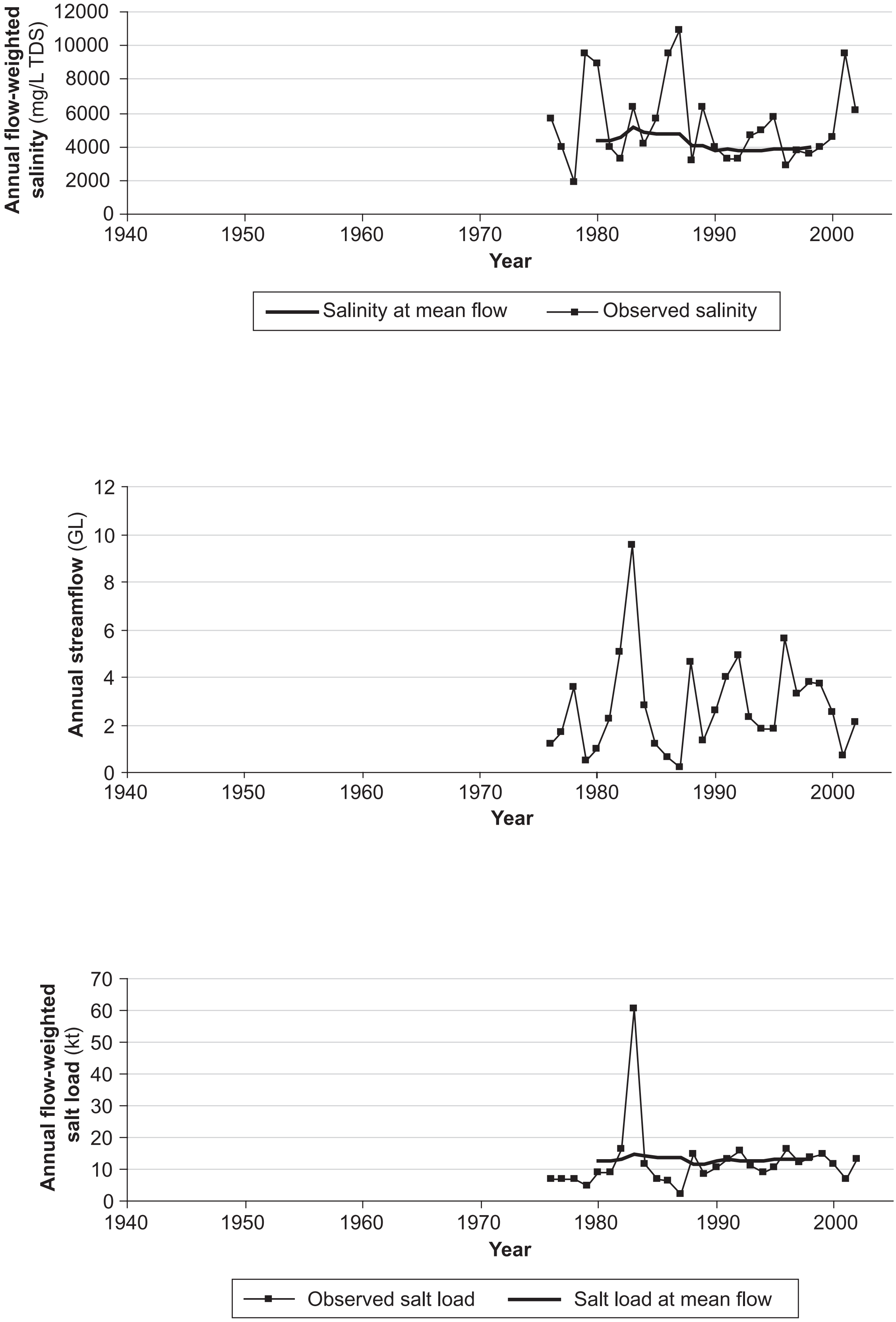
Long-term trends for site 608-151, Donnelly River, Strickland



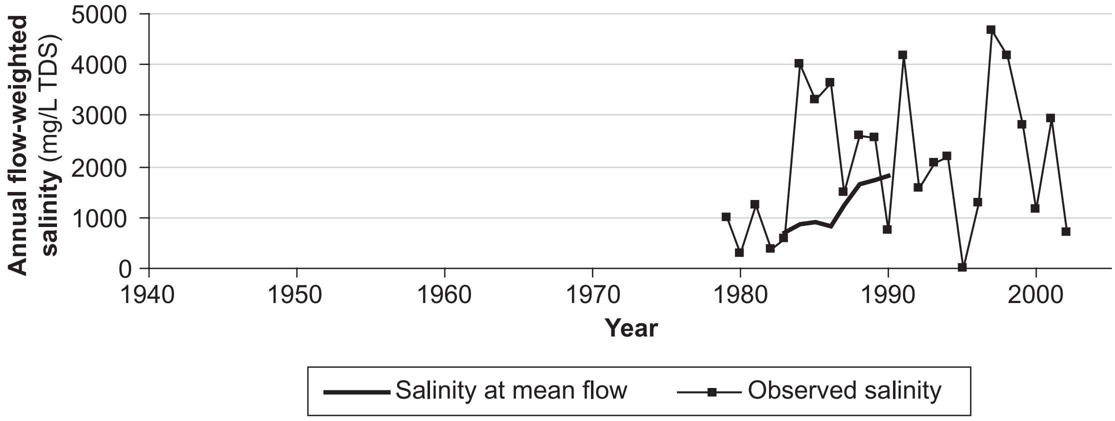


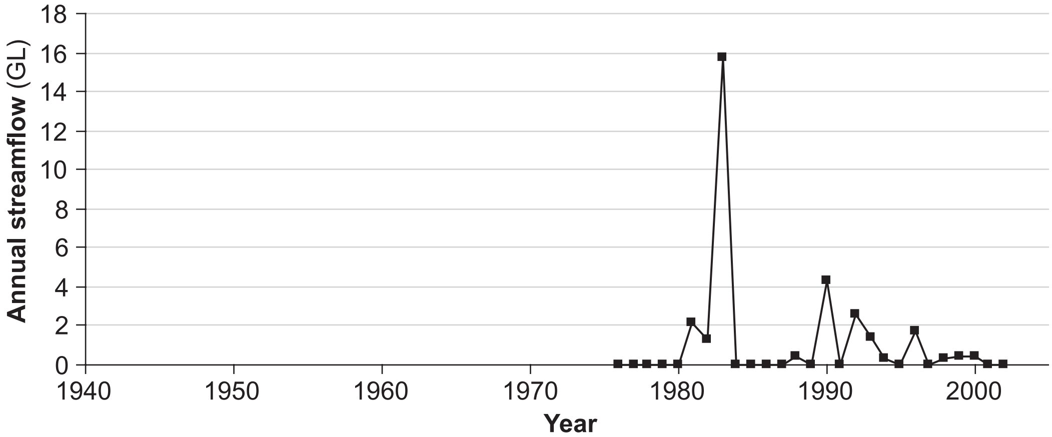


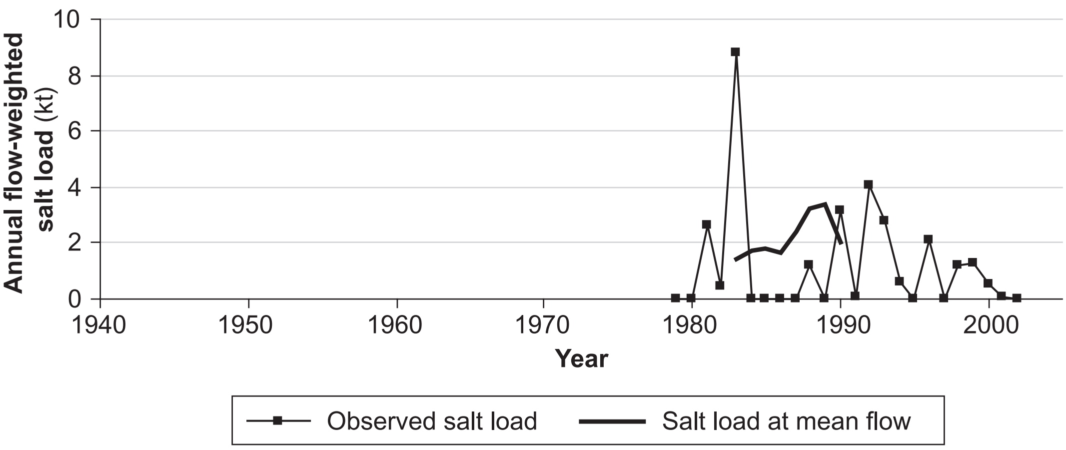
Long-term trends for site 608-171, Fly Brook, Boat Landing Road



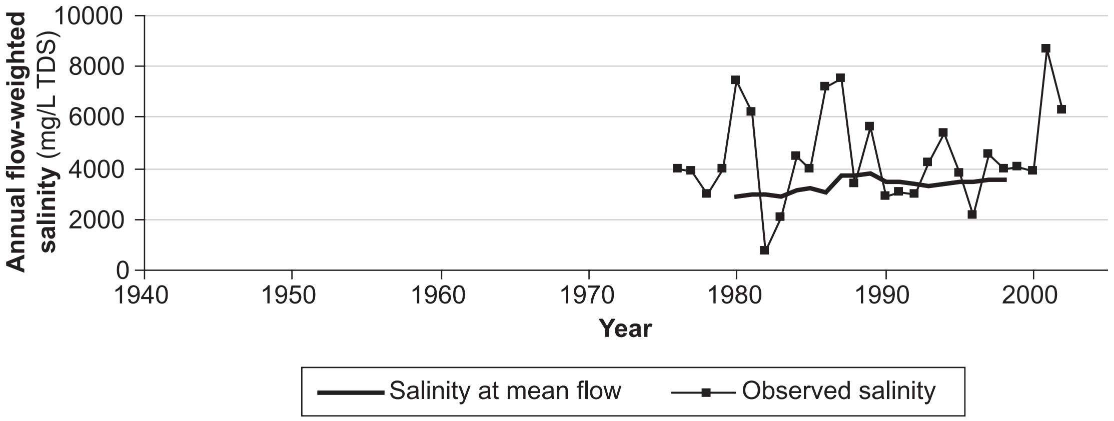
Long-term trends for site 609-005, Balgarup River, Mandelup Pool

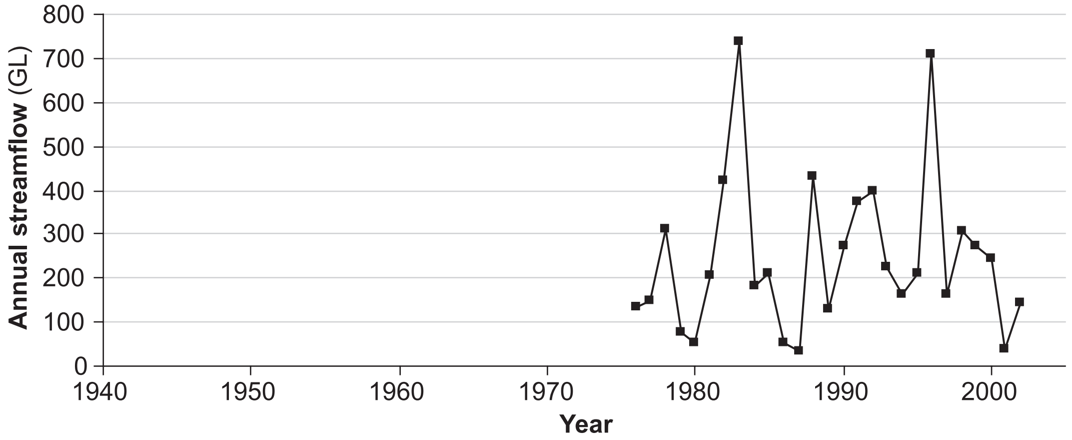


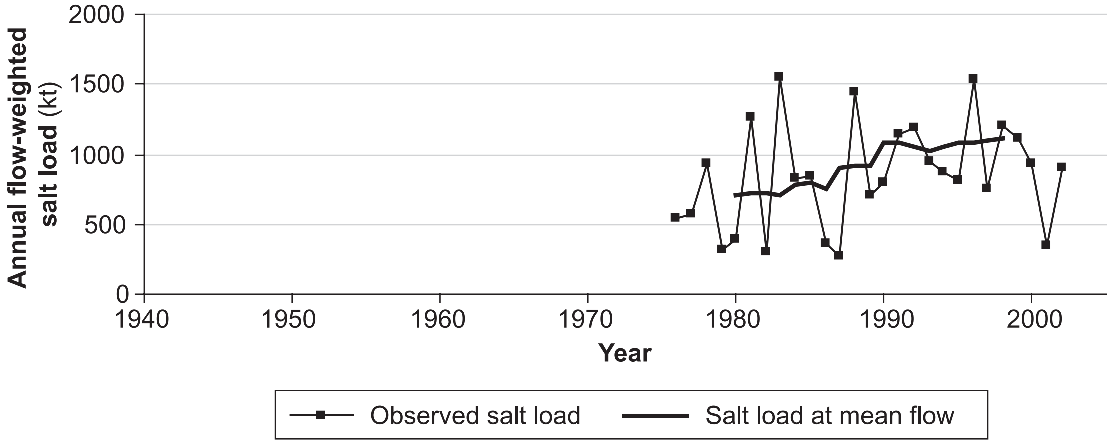




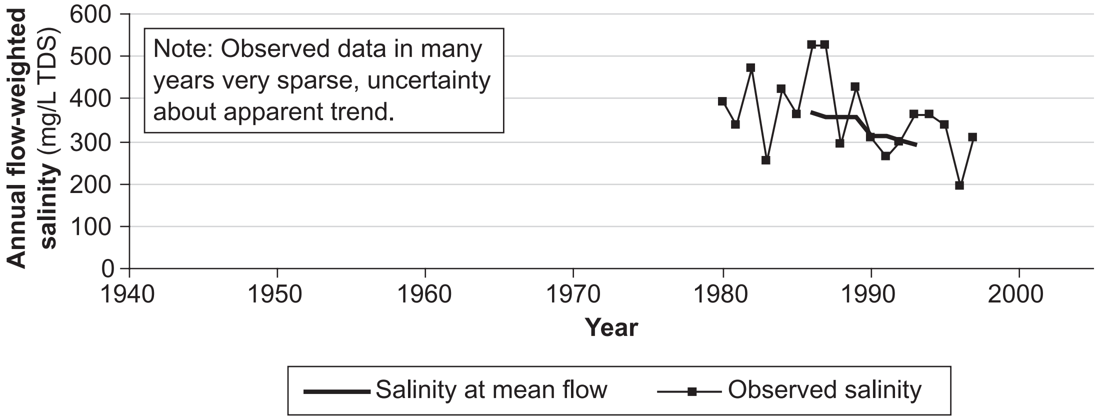
Long-term trends for site 609-010, Northern Arthur River, Lake Toolibin Inflow

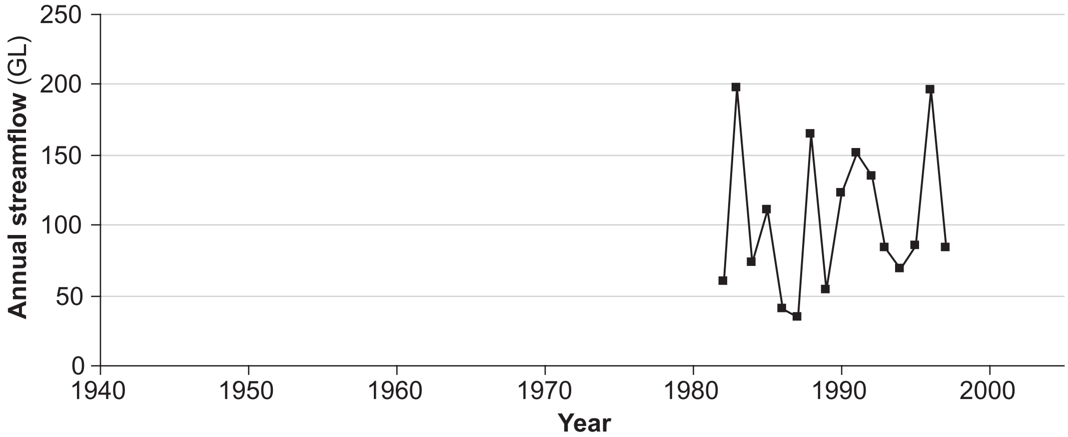


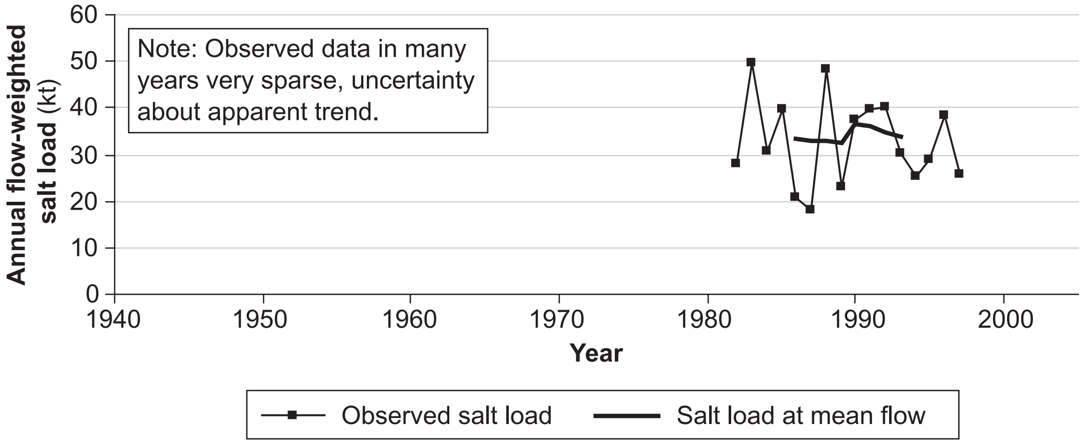




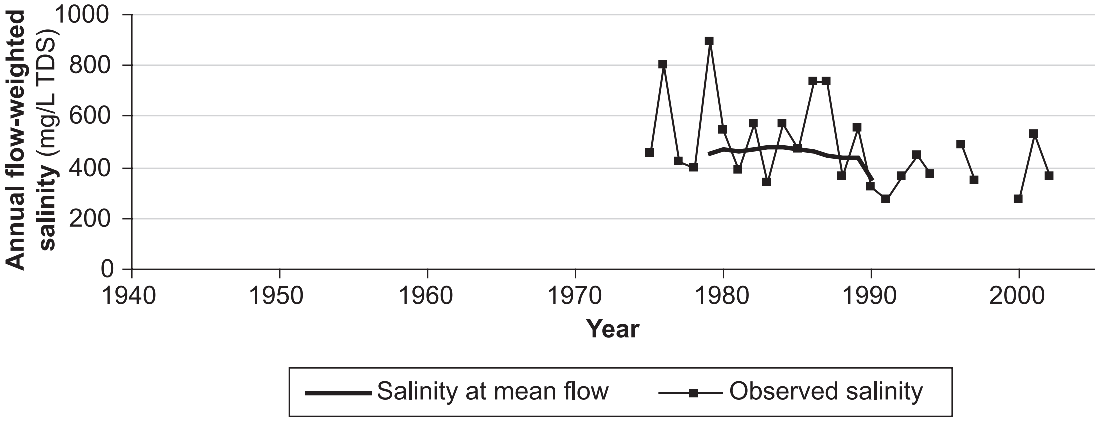
Long-term trends for site 609-012, Blackwood River, Winnejup

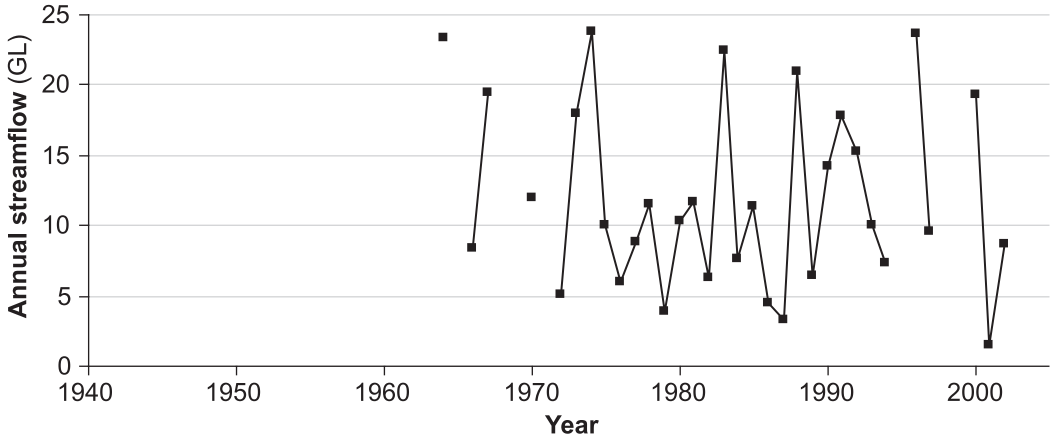


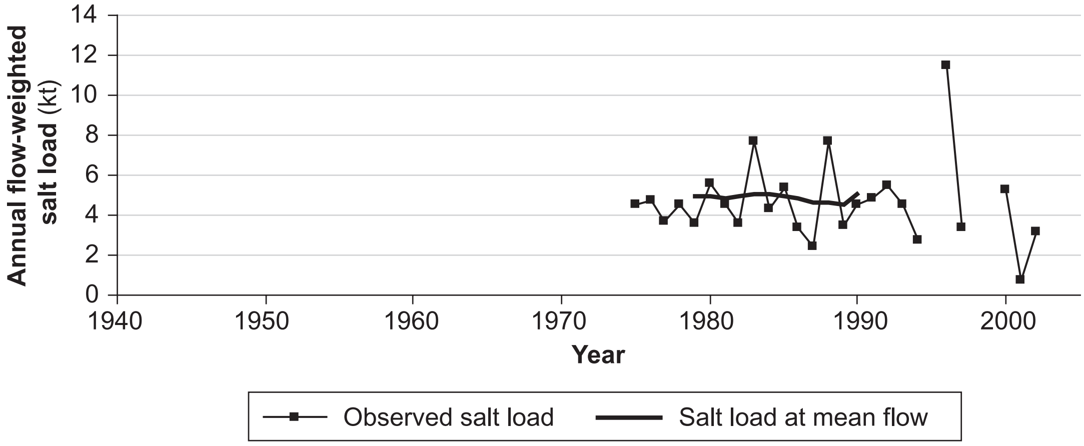




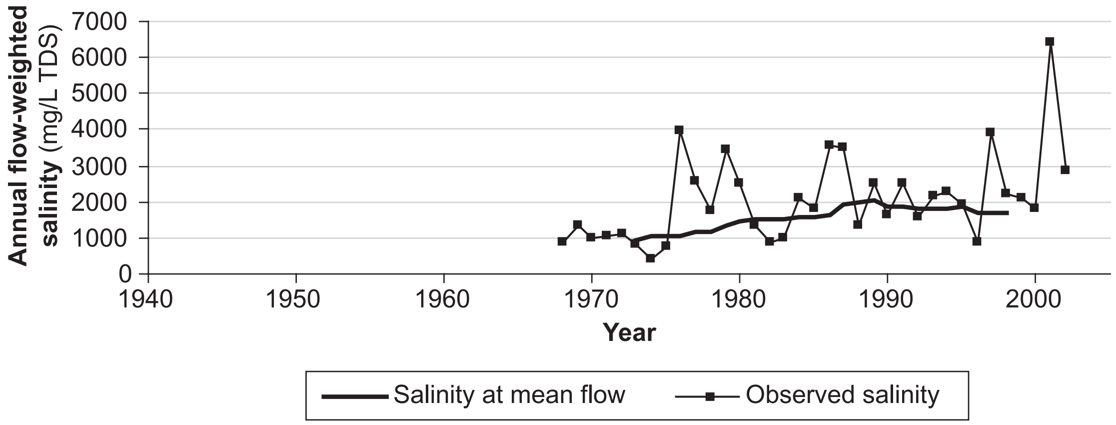
Long-term trends for site 611-004, Preston River, Boyanup

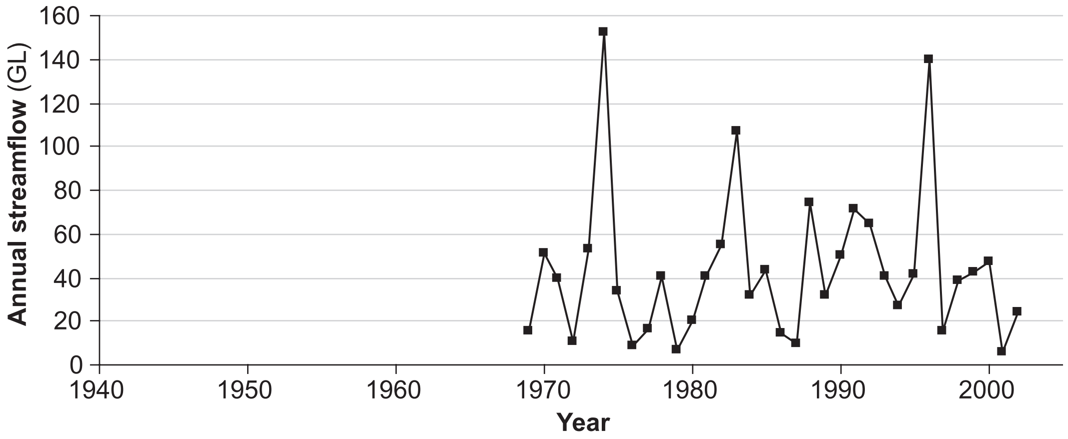


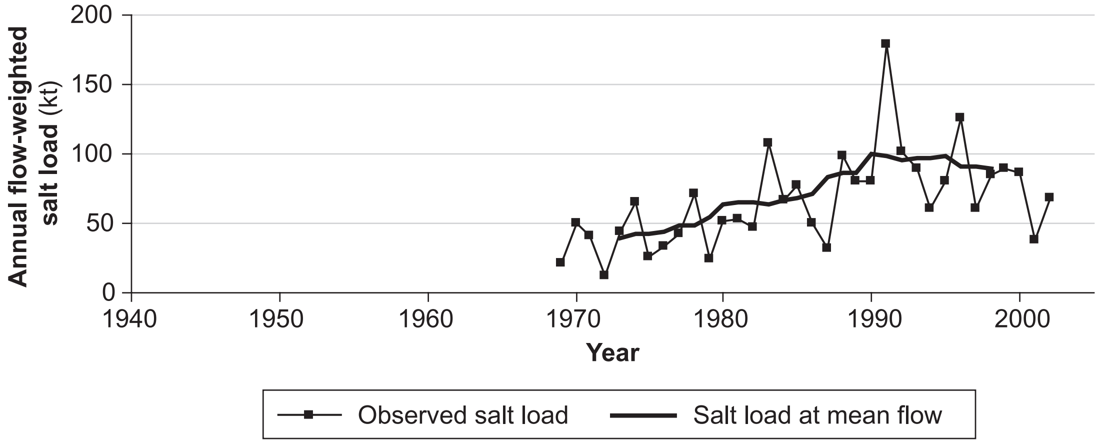




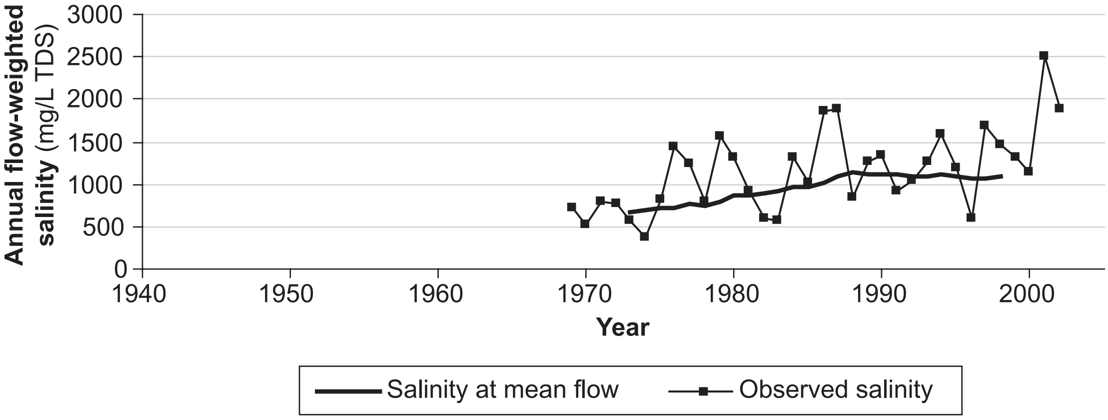
Long-term trends for site 611-111, Thomson Brook, Woodperry Homestead

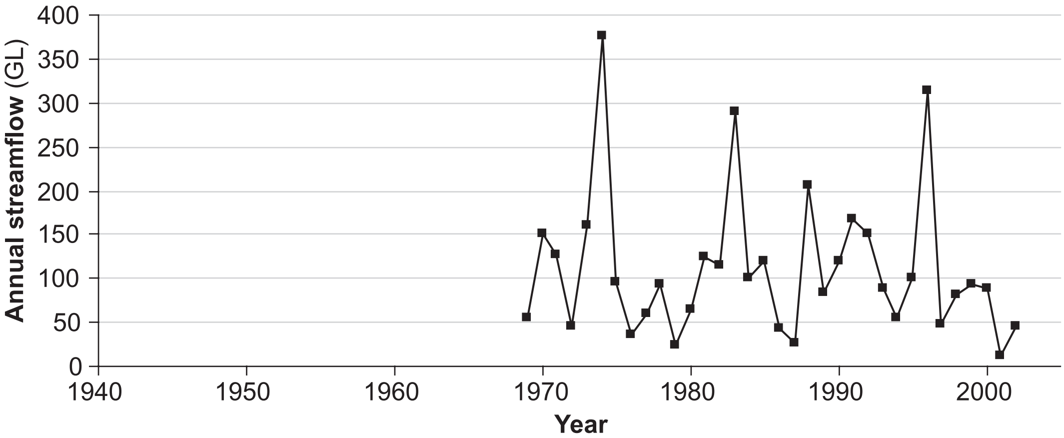


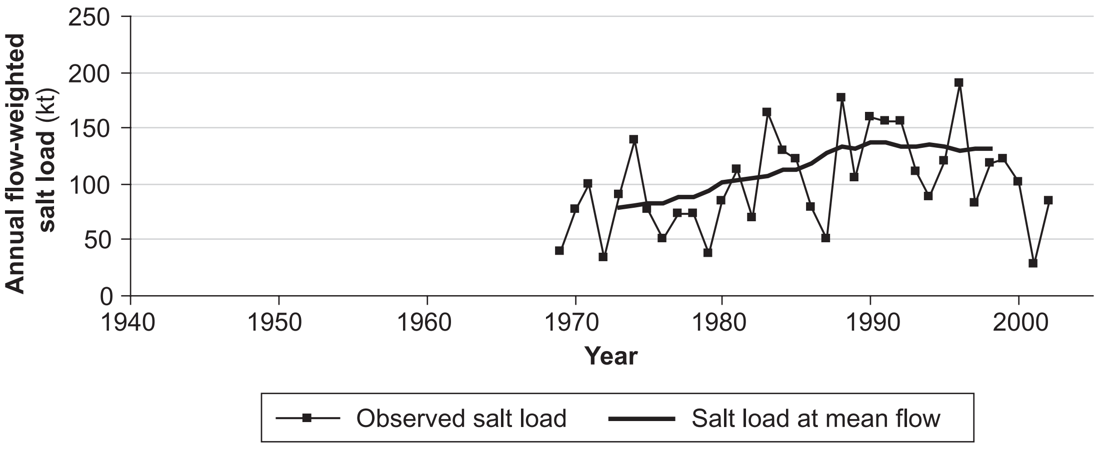




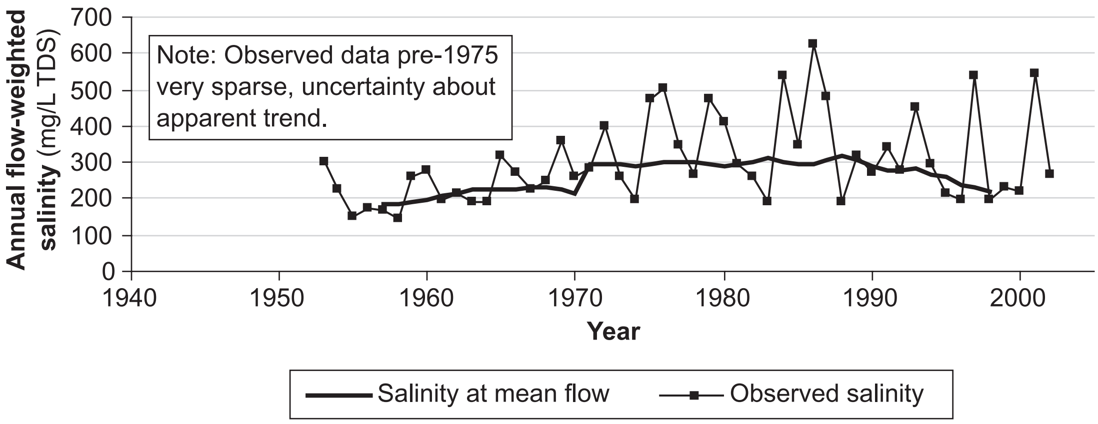
Long-term trends for site 612-001, Collie River East Tributary, Coolangatta Farm

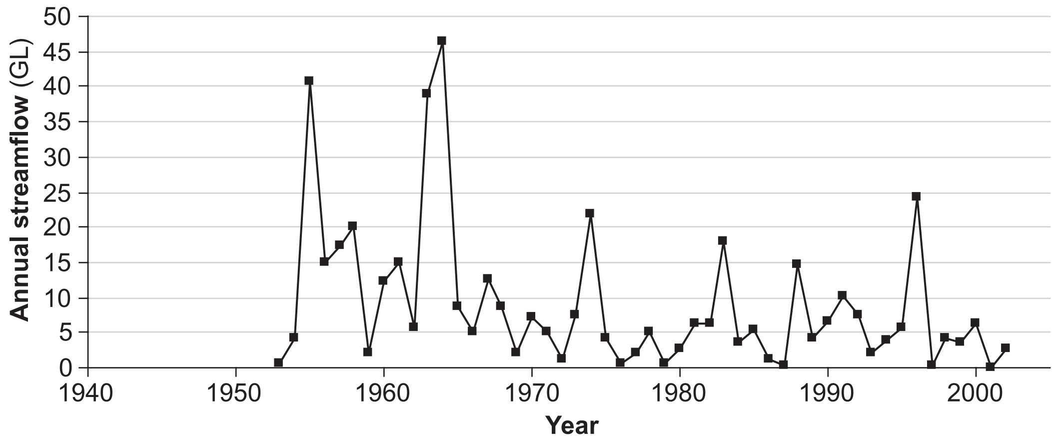


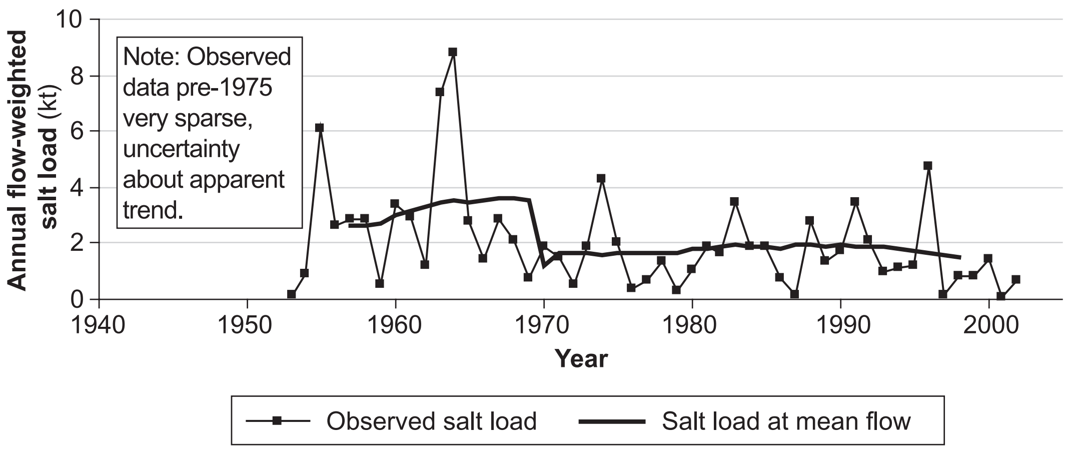




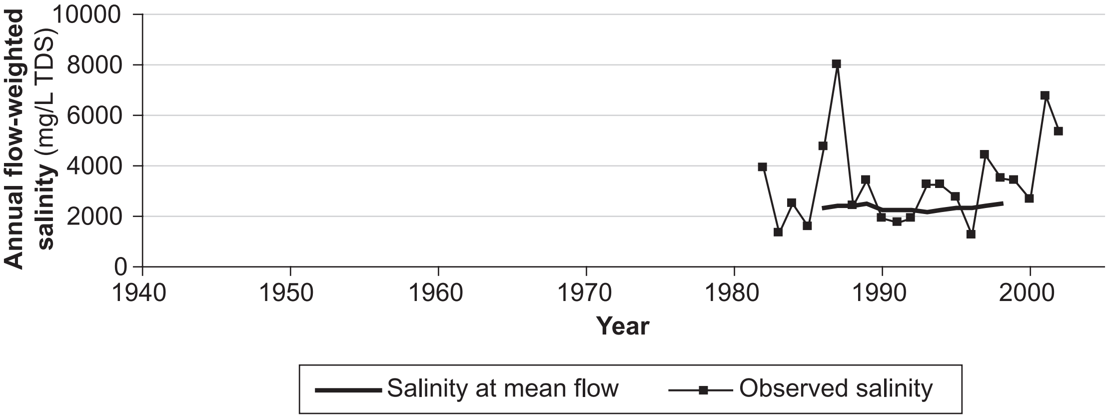
Long-term trends for site 612-002, Collie River, Mungalup Tower

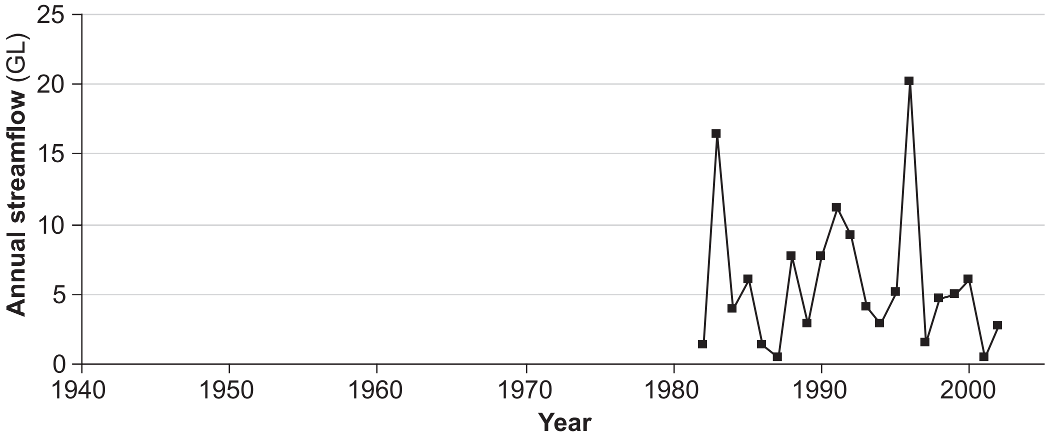


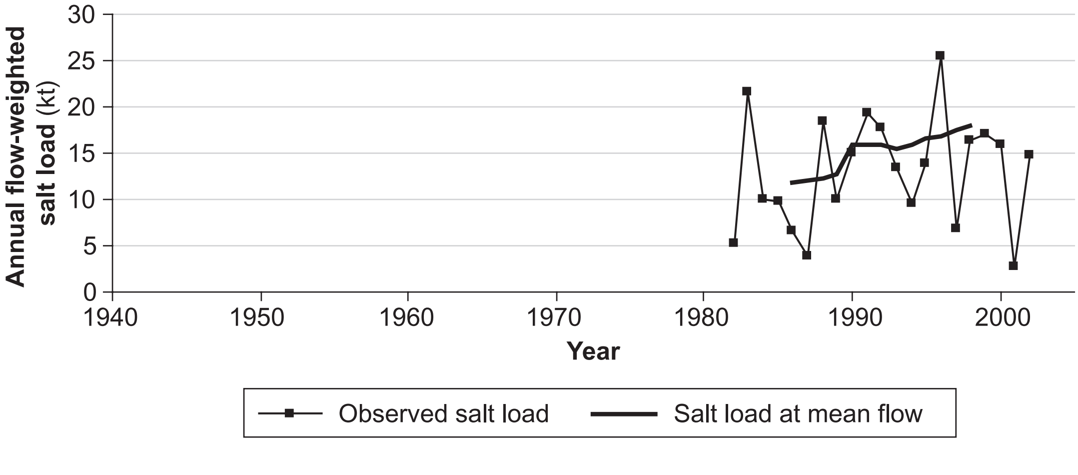




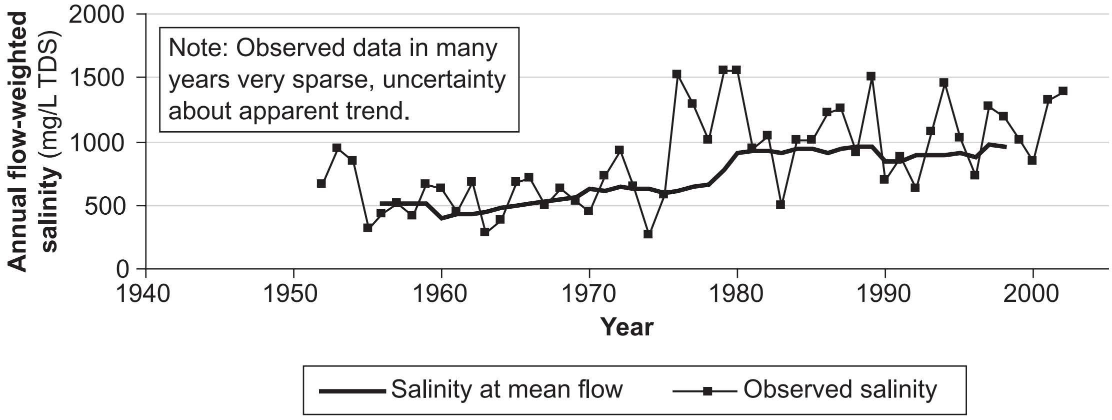
Long-term trends for site 612-014 (/037), Bingham River, Palmer

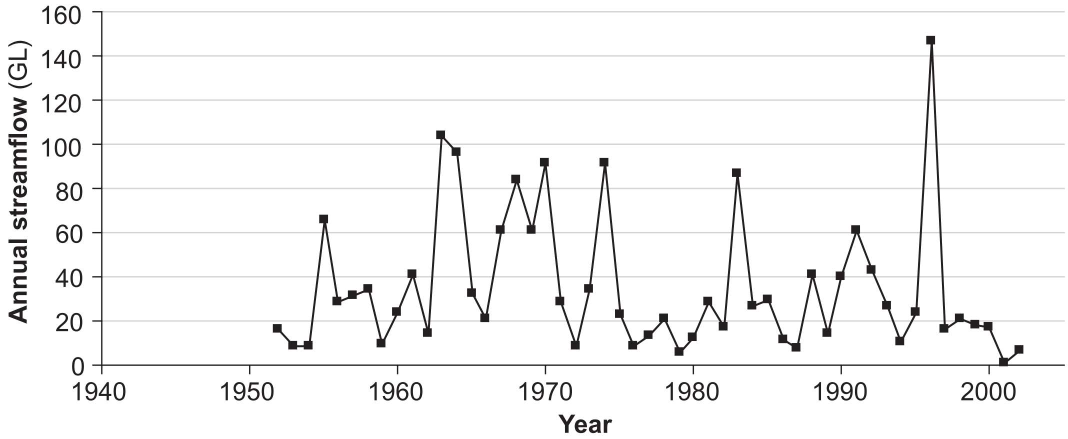


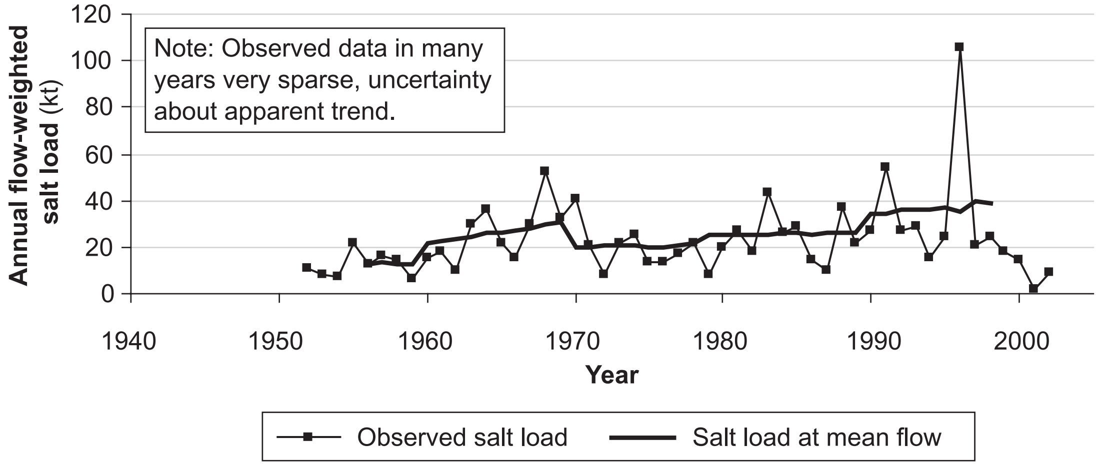




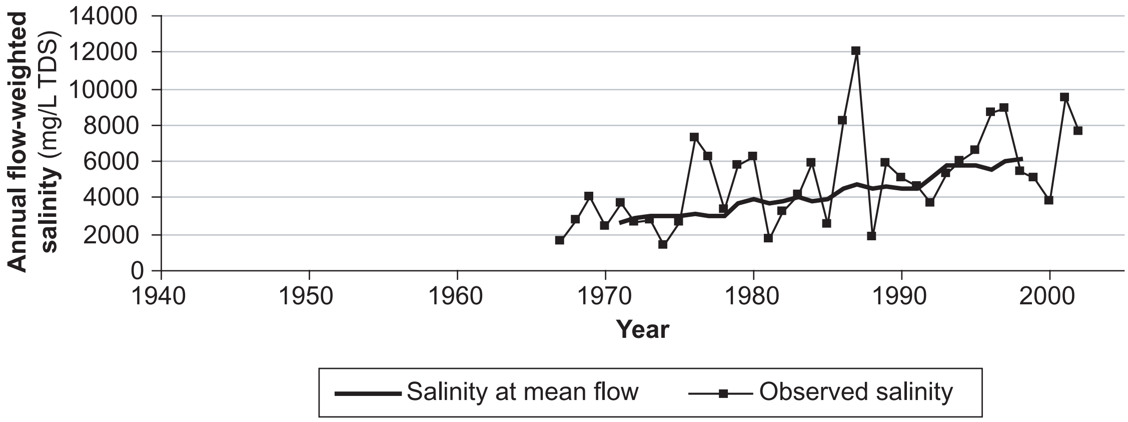
Long-term trends for site 612-025 Camballan Creek, James Well

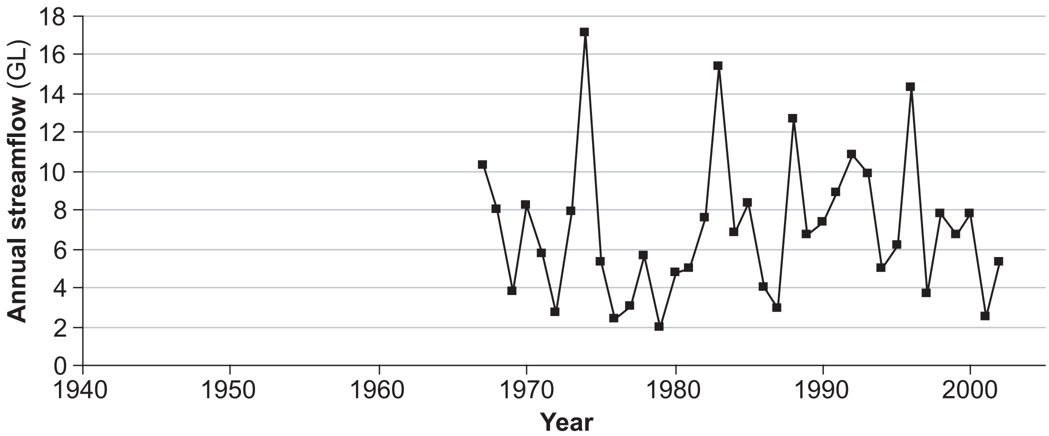


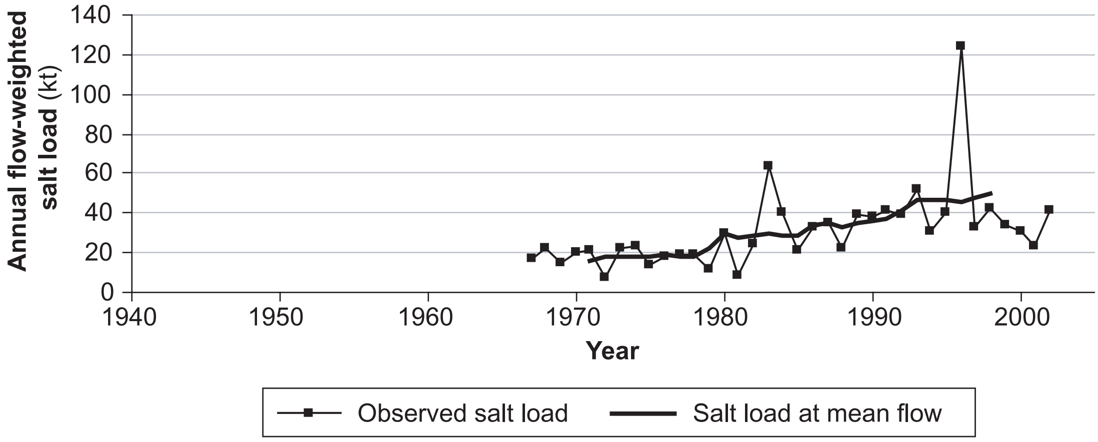




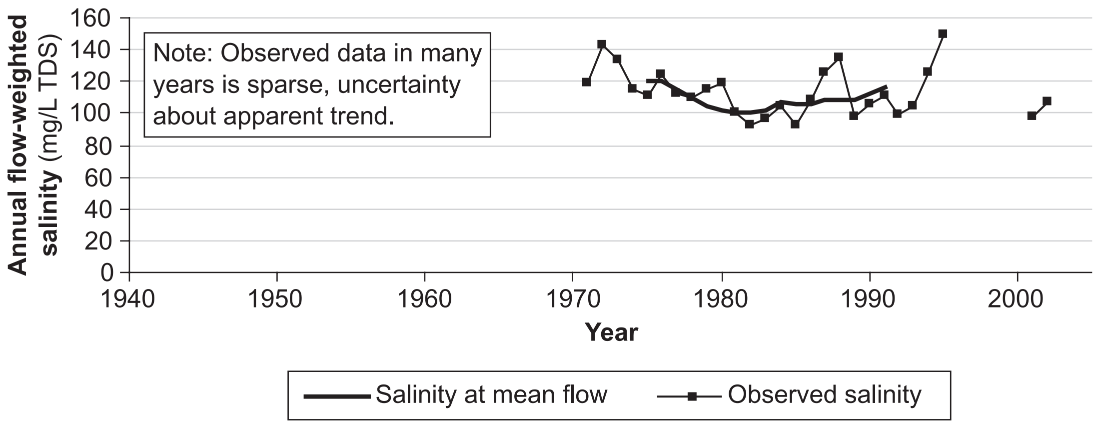
Long-term trends for site 612-034, Collie River, South Branch

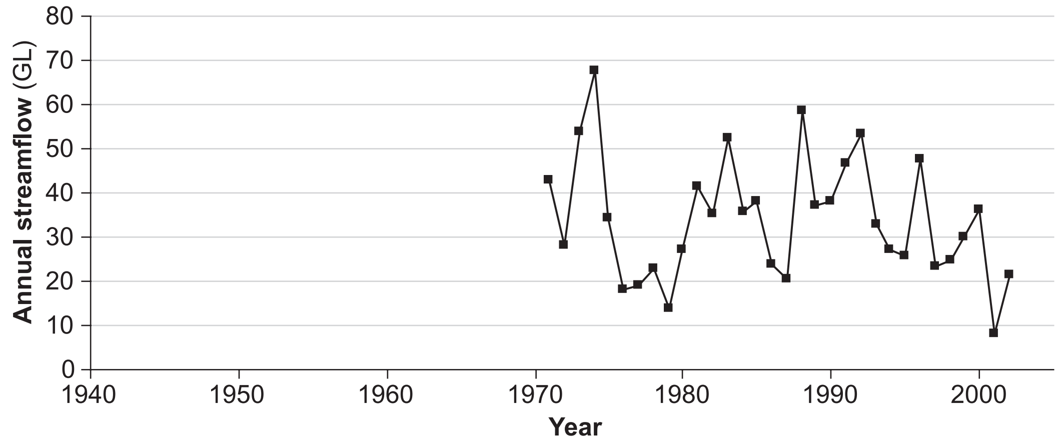


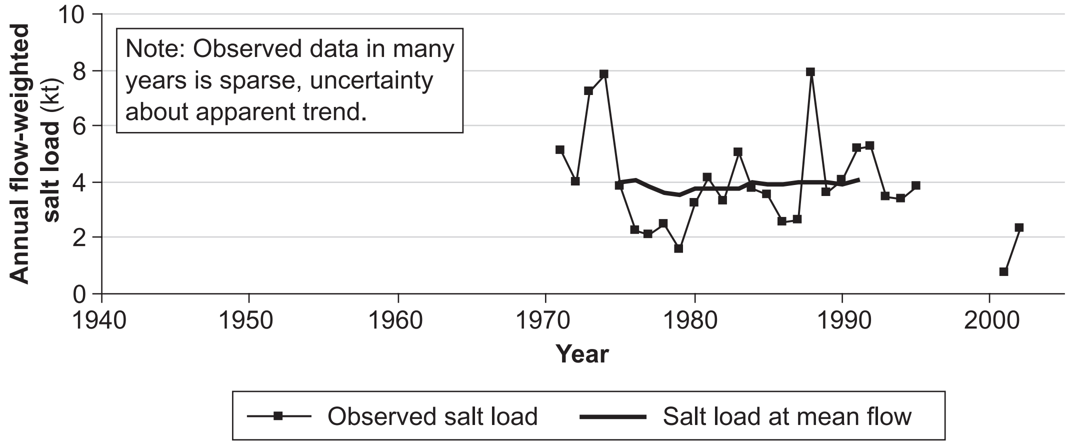




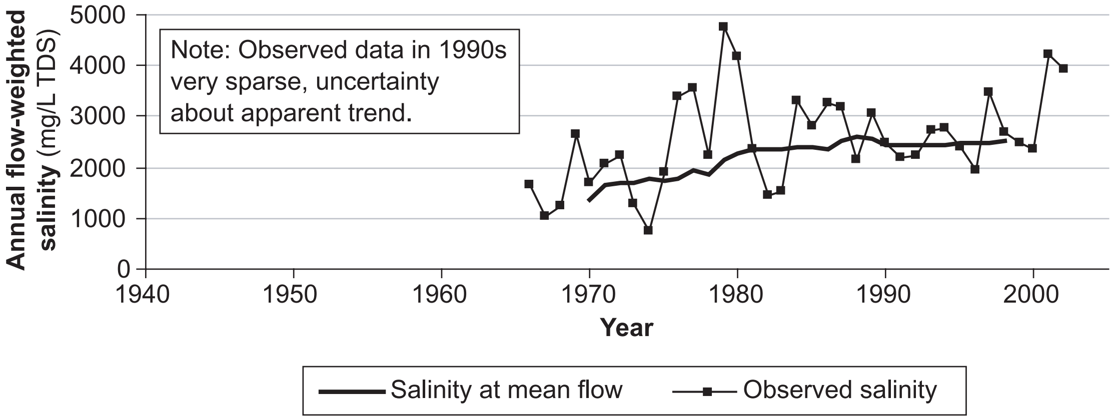
Long-term trends for site 612-230, Collie River East Tributary, James Crossing

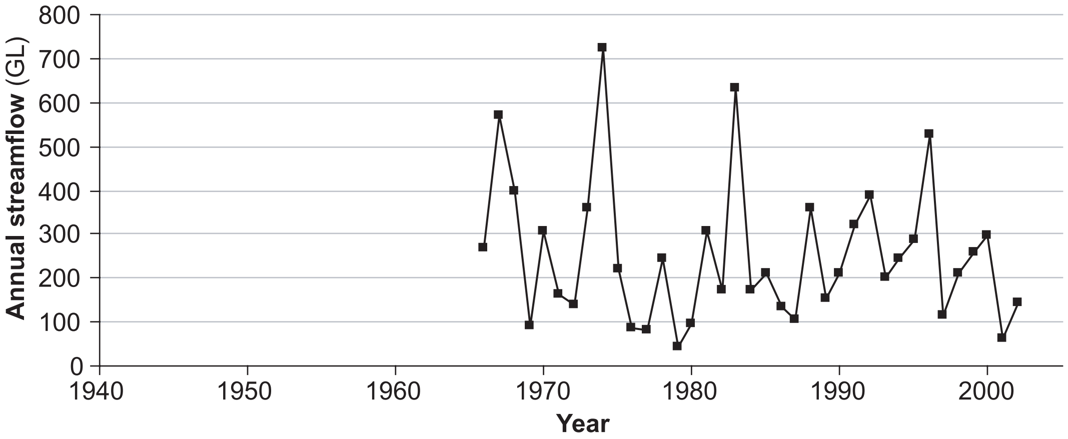


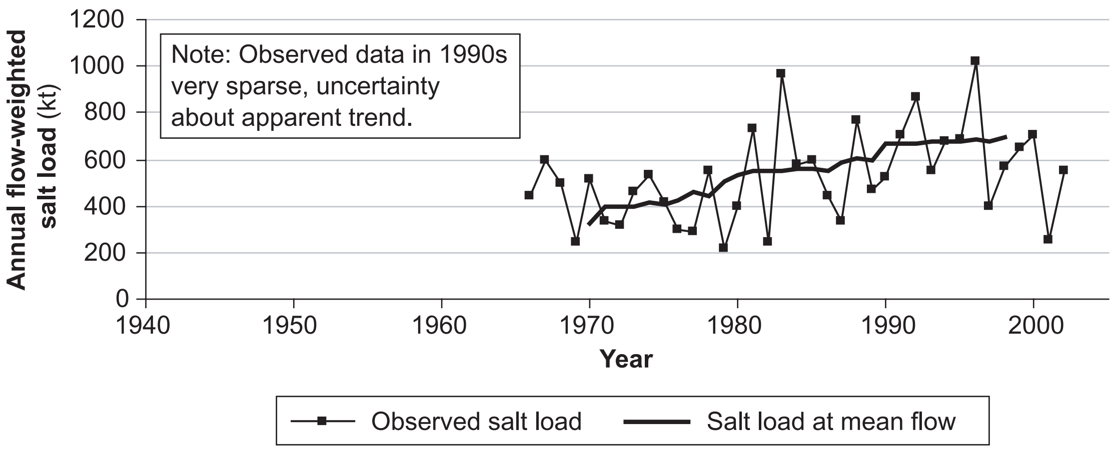




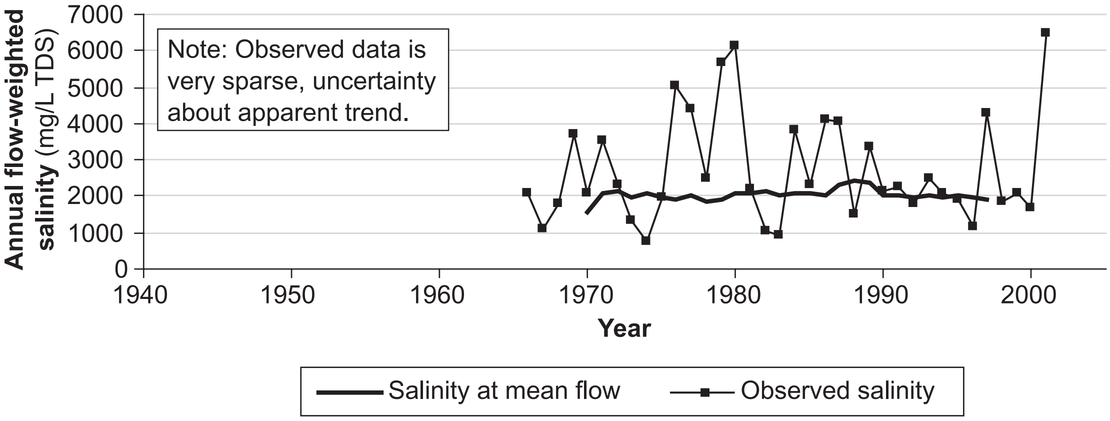
Long-term trends for site 613-002, Harvey River, Dingo Road

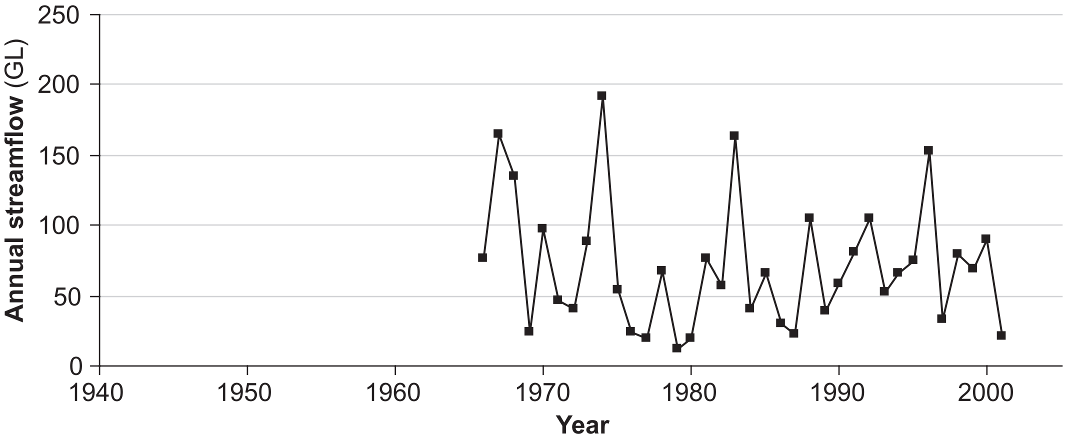


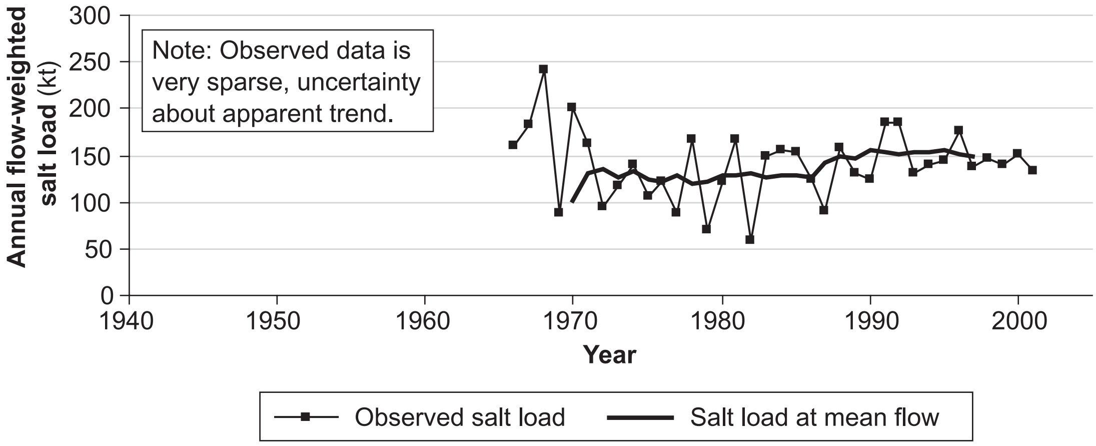




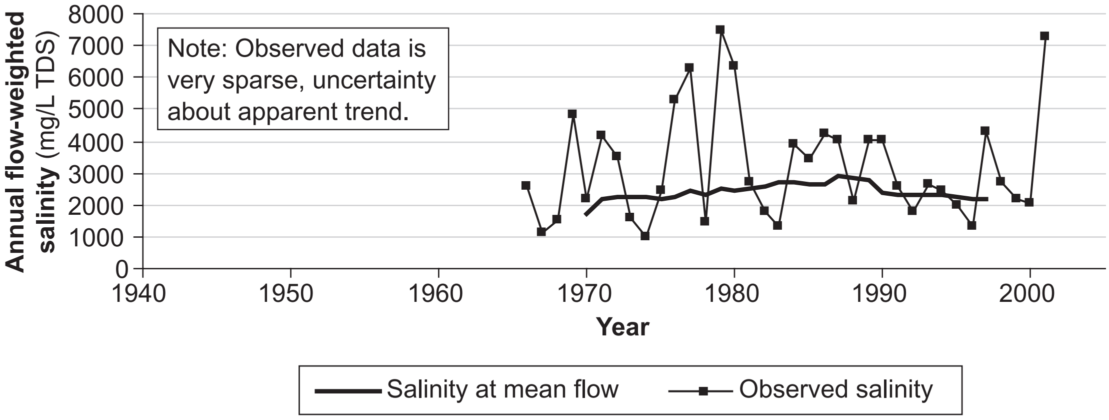
Long-term trends for site 614-006, Murray River, Baden Powell Water Spout

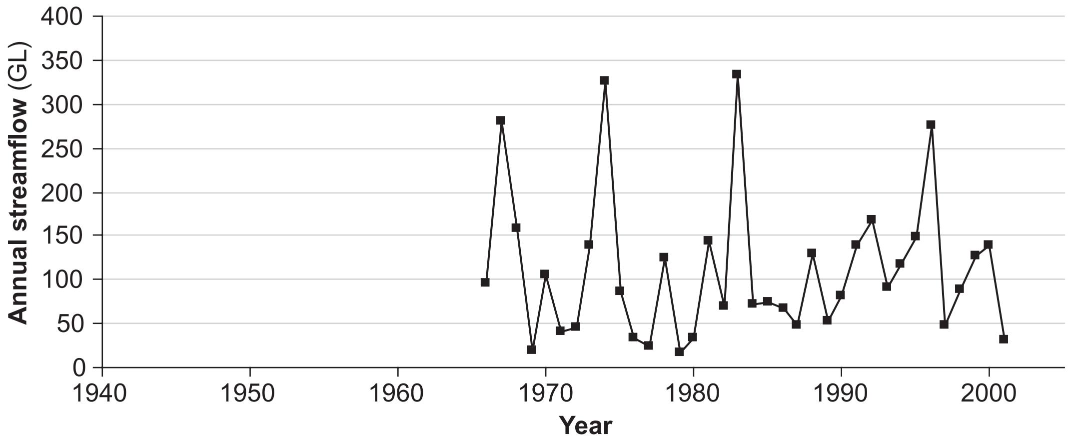


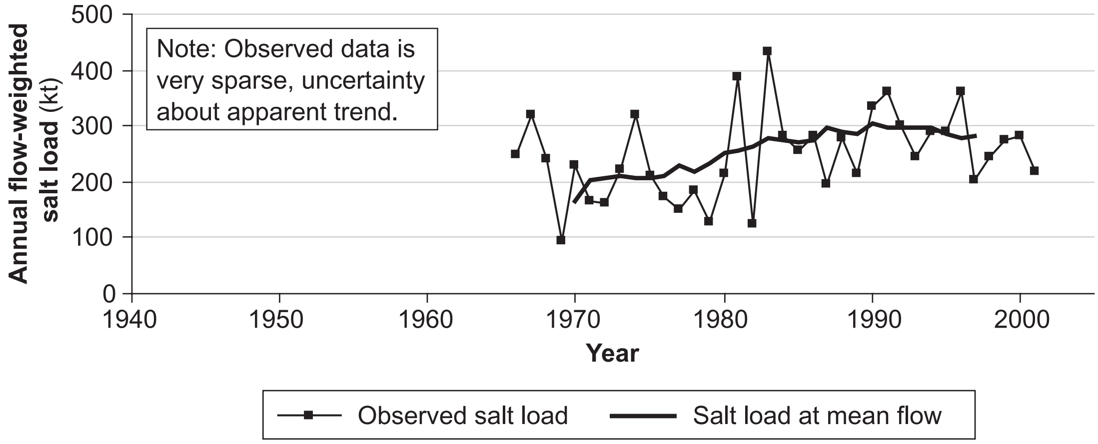




Long-term trends for site 614-196, Williams River, Saddleback Road Bridge







Long-term trends for site 614-224, Hotham River, Marradong Road Bridge

Appendix G
South West Study Area:
catchment characteristics, salinity status, mean and current values, salt output/input ratios and annual trends

South West Study Area:
Catchment characteristics, salinity status, mean and current salinities, salt loads and streamflows

				Characteristics				Mean annuals 1983–1992					Current annuals (mean 1993–2002)				
Site number	Watercourse	Site	Data period[a]	Clearing 1996 (%)	Mean annual rainfall (mm)	Area (km^2)[b]	Salinity status	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability
SHANNON RIVER BASIN																	
606-001	Deep River	Teds Pool		1.3	990	467	Fresh	200	3	7.1	39	1	220	5	7.1	35	1
606-004	Noobijup Brook	Upstream Muir Highway	00–02	71	740	17	Saline	-	-	-	-	-	5400	5	2.6	0.56	2
606-185	Shannon River	Dog Pool	–97	1.5	1230	407	Fresh	140	3	7.6	58	1	140	5	7.8	60	1
606-195	Weld River	Ordnance Road Crossing		1.1	1275	250	Fresh	160	3	6.0	39	1	210	5	7.5	37	1
606-218	Gardner River	Baldania Creek Confluence	93–98	19	1410	393	Fresh	150	3	14	100	1	160	4	15	98	1
WARREN RIVER BASIN																	
607-003	Warren River	Wheatley Farm		35	720	2931	Moderately saline	2500	2	187	97	1	2600	1	190	91	1
607-004	Perup River	Quabicup Hill		16	750	666	Moderately saline	3000	2	34	15	1	2600	1	29	13	1
607-007	Tone River	Bullilup		65	630	983	Moderately saline	4500	1	112	35	1	4400	1	134	38	1
607-022	Lefroy Brook	Cascades	99–02	30	1200	348	Fresh	-	-	-	-	-	220	4	10	51	1
607-144	Wilgarup River	Quintarrup		30	950	460	Marginal	930	2	25	31	1	850	1	19	25	1
607-155	Dombakup Brook	Malimup Track	–97	16	1430	117	Fresh	140	2	4.2	32	2	140	3	5.3	35	2
607-220	Warren River	Barker Road Crossing		31	800	4043	Marginal	890	2	214	259	2	990	2	240	270	1

Note:

Dividing the mean salt load by the mean flow will not give the reported mean salinity because mean salinity was calculated by taking the average of the 10 annual salinity figures.

[a] If the whole period for the 10-year means was not available then whatever data was available within that period was used.

[b] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

South West Study Area:
Catchment characteristics, salinity status, mean and current salinities, salt loads and streamflows (continued)

				Characteristics				Mean annuals 1983–1992					Current annuals (mean 1993–2002)				
Site number	Watercourse	Site	Data period[a]	Clearing 1996 (%)	Mean annual rainfall (mm)	Area (km^2)[b]	Salinity status	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability
DONNELLY RIVER BASIN																	
608-001	Barlee Brook	Upper Iffley	–97	1	1170	159	Fresh	150	3	3.2	23	1	150	5	4.0	26	1
608-002	Carey Brook	Staircase Road		0	1415	30	Fresh	120	2	0.80	7.0	1	110	2	0.73	6.6	1
608-151	Donnelly River	Strickland		20	1110	782	Fresh	230	2	24	109	1	220	3	22	100	1
608-171	Fly Brook	Boat Landing Road	–96	18	1420	63	Fresh	140	4	2.4	18	1	150	5	2.8	18	1
BLACKWOOD RIVER BASIN																	
609-005	Balgarup River	Mandelup Pool		87	530	82	Moderately saline	5600	2	15	3.2	1	5000	1	12	3	1
609-010	Northern Arthur River	Lake Toolibin Inflow		90	415	438	Moderately saline	2500	1	1.7	2.3	1	2200	1	1	0	1
609-012	Blackwood River	Winnejup		84	500	9725	Moderately saline	4300	2	914	282	1	4700	2	942	248	1
609-014	Arthur River	Mount Brown	84–92, 94–97, 01, 02	88	460	2116	Saline	6300	3	156	31	1	7100	3	132	26	1
609-015	Beaufort River	Manywaters	84–97, 01, 02	89	480	1565	Saline	4500	3	109	27	1	6900	4	101	20	1
609-019	Blackwood River	Hut Pool	84–02	64	600	13368	Moderately saline	2000	2	975	540	1	2100	1	1000	566	1
609-021	Coblinine River	Bibikin Road Bridge	97–02	89	400	3915	Highly saline	-	-	-	-	-	21600	1	80	5	1
BUSSELTON COAST BASIN																	
610-001	Margaret River	Willmots Farm	85–96	23	1070	443	Fresh	180	3	16	93	1	210	4	18	87	1
610-003	Vasse River	Chapman Hill	83, 85–97	65	1005	47	Fresh	190	3	1.8	10	1	200	5	2.3	12	1
610-006	Wilyabrup Brook	Woodlands	83–95, 01–02	72[c]	1105	82	Fresh	290	3	7.0	26	1	370	4	5.9	16	1
610-008	Margaret River North	Whicher Range	83–95	2	940	15	Fresh	160	4	0.24	1.5	1	160	5	0.22	1.4	1
610-010	Capel River	Capel Railway Bridge	96–98, 00, 02	35	1000	394	Fresh	-	-	-	-	-	330	4	16	52	1
PRESTON RIVER BASIN																	
611-004	Preston River	Boyanup	82–97	34	980	808	Fresh	370	5	35	108	1	310	3	30	104	1
611-007	Ferguson River	South Western Highway	99–02	48	1050	145	Fresh	-	-	-	-	-	450	4	8.4	21	1
611-111	Thomson Brook	Woodperry Homestead	–94, 96, 97, 00–02	26	960	102	Fresh	470	3	4.9	12	1	400	3	4.5	11	1

Note:

Dividing the mean salt load by the mean flow will not give the reported mean salinity because mean salinity was calculated by taking the average of the 10 annual salinity figures.

[a] If the whole period for the 10-year means was not available then whatever data was available within that period was used.

[b] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[c] Clearing figures not consistent with the other catchments. See Appendix A.

South West Study Area:
Catchment characteristics, salinity status, mean and current salinities, salt loads and streamflows (continued)

				Characteristics				Mean annuals 1983–1992					Current annuals (mean 1993–2002)				
Site number	Watercourse	Site	Data period[a]	Clearing 1996 (%)	Mean annual rainfall (mm)	Area (km^2)[b]	Salinity status	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability
COLLIE RIVER BASIN																	
612-001	Collie River East Trib.	Coolangatta Farm		24	710	1345	Moderately saline	2100	2	87	50	1	2700	1	78	42	1
612-002	Collie River	Mungalup Tower		22	790	2546	Brackish	1200	1	130	131	1	1500	1	105	93	1
612-014	Bingham River	Palmer		5	750	366	Fresh	360	3	2.0	7.1	1	320	1	1.2	5.3	1
612-016	Batalling Creek	Maxon Farm	86–02	38	650	17	Saline	6300	3	2.9	0.61	1	6800	1	2.6	0.47	1
612-022	Brunswick River	Sandalwood	81–89, 91–97	11	1220	116	Fresh	150	2	4.2	29	1	150	3	3.9	25	1
612-025	Camballan Creek	James Well	82–02	40	660	170	Moderately saline	3000	2	13	6.7	1	3600	1	14	5.3	1
612-034	Collie River	South Branch		30	780	661	Brackish	960	2	29	36	1	1100	1	26	29	1
612-230	Collie River East Trib.	James Crossing		52	640	170	Saline	5400	2	37	8.4	2	6700	1	45	6.9	1
HARVEY RIVER BASIN																	
613-002	Harvey River	Dingo Road	–95, 01, 02	0	1195	147	Fresh	110	4	4.4	40	1	120	5	2.8	23	1
613-007	Bancell Brook	Waterous	–97, 02	10	1220	13	Fresh	90	4	0.49	5.2	1	100	5	0.36	3.8	1
613-018	McKnoes Brook	Urquharts	84–95	13	1200	24	Fresh	90	4	0.9	10	1	100	5	0.7	7.0	1
613-052	Harvey River	Clifton Park	84–98	39	1100	727	Fresh	200	4	37	183	1	290	5	41	135	1
613-054	Mayfield Sub G drain	Mayfield	84–94	95	1025	10	Fresh	180	5	0.37	2.1	1	-	-	-	-	-
613-146	Clarke Brook	Hillview Farm	–89, 91–95	10	1150	17	Fresh	130	4	0.7	5.1	1	-	-	-	-	-
MURRAY RIVER BASIN																	
614-006	Murray River	Baden Powell Water Spout		60	750	6757	Moderately saline	2600	2	623	268	1	2900	4	605	234	1
614-036	North Dandalup River	North Road	–98	5	1250	80	Fresh	120	3	0.90	7.6	1	130	4	1.0	7.4	1
614-037	Big Brook	O'Niel road	–98	0	1050	149	Fresh	-	-	-	-	-	120	3	0.47	4.5	1
614-196	Williams River	Saddleback Road Bridge	–99, 01	79	560	1408	Moderately saline	2600	4	145	71	1	2700	5	145	71	1
614-224	Hotham River	Marradong Road Bridge	84–98	69	600	3967	Moderately saline	3100	4	294	117	1	3000	4	267	118	1

Note:

Dividing the mean salt load by the mean flow will not give the reported mean salinity because mean salinity was calculated by taking the average of the 10 annual salinity figures.

[a] If the whole period for the 10-year means was not available then whatever data was available within that period was used.

[b] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

South West Study Area:
Salt output/input ratios and annual trends

Site number	Watercourse	Site	Characteristics: Clearing 1996 (%)	Characteristics: Mean annual rainfall (mm)	Characteristics: Area (km²)[a]	Salinity status	Salt balance: Salt input (t/yr/km²)	Salt balance: Salt output (t/yr/km²)	Salt balance: Salt output/input ratio	Annual salinity trend (mg/L TDS)[b] 1980–1989	Annual salinity trend (mg/L TDS)[b] 1990–1998	Annual salt load trend (kt)[b] 1980–1989	Annual salt load trend (kt)[b] 1990–1998	Annual flow trend (GL)[b] 1980–1989	Annual flow trend (GL)[b] 1990–1998
SHANNON RIVER BASIN															
606-001	Deep River	Teds Pool	1.3	990	467	Fresh	12	15	1.3	-	-	-	-	1.3ns	-
606-004	Noobijup Brook	Upstream Muir Highway	71	740	17	Saline	7.2	152	21	-	-	-	-	-	-
606-185	Shannon River	Dog Pool	1.5	1230	407	Fresh	17	19	1.1	-2.1s	-	-0.12s	-	-1.6ns	-0.82ns
606-195	Weld River	Ordnance Road Crossing	1.1	1275	250	Fresh	19	30	1.6	-0.32ns	-	-0.012ns	-	-0.45ns	-
606-218	Gardner River	Baldania Creek Confluence	19	1410	393	Fresh	24	39	1.7	-0.41s	-	-0.041s	-	-3.6ns	-3.7ns
WARREN RIVER BASIN															
607-003	Warren River	Wheatley Farm	35	720	2931	Moderately saline	6.8	65	10	26s	-4.7s	2.1s	-0.52s	0.80ns	0.13ns
607-004	Perup River	Quabicup Hill	16	750	666	Moderately saline	6.8	44	6.4	-	-40s	-	-0.69s	0.27ns	-0.40ns
607-007	Tone River	Bullilup	65	630	983	Moderately saline	4.8	135	28	-	28s	-	1.2s	0.65ns	0.62ns
607-022	Lefroy Brook	Cascades	30	1200	348	Fresh	16	29	1.8	-	-	-	-	-	-
607-144	Wilgarup River	Quintarrup	30	950	460	Marginal	6.3	40	6.4	0.30ns	-14s	0.01ns	-0.44s	0.20ns	-0.87ns
607-155	Dombakup Brook	Malimup Track	16	1430	117	Fresh	25	45	1.8	-1.1s	-	-0.04s	-	-1.2ns	-0.75ns
607-220	Warren River	Barker Road Crossing	31	800	4043	Marginal	9.3	60	6.4	15s	2.0ns	3.6s	0.62ns	-1.4ns	2.5ns
DONNELLY RIVER BASIN															
608-001	Barlee Brook	Upper Iffley	1	1170	159	Fresh	14	25	1.8	-	-	-	-	-	-
608-002	Carey Brook	Staircase Road	0	1415	30	Fresh	21	24	1.1	-	-0.54s	-	-0.004s	-0.22ns	-0.01ns
608-151	Donnelly River	Strickland	20	1110	782	Fresh	13	28	2.1	1.8s	-1.9s	0.18s	-0.23s	-1.6ns	-0.37ns
608-171	Fly Brook	Boat Landing Road	18	1420	63	Fresh	26	45	1.7	-	-	-	-	-0.30ns	-0.15ns

Note:

[a] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[b] s denotes statistically significant trend at the 95% confidence limit, ns means not statistically significant.

South West Study Area:
Salt output/input ratios and annual trends (continued)

Site number	Watercourse	Site	Characteristics: Clearing 1996 (%)	Characteristics: Mean annual rainfall (mm)	Characteristics: Area (km²)[b]	Salinity status	Salt balance: Salt input (t/yr/km²)	Salt balance: Salt output (t/yr/km²)	Salt balance: Salt output/input ratio	Annual salinity trend (mg/L TDS)[c] 1980–1989	Annual salinity trend (mg/L TDS)[c] 1990–1998	Annual salt load trend (kt)[c] 1980–1989	Annual salt load trend (kt)[c] 1990–1998	Annual flow trend (GL)[c] 1980–1989	Annual flow trend (GL)[c] 1990–1998
BLACKWOOD RIVER BASIN															
609-005	Balgarup River	Mandelup Pool	87	530	82	Moderately saline	3.8	144	38	-30ns	17s	-0.09ns	0.06s	-0.20ns	0.06ns
609-010	Northern Arthur River	Lake Toolibin Inflow	90	415	438	Moderately saline	2.5	2.0	0.79	-	-	-	-	-0.40ns	-0.32ns
609-012	Blackwood River	Winnejup	84	500	9725	Moderately saline	3.5	97	28	-	14ns	-	4.5ns	-8ns	1.9ns
609-014	Arthur River	Mount Brown	88	460	2116	Saline	3.1	62	20	-	-	-	-	-	-0.3ns
609-015	Beaufort River	Manywaters	89	480	1565	Saline	3.2	64	20	-	-	-	-	-	0.5ns
609-019	Blackwood River	Hut Pool	64	600	13368	Moderately saline	5.6	78	14	-	-0.64ns	-	-0.44ns	-	-0.14ns
609-021	Coblinine River	Bibikin Road Bridge	89	400	3915	Highly saline	4.3	21	4.8	-	-	-	-	-	-
BUSSELTON COAST BASIN															
610-001	Margaret River	Willmots Farm	23	1070	443	Fresh	18	40	2.2	-	-	-	-	-	1.4ns
610-003	Vasse River	Chapman Hill	65	1005	47	Fresh	18	48	2.6	-	-	-	-	-0.31ns	0.69ns
610-006	Wilyabrup Brook	Woodlands	72[a]	1105	82	Fresh	31	72	2.3	-	-	-	-	-	-0.037ns
610-008	Margaret River North	Whicher Range	2	940	15	Fresh	15	14	0.94	-	-	-	-	0.023ns	0.18ns
610-010	Capel River	Capel Railway Bridge	35	1000	394	Fresh	14	40	2.9	-	-	-	-	-	-
PRESTON RIVER BASIN															
611-004	Preston River	Boyanup	34	980	808	Fresh	12	37	3.0	-	-	-	-	-	-4.9ns
611-007	Ferguson River	South Western Highway	48	1050	145	Fresh	18	58	3.1	-	-	-	-	-	-
611-111	Thomson Brook	Woodperry Homestead	26	960	102	Fresh	11	44	4.0	-4.1s	-	-0.043s	-	-0.21ns	-0.63ns

Note:

[a] Clearing figures not consistent with the other catchments. See Appendix A.

[b] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[c] s denotes statistically significant trend at the 95% confidence limit, ns means not statistically significant.

South West Study Area:
Salt output/input ratios and annual trends (continued)

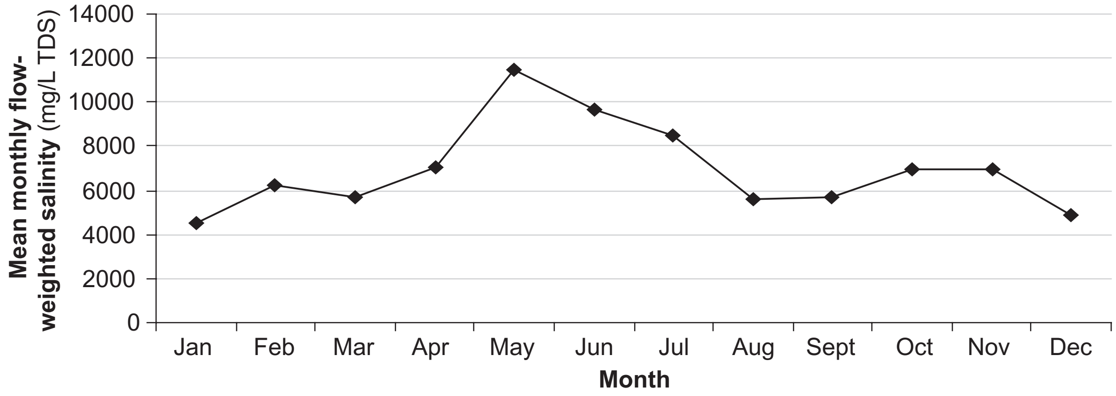
Site number	Watercourse	Site	Characteristics: Clearing 1996 (%)	Characteristics: Mean annual rainfall (mm)	Characteristics: Area (km²)[a]	Salinity status	Salt balance: Salt input (t/yr/km²)	Salt balance: Salt output (t/yr/km²)	Salt balance: Salt output/input ratio	Annual salinity trend (mg/L TDS)[b] 1980–1989	Annual salinity trend (mg/L TDS)[b] 1990–1998	Annual salt load trend (kt)[b] 1980–1989	Annual salt load trend (kt)[b] 1990–1998	Annual flow trend (GL)[b] 1980–1989	Annual flow trend (GL)[b] 1990–1998
COLLIE RIVER BASIN															
612-001	Collie River East Trib.	Coolangatta Farm	24	710	1345	Moderately saline	6.7	58	8.7	67s	-22s	2.9s	-1.2s	-1.0ns	-1.0ns
612-002	Collie River	Mungalup Tower	22	790	2546	Brackish	7.9	41	5.2	33s	-5.9s	3.9s	-0.73s	-2.5ns	-2.8ns
612-014	Bingham River	Palmer	5	750	366	Fresh	7.2	3.3	0.46	2.0s	-8.3s	0.012s	-0.056s	-0.034ns	-0.024ns
612-016	Batalling Creek	Maxon Farm	38	650	17	Saline	5.5	155	28	-	-12ns	-	-0.0064ns	0.00044ns	-0.013ns
612-022	Brunswick River	Sandalwood	11	1220	116	Fresh	16	33	2.1	-	-	-	-	-	-
612-025	Camballan Creek	James Well	40	660	170	Moderately saline	5.7	80	14	-	36s	-	0.25s	-	-0.29ns
612-034	Collie River	South Branch	30	780	661	Brackish	7.9	40	5.0	4.4s	14s	0.12s	0.58s	-1.0ns	-0.14ns
612-230	Collie River East Trib.	James Crossing	52	640	170	Saline	5.4	265	49	110s	200s	0.82s	1.6s	0.093ns	-0.18ns
HARVEY RIVER BASIN															
613-002	Harvey River	Dingo Road	0	1195	147	Fresh	15	19	1.3	-	-	-	-	0.32ns	-2.4ns
613-007	Bancell Brook	Waterous	10	1220	13	Fresh	17	27	1.5	-	-	-	-	-	-
613-018	Mcknoes Brook	Urquharts	13	1200	24	Fresh	17	27	1.6	-	-	-	-	-	-
613-052	Harvey River	Clifton Park	39	1100	727	Fresh	17	57	3.3	-	-	-	-	-	-
613-054	Mayfield Sub G drain	Mayfield	95	1025	10	Fresh	16	25	1.6	-	-	-	-	-	-
613-146	Clarke Brook	Hillview Farm	10	1150	17	Fresh	18	34	1.9	-	-	-	-	-	-
MURRAY RIVER BASIN															
614-006	Murray River	Baden Powell Water Spout	60	750	6757	Moderately saline	5.6	90	16	29s	10s	6.9s	2.8s	-5.5ns	-4.2ns
614-036	North Dandalup River	North Road	5	1250	80	Fresh	16	12	0.79	-	-	-	-	-	-0.43ns
614-037	Big Brook	O'Niel Road	0	1050	149	Fresh	12	3.1	0.27	-	-	-	-	-	-
614-196	Williams River	Saddleback Road Bridge	79	560	1408	Moderately saline	4.6	103	22	-	-	-	-	-1.1ns	0.86ns
614-224	Hotham River	Marradong Road Bridge	69	600	3967	Moderately saline	4.5	67	15	-	-	-	-	-5.0ns	0.34ns

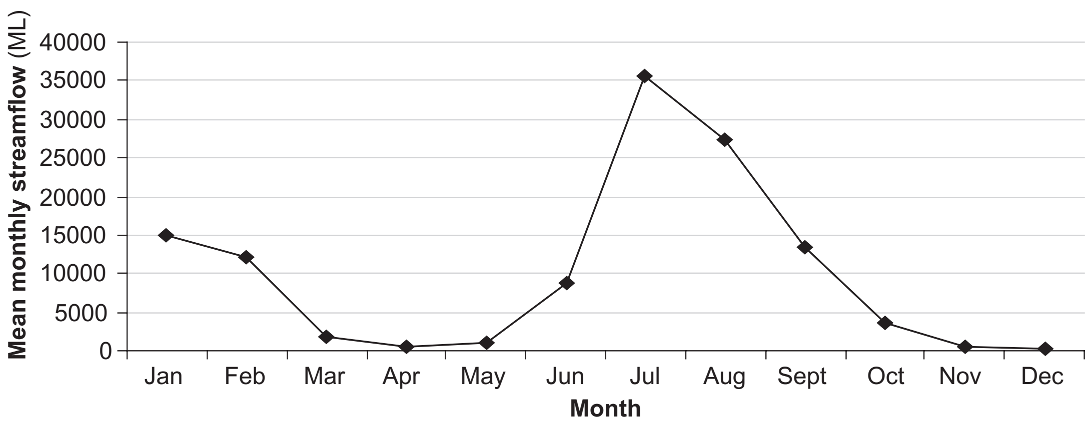
Note:

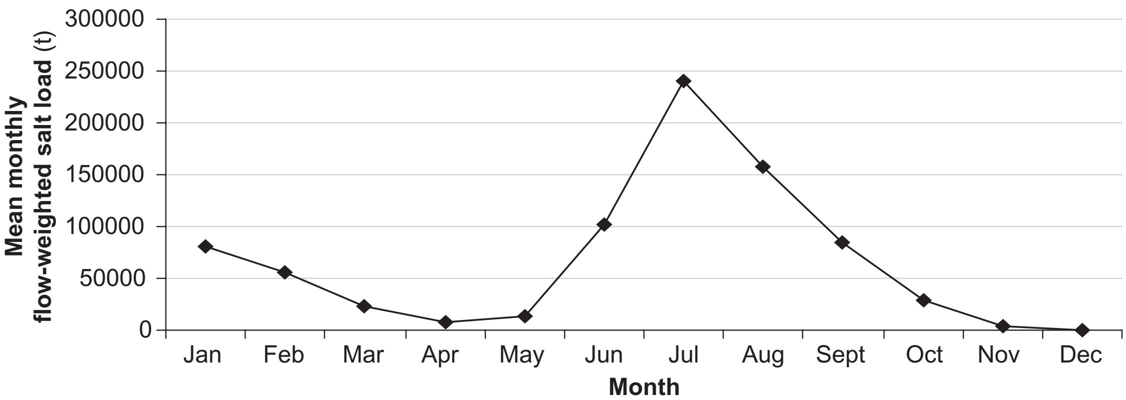
[a] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[b] s denotes statistically significant trend at the 95% confidence limit, ns means not statistically significant.

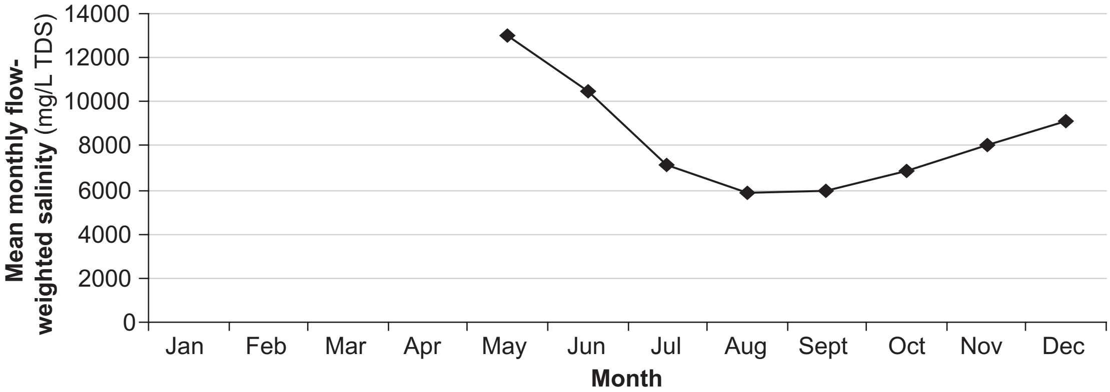
Appendix H
Swan–Avon Study Area:
mean monthly flow, salinity and salt loads

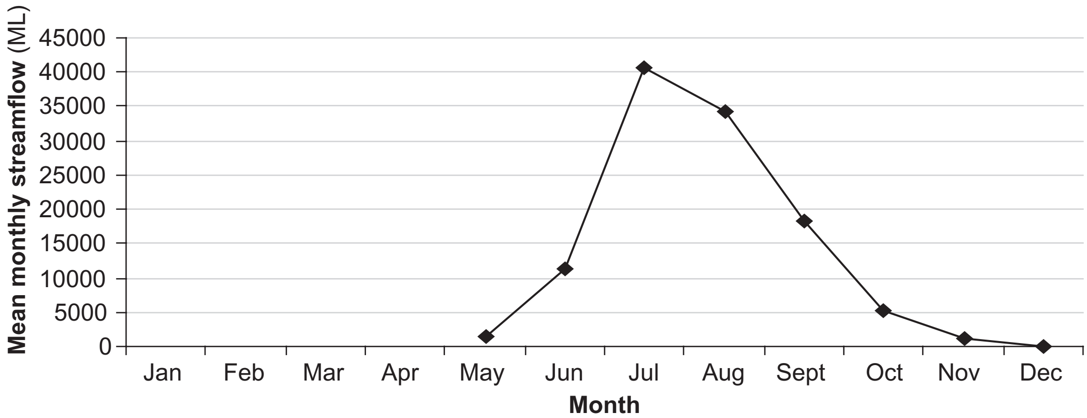


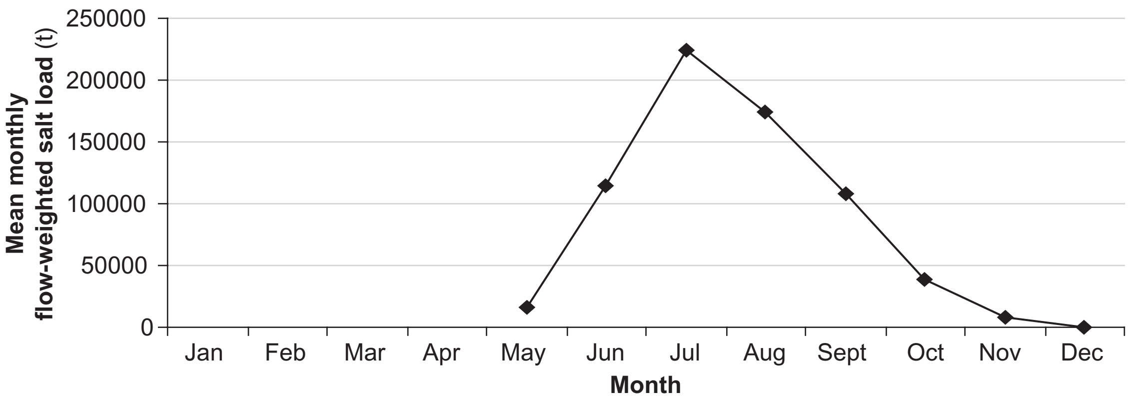




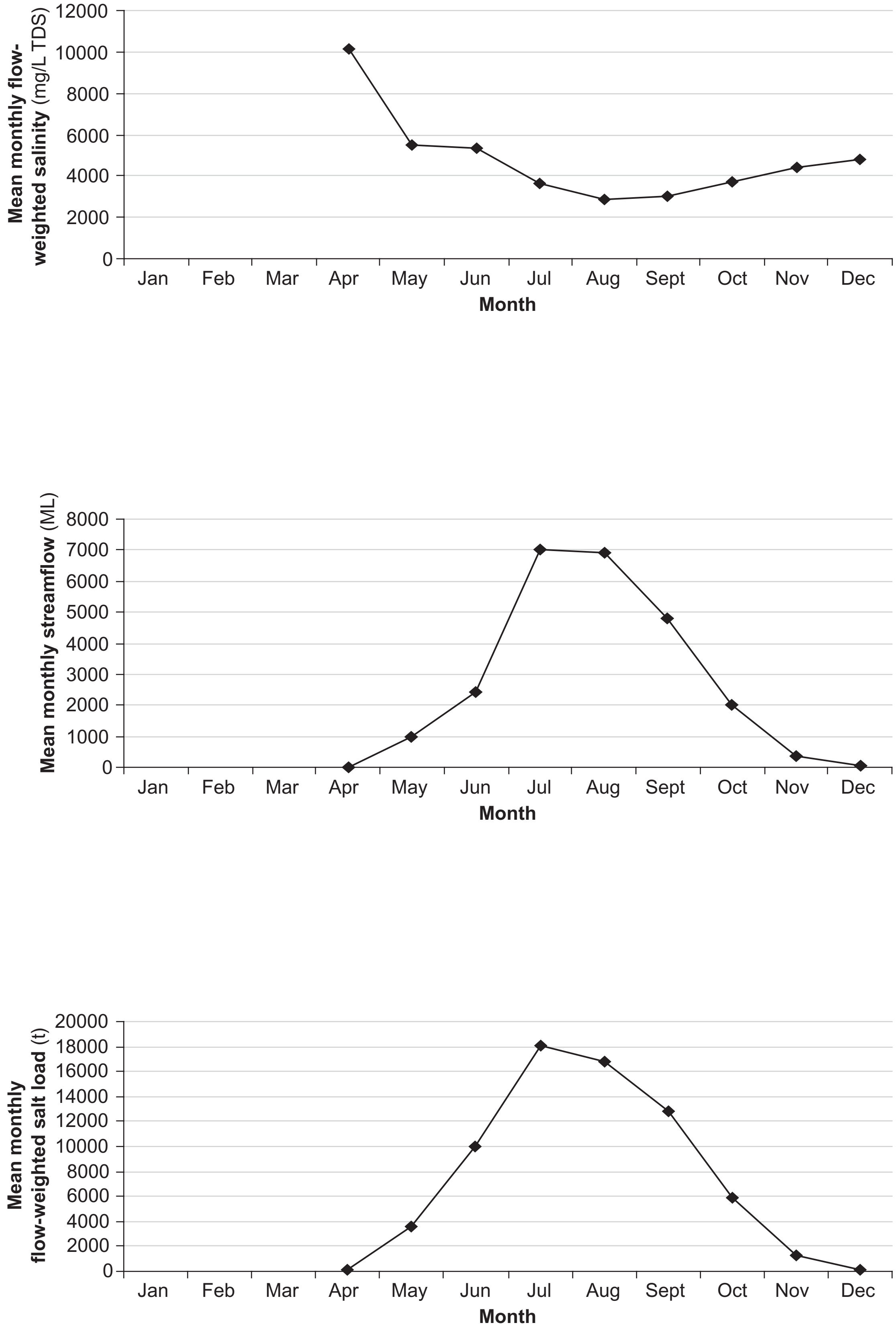
Monthly means (1993–2002) for site 615-014, Avon River, Brouns Farm



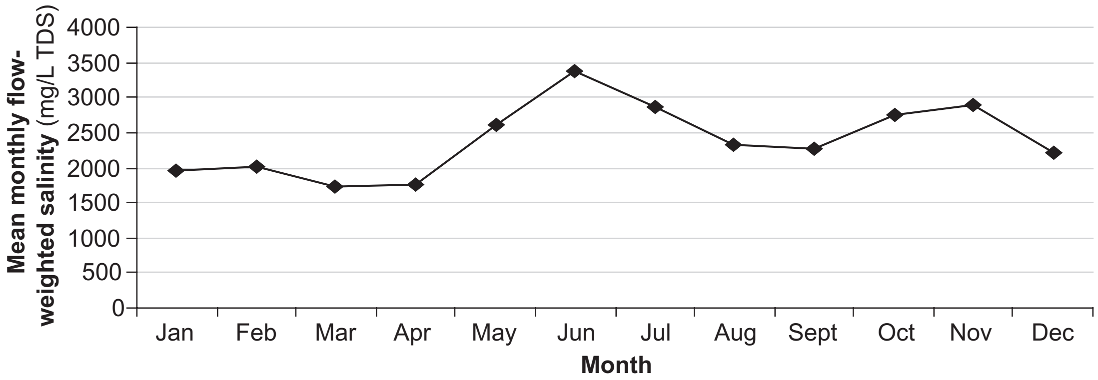


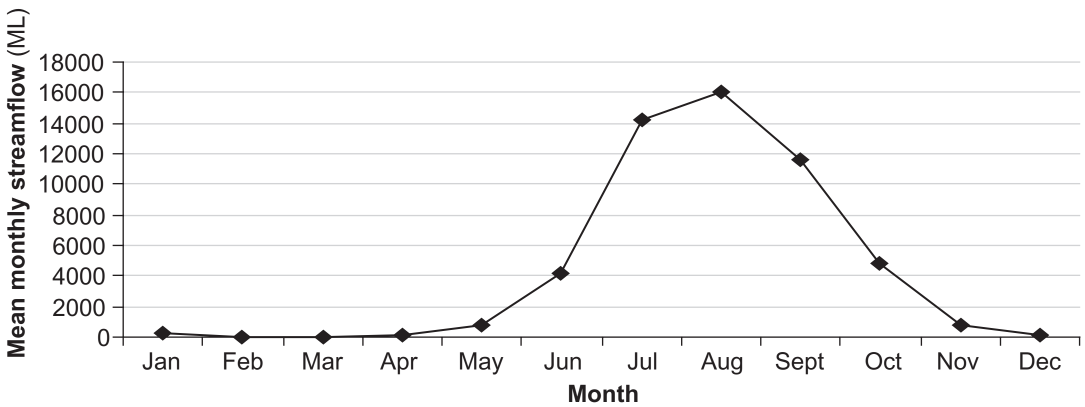


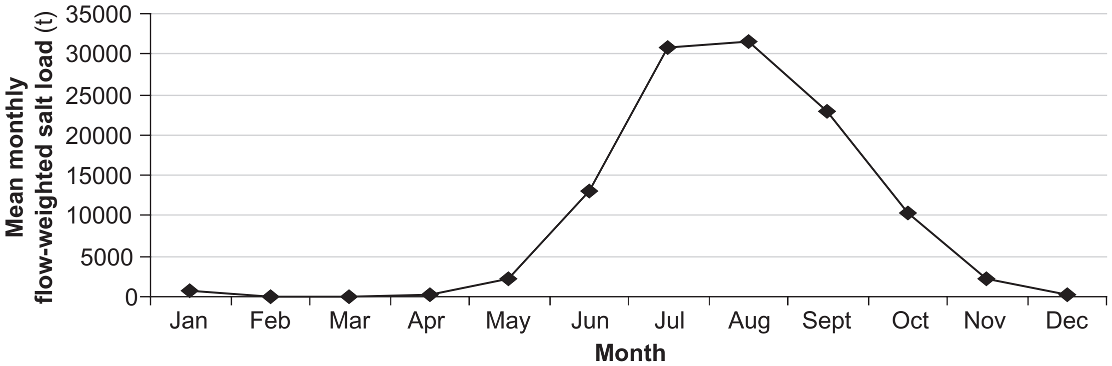
Monthly means (1993–2002) for site 615-062, Avon River, Northam



Monthly means (1993–2002) for site 616-006, Brockman River, Tanamerah

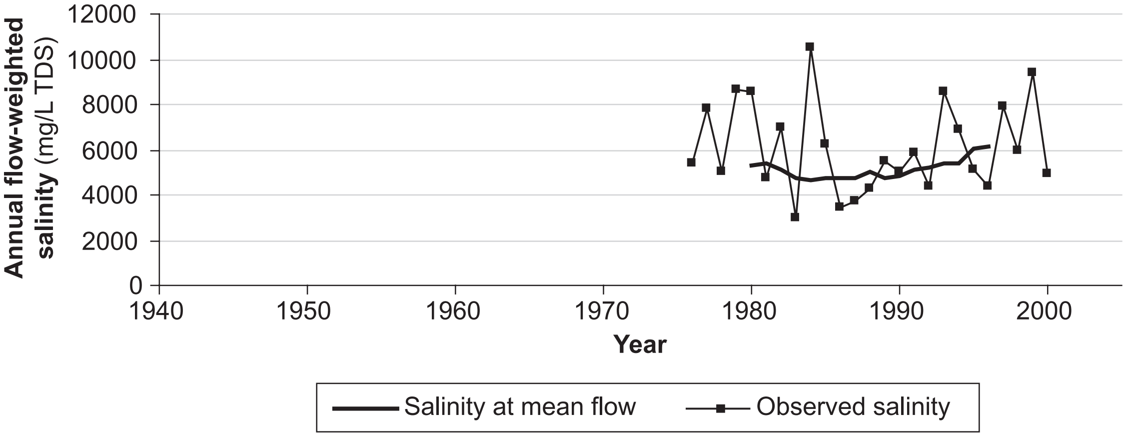


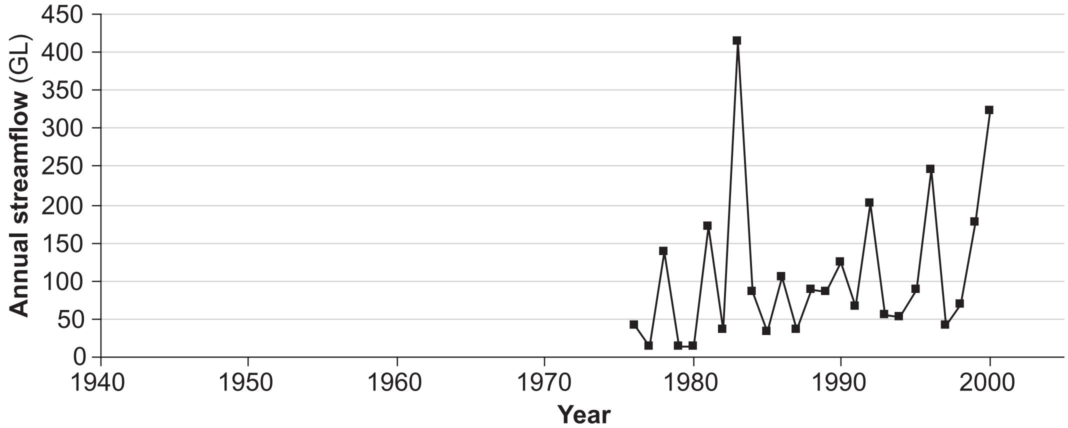


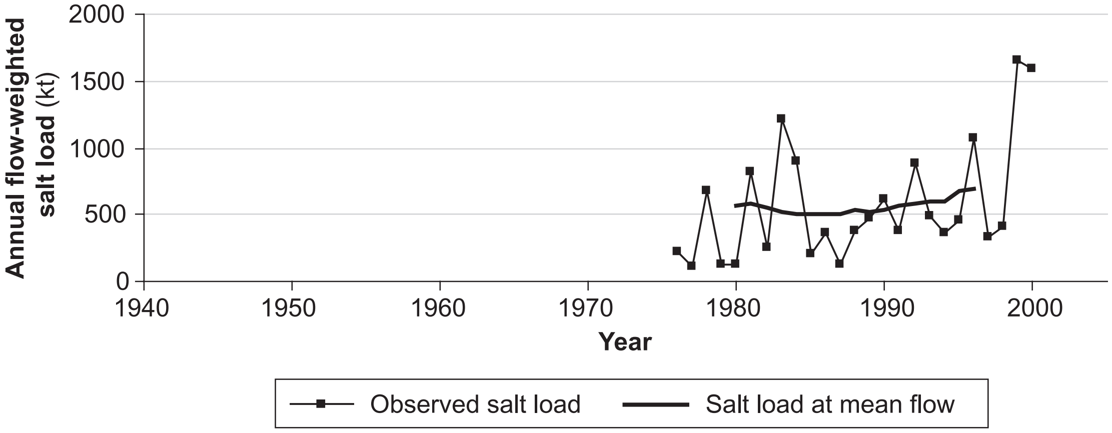


Monthly means (1993–2002) for site 616-019, Brockman River, Yalliawirra

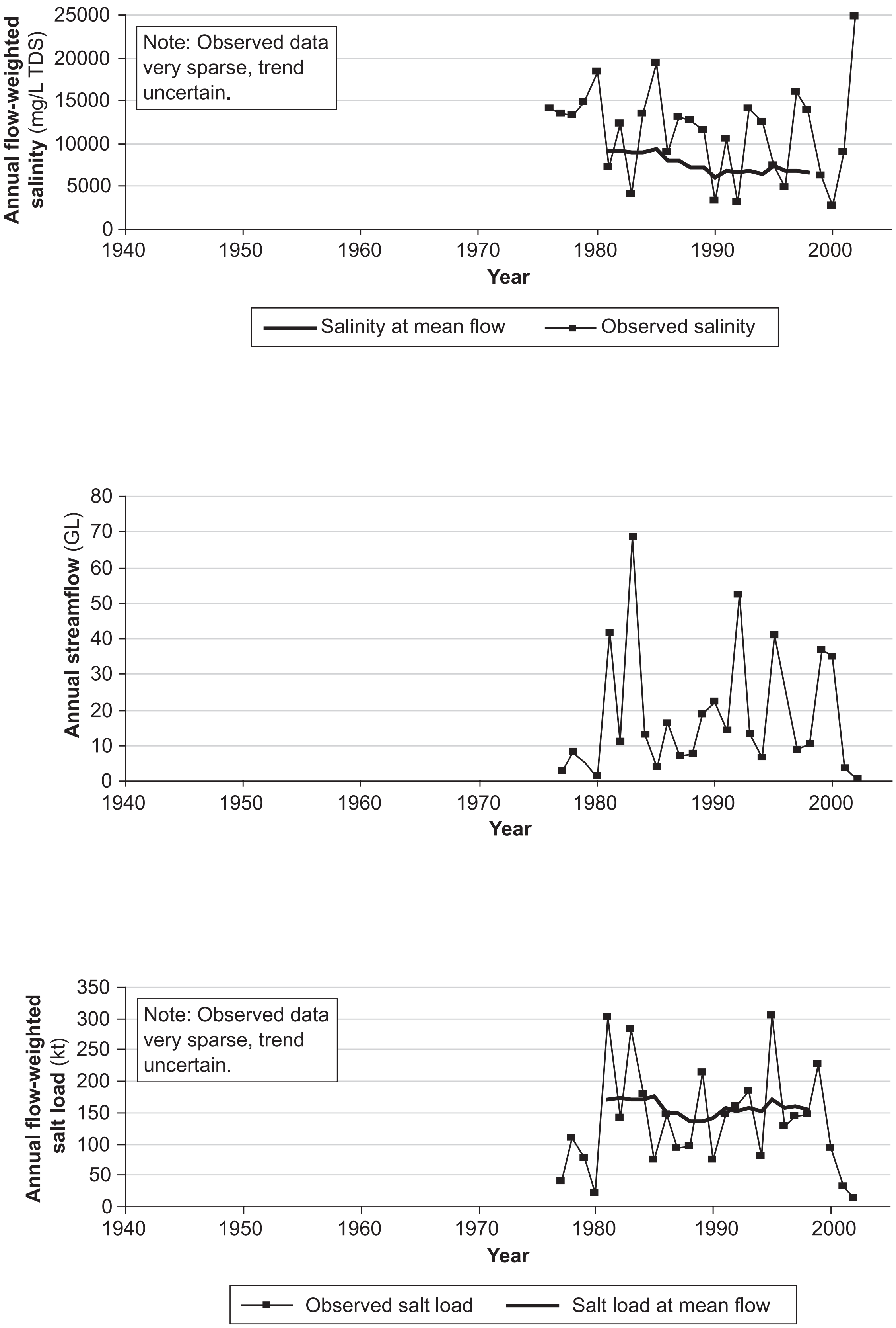
Appendix I
Swan–Avon Study Area: long-term salinity, salt load and flow trends



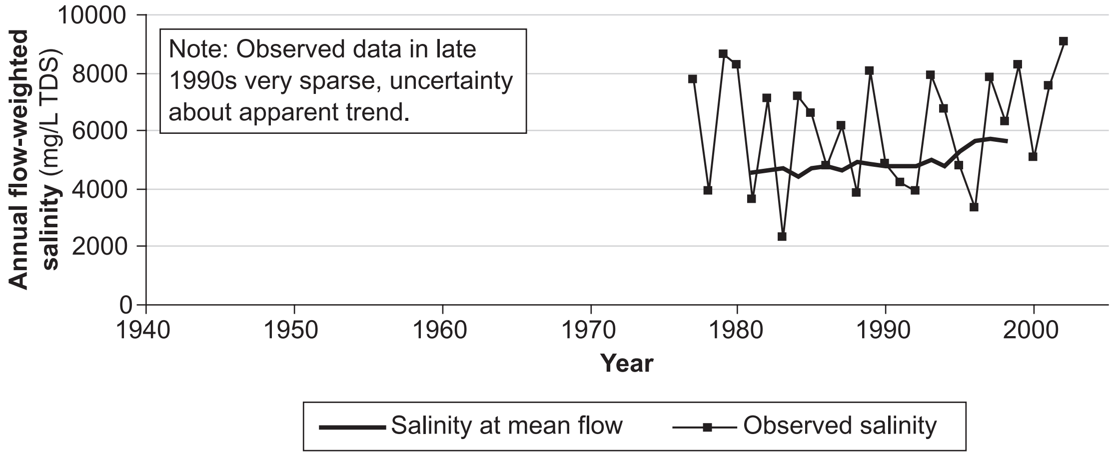


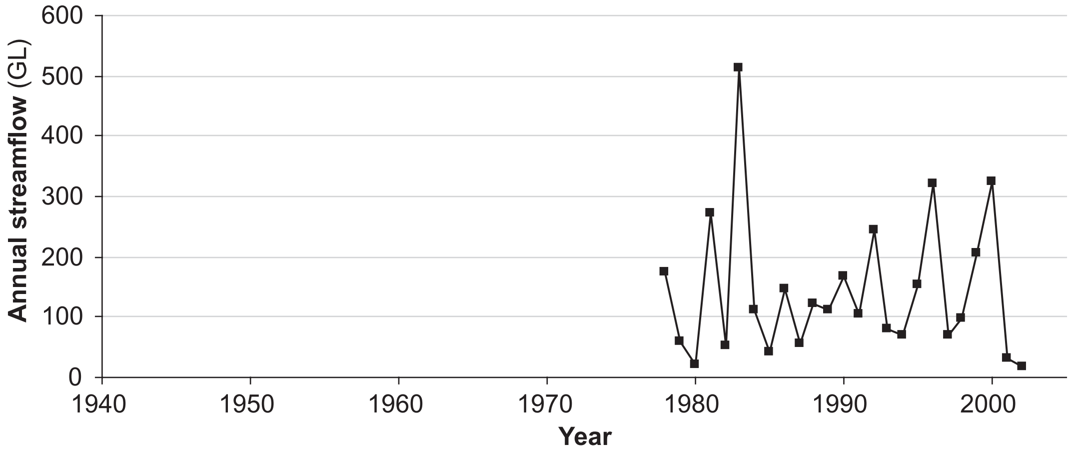


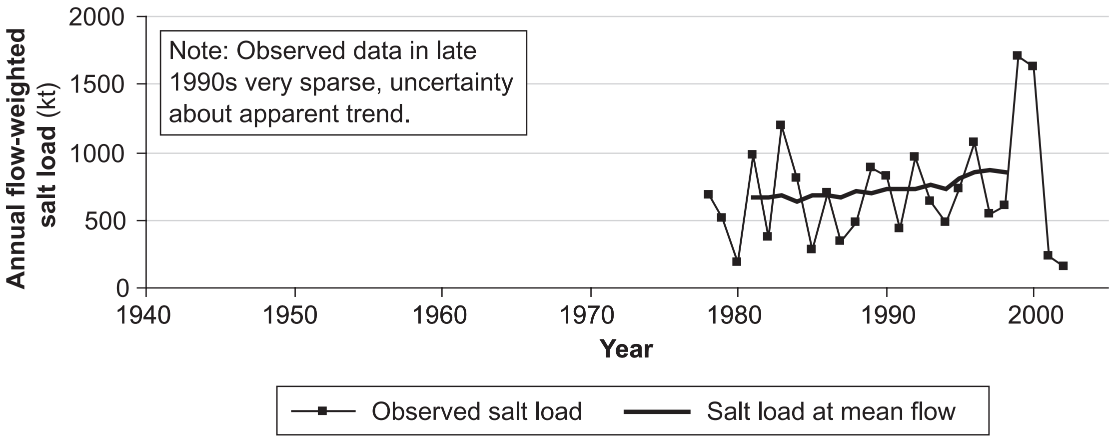
Long-term trends for site 615-014, Avon River, Brouns Farm



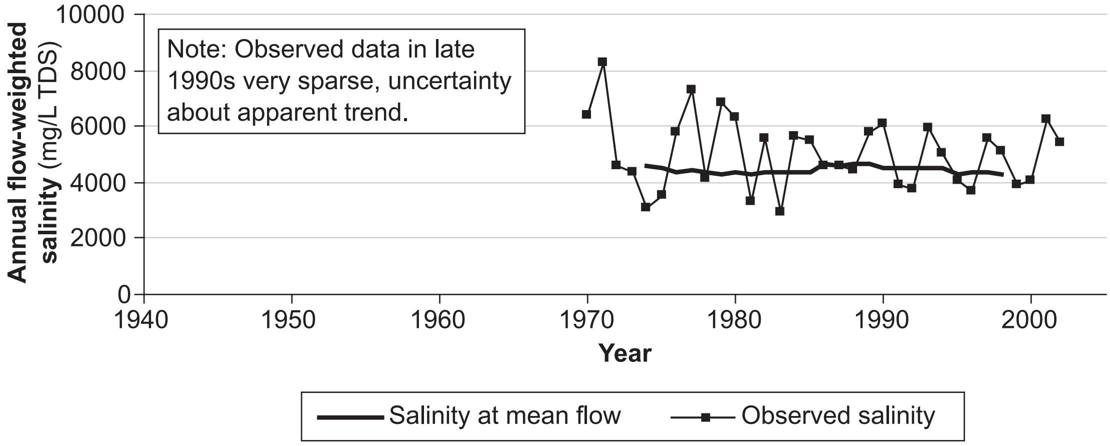
Long-term trends for site 615-020, Mortlock River, O'Driscolls Farm

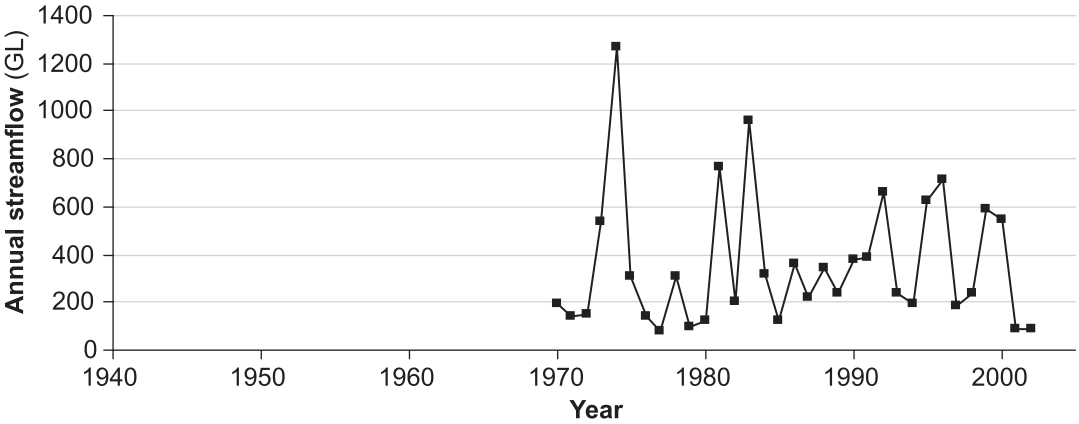


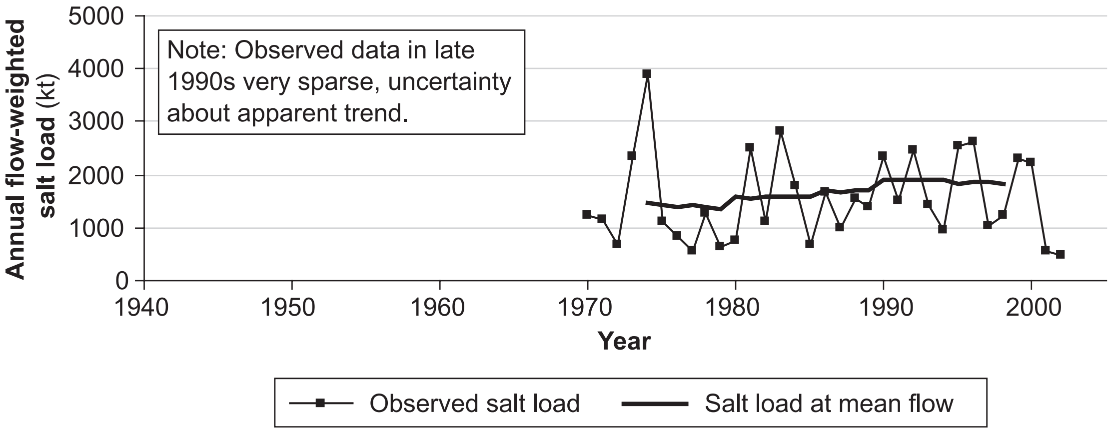




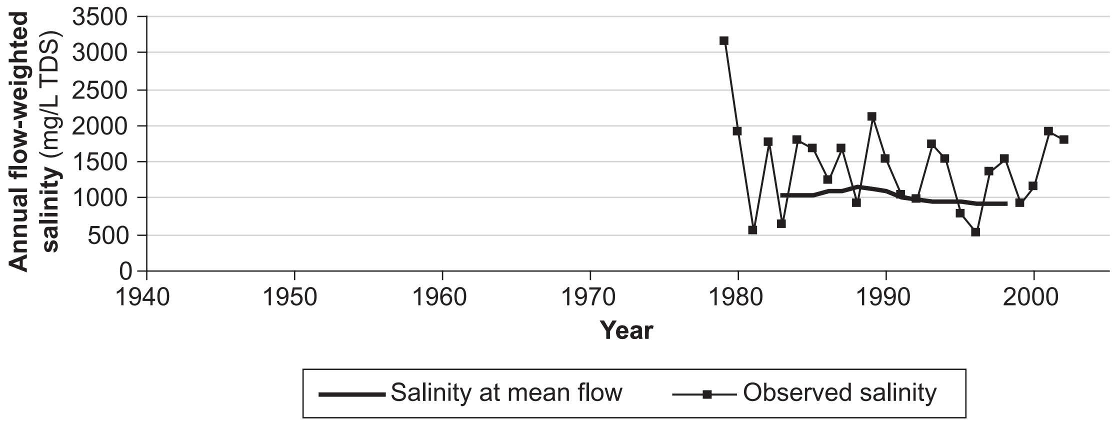
Long-term trends for site 615-062, Avon River, Northam

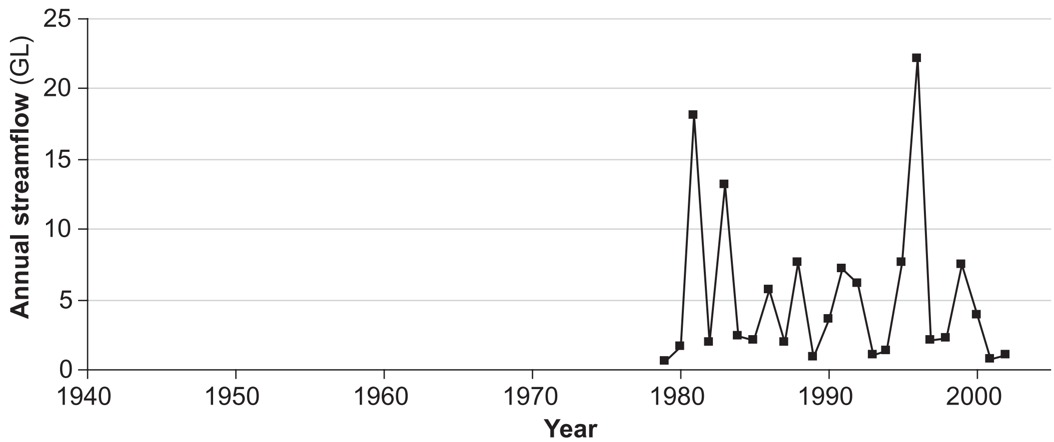


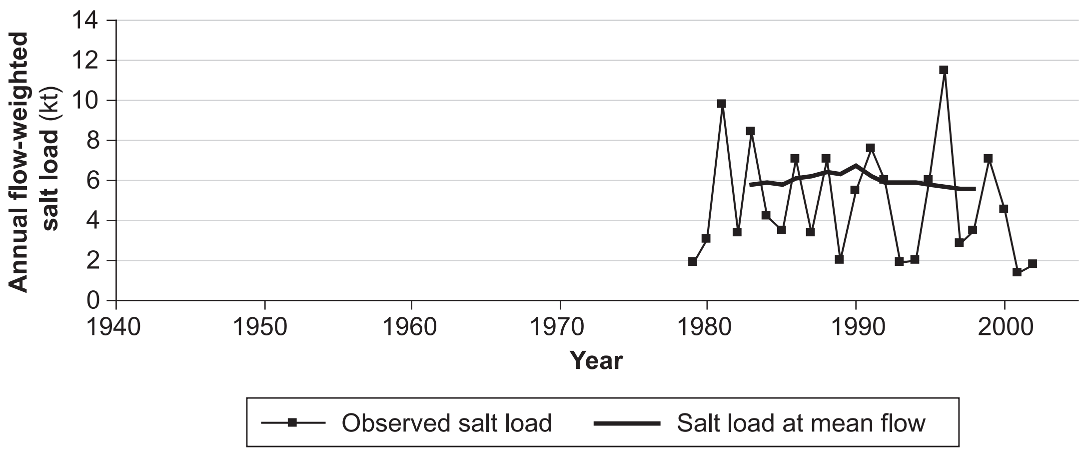




Long-term trends for site 616-011, Swan River, Walyunga







Long-term trends for site 616-216, Helena River, Poison Lease

Appendix J
Swan–Avon Study Area: catchment characteristics, salinity status, mean and current values, salt output/input ratios and annual trends

Swan-Avon Study Area:
Catchment characteristics, salinity status, mean and current salinities, salt loads and streamflows

				Characteristics				Mean annuals 1983–1992					Current annuals (mean 1993–2002)				
Site number	Watercourse	Site	Data period[a]	Clearing 1996 (%)	Mean annual rainfall (mm)	Area (km²)[b]	Salinity status	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability
SWAN-AVON RIVER BASIN																	
615-012	Lockhart River	Kwolyn Hill		90	350	6050	Highly saline	21200	5	156	15	1	33900	4	99	13	1
615-013	Mortlock River North	Frenches	84–02	96	380	2333	Highly saline	13200	4	223	18	1	15000	4	255	24	1
615-014	Avon River	Brouns Farm	–00	86	380	26856	Saline	5200	4	555	124	1	6600	1	795	131	1
615-015	Yilgarn River	Gairdners Crossing		82	310	11540	Highly saline	20700	5	192	12	1	22500	5	64	4.2	1
615-020	Mortlock River	O'Driscolls Farm		97	360	5040	Highly saline	10000	4	147	22	1	11100	4	135	18	1
615-062	Avon River	Northam Weir		86	390	28485	Saline	5200	3	689	162	1	6700	2	778	137	1
615-222	Dale River South	Brookton Highway	–98	64	530	286	Moderately saline	3700	2	24	7.7	1	3700	3	23	7.0	1
616-001	Wooroloo Brook	Karls Ranch		49	850	514	Moderately saline	2000	3	94	49	1	2200	2	88	45	1
616-002	Darkin River	Pine Plantation	83, 85–02	4	730	665	Fresh	180	4	0.67	4.3	1	240	4	0.66	3.3	1
616-006	Brockman River	Tanamerah	81–02	48	610	961	Moderately saline	3200	3	58	21	1	3400	1	69	25	1
616-011	Swan River	Walyunga		85	400	40401	Moderately saline	5000	2	1900	406	2	4900	3	1500	353	1
616-013	Helena River	Ngangag-uringuring	84–02	9	650	327	Brackish	2200	3	3.0	1.5	1	2000	4	2.9	1.9	1
616-019	Brockman River	Yalliawirra		43	700	1521	Moderately saline	2300	2	96	46	1	2500	1	114	53	1
616-039	Canning River	Millars Road	86–98	0	820	146	Fresh	200	4	0.30	1.7	1	210	5	0.31	1.8	1
616-040	Susannah Brook	Gilmours Farm	82–00	58	1000	23	Fresh	380	2	1.7	4.6	1	350	4	1.4	4.1	1
616-065	Canning River	Glen Eagle	85–97	0	880	520	Fresh	210	3	2.6	13	1	210	5	2.4	13	1
616-189	Ellen Brook	Railway Parade		45	780	581	Marginal	550	3	19	36	1	620	4	17	29	1
616-216	Helena River	Poison Lease	–01	8	720	590	Brackish	1400	2	5.5	5.1	1	1300	1	4.3	5.0	1

Note:

Dividing the mean salt load by the mean flow will not give the reported mean salinity because mean salinity was calculated by taking the average of the 10 annual salinity figures.

[a] If the whole period for the 10-year means was not available then whatever data was available within that period was used.

[b] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

Swan-Avon Study Area: Salt output/input ratios and annual trends

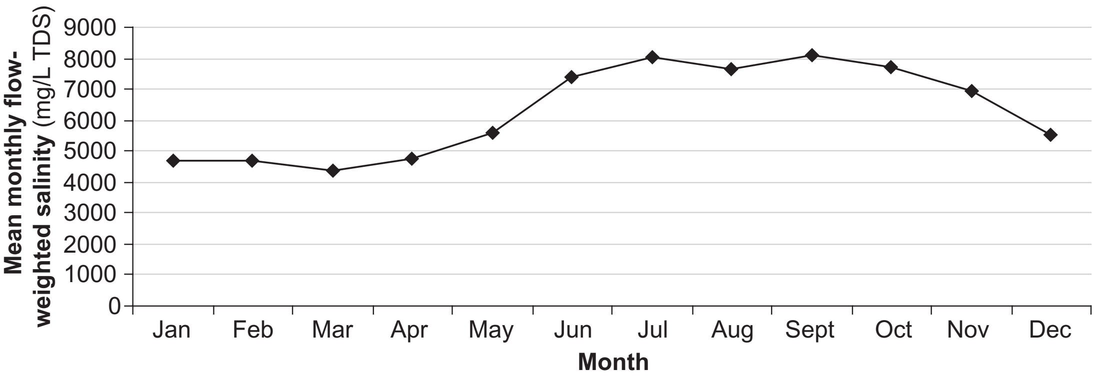
			Characteristics				Salt balance			Annual salinity trend (mg/L TDS)[b]		Annual salt load trend (kt)[b]		Annual flow trend (GL)[b]	
Site number	Watercourse	Site	Clearing 1996 (%)	Mean annual rainfall (mm)	Area (km²)[a]	Salinity status	Salt input (t/yr/km²)	Salt output (t/yr/km²)	Salt output/input ratio	1980–1989	1990–1998	1980–1989	1990–1998	1980–1989	1990–1998
SWAN-AVON RIVER BASIN															
615-012	Lockhart River	Kwolyn Hill	90	350	6050	Highly saline	1.8	16	9.0	-	-	-	-	-	-
615-013	Mortlock River North	Frenches	96	380	2333	Highly saline	2.9	109	37	-	-	-	-	-	-1.1ns
615-014	Avon River	Brouns Farm	86	380	26856	Saline	2.1	30	14	-	-	-	-	-5.6ns	-2.9ns
615-015	Yilgarn River	Gairdners Crossing	82	310	11540	Highly saline	1.5	6	3.6	-	-	-	-	2.4ns	-2.5ns
615-020	Mortlock River	O'Driscolls Farm	97	360	5040	Highly saline	2.3	27	12	-	-	-	-	-1.6ns	-1.4ns
615-062	Avon River	Northam Weir	86	390	28485	Saline	1.0	27	27	-	140s	-	21s	-8.4ns	-2.8ns
615-222	Dale River South	Brookton Highway	64	530	286	Moderately saline	1.0	80	80	-	-	-	-	-0.30ns	-0.067ns
616-001	Wooroloo Brook	Karls Ranch	49	850	514	Moderately saline	9.2	171	19	15ns	-13ns	0.67ns	-0.68ns	-1.9ns	-1.5ns
616-002	Darkin River	Pine Plantation	4	730	665	Fresh	6.8	1.0	0.15	-	-	-	-	-	0.11ns
616-006	Brockman River	Tanamerah	48	610	961	Moderately saline	6.3	72	12	-	25s	-	0.71s	-	0.23ns
616-011	Swan River	Walyunga	85	400	40401	Moderately saline	2.7	38	14	95s	-	35s	-	-23ns	-
616-013	Helena River	Ngangag-uringuring	9	650	327	Brackish	5.8	8.8	1.5	-	-	-	-	-	-
616-019	Brockman River	Yalliawirra	43	700	1521	Moderately saline	7.1	75	11	51s	22s	2.2s	1.4s	-2.4ns	-0.37ns
616-039	Canning River	Millars Road	0	820	146	Fresh	7.9	2.1	0.26	-	-	-	-	-	-
616-040	Susannah Brook	Gilmours Farm	58	1000	23	Fresh	12	60	4.8	-	-	-	-	-	-
616-065	Canning River	Glen Eagle	0	880	520	Fresh	9.0	4.7	0.52	-	-	-	-	-	-
616-189	Ellen Brook	Railway Parade	45	780	581	Marginal	11	30	2.7	-	-	-	-	-	-
616-216	Helena River	Poison Lease	8	720	590	Brackish	6.8	7.2	1.1	15s	-19s	0.081s	-0.11s	-0.62ns	0.30ns

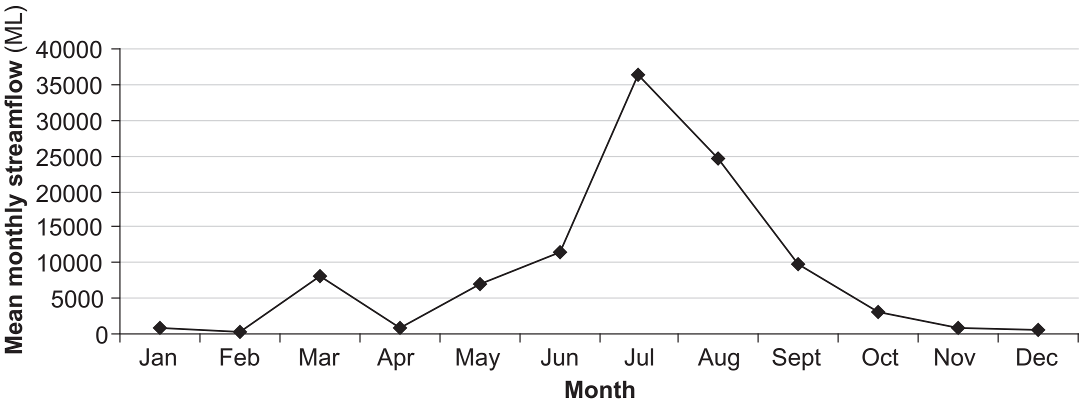
Note:

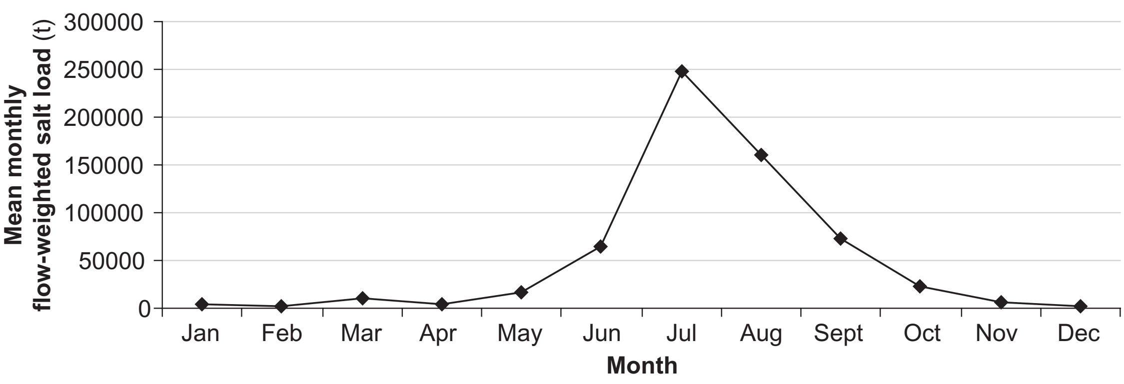
[a] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

[b] s denotes statistically significant trend at the 95% confidence limit, ns means not statistically significant.

Appendix K
Northern Agricultural Study Area: mean monthly flow, salinity and salt load

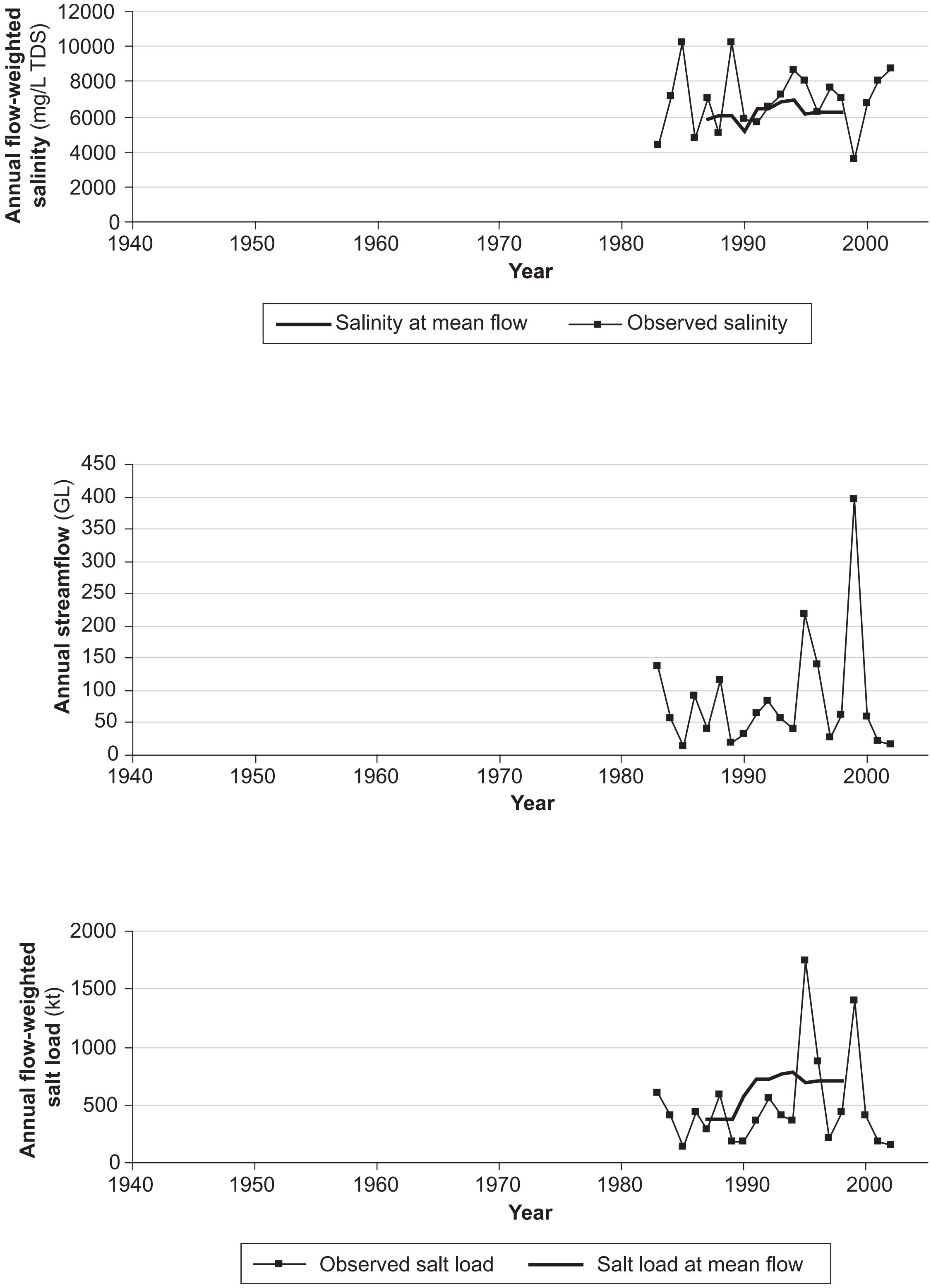




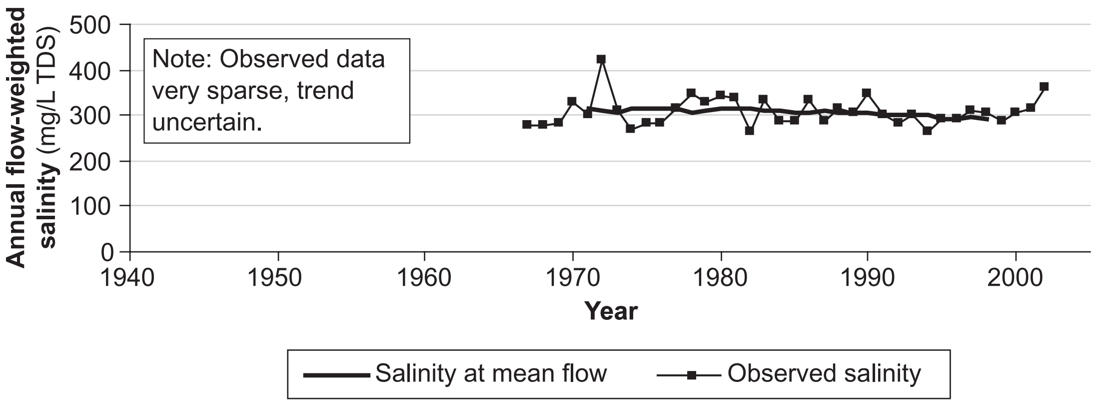


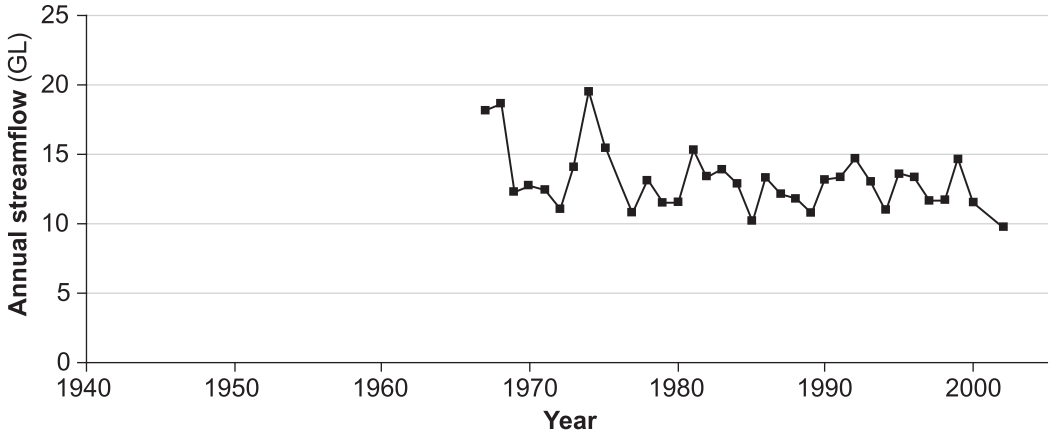
Monthly means (1993–2002) for site 617-001, Moore River, Quinns Ford

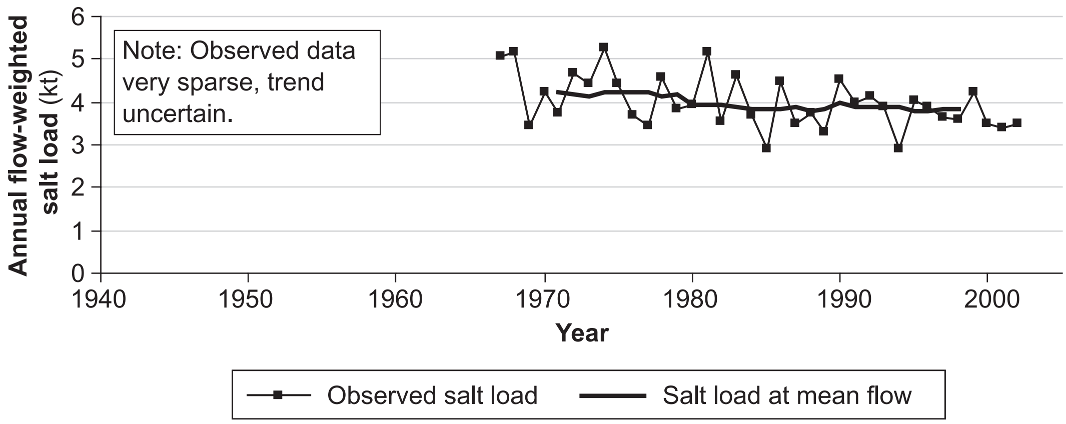
Appendix L
Northern Agricultural Study Area: long-term salinity, salt load and flow trends



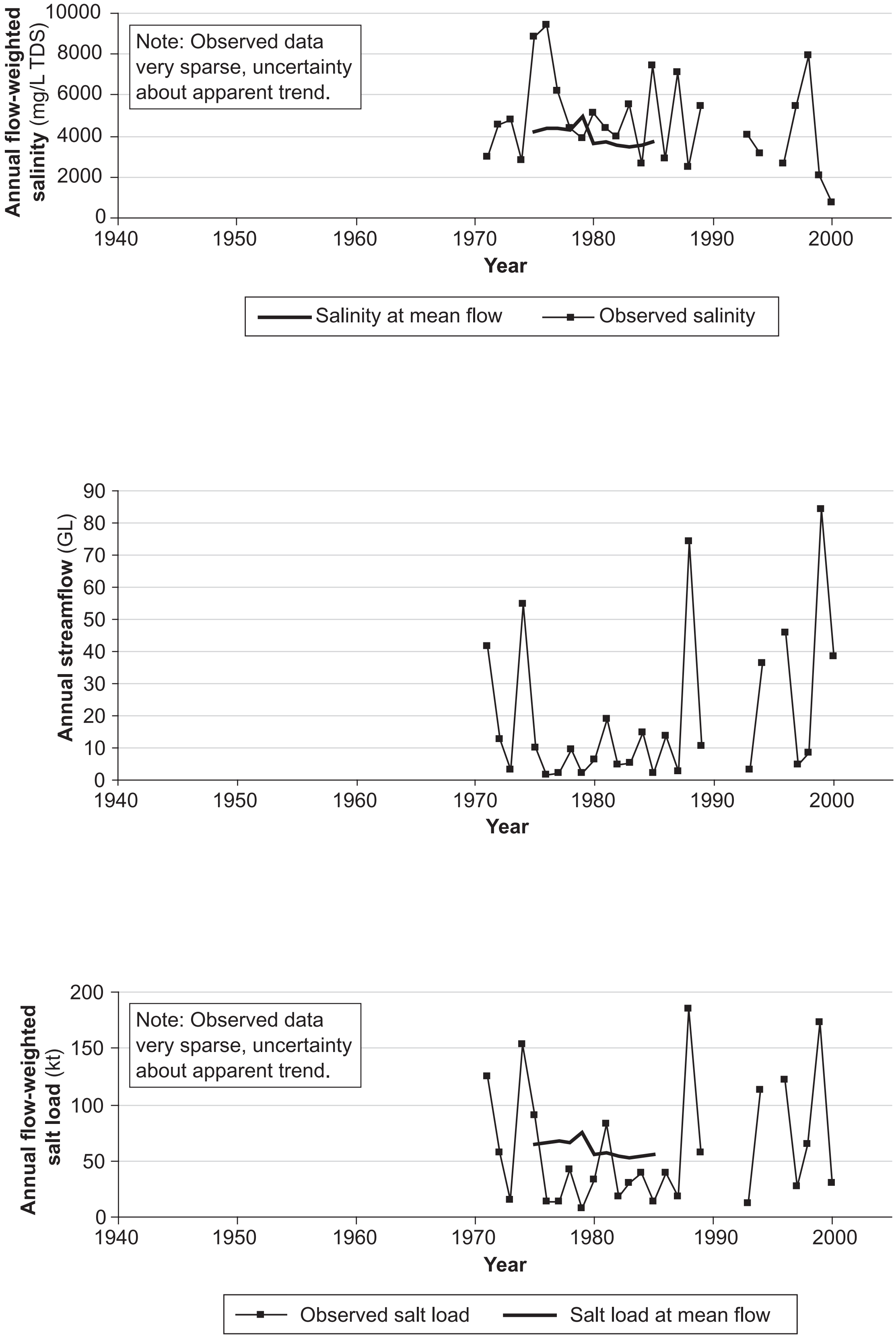
Long-term trends for site 617-001, Moore River, Quinns Ford







Long-term trends for site 617-058, Gingin Brook, Gingin



Long-term trends for site 701-002, Greenough River, Karlanew Peak

Appendix M
Northern Agricultural Study Area: catchment characteristics, salinity status, mean and current values, salt output/input ratios and annual trends

Northern Agricultural Study Area:
Catchment characteristics, salinity status, mean and current salinities, salt loads and streamflow

				Characteristics				Mean annuals 1983–1992					Current annuals (mean 1993–2002)				
Site number	Watercourse	Site	Data period[a]	Clearing 1996 (%)	Mean annual rainfall (mm)	Area[c] (km²)	Salinity status	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability	Salinity (mg/L TDS)	Reliability	Salt load (kt)	Flow (GL)	Reliability
MOORE-HILL RIVERS BASIN																	
617-001	Moore River	Quinns Ford		79	450	9608	Saline	6700	2	375	65	2	7200	1	616	104	1
617-002	Hill River	Hill River Springs		52	530	1141	Brackish	930	3	1.2	2.4	1	1100	4	1.1	2.1	1
617-003	Gingin Brook	Bookine Bookine		44	700	1370	Marginal	790	5	32	41	1	840	5	31	37	1
617-058	Gingin Brook	Gingin		59	720	106	Fresh	310	4	3.9	13	2	300	5	3.7	12	1
617-165	Lennard Brook	Molecap Hill	84–90, 92, 93, 94–00	49	720	59	Fresh	340	4	2.2	6.5	1	390	5	2.9	7.5	1
GREENOUGH RIVER BASIN																	
701-002	Greenough River	Karlanew Peak	–89, 93,94, 96–00	50[b]	330	11736	Moderately saline	4800	4	55	18	1	3700	5	78	32	1
701-005	Arrowsmith River	Robb Crossing	–89, 93, 94, 96–98	83	510	809	Moderately saline	2700	5	11	6.0	1	2900	5	15	6.2	2
701-007	Chapman River	Utakarra	–00	90	470	1 578	Moderately saline	2900	3	54	21	1	2900	3	67	31	1
701-009	Irwin River	Mountain Bridge	–89, 94, 96–02	84	415	5 264	Moderately saline	1900	4	49	31	1	2300	5	71	43	1
MURCHISON RIVER BASIN																	
702-001	Murchison River	Emu Springs	83, 86–90, 92–99, 01	5[b]	220	86777	Brackish	1100	3	113	156	1	2000	4	149	159	1

Note:

Dividing the mean salt load by the mean flow will not give the reported mean salinity because mean salinity was calculated by taking the average of the 10 annual salinity figures.

[a] If the whole period for the 10-year means was not available then whatever data was available within that period was used.

[b] Clearing figures not consistent with the other catchments. See Appendix A.

[c] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

Northern Agricultural Study Area: Salt output/input ratios and annual trends

Site number	Watercourse	Site	Characteristics: Clearing 1996 (%)	Characteristics: Mean annual rainfall (mm)	Characteristics: Area (km^2)[b]	Salinity status	Salt balance: Salt input (t/yr/km²)	Salt balance: Salt output (t/yr/km²)	Salt balance: Salt output/input ratio	Annual salinity trend (mg/L TDS)[c] 1980–1989	Annual salinity trend (mg/L TDS)[c] 1990–1998	Annual salt load trend (kt)[c] 1980–1989	Annual salt load trend (kt)[c] 1990–1998	Annual flow trend (GL)[c] 1980–1989	Annual flow trend (GL)[c] 1990–1998
MOORE-HILL RIVERS BASIN															
617-001	Moore River	Quinns Ford	79	450	9608	Saline	3.5	64	18	-	50ns	-	5.6ns	-	4.7ns
617-002	Hill River	Hill River Springs	52	530	1141	Brackish	5.7	1.0	0.17	-	-	-	-	-0.17ns	0.12ns
617-003	Gingin Brook	Bookine Bookine	44	700	1370	Marginal	9.9	23	2.3	-	-	-	-	0.78ns	-1.8ns
617-058	Gingin Brook	Gingin	59	720	106	Fresh	8.5	35	4.1	-	-	-	-	-	-
617-165	Lennard Brook	Molecap Hill	49	720	59	Fresh	9.0	49	5.5	-	-	-	-	-	-
GREENOUGH RIVER BASIN															
701-002	Greenough River	Karlanew Peak	50[a]	330	11736	Moderately saline	2.6	6.6	2.5	-	-	-	-	2.6ns	-0.43ns
701-005	Arrowsmith River	Robb Crossing	83	510	809	Moderately saline	5.7	19	3.3	-	-	-	-	-	-
701-007	Chapman River	Utakarra	90	470	1578	Moderately saline	7.0	43	6.1	-	-	-	-	-0.50ns	3.6ns
701-009	Irwin River	Mountain Bridge	84	415	5264	Moderately saline	4.1	13	3	-	-	-	-	-	4.9ns
MURCHISON RIVER BASIN															
702-001	Murchison River	Emu Springs	5[a]	220	86777	Brackish	1.1	1.7	1.6	-	-	-	-	-	15ns

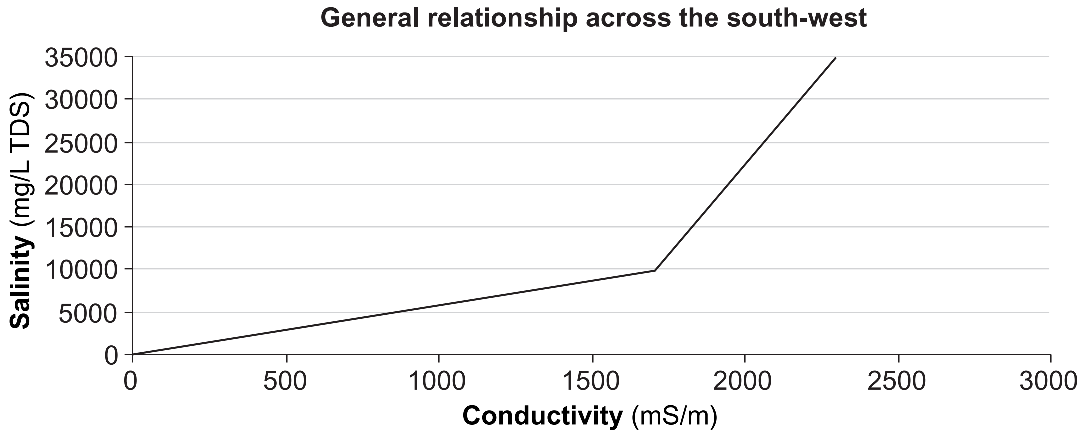
Note:

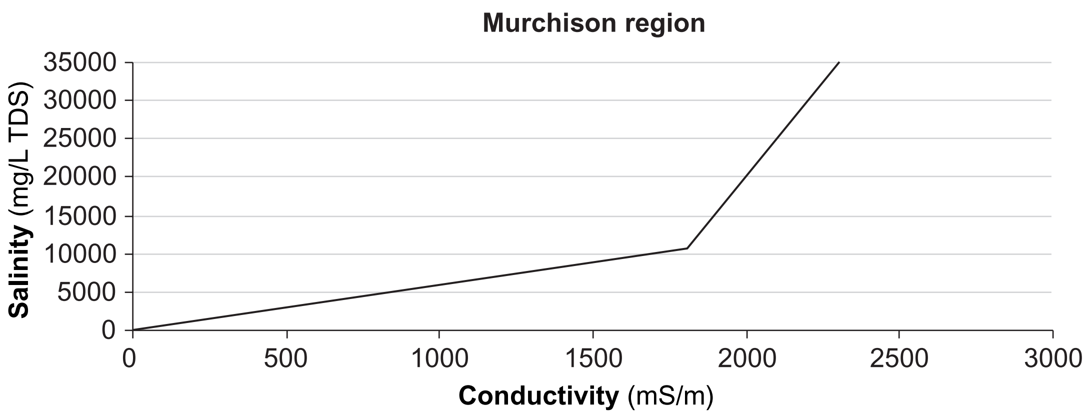
[a] Clearing figures not consistent with the other catchments. See Appendix A.

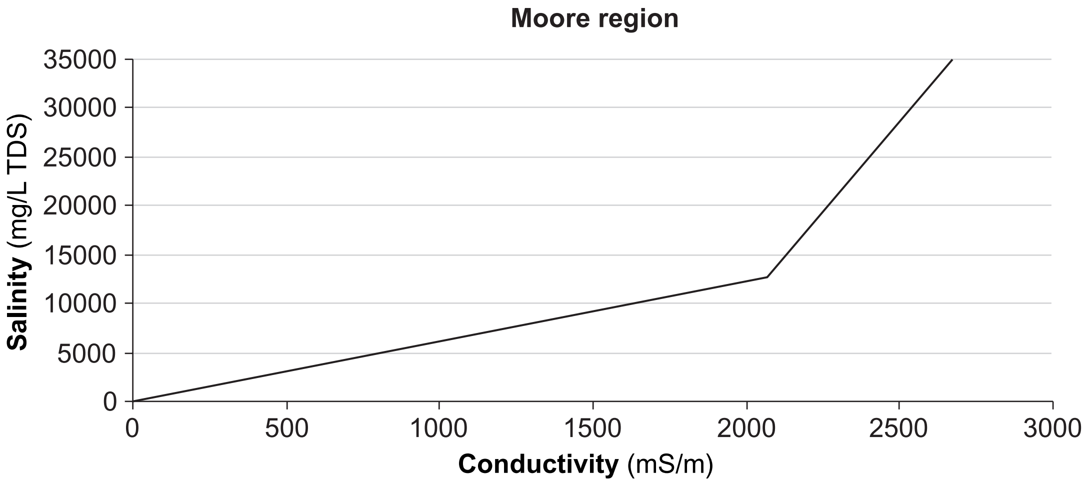
[b] Area that normally contributes (See Appendix O). Clearing percentage and rainfall also based on normal area.

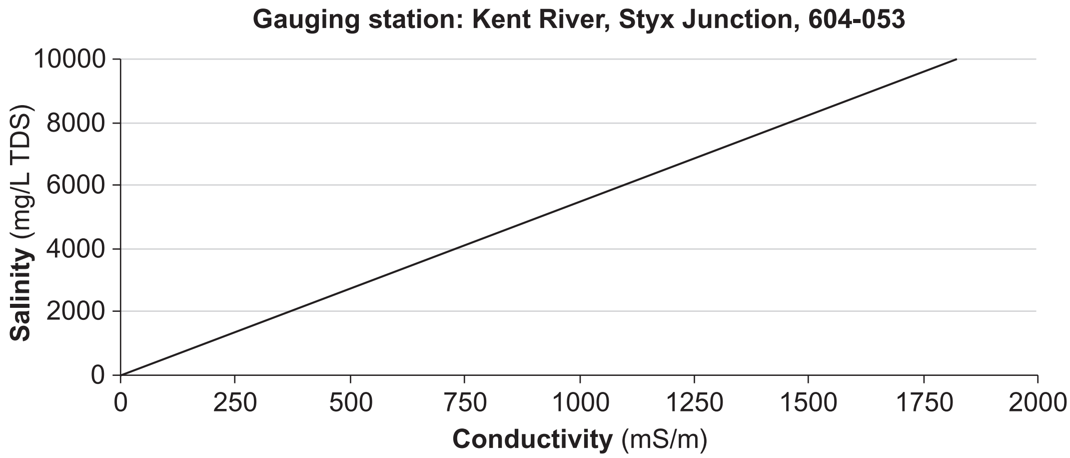
[c] s denotes statistically significant trend at the 95% confidence limit, ns means not statistically significant.

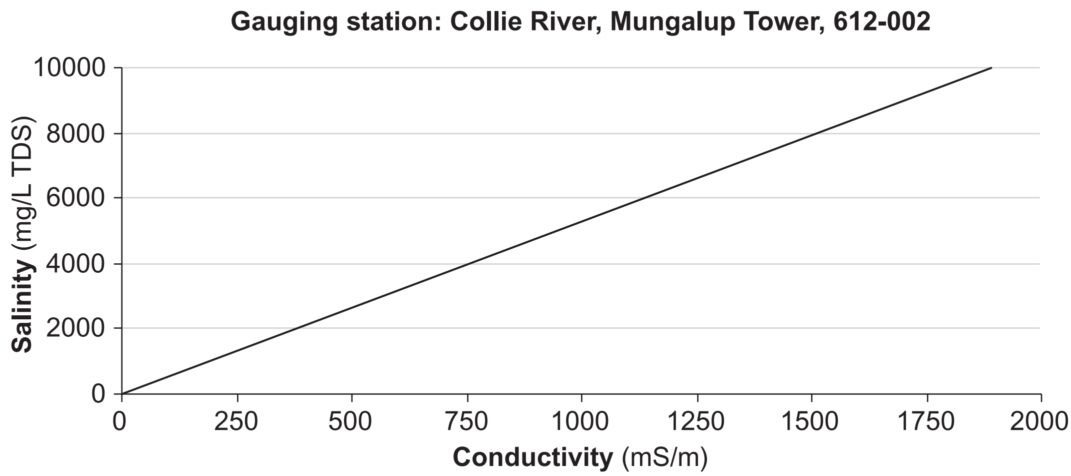
Appendix N
Conductivity (EC) – salinity (mg/L TDS) relationships around the south-west








Gauging station: Kent River, Styx Junction, 604-053
Salinity (mg/L TDS)
10000
8000
6000
4000
2000
0
0
250
500
750
1000
1250
1500
1750
2000
Conductivity (mS/m)


Gauging station: Collie River, Mungalup Tower, 612-002
Salinity (mg/L TDS)
10000
8000
6000
4000
2000
0
0
250
500
750
1000
1250
1500
1750
2000
Conductivity (mS/m)

Appendix O
Catchment areas: normal, flooding and full

Site number	Watercourse	Site	Area that normally contributes (km^2)	Area that contributes during flooding [a] (km^2)	Full catchment area [b] (km^2)
ALBANY COAST BASIN					
602-001	Pallinup River	Bull Crossing	3 327	3 327	4 214
602-009	Robinson Drain	Drop Structure	12	12	18
SHANNON RIVER BASIN					
606-001	Deep River	Teds Pool	467	468	837
BLACKWOOD RIVER BASIN					
609-012	Blackwood River	Winnejup	9 725	17 521	17 521
609-014	Arthur River	Mount Brown	2 116	3 114	3 114
609-015	Beaufort River	Manywaters	1 565	9 361	9 361
609-019	Blackwood River	Hut Pool	13 368	21 164	21 164
609-021	Coblinine River	Bibikin Road Bridge	3 915	5 861	5 861
SWAN-AVON RIVER BASIN					
615-012	Lockhart River	Kwolyn Hill	6 050	30 877	31 641
615-013	Mortlock River North	Frenches	2 333	6 842	6 842
615-014	Avon River	Brouns Farm	26 856	95 204	97 437
615-015	Yilgarn River	Gairdners Crossing	11 540	54 180	55 650
615-020	Mortlock River	O'Driscolls Farm	5 040	5 321	9 658
615-062	Avon River	Northam Weir	28 485	96 834	99 067
616-011	Swan River	Walyunga	40 402	113 540	120 110
MOORE-HILL RIVERS BASIN					
617-001	Moore River	Quinns Ford	9 608	11 180	79 760
MURCHISON RIVER BASIN					
702-001	Murchison River	Emu Springs	86 777	86 777	101 340

[a] Catchment area that will contribute flow in major flood years.

[b] Full catchment: Catchment area based on AWRC (Australian Water Resources Council) basin areas.

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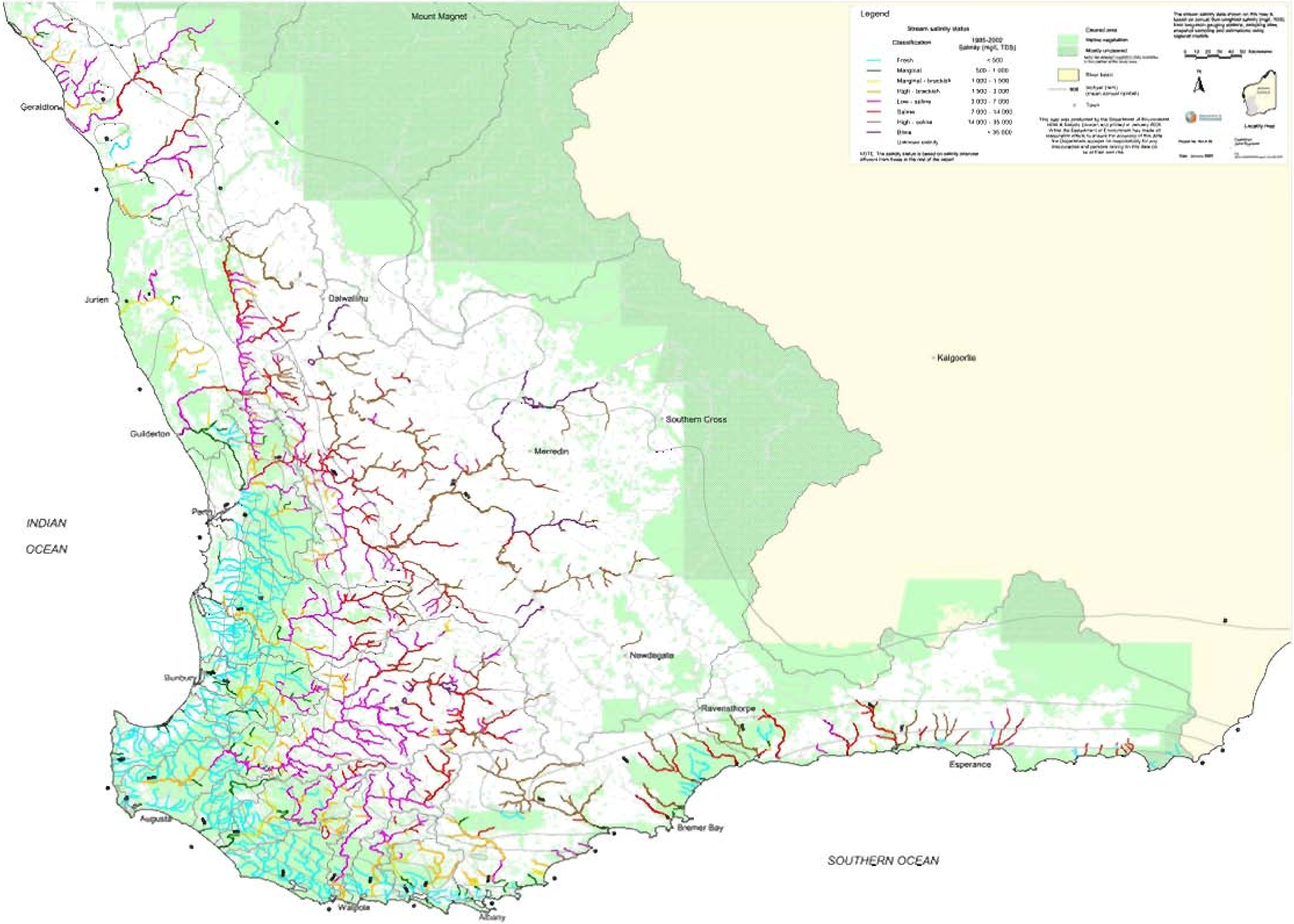

Map. Stream salinity around the south-west of Western Australia www.environment.wa.gov.au

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