An Assessment of Water Resources and Recharge in the Hindmarsh River, Inman River and Currency Creek Catchments

by
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An Assessment of Water Resources and Recharge in the Hindmarsh River, Inman River and Currency Creek Catchments

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by

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Statement of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any University or other institution and, to the best of my knowledge, contains no material previously published or written by another person, except for where due reference has been made in the text. I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

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Executive Summary

The Mount Lofty Ranges lie to the east of Adelaide and contain a significant groundwater resource of low salinity. There are three catchments in the Southern Mount Lofty Ranges where minimal information exists on the sustainable groundwater yield - Hindmarsh River, Inman River and Currency Creek. Effective water allocation in this area requires information on the extent of the water resource and the relationship between surface and groundwater. As this resource is coming under increasing pressure for development it is important to develop appropriate land and water management strategies in order to ensure that future development is sustainable.

The hydrogeology of all three study catchments is directly related to the underlying geological formations which determine both the quantity and quality of groundwater in the area: Cape Jervis Beds, Kanmantoo Formation, Quaternary and Tertiary Limestone. Except for the clearly defined confined Tertiary Limestone aquifer in the Hindmarsh Tiers valley, there does not appear to be any apparent delineation of aquifers in the other formations. The Cape Jervis Bed formations are a mixture of erratic sand and clay layers and wells are completed in both. The "aquifers" in the Cape Jervis Bed formation appear to be small, local and not interconnected. The Kanmantoo Group is tapped by many bores throughout each of the study catchments and water quality and well yields appear to be highly variable and most likely dependent on the fracture zones in which the bore is completed.

There are 84 operational bores in the Hindmarsh River Catchment, 47 of which are listed as irrigation bores. In the Inman River Catchment 70 bores are listed as operational with 45 bores listed as being used for irrigation. In the Currency Creek Catchment, there are 61 bores listed as being operational and 25 irrigation bores. These bores are tapped into different geological formations which impact the quality and quantity of water they can provide.

The Hindmarsh Tiers Basin in the Hindmarsh River Catchment has a well established observation bore network with 25 years of record on water levels. Most of these observation bores are showing a decreasing water level trend over the years which is most likely due to decreasing rainfall and increasing irrigation in the area. The potentiometric surface at the lower southeastern end of the catchment appears to have decreased by 10 metres in the last 25 years.

Salinity in the groundwater varies depending on the geological formation the bore is completed in. In the Hindmarsh River Catchment, the lowest salinity concentrations are evident in the Tertiary Limestone formation and the Kanmantoo Group and Cape Jervis Bed formation appear to have about the same salinity concentrations (Cape Jervis Beds are slightly higher). In the Inman River Catchment, the highest salinity concentrations were found in the Cape Jervis Beds and the average concentrations were almost double those in the Hindmarsh River Catchment. In the Currency Creek Catchment, the

salinity concentrations of bores completed into the Cape Jervis Beds and the Kanmantoo Group had similar average salinity concentrations which were a bit lower than bores in the Hindmarsh River Catchment.

Land use in all three catchments was fairly similar with grazing being the predominant land use followed by dairy. Urban developments accounted for 2% of the land use in the Hindmarsh River and Inman River Catchments which is associated with Victor Harbour. The Currency Creek Catchment has had more land use changes in the past 6 years as the area for growing vines has doubled. Hindmarsh River and Inman River have similar amounts of native vegetation (12%) and Currency Creek has about half (5%).

Water balances were calculated for each of the catchments using direct and indirect estimations of the water balance components: rainfall, runoff, evapotranspiration and farm dam volumes. The highest rainfall was estimated for Inman River followed by Hindmarsh River and Currency Creek Catchments. These results are consistent with the weather coming from the southwest in this area. Analysis of the rainfall data indicates that since the last above average rainfall event in 1992/1993, rainfall has been below average. It is estimated that the Inman River and the Hindmarsh River have similar natural runoff volumes followed by Currency Creek. However, the volume of water reaching the lower ends of these catchments is reduced by diversions into farm dams and irrigation use. The highest water loss through evapotranspiration is in the Inman River Catchment, followed by the Hindmarsh and Currency Creek. Inman River Catchment has the highest estimated volume of water in farm dams followed by Currency Creek and then Hindmarsh River Catchments.

Groundwater recharge was estimated for each of the study catchments by three different methods producing three different results: water balance, chloride and groundwater balance methods. In the water balance method recharge was estimated to be:

- 17,152 ML for the Hindmarsh River Catchment;
- 24, 581 ML for the Inman River Catchment; and
- 6,347 ML for the Currency Creek Catchment.

The recharge estimates from the chloride method were lower by one order of magnitude and were discarded as a salt balance indicated that there is a net export of salt out of these catchments. This implies that the chloride concentrations in these catchments are not in a steady state and this method of calculating recharge is invalid.

The groundwater balance method recharge values were much lower than those estimated through the water balance method:

- 9,736 ML for the Hindmarsh River Catchment;
- 9,114 ML for the Inman River Catchment; and
- 2,721 ML for the Currency Creek Catchment.

This method is dependent on the groundwater use and baseflow and in the Inman River Catchment it was determined that there was very low usage of groundwater which in turn has resulted in a low estimate for recharge for Inman River Catchments. Therefore, the most reasonable estimate of recharge is most likely the water balance recharge results.

Water use was estimated in each of the study catchments through theoretical estimations and a field survey and estimations of domestic and stock use. The results of the field survey estimated irrigation volumes that were considerably less than the theoretical estimations. The results of the field survey should not be considered to be precise, as the rates of use provided by the irrigators were approximations only. Irrigation use in the Hindmarsh Valley Catchment appears to have increased over the years, as indicated by a two-fold increase in the irrigation use in the Hindmarsh Tiers Basin. In the Inman Valley Catchment, there does not appear to be much irrigation which is mainly due to the quality of the groundwater and surface water in the area. In the Currency Creek Catchment, there is no historical irrigation data for comparison but it is assumed that there is increasing irrigation in this catchment due to the development of vines and olive orchards. The following irrigation volumes were estimated through the field survey:

- 4,854 ML in the Hindmarsh River Catchment;
- 156 ML in the Inman River Catchment; and
- 909 ML in the Currency Creek Catchment.

The following results are for the total water use in each catchment. The higher end of each range is based on theoretical estimations only and, as seen, these numbers appear to be much higher than the estimations based on the field survey. The largest water use was in the Hindmarsh River Catchment where the total water use ranged from 5,087 to 10,382 ML per year. This catchment also had the highest groundwater use with the volumes ranging from 5,464 to 8,784 ML per year. The next highest water use was seen in the Currency Creek Catchment with the total water use ranging from 1,095 to 8,795 ML per year and the groundwater use ranging from 634 to 3,986 ML per year. The smallest water use was apparent in the Inman River Catchment with total water use ranging from 432 to 10,164 ML per year and groundwater use from 109 to 534 ML per year. The largest use of groundwater is in the Hindmarsh River Catchment followed by Currency Creek. Inman River Catchment only uses a small amount of groundwater. Caution should be taken in the accuracy of all these estimations and if more accurate data is made available, these numbers should be revised.

It has been proposed that the sustainable yield for groundwater should not exceed 75% of the estimated recharge. In the Hindmarsh River Catchment, the current level of groundwater use is most likely around 50% of the recharge for the catchment. There is intensive groundwater irrigation in the Hindmarsh Tiers Basin which has more than doubled in the last 25 years. Although the groundwater use in this catchment is below the adopted 75% of recharge, the groundwater usage should be carefully monitored on a regular basis to ensure that the reduction of water levels in the Tertiary Limestone aquifer are not being impacted further from groundwater extraction. The total water use for this catchment is slightly higher and could be up to 60% of the annual recharge.

In the Inman River Catchment, the groundwater use is very low and well below any level of concern with respect to groundwater sustainability. There is not a lot of irrigation currently occurring in this catchment due in part to the high salinity levels found in both the groundwater and surface water in the summer. There is more concern in this catchment with the surface water resource and care should be taken to ensure that dams and water diversions are constructed and managed in such a way to protect the rights of the downstream users and to ensure that there are adequate environmental flows to protect catchment ecosystems.

In the Currency Creek Catchment, the estimated groundwater use is below the estimated 50% of recharge but the total water use is approximately 50% of the annual recharge. The low groundwater use has been estimated from the results of the field survey where it was found that surface water and groundwater were used in almost equal portions for irrigation. In addition, like the Inman River Catchment, the quality of the groundwater in parts of Currency Creek deters its use for irrigation, stock and domestic use. The level of development in the Currency Creek Catchment is in more of a dynamic state than the other two catchments and future developments should be closely monitored with respect to their impacts on the existing water resources to ensure their sustainability.

Recent changes in the *Water Resources Act* have placed the burden of water management on local governments and Catchment Water Management Boards. In areas that are not proclaimed waterways, this burden is more pronounced as water management is an invasive issue and in some cases beyond the control and resources of local governments. This presents a challenge to all those involved and it is hoped that this study will in some way assist in the future management of the important water resources in the Hindmarsh River, Inman River and Currency Creek Catchments.

1.0 Introduction

The Mount Lofty Ranges lie to the east of Adelaide (see Figure 1) and contain a significant groundwater resource of low salinity. As this resource is coming under increasing pressure for development it is important to gain an understanding of the extent of the resource and to develop appropriate land and water management strategies in order to ensure that future development is sustainable.

There are three catchments in the Southern Mount Lofty Ranges where minimal information exists on the sustainable groundwater yield - Hindmarsh River, Inman River and Currency Creek. Effective water allocation in this area and other parts of the central and southern Mount Lofty Ranges requires information on the extent of the water resource and the relationship between surface and groundwater. The collection and assessment of this type of information should assist decision makers in ensuring that the most sustainable water uses and economic uses are allocated for future development.

This report has compiled the best available information on the water resources in the Hindmarsh River, Inman River and Currency Creek Catchments. There are limitations and constraints associated with most of the water resource information collected that should be recognised and taken into consideration when reviewing the results. A field survey was conducted to collect information on current irrigation practices in the study catchments and to provide an estimation of the volumes of water used for irrigation purposes. Groundwater recharge estimations were calculated for each of the study catchments and discussed in terms of sustainability. This report concludes with a list of recommendations for management of the water resources in these catchments. The information provided in this report should be useful to decision makers in ensuring that the future management of the water resources in the study catchments is done in a sustainable manner.

Figure 1. Location of Hindmarsh River, Inman River and Currency Creek Catchments
ADELAIDE
BRIDGEWATER
MOUNT BARKER
STRATHALBYN
GOOLWA
VICTOR HARBOR
138°20'
138°40'
35°00'
35°20'
35°40'

2.0 Catchment Descriptions

2.1 Hindmarsh River

The Hindmarsh River catchment is located about 55 km south of Adelaide (see Figure 1) and is 11,302 ha in total area (see Table 1).

2.1.1 Topography

The upper portion of the catchment is occupied by the Hindmarsh Tiers Basin which is a small elongated valley of about 7 km^2 (700 ha) located to the east of Myponga in the central part of the southern Mount Lofty Ranges. There are several dairy operations in this valley and groundwater is used to irrigate green pasture for dairy cows. The lower portion of the Hindmarsh River Catchment is a narrow valley with hills on either side ending at Victor Harbour on the coast. Peeralilla Hill and Mount Billy are in the lower end of the catchment.

2.1.2 Soils

There are three common soil types in the Hindmarsh River Catchment (SCRN et al, 2000):

- Thick, grey, acid sand with a leached A2 layer over a brown grey and yellow, mottled clay, grading to alluvium or Permian glacial sediments. These soils are infertile, often poorly drained and susceptible to acidification. This soil type is used for grazing only and covers 20% of the catchment.

- Acid loam to clay loam over well-structured, brown or orange clay, grading to siltstone or shale within 100 cm. These soils are fertile and deep and are used for improved pastures and horticulture where water is available. This soil type covers 15% of the catchment.

- Acid, loamy sand to sandy loam over friable, brown, sandy clay to clay, grading to sandstone or schist basement rock within 100 cm. These soils have low to moderate fertility, are prone to acidification and are highly erodible and are mainly used for grazing. This soil type covers 15% of the catchment.

2.2 *Inman River*

The Inman River catchment is located approximately 70 km south of Adelaide (see Figure 1). The catchment runs in an easterly direction from Bald Hills through to Victor Harbour and has an area of 19,509 ha (see Table 1).

2.2.1 Topography

Hills enclose the Inman River Catchment and the Inman River flows through an expansive flood plain. The major watercourses in the catchment are believed to follow ancient valleys or basins. Many watercourses in the catchment were originally marshy wetlands with no defined channel (Burston and Good, 1995). Natural erosion over the years has resulted in undulating to rolling landscape in the valley floor which is quite distinct from the steeper and higher hills of the surrounding landscapes.

2.2.2 Soils

The three most common soil types are similar to those described above for the Hindmarsh River Catchment. The majority of the soils in the valley floor are derived from Permian glacial sediments and generally have a sandy to loamy surface. Isolated remnants of the old ferricrete capping occur high in the catchment landscape as the resistant ironstone has prevented the erosion of the softer underlying sediments (Burston and Good, 1995).

2.3 *Currency Creek*

The Currency Creek Catchment covers 9,224 ha (see Table 1) and is located on the western shores of Lake Alexandrina. It is bounded to the north by Deep Creek (Lakes) and Tookayerta Catchments, to the east by the Hindmarsh Catchment to the south by the Middleton and Sturt Point Catchments.

2.3.1 Topography

The Currency Creek Catchment extends from south of Mount Compass to the shores of Lake Alexandrina. The headwaters of Currency Creek rise in the hills around Mount Jagged and the topography ranges from a rolling landscape in the west through undulating hills to the gently sloping flats adjacent to Lake Alexandrina.

Native vegetation is found across the catchment and mainly on the steeper slopes. The southern half of Scott Conservation Park is situated on the northeastern boundary.

2.3.2 Soils

There are three dominant soil types in the Currency Creek catchment (SCRN et al, 2000):

- Acid loam to clay loam over well-structured, brown or orange clay grading to siltstone or shale within 100 cm. These soils have high water holding capacities and are widely used for pasture for dairying, other grazing and some horticulture. This soil type covers 35% of the catchment.
- Thick, acid grey sand with a strongly bleached A2 layer over brown and yellow sandy clay to heavy clay grading to Permian glacial sediments. These soils are infertile, often imperfectly drained, susceptible to acidification and highly erodible. The vegetation supported by these soils mainly supports grazing. This soil type covers 35% of the catchment.
- Shallow, acid, stony, loamy sand to sandy loam directly overlying sandstone or schist basement rock within 50 cm. These soils are infertile and have very low water holding capacities and are most undeveloped. This soil type covers 10% of the catchment.

Table 1. Area of the study catchments.

Catchment	Area (ha)
Hindmarsh River	11,302
Inman River	19,509
Currency Creek	9,224

2.4 Geology

All three of the catchments are located in the south central part of the Mount Lofty Ranges. The ranges were formed from a wide variety of Cambrian and Precambrian metasediments and metamorphic rocks (see Figures 2-4). The study catchments are underlain by Kanmantoo Group schists and gneisses (Inman and Hindmarsh River) and phyllites and clayey sandstones (Currency Creek). Extensive glaciation has left broad valleys infilled with Permian sand together with overlying Tertiary limestone in some cases.

The oldest rocks in the area are the Early Proterozoic mica schists, epidote gneisses and epidote quartzites of the Barossa Complex (1400 to 1800 million years old). These rocks form the southern and northern boundaries of the Hindmarsh Tiers and were intensely folded, metamorphosed and injected with quartz reefs and basic dykes before the Late Proterozoic (Furness et al, 1981). The Late Proterozoic rocks, consisting of quartzites, sandstones and slates, were deposited in the Adelaide Geosyncline and are part of the Adelaidian System.

Sediments of the metamorphosed Kanmantoo Group consisting mainly of phyllites, greywackes, quartzitic schists and micaceous quartzites, were deposited during the Cambrian Period about 500 million years ago. A large trough was formed by rapid subsidence of the eastern and southern part of the Adelaide Geosyncline in a broad arc around the eastern side of the Mount Lofty Ranges. These are generally fine grained siltstones and feldspathic sandstones that filled the trough and which have been partially altered by heat and pressure. The apparent thickness of this formation is about 21,000 metres (Barnett and Zulfic, 1999b).

There were three distinct periods of sedimentation since the Cambrian:

- Permian fluvioglacial clays, sands and conglomerates (oldest sediments);
- Tertiary fossiliferous limestones; and
- Pleistocene age mottled clays with occasional interbedded sands and gravels.

The region was covered with ice in the early Permian Period about 250 million years ago. The remnants of glacial topography and the nature of the glacial deposits indicate that the elevated mountain chain built up by the Palaeozoic orogeny was still present in the Fleurieu Peninsula during the Permian Period (Furness et al, 1981). Sediments (clay and sands) were deposited and filled the glacial valleys of the Fleurieu Peninsula. The Inman River Valley, Hindmarsh River Valley and Myponga are examples of U-shaped valleys the glaciers carved out. A maximum recorded thickness of Permian formations is 300 metres in Back Valley (Bourman, 1969). Permian till, sands and clay crop out at Hallett Cove on the Fleurieu Peninsula and on Kangaroo Island.

During the time interval between the Permian and Tertiary, the Permian surface was reduced to a peneplain which has since been uplifted and eroded. The Permian sediments are usually overlain by Tertiary fossiliferous limestones which are probably correlated with the Port Willunga Beds of the St. Vincent Basin (Furness et al, 1981). In the early Tertiary period, which occurred about 50 million years ago, the final separation of Australia from Antarctica was achieved and the St. Vincent Basin began to subside. Tertiary marine limestones and sands were deposited in the basin, which is divided into two important subbasins: Willunga and Noarlunga Embayments. The irregularities in the thickness of the overlying clays suggest erosion of the exposed limestones prior to or during the deposition of the Pleistocene sediments. The overlying clay may give rise to seasonal artesian conditions. Near the centre of the Hindmarsh Tiers Basin there is a sequence of carbonaceous clays overlying the Tertiary limestones representing a marine regression with swampy conditions. Occurrences of black clays within the limestones indicate that minor marine regression took place during the Tertiary.

Late and post-Tertiary tectonic movements have elevated the sediments at least 200 m above the level at which they were deposited (the valley floors are 220 to 240 m above sea level). The geologically recent sediments consist of sand, gravel and silt of alluvial origin found in existing creek beds.

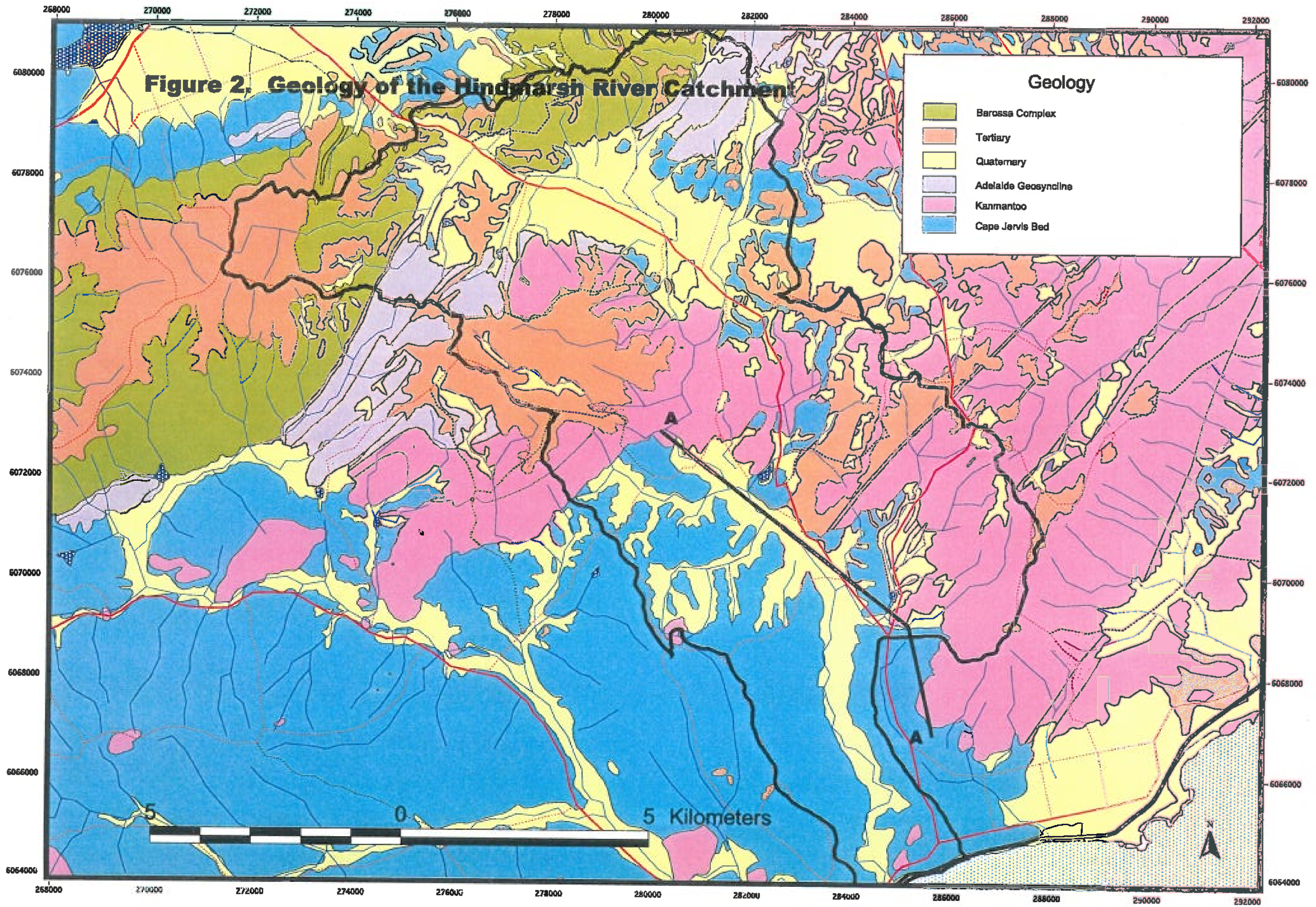


Figure 2. Geology of the Hindmarsh River Catchment
Geology
Barossa Complex
Tertiary
Quaternary
Adelaide Geosyncline
Kanmantoo
Cape Jervis Bed
A
A
5
0
5 Kilometers
N

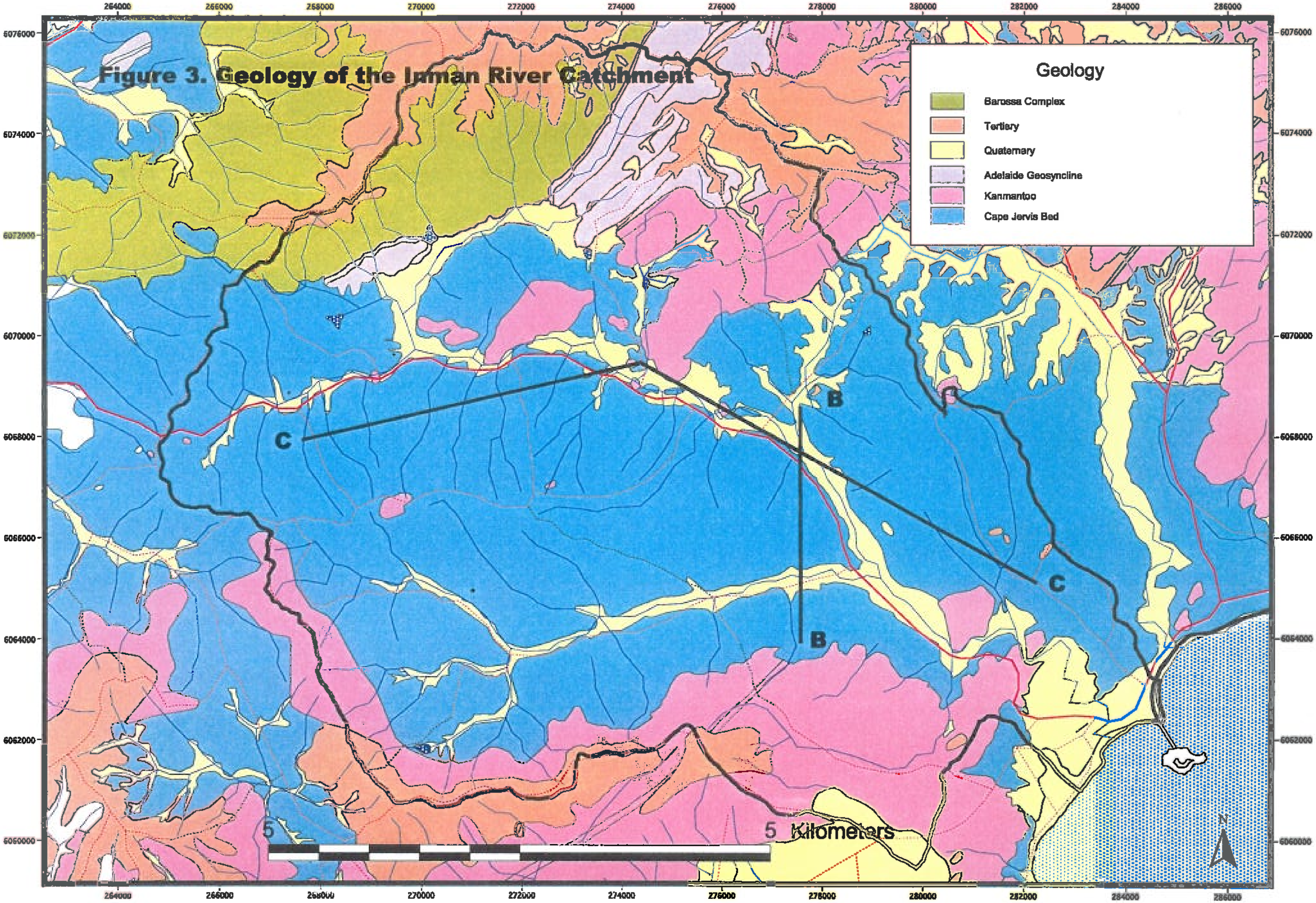


Figure 3. Geology of the Inman River Catchment

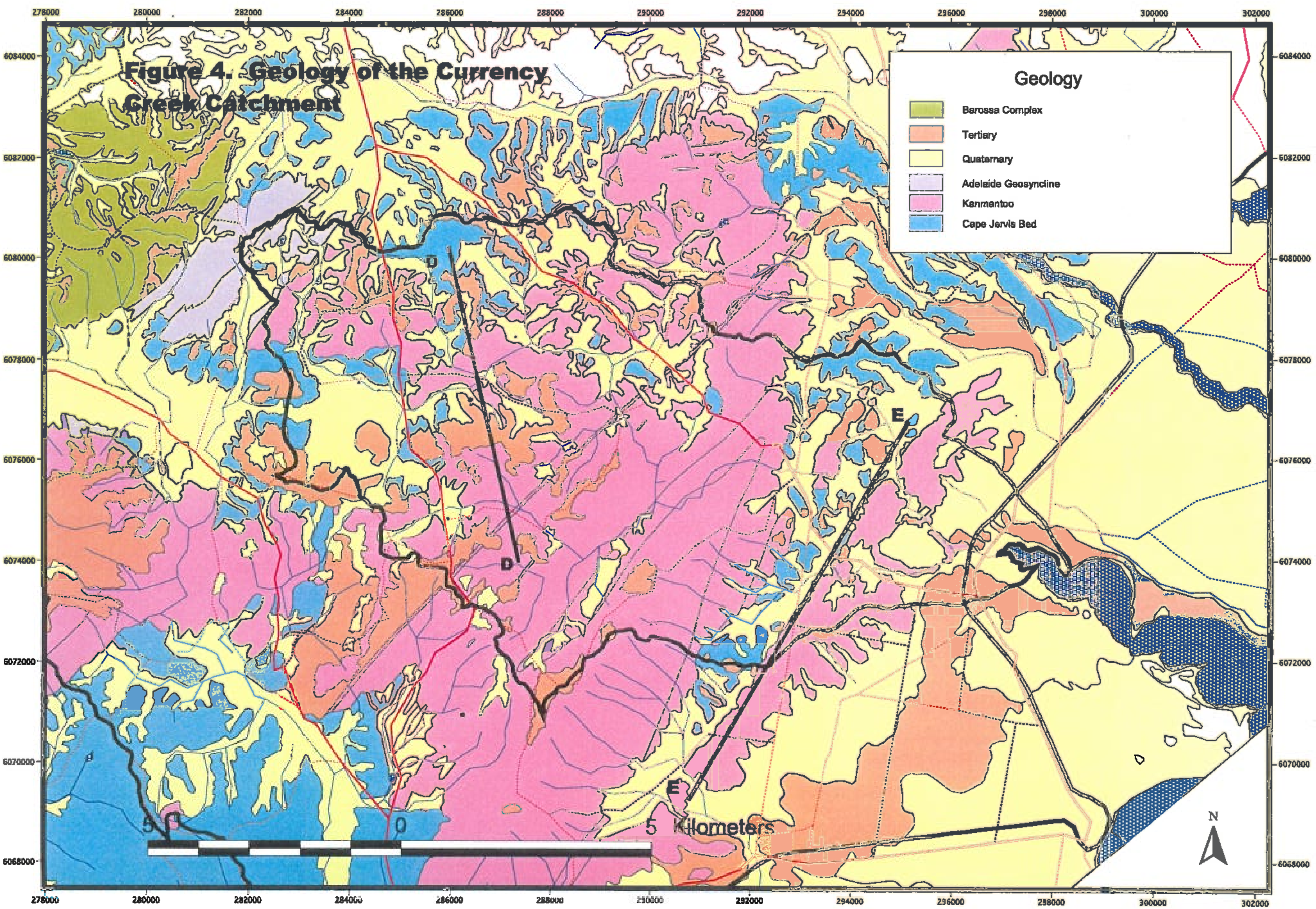


Figure 4. Geology of the Currency Creek Catchment
Geology
Barossa Complex
Tertiary
Quaternary
Adelaide Geosyncline
Kanmantoo
Cape Jervis Bed
D
D
E
E
5 0 5 Kilometers
N
278000
280000
282000
284000
286000
288000
290000
292000
294000
296000
298000
300000
302000
6084000
6082000
6080000
6078000
6076000
6074000
6072000
6070000
6068000

3.0 Hydrogeology

The hydrogeology of all three study catchments is directly related to the underlying geological formations. There are four geological formations that determine both the quantity and quality of groundwater in the area: Cape Jervis Beds, Kanmantoo Formation, Quaternary and Tertiary Limestone. Table 2 summarises the hydrogeology, yields and salinities of the various geological formations.

Table 2. Summary of geology and hydrogeology of the southern Mount Lofty Ranges (Furness et al, 1981).

Age	Stratigraphic unit and lithology	Thickness (m)	Hydrogeology
Quaternary	*Alluvium* mottled, iron-stained clays and sands	10-90	Water table aquifer under slight pressure locally. Recharged by rainfall and lateral groundwater flow
Tertiary (Miocene)	*Port Willunga Beds equivalent* – fossiliferous sandy limestones, some marly bands	3-180	*Leaky confined aquifer* recharged from surface flow and lateral groundwater flow. Main irrigation aquifer with yields of 650 to 1700 m^3/day of less than 1000 mg/L TDS
Permian	*Cape Jervis Beds* – fluvioglacial silty, clays and sands	10-125	*Unconfined aquifer* outside the plain area. Confined aquifer below the central plain and along the edges of basement ridges outside the plain. 200 to 1000 TDS. Yields vary from 100 to 560 m^3/day. Recharged from rainfall and lateral groundwater flow.
Cambrian	*Kanmantoo Group* – phyllites, greywackes, schists and quartzites		*Water table aquifer.* Usually small supplies of medium to poor quality water (4000 to 10,000 mg/L). Yields 50 to 100 KL/day. Recharged from rainfall.
Late Proterozoic	*Adelaidian System* – quartzites, sandstones and slates		*Water table aquifer.* Moderate supplies of medium quality water (500 to 3000 mg/L TDS). Yields up to 1000 KL/day in sandstones and quartzites. Recharged from rainfall.
Early Proterozoic	*Barossa Complex* – mica schists, epidote gneisses and epidote quartzites		*Water table aquifer.* Usually small supplies of medium to poor quality water. Yields generally <50 KL/day. Recharged from rainfall.

In the older rocks of the Barossa Complex, groundwater can be stored in interconnected fractures but as these rocks are deeply weathered and many fractures have been filled with clay weathering products they are poor aquifers. None of the bores in the study catchments were completed into this formation. Sandstone and quartzite beds can form high yielding aquifers and may also provide artesian bores if the orientation of the beds is favourable in the Adelaidian System. None of the bores in the study catchments were completed into this formation. In the Kanmantoo Group, fractures are well developed at the surface but close rapidly with depth. Groundwater is stored in and transmitted through the fine-grained sediments in the Cape Jervis Beds but yields are not high. Artesian wells completed into the Cape Jervis Beds are not uncommon in valley floors. Groundwater from the sediments formed in the late and post-Tertiary tectonic movements provide variable yields and salinities.

Geological cross sections have been drawn for each of the study catchments and are discussed in the following sections. Locations of these cross sections are shown in Figures 2-4. Except for the clearly defined confined Tertiary Limestone aquifer in the Hindmarsh Tiers valley, there does not appear to be any apparent delineation of aquifers in the other formations. The Cape Jervis Bed formations are a mixture of erratic sand and clay layers and wells are completed into both. The "aquifers" in the Cape Jervis Bed formation appear to be small, local and not interconnected. There is no consistent sand layer in the Cape Jervis Beds and there appears to be low interconnection between the clay and sand layers. The Kanmantoo Group is tapped by many bores throughout each of the study catchments and water quality and well yields appear to be highly variable and most likely dependent on the fracture zones in which the bore is completed.

3.1 Hindmarsh River

The substantial groundwater resource found in the Hindmarsh Tiers (see Figure 5) is stored in the Tertiary limestone and Cape Jervis Beds or Permian sands. Yields of 0.3 to 56 L/s can be obtained from wells completed into the Tertiary limestone aquifer, with drawdowns of only a few metres despite the confined nature of the aquifer. Figure 6 shows the locations of the geological cross sections and Figure 7 shows the geological cross sections across the basin showing a confined layer of a Tertiary limestone formation - from Furness et al, 1988 report. There are bores completed into the Cape Jervis Bed formations in this area as well which are used for irrigation purposes.

Figure 5. Location of the Hindmarsh Tiers Basin.

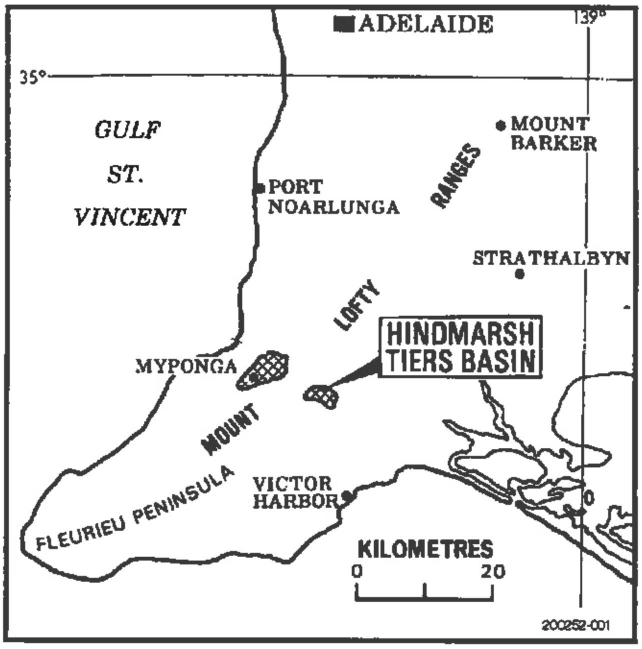


Fig. 5 Locality plan of Hindmarsh Tiers.

Groundwater flows to the east where it is lost from the aquifer system by evapotranspiration and discharge into the Hindmarsh River as shown in Figures 7, 14 and 15. There are several pathways for local recharge where the limestones crop out or are present at shallow depth around the margin of the basin (Furness et al, 1981):

- through lateral flow and possibly upward flow from the surrounding Permian sands; and/or
- though water infiltrating the soil, stored in the Pleistocene sandy clays and later permeating down into the aquifer (accelerated by pumping as pressure is locally reduced).

The subsurface clays throughout the valley floor infer that recharge there will be small (Furness et al, 1981). Most recharge will most likely occur at the foot of the hills where the limestones may occur near the surface and in the areas of Permian sands to the west. The geology and topography of the area suggest that groundwater underflow out of the area is unlikely except as a small flow through fractured basement down the Hindmarsh River Valley (Furness et al, 1981). The confined nature of the aquifer also supports the hypothesis of recharge at the edge of the sedimentary basin, which is at a higher elevation than the central flats where most bores are located (Furness et al, 1981).

Aquifer tests were performed on the limestone aquifer in the Hindmarsh Tiers Basin. Transmissivity values of 8×10^3 $m^3day^{-1}m^{-1}$ and 11.6×10^3 $m^3day^{-1}m^{-1}$ were determined for drawdown and recovery data, respectively. The hydraulic conductivities were estimated to range between 85 to 125 $m^3day^{-1}m^{-2}$. The hydraulic conductivity suggests that flow through the aquifer in the Hindmarsh Tiers may be controlled by solution cavities (Furness et al, 1981). The storage coefficient can be estimated at 0.1 to 0.2 for the unconfined situation. This which would apply if water levels declined because of over-exploitation but as the aquifer is confined, the storage coefficient is probably of the order of 10^{-3} to 10^{-2} (Furness et al, 1981).

Figure 8 shows a geological cross section for the central part of the catchment. This is an area of basement or Kanmantoo Group overlain with Cape Jervis Beds and Quaternary sands and gravels. The water table in the lower part of the catchment is elevated and the water quality is poor. The Cape Jervis Beds are a mixture of sand and clay layers. Bore number 6627 7992 is completed in the Cape Jervis Bed formation and is 231 metres in depth and a flowing artesian bore. The salinity values for these bores ranged from 2235-3637 mg/L.

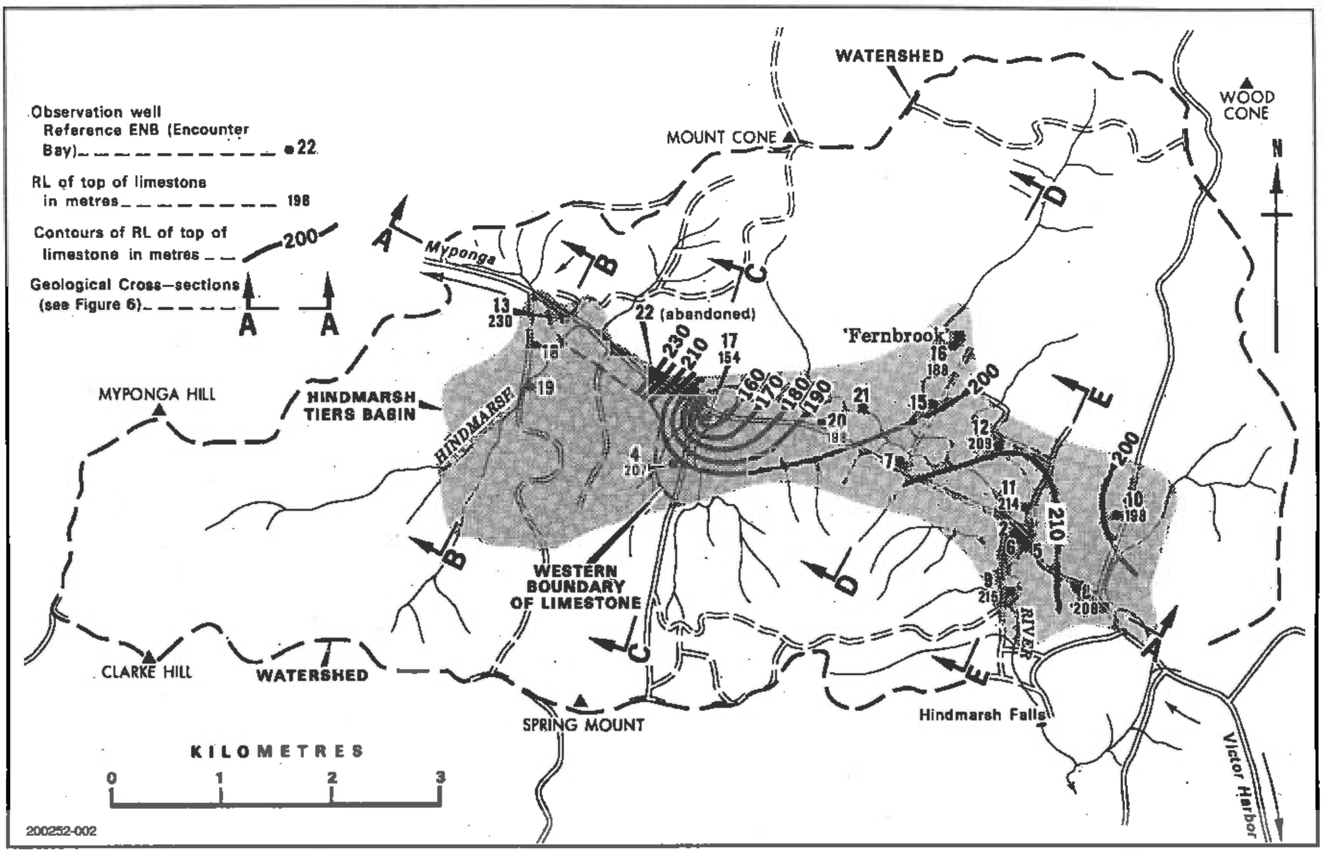


Fig. 6 Locations of geological cross sections for Hindmarsh Tiers.

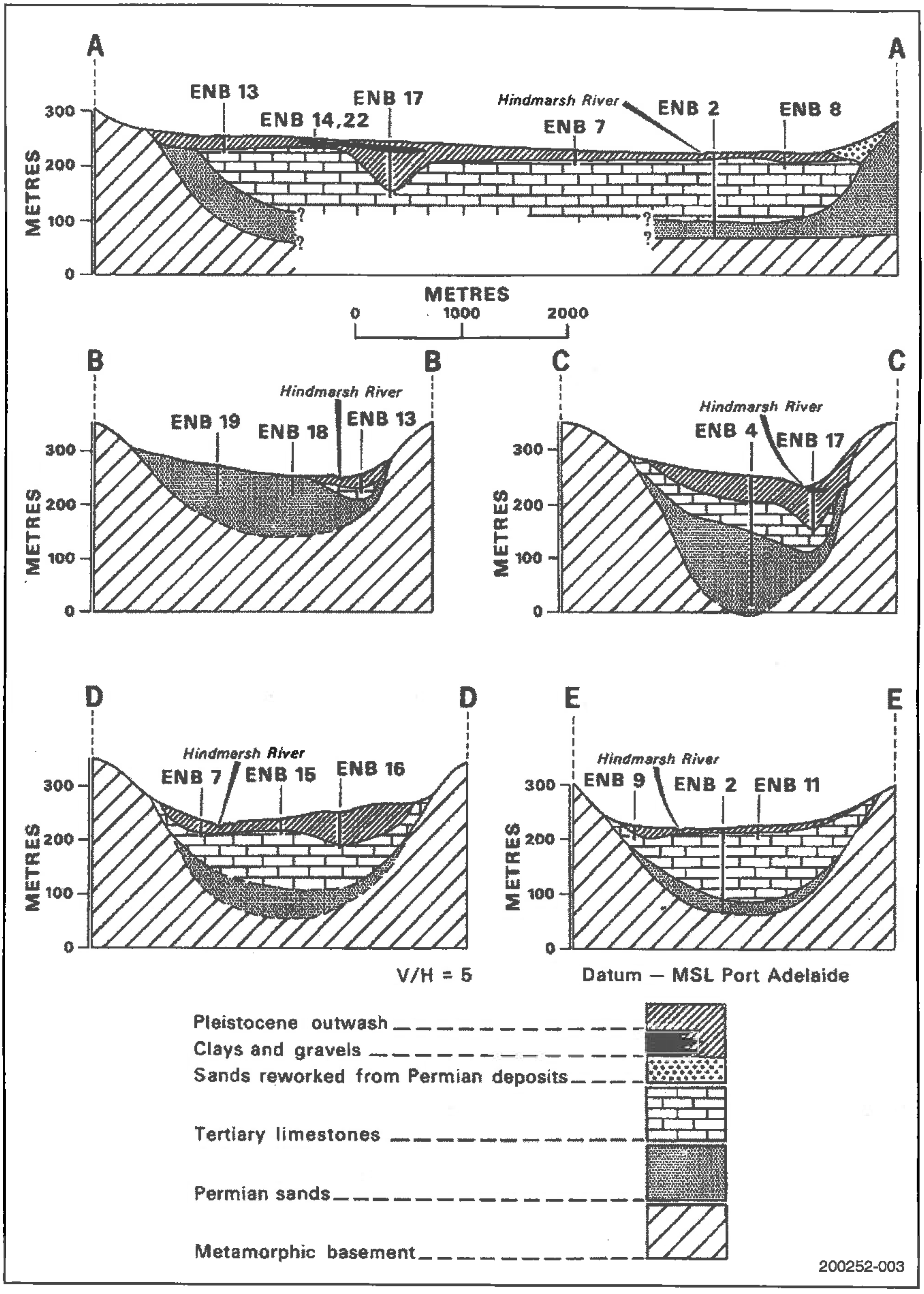


Fig. 7 Geological cross sections across Hindmarsh Tiers Basin.

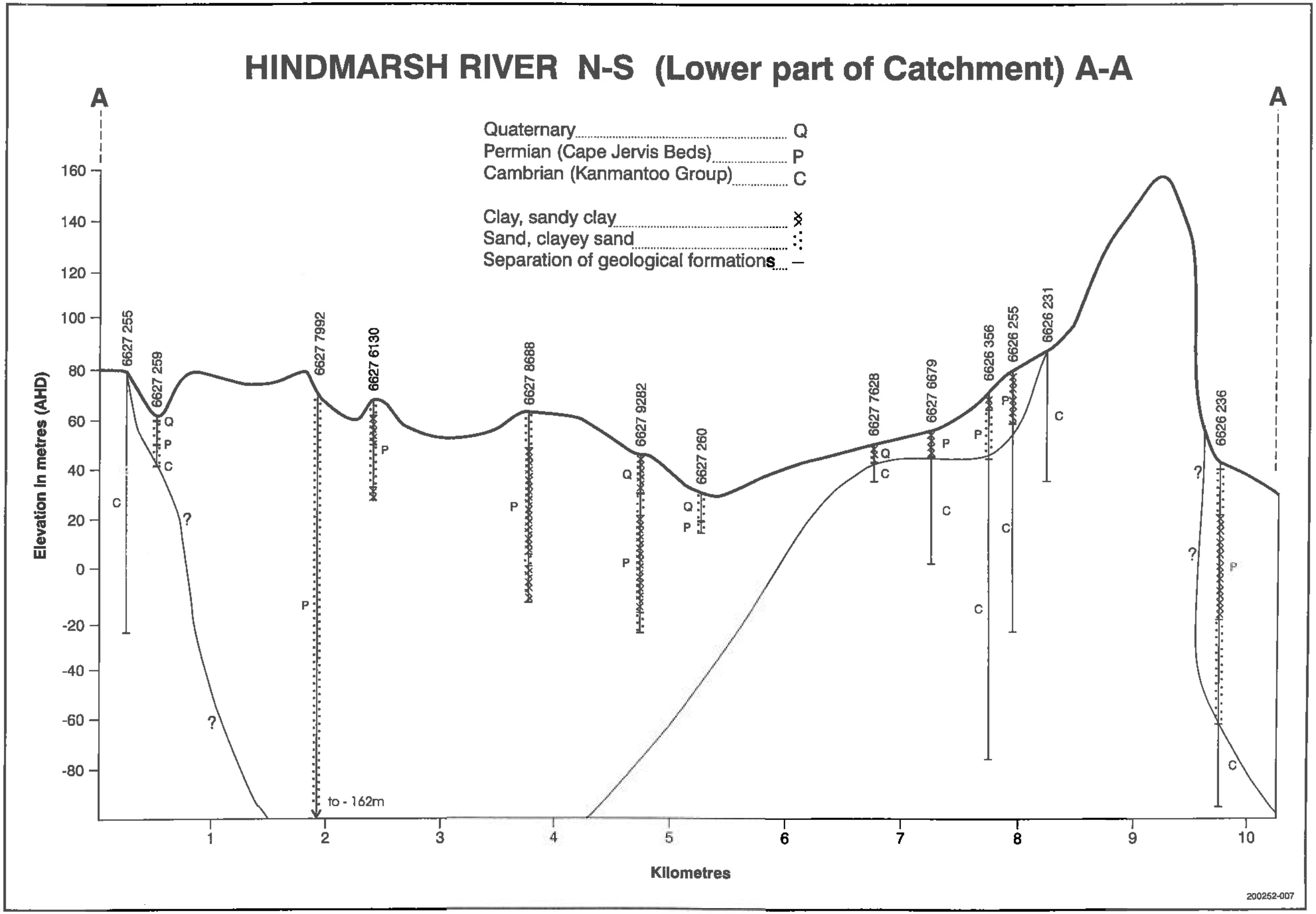


Fig 8 Geological cross section of the lower portion of the Hindmarsh River Catchment (A-A)

3.2 Inman River

The landforms in the Inman River catchment show evidence of former large scale glaciation (Bourman, 1969). The Inman Valley was carved out during the Permian Age (approximately 270 million years ago) by a glacier. The following 200 million years (Mesozoic epoch) was a period of erosion, reducing the region to an area of low relief. In the Tertiary period (50 million years to present), tectonic uplift occurred, rejuvenating the water courses.

The hills that enclose the catchment are mostly resistant metamorphic rocks of the Kanmantoo group (see Figure 3). The Kanmantoo rocks are composed of schists, greywacke, quartzite, phyllite and coarse grained arkose.

The major watercourses of the catchment are believed to follow ancient valleys or basins which were cut into the underlying basement rocks prior to Permian glaciation. Many watercourses in the catchment were originally marshy wetlands with no defined channel (Burston and Good, 1995). The Permian glaciation deepened the ancient valleys but left considerable depths of glacial and glacio-fluvial deposits. Bores drilled along Back Valley Creek have passed through nearly 300 m of glacial sediments before striking basement rock (Bourman, 1969).

Following the uplift of the region in the Tertiary period, the rejuvenated Inman River again removed the glacial sediments and cut down through the bedrock. At a location known as Inman Gorge, the river has cut a gorge 30 metres in the steeply dipping Kanmantoo base rock to create an incised meander (Burston and Good, 1995).

Natural erosion during the past 250 million years has removed most of the Permian glacial and fluvial sediments resulting in an undulating to rolling landscape in the valley floor, quite distinctive from the steeper and higher hills of the surrounding hard rock landscapes. In several areas, the valley floor is underlain by consolidated Permian sand.

Figures 9 and 10 show the geological cross sections for locations both north to south and west to east (see Figure 3). Figure 9 shows that the Kanmantoo Group rises to a point in the valleys between the 6 to 9 km point of cross section C-C with Cape Jervis Bed sands and gravels on either side of this rise. Bore water quality in this area is quite poor with salinity ranging from 1800 to >9000 mg/L. Figure 10 shows the geological cross section crossing the valley from north to south. The Kanmantoo Group has been inferred in this Figures as no bores were completed into this formation in this area. Salinity concentrations were similar to those in the other cross section.

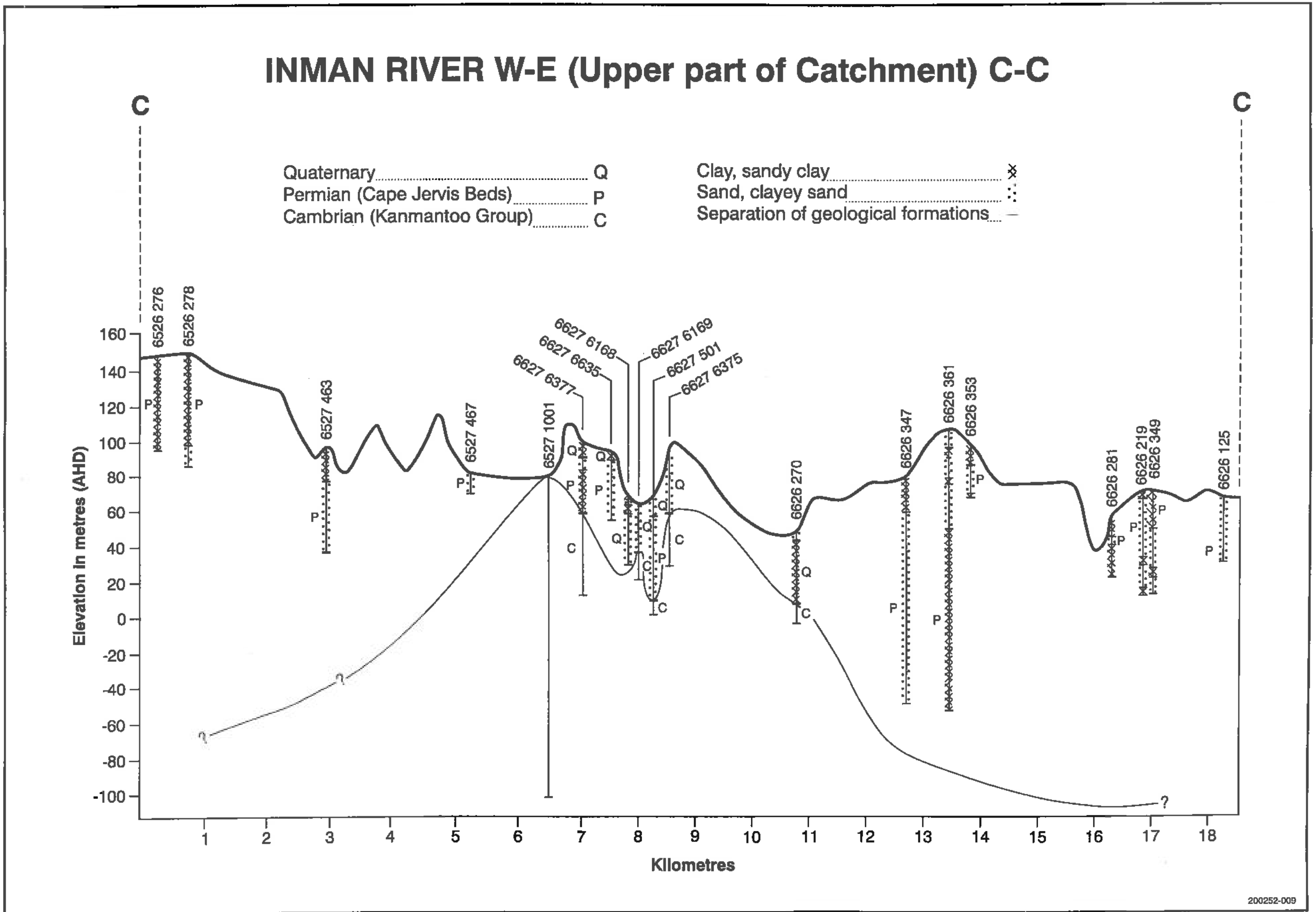


Fig 9 Geological cross section of the Inman Valley from west to east (C-C)

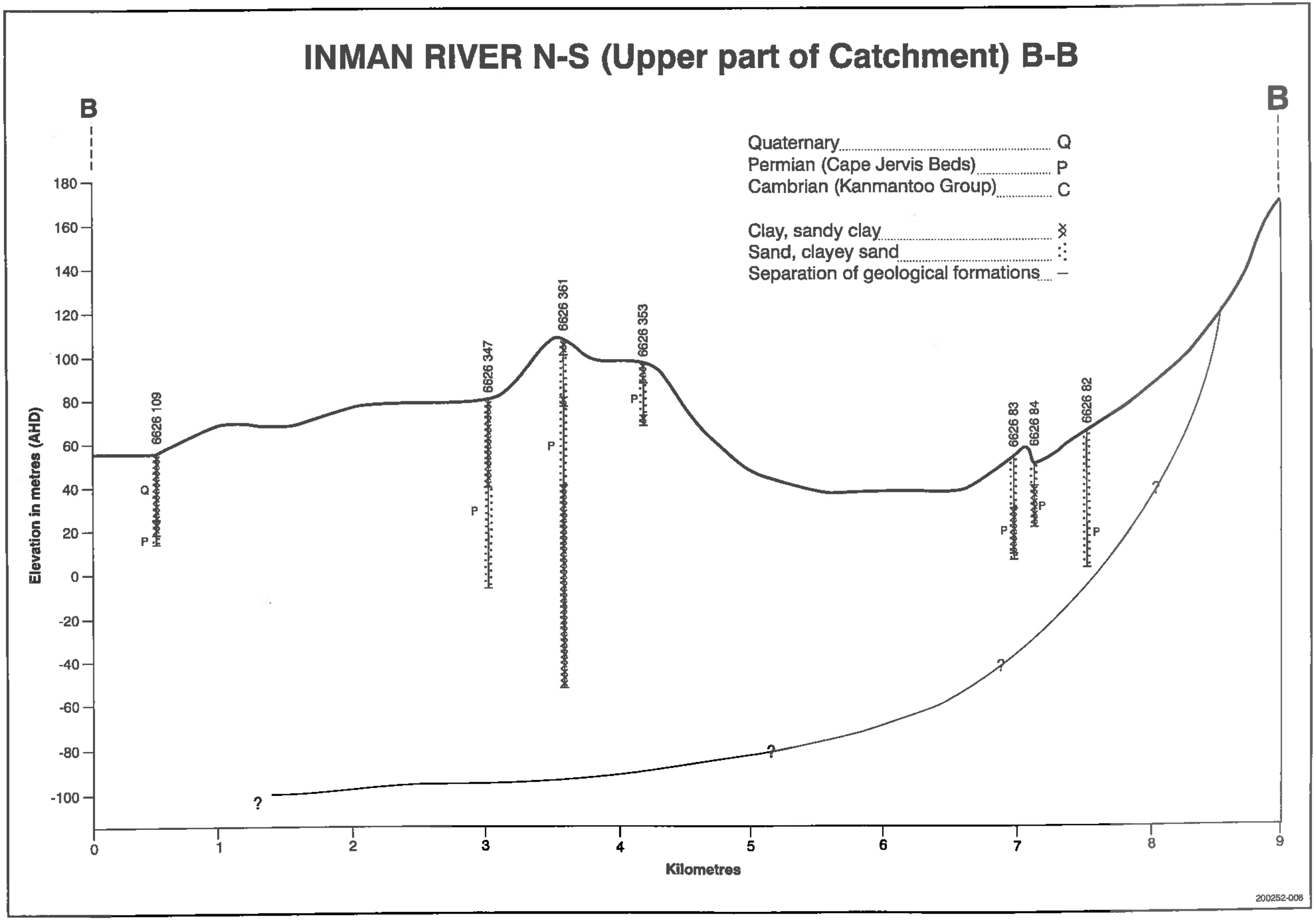


Fig 10 Geological cross section of the Inman Valley from north to south (B-B)

3.3 Currency Creek

The basement rocks of the Kanmantoo Group are, in general, tight and impermeable with few open systems of fractures and joints in which groundwater is stored and transmitted. This is evident by the general low yield of the bores completed into the Kanmantoo formation in the Currency Creek Catchment. However, there are 8 bores in the Kanmantoo formation with recorded yields greater than 10 L/s with the highest recorded yield being 31 L/s. There are several bores used for irrigation purposes completed into the Kanmantoo formation (see Water Use Section 6.7.2.3).

Clayey weathered materials have infilled joints and fractures and soluble components of these materials can dissolve and raise the salinity of the groundwater. The clays can also restrict the infiltration of rainwater.

In the broad valley in Currency Creek, Permian sediments are present and lower salinity values are evident in the groundwater. Figure 11 shows the geological cross section of the valley from north to south paralleling the Adelaide - Victor Harbour road (western part of catchment). At the top end of the catchment there is a deep layer of Cape Jervis Bed sands and clays overlaying the Kanmantoo group. Bore 6627 9975 is 143 metres deep and has good water quality (99 mg/L). Other bores in this area also have low salinity concentrations which may be the result of fresh recharge in this area or that the bores completed into the Kanmantoo group are tapping a fracture with few infilled joints.

One interesting finding of this study was locating a pocket of Tertiary limestone in a small valley along Mosquito Hill Road. The extent of this formation is unknown as there were only two bores completed into this formation. Anecdotal information provided by irrigators in the field survey related that there were shark's teeth and shells evident in bore cuttings from drilling. Wells completed into this formation have high yields and good quality water.

Figure 12 shows that in the eastern portion of the catchment, the Kanmantoo Group is overlain by Cape Jervis Bed and Quaternary clays and sands. The water quality of bores in this portion of the catchment is not as good as that on the western side and yields are not as high.

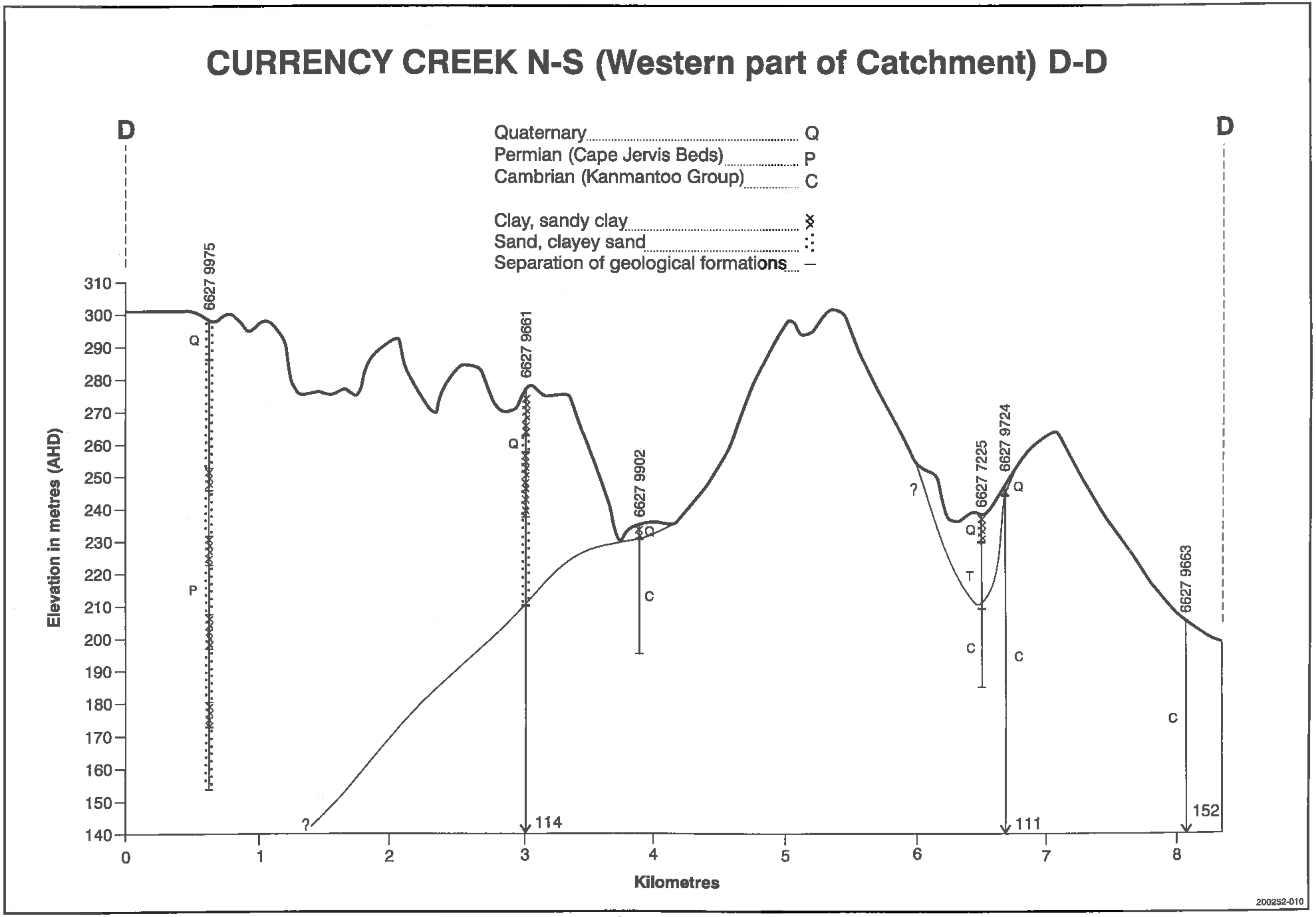


Fig 11 Geological cross section of the Currency Creek Catchment western portion from north to south ***(D-D)***

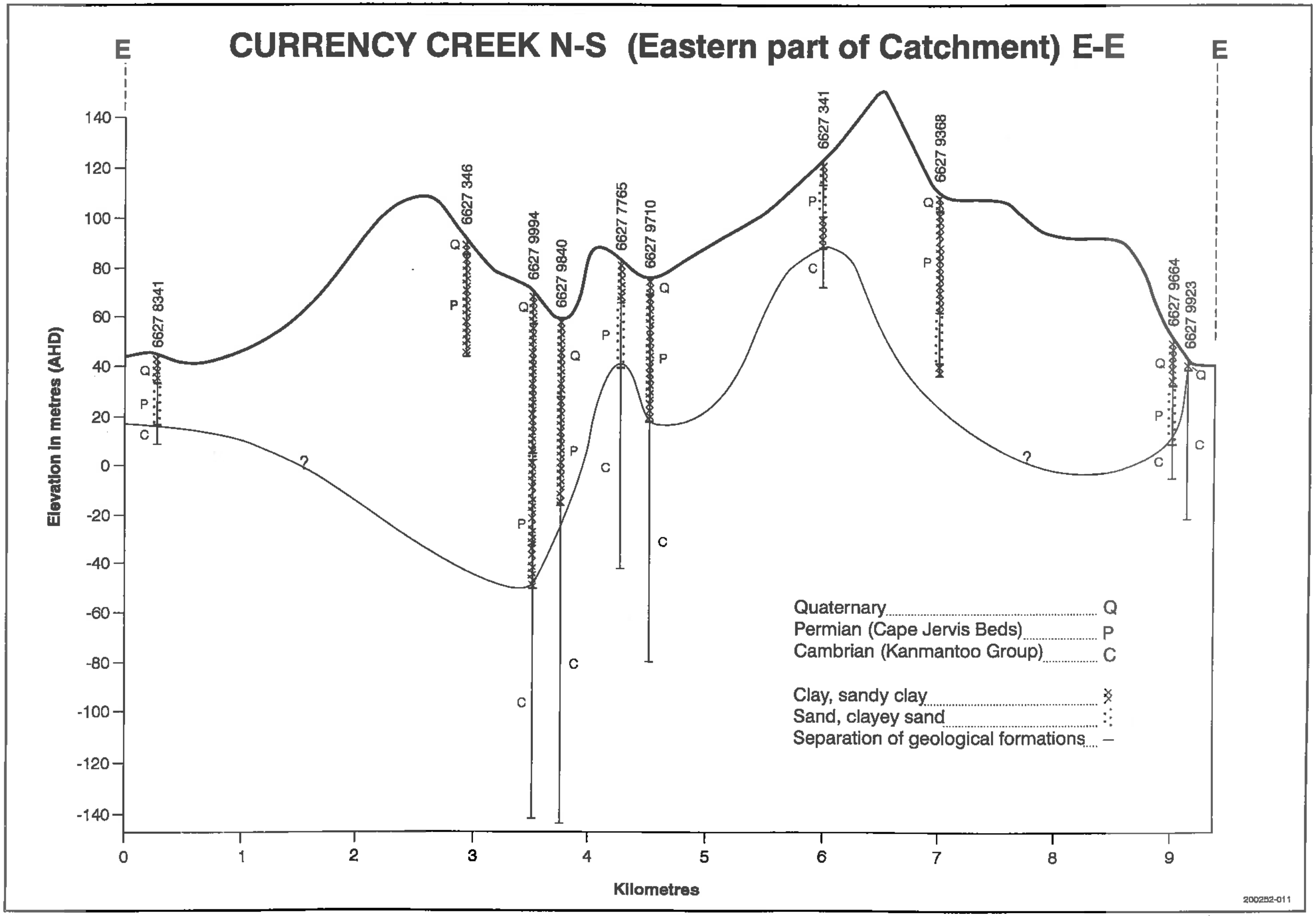


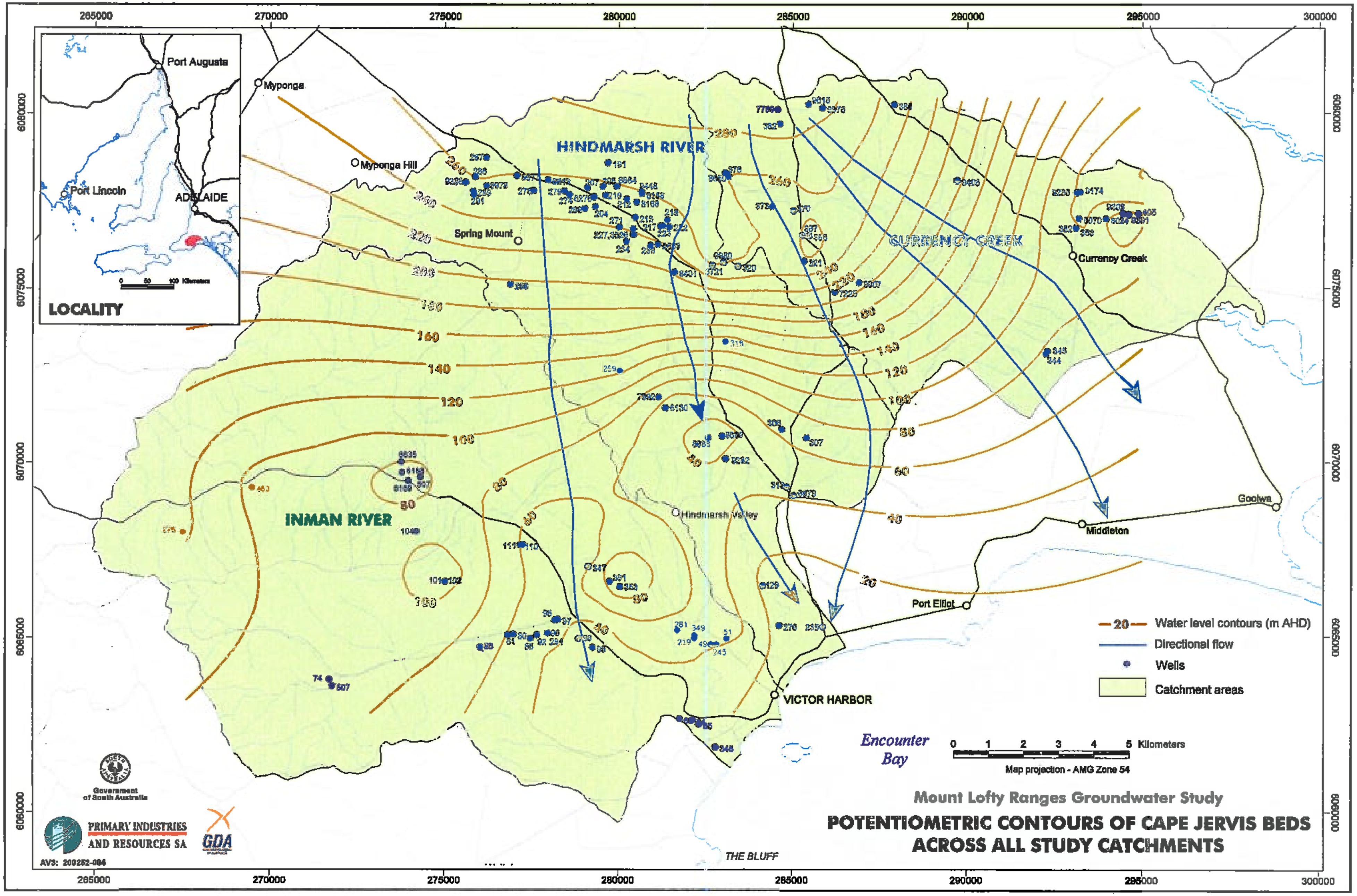
Fig 12 Geological cross section of the eastern portion of the Currency Creek Catchment from north to south (E-E)

3.4 Potentiometric Surfaces

Available data on standing water levels for bores completed in the Cape Jervis Beds was obtained from SA-GEODATA. These measurements were recorded at the time of drilling, during a field survey or provided by the landowner. Contour lines were drawn using Surfer16 using the Kriging estimation method with 20 metre intervals. Figure 13 shows these water table contours for bores completed in the Cape Jervis Bed formation. As shown, groundwater flows from the higher groundwater elevations located in the northeast down to the coast following the topography of the area. The circles on Figure 13 could represent local areas of recharge but this needs to be verified.

Figures 14 and 15 shows the potentiometric surface contours for the observation bores in the Hindmarsh Tiers Basin. Data for the standing water levels for these bores was obtained from the OBSWELL database and water levels recently measured in the field. Surfer16 was used to generate the contour lines and the Minimum Curvature estimation method was used with 5 meter intervals. The configuration of the potentiometric surfaces or water table contours in this area is difficult as the area is small and the aquifer has a high transmissivity. There is no point in the basin that is more than 1 km from a hydraulic boundary and the irrigation bores are not far enough away from the observation bores to avoid some exaggeration of the drawdown in the aquifer.

Figures 14 and 15 indicate that there is a throughflow of groundwater through the Hindmarsh Tiers Basin from areas of recharge at the western boundary of the basin to the discharge areas in the southeastern side. One noticeable feature of these figures is the difference of about 10 metres between the lowest potentiometric surface in the southeastern side of the catchment from November 1976 to November 1999. This difference can be explained by lower rainfall and by increased irrigation in certain parts of the Hindmarsh Tiers Basin and will be discussed further in Sections 6.2 and 6.7.2.1.



Mount Lofty Ranges Groundwater Study

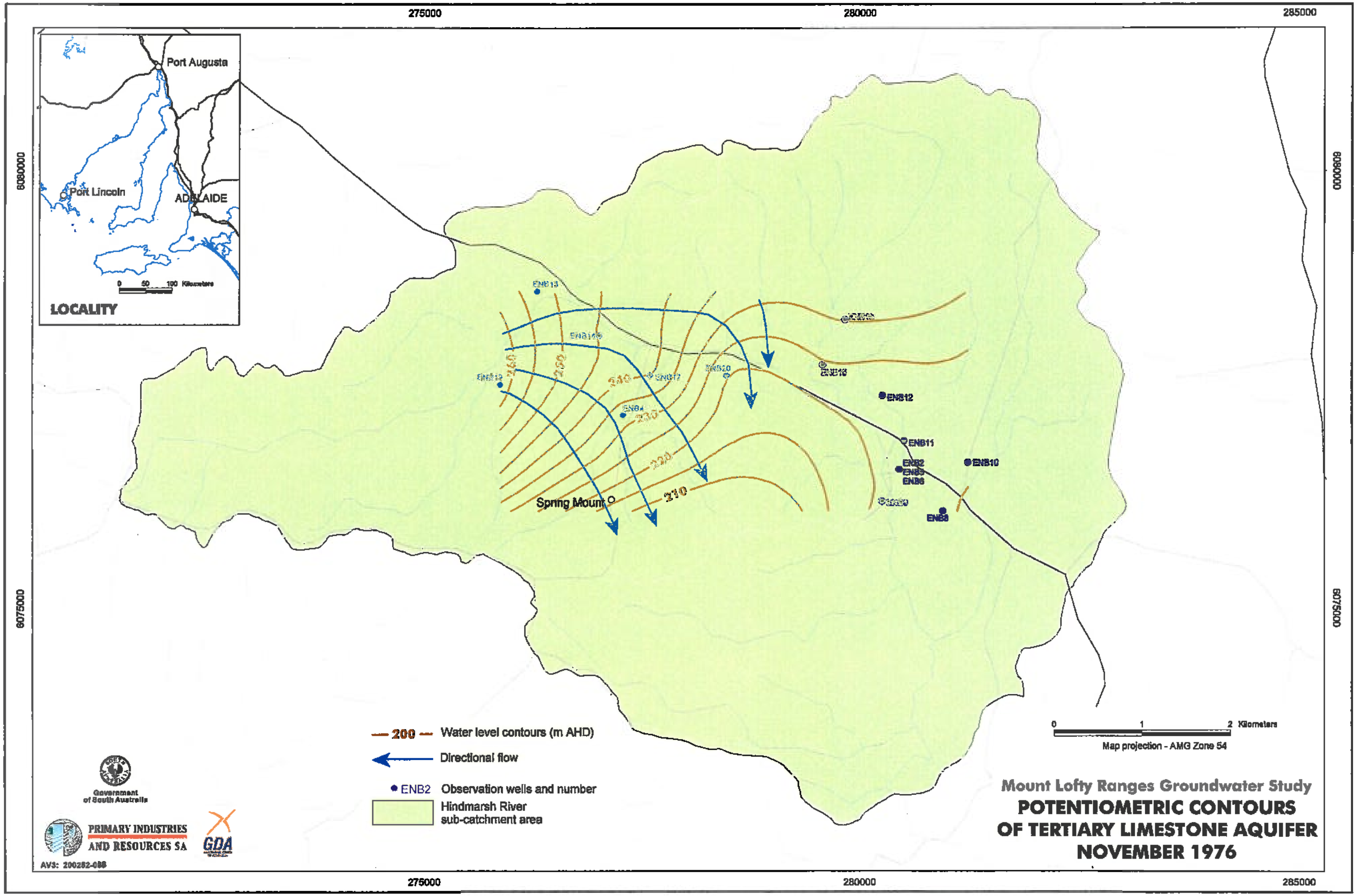
POTENTIOMETRIC CONTOURS OF CAPE JERVIS BEDS ACROSS ALL STUDY CATCHMENTS

Government of South Australia

PRIMARY INDUSTRIES AND RESOURCES SA

AVS: 200252-004

Figure 13



Mount Lofty Ranges Groundwater Study

POTENTIOMETRIC CONTOURS OF TERTIARY LIMESTONE AQUIFER NOVEMBER 1976

Figure 14

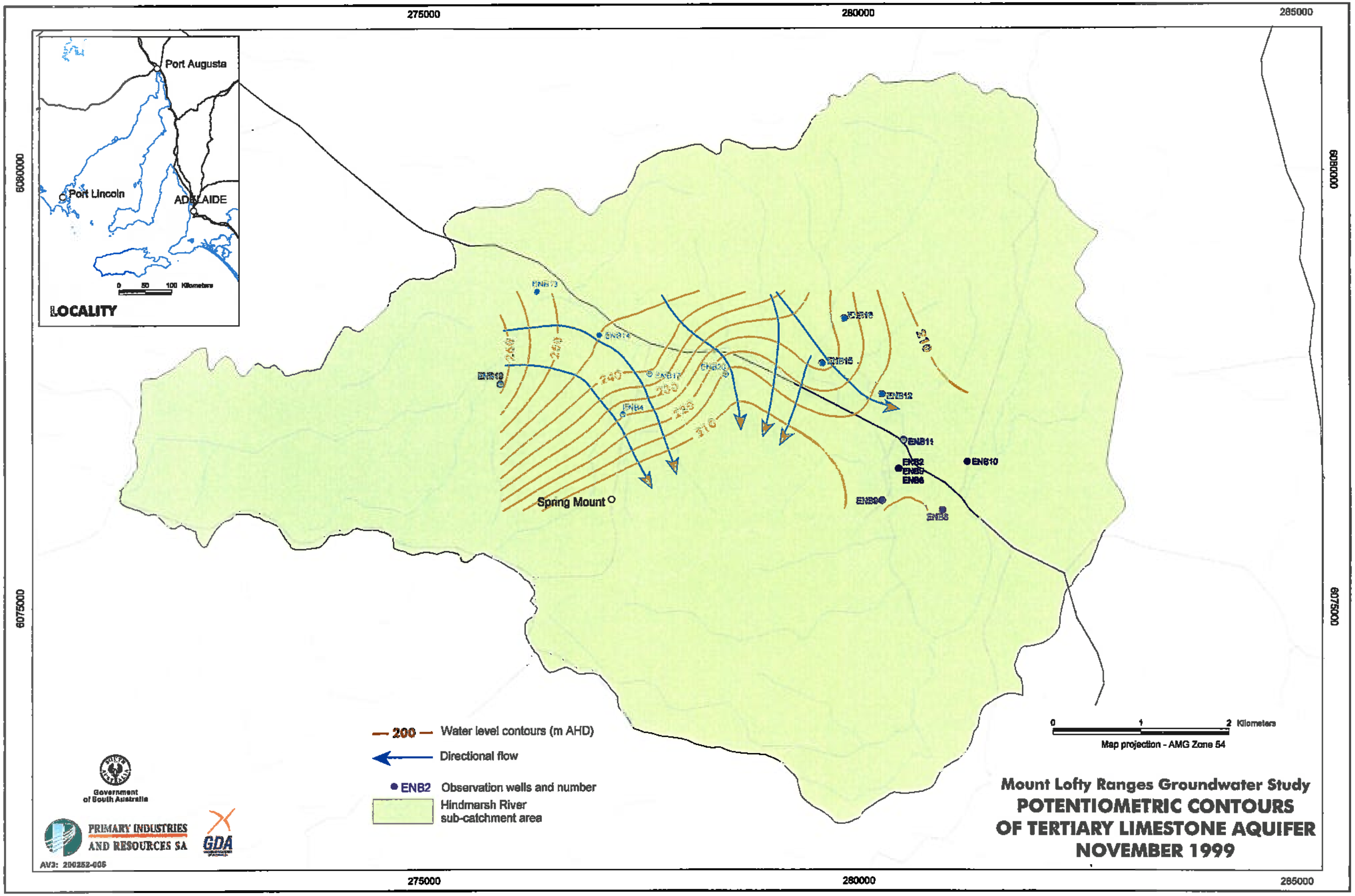

275000
280000
285000
6080000
6075000
Port Augusta
Port Lincoln
ADELAIDE
0 50 100 Kilometers
LOCALITY
Spring Mount
— 200 — Water level contours (m AHD)
Directional flow
• ENB2 Observation wells and number
Hindmarsh River sub-catchment area
0 1 2 Kilometers
Map projection - AMG Zone 54
Government of South Australia
PRIMARY INDUSTRIES AND RESOURCES SA
GDA
AV3: 200252-005
Mount Lofty Ranges Groundwater Study
POTENTIOMETRIC CONTOURS
OF TERTIARY LIMESTONE AQUIFER
NOVEMBER 1999

Figure 15

4.0 Water Resources Management in South Australia

There are three main statutes within the South Australian legislative system that deal with the development, management and protection of water resources:

- *Water Resources Act 1997;*
- *Development Act 1993;* and
- *Environmental Protection Act 1993.*

4.1 Water Resources Act 1997

The *Water Resources Act 1997* replaced the *Water Resources Act 1990* and the *Catchment Water Management Act 1995* and provides the Minister with extensive powers to control the use of water resources within the state. The Act establishes a formal property rights system for access to water in respect to licensed water resources. Licensing regimes are reserved for prescribed surface and groundwater areas where pressure on the resource from economic or environmental perspective demands intervention in the sharing of access. Access to water in unlicensed areas is dealt with via a statement of rights, coupled with provision for civil enforcement. Water licences under the Act are personal to the holder and are not linked to land title. Licences must show the conditions attached, including the allocation.

The Act provides that water will be allocated through the licence system for consumptive uses only after the environmental requirements of the particular resource have been properly assessed. Where water systems are overcommitted, the Act empowers the Minister to reduce allocations in licensed areas or to restrict water use in unlicensed areas.

The administration of the Act revolves around water resources management planning. All plans must seek to further the object of the Act and be consistent with the State Water Plan. Water allocation plans are required to assess:

- The quantity and quality of water needed by the ecosystem using the resource;
- The effects of taking water on other resources;
- The provision for the allocation and use of the remainder of the water; and
- For monitoring of the capacity of the resources to meet the demands made upon them.

Catchment water management plans are prepared by Catchment Water Management Boards whose members are appointed by the Minister. The Board's plans must include an assessment of all water resources in the area, including its quantity and quality , the threat that faces the resources and the opportunities for their ecologically sustainable development.

There are at present a total of six water management authorities established under the *Water Resources Act*: Torrens, Patawalonga, River Murray, Onkaparinga, Northern Adelaide and Barossa and the South East. The Act maintains the authority of the previous water resource committees responsible for the numerous 'proclaimed water resource areas' across the state. These committees have responsibility to produce water allocation plans for prescribed resources, unless the resource exists within the boundary of a catchment board. There is no formal management in areas that are not proclaimed water resource areas other than the requirements for a permit for drilling purposes or farm dam construction (see below).

Groundwater is legislated under the *Water Resources Act* and permits are required throughout the state to drill a new bore of alter or deepen the casing or screen of an existing well deeper than 2.5 metres. The work must be carried out by a licensed driller, except that a land owner may carry out work to a maximum depth of 15 metres on his/her own well after obtaining a permit. Drillers are required to submit detailed information on bore construction including lithology, well depth and yield to the appropriate government agency. The *Water Resources Act 1997* added two new provisions relating to groundwater: rights to take water and protection of the resource. If a person has lawful access to a well, that person has the right to take water from the well provided it does not affect the rights of others taking water from the same aquifer or is not restricted by the terms of a relevant water plan. The well owner is obliged now to maintain any well on his/her property and may be required to undertake remedial work.

Farm dams are another use of the water resource and have complex legislative arrangements. The *Local Government Act* formerly determined that a person may not construct a farm dam unless they had permission from their local council. However, this part of the legislation was repealed from the *Local Government Act* and enacted in the *Water Resources Act* 1997 so the construction of farm dams is now covered under the *Water Resources Act* 1997. The Minister may delegate this function to Catchment Water Management Boards who in turn may seek to delegate the function to Local Government thereby retaining the status quo.

The *Water Resources Act* requires a permit for the “erection, construction or enlargement of a dam or other structure in any stream or watercourse within a watershed". These measures were introduced in 1974 and a system of permits was established in early 1992. Responsibility for administration of the *Water Resources Act* presently rests with the Minister for Environment Heritage and Aboriginal Affairs (DEHAA) while day to day responsibility for implementation of the Regulations, as they relate to permits for farm dams, has been delegated to officers of the Environment Protection Authority (EPA) of DEHAA. To date, the primary factor in determining the eligibility of a particular dam proposal is that the maximum volume of any dam or dams should not exceed 50% of the mean annual run-off, based on a 10% coefficient of runoff, expected from the property (Certificate of Title) on which the dam is located (Lenz, personal communication).

An important feature of the *Water Resources Act* 1997 is its attempt to achieve better integration between water resources management and the management of other natural resources. The fundamental link between the *Water Resources Act* and the *Development Act* is the requirement for consistency, as far as practicable, between water plans and the relevant development plan. The inclusion of a process for amending development plans is one direct and very important link that the *Water Resources Act* has to recognise the importance that sound development plans can play in sustainable water resources management.

4.2 Development Act 1993

The *Development Act* 1993 provides for proper, orderly and efficient planning and regulation of development in the State and regulates the use and management of land and building, the design and construction of land and buildings, where appropriate, and planning for other purposes.

Development plans, which are statutory documents, describe the desired character for different parts of the area concerned, the types of development preferred and the policies and standards against which development applications will be assessed. The plans list those kinds of development which 'comply' with the purpose of the zone concerned or list those developments that are 'non-complying'. The council assesses any form of development that is not included as either complying or non-complying on its merit in accordance with the policies in the development plan.

With respect to farm dams, the *Development Act* states that a mound or levee having a height greater than 3 metres is a development and requires planning approval. If the dam is not a farm dam then it requires planning approval. There has been a recent Environment Resources and Development Court determination that dams are structures and therefore all dams are development (Lenz, personal communication).

4.3 Environmental Protection Act 1993

This Act reflects current thinking about environmental protection based on the principles of ecologically sustainable development. There is an emphasis placed on pollution prevention rather than a reliance on a traditional command and control approach. There is a degree of integration of the *Environmental Protection Act* and both the *Development Act* and the *Water Resources Act*.

4.4 Water Management Organisations and Agencies

There are numerous organisations and agencies that play a role in the management of water resources in the study catchments:

- Alexandrina Council,
- District Council of Victor Harbour,
- Southern Hills Soil Conservation District,
- River Murray Catchment Water Management Board, and
- Mount Lofty Ranges Catchment Program.

There is no Catchment Water Management Board for any of the catchments in the study area. The regional development board is the Fleurieu Regional Development Board. In preparing this report many individuals working for and living in the study catchments were contacted. For most, there is a strong feeling that there needs to be more direct management of their water resources, especially in the absence of a water management plan.

5.0 Methodology

There have been many different sources and types of data used in this study. Sources of data and methods of analysis are outlined in the sections below. Best available data has been used and some estimations have been made based on modelled data or expert opinion.

5.1 Drillhole Data

All drillhole data on bores such as geological logs, water levels, salinities and bore yields are stored within Primary Industries and Resources of South Australia's (PIRSA) corporate database SA-GEODATA. All bore records in the database were verified and SA-GEODATA was updated using detailed information obtained from microfiche records before any analysis was initiated. Data on these bores varied greatly in quality and quantity of information that was available. The interpretation of the data from SA-GEODATA (drillhole database) in conjunction with the Geographical Information System (GIS) assisted in the interpretation of groundwater information and its relationship with areal coverage such as geological formations, land use and irrigation coverage.

Well yield data was used only if the database indicated that the data was collected during drilling. However, this information is not necessarily indicative of the actual operational or production yield of the bore. Depths are recorded where samples for water analysis were taken. Where this data was not recorded, estimations were made based on past sampling or if no other information was provided the depth of the well was used.

Bore lithologies were used to interpret the geological formation in which the bore was completed and to complete the geological cross sections. There is no standard nomenclature used by drillers for different geological formations such as types of sand, clay, quartz, shale, etc. In addition, the bore lithologies varied in amount of descriptive narrative. In some interpretations, advice was sought from individuals with experience and knowledge in the area in order to assign a geological formation to a particular bore. Geological maps were also consulted to assist in confirmation of the interpretation.

Drillhole data in SA-GEODATA has its limitations. Most data in SA-GEODATA is provided by drillers and, in some instances, bore locations were not accurately provided. In addition, because there was no mandatory requirement for driller data submissions prior to 1976, there are many bores with missing information on depth, well yield, lithologies, surface water levels, and locations. Field surveys have been completed for many bores which has enhanced the data but there are many inaccuracies in the database such as bore locations.

5.2 Catchment Boundaries

The basic unit of surface water hydrology is the drainage basin which includes all the land area sloping toward a particular discharge point and outlined by topographic divides. Because of the close relationship between groundwater divides and surface water divides and also because of legislative requirements for water management, the groundwater resources have been assessed on a catchment basis. Boundaries within "Catch99" prepared by staff at the Department of Environment and Aboriginal Affairs (DEHAA) were used. This designates the catchment boundaries of watersheds.

5.3 Land Use Classification

Land use mapping is the responsibility of the Sustainable Resource Branch of PIRSA. Land use data in the Mount Lofty Ranges was collated through the use of air photos and groundtruthing and put into the corporate GIS using ArcView and ArcInfo.

There are two land use classifications referred to in this report - 1993 and 1999. The 1993 land use classifications were derived from air photos that were updated with local knowledge over the period of a year in 1993.

In 1999, the land use mapping was done using image registration, Digital Cadastral Database (DCDB), editing and re-classification process and field validations. The methodology reported here is outlined in the Flavel, 2000 report. Panairama 1998 photos were taken in the summer of 1997/1998. Base imagery (1:20,000) in the form of scanned colour aerial photographs were supplied by DEHAA. The imagery, registered to at worst an accuracy of 35 metres relative to the DCDB, provides a means of land use code classification.

The 1999 land use classifications used were completed using the 1993 Land Use classifications as a base. The 1993 land use classifications were imported from an ArcInfo export file as vector polygons and edited in ArcView and ArcInfo according to changes sighting in the 1998 air photos, site visits and to a lesser degree valuation, Land Use codes and street directory information. The 1993 land use codes were translated up to the Australia and New Zealand Land Use Codes (ANZLUC).

The DCDB provides the primary spatial framework for all classifications and image registrations. Validation of Land Use codes in some areas also served as supplementary data in the editing and re-classification process.

An extensive field validation process was done after the editing and reclassification process. Validated polygons refer to the polygons where there was both an interpreted land use and a field checked land use. A higher percentage of polygons were validated in rural areas because of improved line of sight distances and accessibility.

Apart from certain land uses of particular interest (such as horses), land use polygon areas of less than 4 hectares have been dissolved into the surrounding dominant land use. Horses and dairy were hard to detect from aerial photography and the 1993 classifications were adopted.

5.4 Groundwater Recharge

Groundwater recharge is an essential component of groundwater sustainability. Recharge is the amount of infiltrated water that reaches a specific groundwater system and it occurs when too much water is available to be used by vegetation or to be stored in the root zone (Zhang et al, 1999). It is difficult to estimate and can be measured indirectly. Recharge is variable over any given catchment due to its dependence on other variable factors such as soil type and amount and type of vegetation cover. The methods that were used to estimate recharge are outlined below.

5.4.1 Water Balance

The concept of the water balance provides a framework for studying the hydrological behaviour of a catchment and it can be used to identify changes in water balance components (Zhang et al, 1999). The water balance for a catchment can be written as:

$$P = ET + R + D + \Delta S \quad or$$
$$D = P - (ET + R + \Delta S)$$

Where:
P = precipitation
ET = evapotranspiration
R = surface runoff
D = recharge to groundwater
ΔS = change in soil water storage (assumed to be zero in this study)

An advantage of the water budget or water balance method is that the aquifer does not have to be in dynamic equilibrium in order to use it (Fetter, 1988). In addition, many of the parameters used in this calculation of the hydrological budget are measured directly such as rainfall, streamflow, and evaporation. Farm dams are prevalent in the study catchments and have also been included as part of the runoff estimation. Modelled and derived data have been utilised when direct measurements were not available. Geographical Information Systems (GIS) and other data systems utilised existing datasets and facilitated the estimation of some of the various water balance components. The water balance components used in this study were measured or estimated with varying degrees of rigour and accuracy.

The last term in the water balance is the change in soil water storage. Over a long period of time (ie 5 to 10 years), it is reasonable to assume that changes in soil water storage are zero (Zhang et al, 1999). Recharge and change in soil water storage is often only 5 to 10% of the annual water balance (Zhang et al, 1999), therefore over an extended period of time the assumption that changes in soil water storage are zero is reasonable.

Some of the datasets for rainfall and streamflow had missing data ranging from a month to several years. Patching of these datasets was done to maximise the existing datasets using correlations with other existing nearby stations and regression slopes to fill in the data gaps.

5.4.1.1 Rainfall

Rainfall is the inflow component of the water balance equation and is the main driving force of the hydrological cycle. Rainfall is the largest term in the water balance equation and varies both temporally and spatially. For most of the hydrological applications, the orographic effect of vegetation on precipitation can be ignored and it is appropriate to assume that precipitation is independent of vegetation types (Zhang et al, 1999). However, there can be an effect of vegetation on rainfall and microclimate formation (Daniell, personal communication).

In Australia there are over 7000 observation stations which measure rainfall daily (Lavery et al, 1992). The Bureau of Meteorology records this data which is made available to the public and government agencies. Rainfall data was sourced from the Water Monitoring Station (WSTN) spatial dataset from the Bureau of Meteorology's rainfall data. Patching of these rainfall datasets was done to maximise the number of data available. Missing data was "patched" using correlations with existing stations to fill in the monitoring gaps.

One methodology used to estimate catchment rainfall was the Triangulated Irregular Network (TIN) data structures. Average monthly rainfall values for all rainfall gauge stations in or close to each of the study catchments were calculated and added to the spatial dataset. Catchment rainfall volumes are calculated through processing this data using Triangulated Irregular Network (TIN) data structures in GIS.

Catchment rainfall estimates have also been presented in this report that have been calculated using the isohyet method. The methodology used for these estimations is outlined in the SCRN et al, 2000 report.

In South Australia the predominant rainfall occurs in the winter months and most of the summer rainfall is lost by evaporation before it has a chance to percolate down to the plant root zone or the water table. Only the winter rainfall (April to October) is considered to be effective in contributing to the water balance. Both total and "effective" annual rainfall volumes were calculated for each catchment but only effective rainfall has been used in the water balance estimations.

Cumulative deviations from the mean monthly rainfall have been calculated and plotted for all rain gauge stations with greater than 10 years of recorded data. Data records with missing periods were patched using correlations with

other stations and regression slopes. Monthly rainfall means ($\bar{x}$) were calculated and a cumulative deviation derived as follows:
$\Sigma x_i - \bar{x}_j$ (where x_i = total monthly rainfall and $\bar{x}_j$ is the monthly mean, j=1-12)

5.4.1.2 Surface Water

In the water balance equation, the surface water resources or streamflow should ideally be presented as natural flows within the catchment. However, the flows within the study catchments are not natural flows as all have been affected by water storages (such as farm dams) and water uses (such as irrigation). The methodology described below has attempted to adjust station flows to estimate natural flows.

There is a network of 70 continuous recording gauging stations in the Mount Lofty Ranges that are maintained by the Department of Environment, Heritage and Aboriginal Affairs (DEHAA). The majority of this continuous streamflow data is stored in DEHAA's corporate database HYDSYS. In the study catchments varying amounts and quality of streamflow data exist:

- in Currency Creek a gauging station 426530 was operated from June 1972 to August 1993;
- in Hindmarsh River a gauging station 501500 situated 2.5 km south of Hindmarsh Falls has been operated since March 1969 to present; and
- In Inman River a gauging station 501503 was installed in January 1995 and is still in operation.

A model was developed based on multiple regression analysis which establishes a relationship between annual runoff, winter rainfall and 30 different catchment characteristics for gauged catchments (SCRN et al, 2000). The model was used to predict streamflow, including annual variability (10^{th} to 90^{th} percentiles) in ungauged catchments and sub-catchments where the catchment characteristic data was available. There are limitations to this modelling process:

- The extent and quality of the catchment characteristics; and
- The modelling estimations were based on a limited dataset which did not represent the characteristics of all the ungauged catchments.

However, this modelling does give a good indication, based on best available information, of runoff in the catchments studied and have been used in estimating total streamflow.

Streamflow consists of two components: runoff and baseflow. Baseflow is the contribution to streamflow provided by groundwater discharge. HYDSYS was used in this study to estimate runoff and baseflow from the stream gauge station data. HYBASE is a function within HYDSYS which reads a file of streamflow data and produces another file which contains the separated baseflow of the original data. The method for this baseflow separation used was to separate baseflow using a digital filtering algorithm. This technique has been compared with other more rigorous baseflow separation algorithms and it was concluded that the digital method was simpler and produced as good a result as the alternatives (Nathan and McMahon, 1990). One problem experienced with using the default filter was that this filter is not ideally suited for streams in South Australia. Adjustments were made to both the filter and the filter interval to find the most appropriate values for each study catchment.

HYBASE tolerates periods of record with missing or bad data and interpolates the values of the missing data as a straight line joining the good data on either side. Data that is considered bad often turns up as zero by the analysis routines. The filter attempts to smoothly join periods of zero data with the surrounding non-zero data, propagating the effect forwards and backwards by hundreds of intervals.

Baseflow indices (portion of the total streamflow attributed to baseflow) were estimated from the data produced by HYBASE and applied to the total streamflow estimated through modelling.

5.4.1.3 Evapotranspiration

Water molecules are being continually changed between a liquid and atmospheric water vapour. If the number passing to the vapour state exceeds the number joining the liquid the result is evaporation. Evaporation of water takes place from free-water surfaces such as lakes, reservoirs, dams, etc. Solar radiation is the driving energy force behind evaporation and the rate is also related to the wind. Evaporation is an important consideration in the water balance and is a key component in determining the amount of water from rainfall which is absorbed by plants and trees through their roots and also controls how much water is required for irrigated crops during summer.

Evaporation data was sourced from the "Climate Atlas of Australia" provided by the Bureau of Meteorology. Lines depicting the average monthly and annual evaporation contours were digitised and built into spatial datasets and then processed using GIS software at a grid cell size of 2 km. Evaporation values were then interpolated from the grids and posted against the rainfall sites.

Evapotranspiration is a key output in the water balance equation and involves plants, grasses and trees absorbing water that remains in the surface soil layers through their roots. Water is also evaporated from the topsoil and leaves of the tree canopy. In arid and semi-arid areas evapotranspiration is often nearly equal to precipitation (Zhang et al, 1999). In the study area, this occurs usually between the months of April to October and is often the largest water output component in the water balance equation.

Crop Evapotranspiration

A methodology for estimating evapotranspiration or plant water use has been developed where evapotranspiration or plant water use is calculated by multiplying the annual evaporation rate by a "crop factor" (Thomson, 2000). The following methodology outlined below has been extracted this report.

Reference crop evapotranspiration (ETo) is calculated depending on the type of evaporation pan used (unguarded pan or bird-guarded pan):

i. related to evaporation from an unguarded pan, Epu reference crop evapotranspiration, ETo, is calculated using pan coefficients, Kp, from

ETo = Kp x Epu

When using evaporation from a bird-guarded pan, Ep, and Kernich's bird guard coefficients, Kg, the evaporation from an unguarded pan, Epu, is

Epu = Kg x Ep

ii. related to a bird guarded pan

ETo = Kp x Kg x Ep

Using reference crop water use, ETo, crop water use, ETc, is calculated using crop coefficients, Kc:

ETc = Kc x Eto (Related to a bird-guarded pan ETc = Kc x Kg x Kp x Ep)

Using crop factors, fg, related to evaporation from a bird-guarded pan, Ep
ETc = fg x Ep
so
fg = Kc x Kg x Kp

The monthly values used for Kg and Kp are:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kg	1.080	1.087	1.075	1.057	1.042	1.042	1.053	1.084	1.085	1.070	1.094	1.095
Kp	0.593	0.534	0.577	0.520	0.537	0.528	0.560	0.710	0.802	0.748	0.658	0.584

Crop factors are determined by a number of components, such as the rooting depth of the crop, the leaching fraction required to flush salt from the root zone, the method of irrigation and the salinity of the irrigation water. Crop factors that were used in this study are shown in Appendix 1.

The GIS uses grid arithmetic functions (gridding point data at 1 km) to calculate reference crop water use on a monthly basis and post these results against the known rainfall sites. By utilising this information and the area of particular crops in a catchment, the volume of crop water use or evapotranspiration for the catchment can be estimated. The volume calculations for rainfall, crop water use, and target information needs for the individual catchments were derived from the same point data using Triangulated Irregular Network (TIN) processing in GIS.

Appendix 2 gives an example of how the reference crop water use is calculated for a particular location and how target irrigation needs are estimated.

Native Vegetation and Forested Area Evapotranspiration

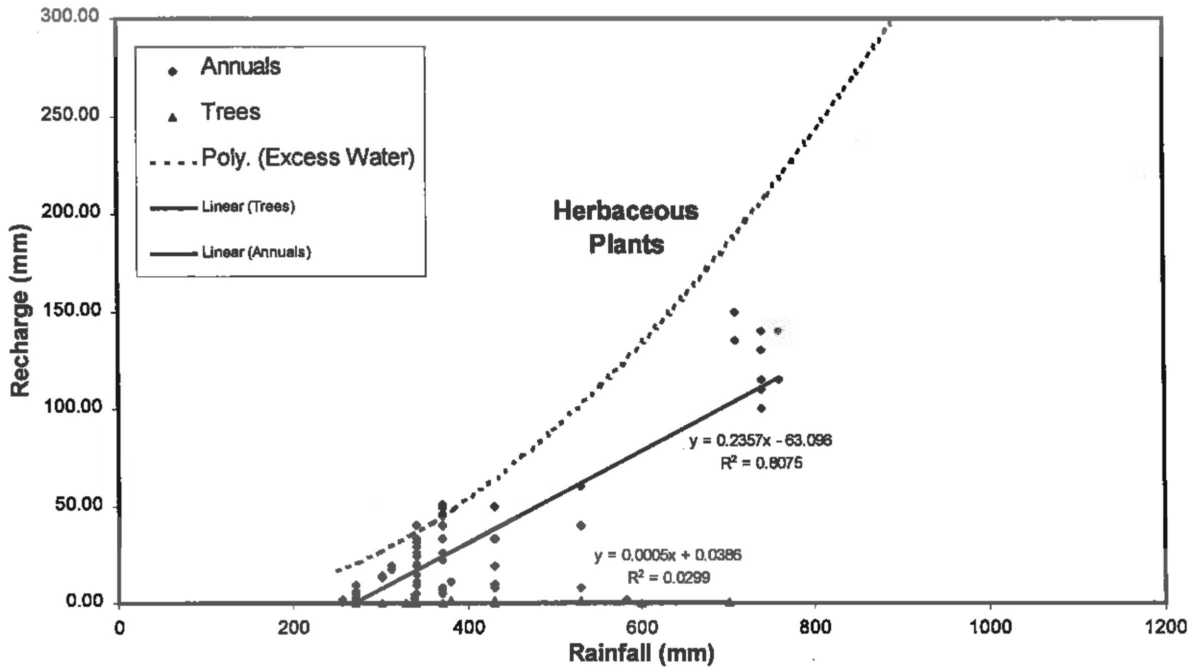
Work conducted by the CSIRO Land and Water Group in Canberra has recently been done to develop and test generic relationships for assessing the impact of land-use change on recharge (Zhang et al, 1999). It was found that there is a strong relationship between recharge and rainfall for annuals on sandy soils which is shown in Figure 16 (Petheram et al, 1999). In the study catchments, the predominant surface soil type was sand to loamy sand which, in general, can be grouped as sandy soils. Research has shown that there is a strong regression for herbaceous plants grown in sandy soils and average annual rainfall and recharge, where the regression equation derived from experimental data is:

$\boldsymbol{y = 0.2357\,x - 63.096}$ (R^2 = 0.8075) (Petheram et al, 1999)

Where:
y = recharge (mm) and x = rainfall (mm)

There was not such a strong relationship evident between trees grown in sandy soil and average annual rainfall (R^2 = 0.0299) (Petheram et al, 1999). Both these regression equations were used to estimate recharge and evapotranspiration for native vegetation and plantation forests.

Figure 16. Recharge vs rainfall for sand soils (Petheram et al, 1999).



5.4.1.4 Farm Dam Storage

Farm dams are common throughout much of the southern range of the Mount Lofty Ranges. These dams influence the flow of water through the catchment and are considered to be an outflow component of the water balance. The total capacity of these farm dams would otherwise contribute to runoff assuming the dams fill and empty each year. It is also assumed that the dams are full at the end of winter/spring and receive no more inflows during summer.

A method developed to estimate the volume of water stored in farms dams has been applied to the South-Central Mount Lofty Ranges (McMurray, 1996). The method involved scanning aerial photography (Infrared (IR) aerial photographs captured at a 1:40,000 scale) taken in December 1995 and January 1996. Farm dams were assumed to be at full capacity at the time of the photography. The aerial photography was processed electronically to extract the outline of water in the farm dams. A 2 m buffer was added to all dam outlines to deal with the greater IR reflectance in shallow water round the edge of dams and in smaller dams. The farm dam volume of water was then estimated using a formula developed from a sample of surveyed farm dams.

$$V = 0.044S^{1.4}$$

Where
V = Volume (m^3 or kL)
S = Surface area (m^2)

Not all the smaller dams were detected due to the shallow water in these dams reflecting IR light off the bottom surface (in deeper dams light is absorbed and not reflected). A correction factor was determined for each size class based on a subjective judgement made during the preparation of the GIS datasets:

Total Volume = 1.05 x (vol of dams > 5ML) + 1.1 x (vol of dams 2-5ML) + 1.5 (vol of dams 0.5-2ML) + 2 x (vol of dams < 0.5ML)

There are several sources of potential error in this methodology including errors in the creation of the GIS datasets and errors in estimating the farm dam volumes as stated in the McMurray 1996 report. In creating the GIS dataset there are errors of scale due to the use of a simple linear warp algorithm on the scanned aerial photos. Also, due to the use of low reflectance in the IR band to detect water in farm dams, errors may have occurred as shadows also have low IR reflectance. A 2 metre buffer was added but errors could exist as not all dams may require the same buffer. Subjective correction factors were applied to estimate the total farm dam volume and could be another source of error. As the Southern Fleurieu was covered in cloud when the aerial photography was captured, there is a possibility that not all of the farm dams were included.

The greatest error in estimating the volumes results from there being no allowance made in the formula for different dam profiles. The correction factors are also a potential source of error and possibly increase the total volume by 10-20%. The major source of uncertainty in the volume estimation lies in the formula. The formula has been proved valid when applied to 26 surveyed farm dams in one catchment indicating that it is reasonable to use in estimating farm dam volumes but as the formula has only been validated by a relatively small number of dams this may be a major source of error.

Recent work to develop an understanding of the water resources in the central and southern Mount Lofty Ranges assessed existing farm dams datasets. It was felt that the farm dam dataset generated by the McMurray, 1996 study did not adequately determine the number and capacity of farm dams throughout the Mount Lofty Ranges for the purposes of their project and consequently were not used. However, the objectives of the 1996 study were to determine the volume of water in farm dams at the time of the air photography, not the maximum capacity. At the time of the study it was acknowledged that there would be large errors in detecting and estimating the volume of the smaller dams. The latter was not considered a serious problem as the majority of water stored in farm dams is held in the larger dams.

5.4.1.5 Farm Dam Evaporation

Surface areas derived from the farm dam database were multiplied by the annual evaporation rate for each catchment to calculate the total catchment evaporation volume from farm dams. This estimate could be slightly higher than actual evaporation volumes as surface areas were used for farm dams assumed to be at full capacity. In addition, all the errors associated with the farm dam database as listed above would apply to this estimation as well.

5.4.2 Chloride Balance

The chloride ion can be used to estimate recharge provided that it is not dissolved from rocks or minerals. After rain falls, evapotranspiration removes the water from the soil and the conservative chloride ion remains and is concentrated in the reduced amount of water that percolates down to recharge the groundwater. Recharge can be calculated as follows:

$$\text{Recharge} = (\text{Annual rainfall} - \text{Runoff}) \times \frac{Cl_{rf}}{Cl_{gw}}$$

Where:
Cl_{rf} = chloride in rainfall (mg/L)
Cl_{gw} = chloride in groundwater (mg/L)

Interpretation of the results from this calculation must be careful to take into account that intensive irrigation may result in recirculation of the groundwater with further evaporative concentration of the chloride ion. Also, additional chloride may be added by the application of fertilisers.

An important hydrological input is the salt accession from the atmosphere. The principal pathway for the seasalt incursion is by breaking waves, which inject aerosol into the atmosphere (Monahan, 1971). This reservoir impacts the atmosphere in two ways:

- heavier particles are deposited directly in the near coastal zone; and
- light particles are diffused much further inland and deposited mainly through rainfall.

The most important historical dataset was obtained by Hutton and Leslie (1958) for south-western Victoria between 1957-1958 and the following formula was derived:

$$\text{Chloride (milli-equivalents/litre)} = [0.99d]^{-0.25} - 0.23$$

Where:

d = distance from the ocean in the direction most likely to contribute maximum oceanic salt (km)

This formula is most applicable where the distance is between 0.5 and 300 km and average annual rainfall exceeds 500 mm/year (Hutton, 1976).

A three year study in South Australia uncovered a pattern of high dry accession confined to the near coastal area which probably consists of the large aerosol particles together with a residual dry accession inland which probably is due mainly to the small aerosol particles (Kayaalp and Bye, 1999).

The wet accession is due mainly to rainfall and decreases in concentration inland from the coast. The annual wet accession rate was found almost to be independent of the annual rainfall. The variation of annual chloride concentrations in rainfall (wet chloride) with distance to the ocean can be related with the following exponential function:

$$C_{CL} = \hat{C} + C_o e^{-x/dr}$$

Where:
C_{Cl} = chloride concentration (mg/L)
$\hat{C}$ = an asymptotic concentration (mg/L) = 1.1 mg/L
C_o = 2.98
x = distance from the coast (km)
dr = constant distance = 111 km

Rearranging this equation to include the constants, the formula becomes:

$$C_{Cl} = 1.1 + 2.98\, e^{-x/111}$$

Near the coast salts derived from oceanic spray dominate the contribution from rainfall but further from the coast the dry accession rate is most likely dominated by a dry fallout of the smaller aerosol particles (Kayaalp and Bye, 1999). The dry accession rate can be calculated as follows:

$$D_{Cl} = \hat{D} + D_o e^{-x/dd}$$

Where
D_{Cl} = dry chloride accession rate (kg/km^2/month)
$\hat{D}$ = dry chloride accession rate = 60 kg/km^2/month
D_o = dry chloride accession rate = 1043 kg/km^2/month
X = distance from the ocean (km)
dd = the decay distance = 2.7 km

Rearranging this equation to include the constants:

$$D_{Cl} = 60 + 1043\, e^{-x/2.7}$$

The chloride concentrations were obtained from SA-GEODATA and the distances were estimated using GIS.

5.5 *Water Use in Study Catchments*

Groundwater and surface water are used for many purposes in all three catchments: domestic, stock, processing milk and washing down in dairy operations and irrigation. Because none of the bores in any of the catchments are metered there was no available information on groundwater extraction measurements for irrigation bores and therefore, indirect methods were used to estimate groundwater and surface water use.

Irrigation is the most significant water use in the study catchments and determining the volume of water used for irrigation purposes was estimated by two different methods: field investigation and GIS land use survey coverage.

5.5.1 Field Investigation for Irrigation Volumes

Aerial photography (1996) using false colour Infrared film at a scale of 1:40,000 was used to first identify irrigated areas for further investigation. The aerial photos were obtained from the Department of Environment Heritage and Aboriginal Affairs (DEHAA) and were previously used in a farm dam storage assessment (McMurray, 1996).

A field investigation was conducted November 18th-23rd, 1999 and January 28th, 2000 in the study catchments. Areas identified as being irrigated were first visited and inspected for signs of irrigation. If the land was being irrigated or there was irrigation equipment present the owners were sought out and interviewed (see Appendix 3 – Bore Survey Form) and samples were collected from one or more active irrigation bores. No samples were collected from irrigators that used farm dam water for irrigation purposes. Samples were analysed at the PIRSA's Glenside Core Library and results were sent back to the respective irrigator.

Another means of identifying irrigation operations was by word of mouth. Often one irrigator would know and identify another and this proved to be a useful means of collecting the data. A further means was to drive through the study catchments and carefully watch for signs of irrigation. There is no means of estimating the number of irrigators that were not interviewed or identified in this field survey.

As irrigation practices are closely linked to weather conditions (temperature and rainfall), the estimates provided by the major irrigators interviewed are considered to be conservative and a general approximation of the volume of water used for irrigation purposes in the study catchments.

Irrigation logs were handed out to all groundwater irrigators. Irrigators were encouraged to record the actual number of hours of irrigation during the 1999/2000 summer season. These bore logs will be collected from the irrigators in April and the results assessed by Groundwater Program staff.

5.5.2 GIS Land Use Survey Coverage for Irrigation Volumes

Data from the 1993 and 1999 GIS land use survey were used to provide an estimate of the area and crop type irrigated. An approximate estimation of the total volume extracted was made using the estimates for irrigation requirements for crops grown in the study area. The percentage of land irrigated was approximated based on knowledge of the study catchments and expert opinion.

5.5.3 Domestic Use

The estimates for groundwater extraction for domestic use is based on an estimate of number of households in each catchment. These numbers were provided by the District Council of Victor Harbour from their Rapid Number database which is used for fire protection. Each household in the area has a post outside their property with a unique identification number - Rapid Number. Maps of the study catchments were provided to the District Council and a best estimate was made on the number of households in each catchment. Households within 15 km of Victor Harbour were not included in the estimates as these households are provided with SA Water mains water. The catchment household estimates are approximately 90% accurate.

In estimating the average daily consumption per person, data from usage in Adelaide was utilised to determine annual volumes. It was assumed that an average household has 3 individuals.

5.5.4 Stock Use

Stock need to drink enough water or else their production will suffer. The normal water intake for the following animals is estimated (Solomon and Ashton, 1997) to be:

- sheep (Merino ewe) - 1.6 L per day (average over a year);
- dairy cows - 70 L per day;
- horses - 45 L per day; and
- beef cows 35 L per day (average over a year).

These values were used to estimate the total annual volume consumed by different stock in each catchment.

The number of stock in each catchment was estimated through discussions with staff at the Dairy Authority and PIRSA.

5.5.5 Processing in Dairy Operations

There are a number of dairy operations in each of the study catchments. There is a large volume of water that is used in these operations in washing down the machinery and pens and for cooling units that are used for processing milk. This water is then directed to waste water lagoons on site.

There were no sources of information to provide a reasonable estimation of the water use for this purpose. It has been assumed that approximately 1000 kL per year per dairy operation is used for these purposes. This assumption should be validated for a more accurate assessment volume. However, as this volume of water is relatively small in comparison to the irrigation water use and because this water is eventually discharged back into the ground, it is a less significant component of the water balance.

5.6 Hindmarsh Tiers Observation Bore Network

Analysis was done on the observation bore network established in the Hindmarsh Tiers in 1975. Water levels for these irrigation bores were regularly monitored on a monthly basis from 1975 to 1993. Since 1993 only sporadic sampling has been done on this observation bore network. Water level measurements were collected for all the active observation bores in September and November 1999 as part of this study. In January 2000, four observation bores were also measured.

One of the bores (ENB18) is artesian and was fitted with a pressure gauge. Problems with the pressure gauge have made this data set unreliable and consequently it has not been used in any of the analyses in this report.

Before any analysis was initiated, the water level data was “corrected”. Obvious errors in recording water levels were adjusted to provide a more consistent data set (0 to 5 values were adjusted in each observation bore). When there was more than one value for a month, the last recorded measurement was used in the analysis.

In the Hindmarsh Tiers Basin there are two rainfall gauge stations: Fernbrook and Springmount. The data are collected at Fernbrook, elevation 250 m, with a standard 200/203 mm diameter funnel and a tipping bucket rain gauge. The station is located on the northern margin of the basin in the valley and data has been collected there for 64 years. The other rainfall collection station, Springmount, is located on the hill slope on the southern margin of the watershed. Originally the collection device was mounted at a height of 1.5 metre and in recent years the gauge has been lowered to a 1 metre height. The Springmount station is orientated more to the eastern side of the catchment and is surrounded by pine trees which may have had an influence on the rainfall results. Therefore, the rainfall data from the Fernbrook gauging station was used in the analyses of water level data from the Hindmarsh Tiers observation network.

6.0 Results and Discussion

6.1 Bores in the Study Catchments

In 1976, the *Water Resource Act* required that for the construction of a well deeper than 2.5 metres a permit was required. In addition, drillers were required to submit data on the bore construction to the appropriate government agency. There was no requirement to submit this information prior to 1976 which has resulted in a lack of information on many bores drilled prior to 1976.

The following information on bores in the study catchment areas has been obtained from the corporate database SA-GEODATA. Before any analysis was initiated, all bores in the study catchments were validated against original microfisched bore records. Bore lithologies, where available, and geological maps were also assessed and geological formations were assigned to the bore production zones. There is no system of standard nomenclature for different geological formations such as clays, sands and rock types. This, in addition to the diversity of details provided by individual drillers can make the interpretation of individual bore lithologies a challenge.

Locations of bores are provided by the driller and entered into the database and onto bore location maps. In the study catchments there are very few bores that were georeferenced using GPS. Elevations of bores were assigned to bores with no elevation data using topographic maps. However it should be noted that many of the bores in SA-GEODATA may not be accurately located as was discovered during the field work component of this study. In addition there were many bores that have not been located at all.

Well yields in SA-GEODATA are estimations made by the driller at the time of drilling through a variety of different methods that don't necessarily test the capacity of the bore. The well yield entered in the database may not be an accurate representation of the actual production yield of the bore and shouldn't be relied on to be representative of the actual production capacity of the bore. For instance, the well yields listed in SA-GEODATA for some of the irrigation bores surveyed were much lower than the actual production yield for the irrigation bore. Only well yields recorded during drilling have been presented below and in some instances there is more than one bore yield recorded for a bore.

The status and purpose of the drilled bores are also recorded in the database. All this information was collected during drilling and, unless updated through field surveys, may not be representative of the current status of the bore. Bores originally listed as irrigation bores may not necessarily now be used for production purposes. In some instances, garden watering has been listed as irrigation for purpose. In addition, there were several bores listed in the SA-GEODATA as operational that were identified as being either abandoned or back filled in the field survey. This may imply that there may be others with incorrect status in the database.

6.1.1 Hindmarsh River Catchment

Status

In the Hindmarsh River Catchment there are 121 bores listed in SA-GEODATA as shown in Table 3. A total of 16 have been abandoned since drilling took place and 84 bores are listed as operational. The status of 18 bores is unknown.

Table 3. Hindmarsh River Catchment bore status.

	Abandoned	Dry	Flowing	Operational	Unknown	Total
Number of bores	16	1	2	84	18	121

Purpose

The primary purpose for each bore listed as operational or unknown are listed in Table 4. Of these bores, 15 had no purpose entered and there was one bore listed as industrial and one as investigation. The database allows two purposes to be listed and therefore many bores have more than one purpose listed. For instance, 7 of the domestic bores are also used for irrigation purposes and 6 for stock. Of the irrigation bores, 19 are also listed as being used for stock purposes.

Table 4. Primary purposes of bores listed as operational or unknown in the Hindmarsh River Catchment.

	Domestic	Industrial	Irrigation	Observation	Stock	Total
Number of bores	11	1	47	19	9	87

Geological Formations

Bores logs were examined to determine the geological formation that the bore was completed into. Table 5 shows the distribution of bores and geological formations. There were 68 bores where no geological formation was assigned due to either no well log being available or incomplete information in the existing well log. Most of the bores in the Hindmarsh River Catchment were completed into Tertiary Limestone. There bores are located in the Hindmarsh Tiers Basin and many are used for irrigating the pastures in the area.

Table 5. Hindmarsh River Catchment bores completed into geological formations.

	Cape Jervis Beds	Kanmantoo Group	Quaternary	Tertiary Limestone	Total
Number of bores	26	22	13	41	102

Well Yields

Appendix 4 shows graphs of the well yields for bores in the Hindmarsh River Catchment by depth of the well and by geological formations that the bore is completed. Depth of the bore did not appear to have any noticeable impact on the well yield for any of the geological formations.

Table 6 shows the average, minimum and maximum well yields for each geological formation that were recorded when the bore was drilled. At the time of drilling, yields measured for bores completed into the Tertiary Limestone formations had an overall higher average well yield than the bores in the other formations - 4 times as high as the Kanmantoo Group and 6 times as high as the Cape Jervis Beds. The maximum well yield recorded in the Tertiary Limestone formation was 56.3 L/s. In the Hindmarsh River Catchment, at the time of drilling, bores completed into the Kanmantoo Group had a higher well yield than those completed into the Cape Jervis Beds.

Table 6. Well yields for the various geological formations in the Hindmarsh River Catchment.

Well Yield	Cape Jervis Beds (30 values)	Kanmantoo Group (39 values)	Quaternary (9 values)	Tertiary Limestone (27 values)
Average (L/s)	3.0	4.8	1.7	19.1
Minimum (L/s)	0.06	0.2	0.1	0.63
Maximum (L/s)	8.5	24	12.5	56.3

6.1.2 Inman River Catchment

Status

In the Inman River Catchment there are a total of 148 bores listed in SA-GEODATA as shown in Table 7. A total of 16 bores have been either abandoned, backfilled or are not in use since drilling took place and 79 bores are listed as operational. There are a large number of bores in this catchment where the status of the bore is unknown (52 bores).

Table 7. Inman River Catchment bore status.

	Abandoned	Back-filled	Flowing	Not in Use	Operational	Unknown	Total
Number of bores	9	1	1	6	79	52	148

Purpose

For the bores that are listed as operational or unknown the types of primary purposes are listed in Table 8 (there were 24 bores that had no purpose listed). Several bores had more than one purpose listed. For instance, 2 of the domestic bores is also used for irrigation purposes and 6 for stock. Of the irrigation bores, 10 are also listed as being used for stock purposes. There are the same number of bores used for stock purposes as for irrigation purposes. There were 30 bores drilled for mineral exploration purposes.

Table 8. Primary purposes of bores listed as operational or unknown status in the Inman River Catchment.

	Domestic	Drainage	Explora-tion	Irrigation	Observation	Stock	Total
Number of bores	12	3	30	35	1	35	131

Geological Formation

All bores logs, where available, were examined to determine the geological formation that the bore was completed into. Table 9 shows the distribution of bores and geological formations. There were 70 bores which had no geological formation assigned due to either no well log being available or incomplete information in the existing well log. Most of the bores in the Inman Valley Catchment were completed into the Cape Jervis bed formation and were located along the river valleys (Inman and Back Valley Creek).

Table 9. Inman River Catchment bores completed into geological formations.

Number of bores	Cape Jervis Beds	Kanmantoo Group	Quaternary	Total
	46	23	10	79

Well Yield

Appendix 4 shows graphs of the well yields for bores in the Inman River Catchment by depth of the well and by geological formations that the bore is completed into. Depth of the bore did not appear to have any noticeable impact on the well yield for any of the geological formations. However, there was only one deep bore drilled into the Cape Jervis Beds formation (290 metres). For bores completed into the Kanmantoo Group the well yields do not appear to be influenced by bore depth.

Table 10 shows the average, minimum and maximum well yields for each geological formation at the time of drilling. Bores completed into the Cape Jervis Bed and Kanmantoo Group have the same average well yields. The highest well yield recorded in SA-GEODATA for Inman River Catchment bores was 18.8 L/s for a bore completed into the Kanmantoo Group. There was no well yield data recorded during drilling for the bores completed into the Quaternary formation but information obtained from field surveys indicate that the average well yield for bores completed in the Quaternary formation was 1.4 L/s with a maximum yield of 9.5 L/s.

Table 10. Well yields for the various geological formations in the Inman River Catchment.

Well Yield	Cape Jervis Beds (40 values)	Kanmantoo Group (50 values)
Average (L/s)	2.9	2.9
Minimum (L/s)	0.1	0.03
Maximum (L/s)	12.0	18.8

6.1.3 Currency Creek Catchment

Status

In the Currency Creek Catchment there are a total of 79 bores listed in SA-GEODATA as shown in Table 11. A total of 12 bores have been either abandoned, backfilled or not in use since drilling took place and 61 bores are listed as operational. There were 5 bores listed with the status unknown.

Table 11. Currency Creek Catchment bore status.

	Abandoned	Back-filled	Flowing	Not in Use	Operational	Unknown	Total
Number of bores	10	1	1	1	61	5	79

Purpose

The database also stores data on the purpose of the bores. For the bores listed as operational or unknown the types of purposes are listed in Table 12 (4 bores had no purpose listed). Several bores have more than one purpose listed. For instance, 5 of the domestic bores are also used for irrigation purposes and 17 for stock. Of the irrigation bores, 4 are also listed as being used for stock purposes. As in the Inman River Catchment, there are a large number of bores that have been listed for stock purpose. In addition, there are 29 bores listed as domestic bores which is a higher number than the other two catchments.

Table 12. Primary purposes of bores listed as operational or unknown in the Currency Creek Catchment.

Number of bores	Domestic	Irrigation	Stock	Total
	29	20	18	63

Geological Formation

Bores logs were examined to determine the geological formation that the bore was completed into. Table 13 shows the distribution of bores and geological formations. There were 9 bores which had no geological formation assigned due to either no well log being available or incomplete information in the existing well log. Most of the bores in the Currency Creek Catchment were completed into the Kanmantoo Group formation. There were two bores completed into the Tertiary Limestone formation located in a small valley on Mosquito Hill Road.

Table 13. Currency Creek Catchment bores completed into geological formations.

	Cape Jervis Beds	Kanmantoo Group	Quaternary	Tertiary Limestone	Total
Number of bores	27	53	4	2	86

Well Yields

Appendix 4 shows graphs of the well yields for bores in the Inman River Catchment by depth of the well and by geological formations that the bore is completed into. Bores completed into the Cape Jervis Bed formation appear to show a trend to deeper bores having a greater well yield. However, there are only a handful of bores deeper than 60 metres and the trend may not apply to the whole catchment. Bore depths for bores completed into the Kanmantoo Group do not appear to have any noticeable impact on the well yield for any of the geological formations.

Table 14 shows the average, minimum and maximum well yields for each geological formations. At the time of drilling bores completed into the Cape Jervis Bed and Kanmantoo group appear to have about the same well yields on average. The highest well yield recorded in SA-GEODATA for Inman River Catchment bores was 18.8 L/s for a bore completed into the Kanmantoo Group.

Table 14. Well yields for the various geological formations in the Inman River Catchment.

Well Yield	Cape Jervis Beds (27 values)	Kanmantoo Group (108 values)	Tertiary Limestone (6 values)
Average (L/s)	2.0	3.2	9.6
Minimum (L/s)	0.0001	0.0001	4.9
Maximum (L/s)	6.25	31.3	12.5

6.2 *Hindmarsh Tiers Observation Network*

There is only one of the study catchments with a well established observation bore network - Hindmarsh River Catchment. In 1975, a total of 21 observation wells were drilled in the Hindmarsh Tiers Basin. There were 13 bores successfully completed into the limestone aquifer. Of the remaining bores, two were completed in the Permian sands, two in Pleistocene gravels, and four were unsuccessful. Their locations are shown in Figures 6, 14 and 15 and details of the observation bores is shown in Table 15. Over the years the following observation bores have been abandoned: ENB7, ENB21 and ENB22.

Table 15. Summary of observation well details, Hindmarsh Tiers.

Well Number		Tertiary Limestone Aquifer			
Observation	**Unit**	**Depth (m)**	**From (m)**	**To (m)**	**Remarks**
ENB2	6627 231	156.0	7.0	126.0	Limestone aquifer
ENB4	6627 283	243.0	45.0	106.0	Limestone aquifer
ENB5	6627 233	16.0	6.0	16.0	Limestone aquifer
ENB6	6627 232	16.0	6.0	16.0	Limestone aquifer
ENB7	6627 204	30.0	22.0	30.0	Limestone aquifer – abandoned
ENB8	6627 239	26.0	18.0	26.0	Limestone aquifer
ENB9	6627 234	19.0	12.0	19.0	Limestone aquifer
ENB10	6627 217	36.0	30.0	36.0	Limestone aquifer
ENB11	6627 213	20.3	10.0	20.3	Limestone aquifer
ENB12	6627 212	30.0	20.0	30.0	Limestone aquifer
ENB13	6627 285	32.0	22.0	32.0	Limestone aquifer
ENB14	6627 281	10.8	2.5	10.8	Shallow quartz arenite aquifer
ENB15	6627 205	28.0	24.0	28.0	Limestone aquifer
ENB16	6627 190	65.0	61.0	65.0	Limestone aquifer
ENB17	6627 278	99.0	4.0	50.0	Shallow quartz arenite aquifer
ENB18	6627 286	36.0	?	36.0	Permian sands – flowing
ENB19	6627 291	49.1	?	49.1	Permian sands
ENB20	6627 279	58.5	44.0	58.5	Limestone aquifer
ENB21	6627 207	41.7	32.0	41.7	Limestone aquifer - abandoned
ENB22	6627 282	21.0	13.0	21.0	Limestone aquifer but probable leakage from shallow quartz arenite aquifer – abandoned

6.2.1 Water Elevations

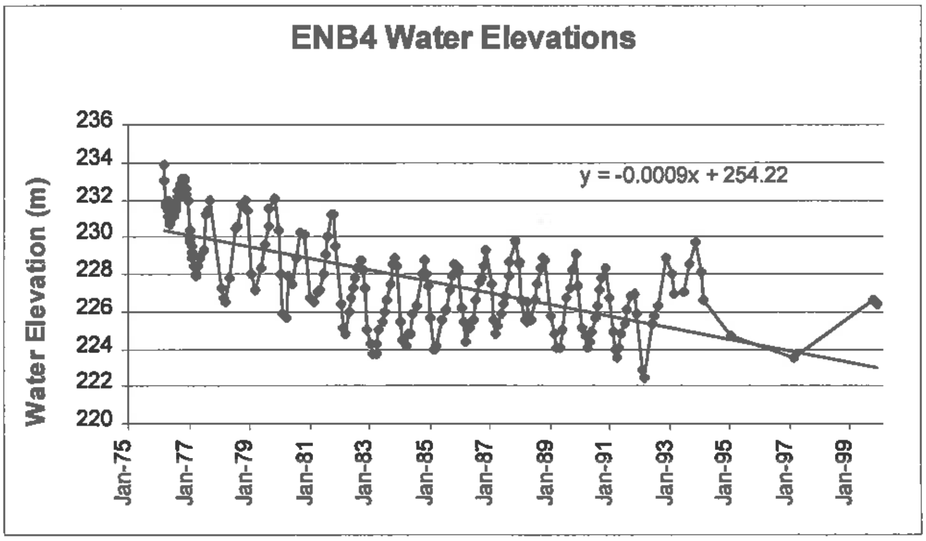
Water level measurements were taken on the earliest drilled observation wells in October 1975. Monthly records have been regularly kept on the water levels for 17 observation bores between 1975 and 1993. Since 1993, there have been a total of 7 water level measurements taken for most of the observation bores and 3 of these measurements were taken as part of this study.

Several of the observation bores are no longer functional. The lid on ENB14 cannot be removed and there have been no measurements taken on this bore since 1995. In September 1999, several of the bores were not located due to the areas they were in being overgrown. A metal detector assisted in locating these bores in November 1999. The pressure gauge on ENB18 does not appear to be functioning properly and the results from the sampling of this bore have not been included in the following results.

Analysis was done on the water level records for the 16 active observation bores in the Hindmarsh Tiers network. Appendix 5 shows graphs for the water elevation changes over time for all the observation bores and the regression lines and equations derived for the water elevation data. The lines drawn on these graphs from 1993 to 1999 are misleading as there were very few data points in this period and it is not known what the trends are for this period. This is an unfortunate gap in the dataset and hinders the interpretation of some of the trends discussed below. The graphs show three different trends with respect to water elevation changes: decreasing, increasing and level.

There are 10 observation bores where the water elevations are clearly showing a decreasing trend (slopes of the regression curves vary from -0.005 to -0.009). Most of these bores (8) are located at the southeastern end or discharge point of the aquifer formation. Two of the bores are located in the central part of the valley. Figure 17 shows the water elevations measured over time for the observation bore ENB4.

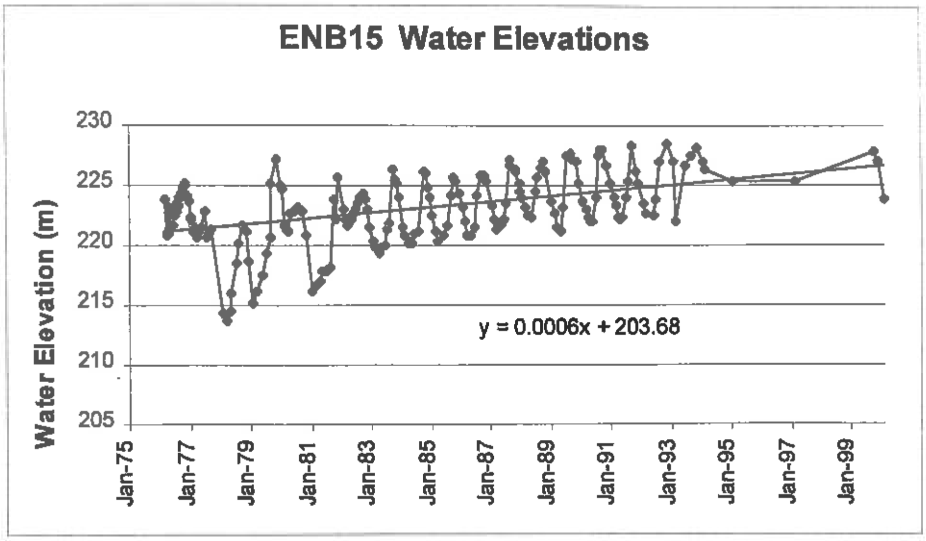
Figure 17. Water elevations for observation bore ENB4.



There were 3 observation bores that showed an increasing trend (slopes of the regression curves ranged from 0.00005 to 0.0006): ENB15, ENB17, ENB19. Each of these bores was completed into a different formation: Tertiary Limestone, Cape Jervis Beds and Quaternary. The observation bore with the largest increasing trend is located slightly upslope from the valley floor in the central part of the valley. The water elevations for ENB19 showed an increasing trend from 1983 to 1993. It appears from the more recent sampling that this trend has not continued and that the water elevation has dropped considerably. This trend may be due to increased irrigation in this area which is impacting the water elevation. However, because there were only sporadic measurements taken from 1993 to present, it is hard to say what is actually occurring with this bore completed into the Cape Jervis Beds.

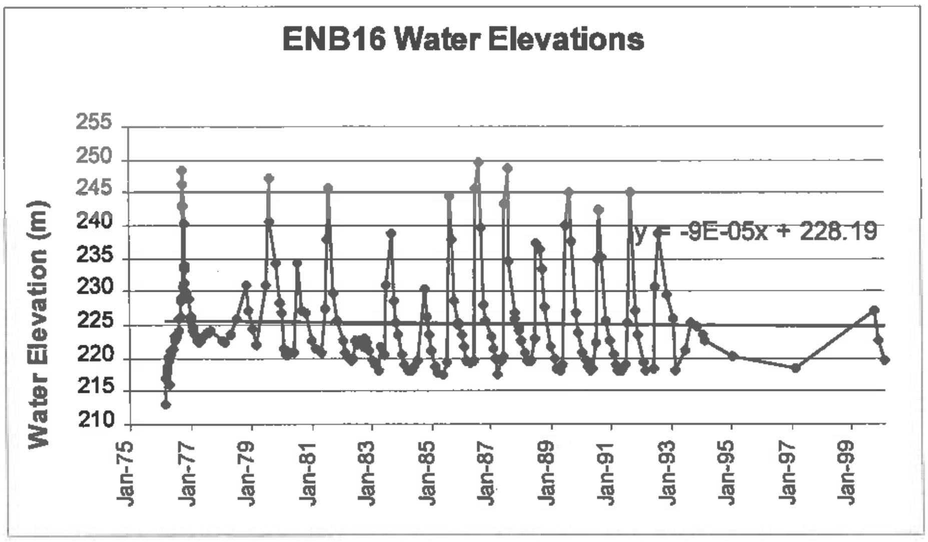
Figure 18 shows that the water elevations for observation bore ENB15 are increasing over the period monitored.

Figure 18. Water elevations for observation bore ENB15.



There were 3 observation bores with fairly stable water elevations: ENB13, ENB14, and ENB16. Two of these observation bores are in the top end of the aquifer (ENB13 and ENB14) and ENB16 is located on a hillslope up from the valley in the southeastern end of the catchment. Figure 19 shows the water elevations for observation bore ENB16.

Figure 19. Water elevations for observation bore ENB16.



Water elevation trends are linked to both rainfall events and groundwater extraction in the area. In order to examine the relationship between groundwater elevations and rainfall, the cumulative deviation from the monthly mean has been plotted for the rain gauge station at Fernbrook.

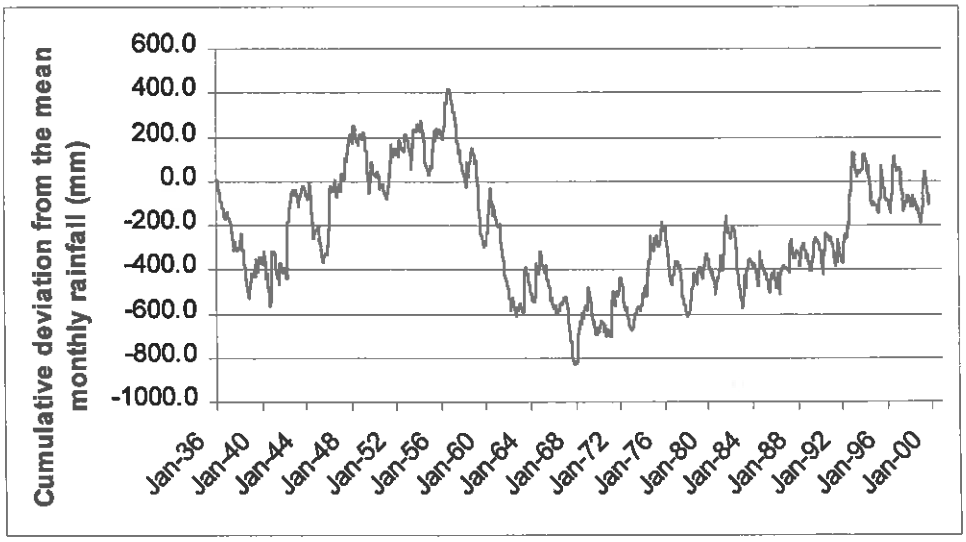
A total of 64 years of monthly rainfall data has been collected at the Fernbrook rain gauge station. The summary statistics for the rainfall data collected at this meteorological station are shown in Table 16. The overall annual average rainfall at the Fernbrook station is 864 mm. The median annual rainfall is 893 mm and the range was from 483 to 1,344 mm. Most of the rainfall occurs from April to October.

Table 16. Summary statistics for the rainfall in mm at the rain gauge station at Fernbrook.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Average	32	30	32	72	102	115	136	113	87	68	43	37	864
Median	22	20	21	60	94	108	125	116	82	62	37	28	893
Min	1	0	0	3	29	24	38	21	26	11	2	6	483
Max	260	173	114	201	232	250	290	208	189	172	122	156	1344

The cumulative deviation from the mean monthly rainfall is a useful means of investigating the relationship between water level trends and rainfall events. The cumulative deviation is the sum of the differences between the actual measured total monthly rainfall and the average monthly rainfall for the whole dataset. An upward trend on the graph indicates a period of above average rainfall or a wet period and a downward trend indicates below average rainfall or a dry period. Figure 20 shows the cumulative deviation from the monthly mean for the entire rainfall record collected at Fernbrook.

Figure 20. Cumulative deviation from the mean monthly rainfall for the rain gauge station at Fernbrook (station number 23823).



The graph in Figure 20 shows the rainfall trend from 1936 to present. From 1941 to 1959 rainfall in the area shows general trends of above average rainfall. However from 1956 to a low point in 1968 rainfall has been steadily decreasing indicating a period of dry years. Since 1968, the rainfall trend has been fairly consistent with periods of increasing rainfall in 1974, 1981 and

1993. Since 1959 rainfall has been in a deficit situation (below zero) in this area which indicates from this time rainfall has been below the average for the period of the rainfall record.

Figure 21 shows the relationship between the cumulative deviation from the mean monthly rainfall and the water elevations in observation bore ENB2. Only the period of the rainfall record that overlaps the water elevation measurements has been plotted. The water elevations follow the deficit or decreasing rainfall trend observed in Figure 20. It appears there was a slight increase in the water elevations in response to the 1993 above average rainfall. It appears from the 1999/2000 water elevation data that the water levels have risen to some extent but not to the original 1975 levels. The same trends were observed in observation bores ENB4-6, ENB8-12, ENB16 and ENB20. These results would indicate that recharge for these bores is closely related to precipitation events. Unfortunately, the lack of data from 1993 to present limits the interpretation of the results.

Figure 21. Fernbrook rain gauge station cumulative deviations from the mean monthly rainfall and water elevations at ENB2.

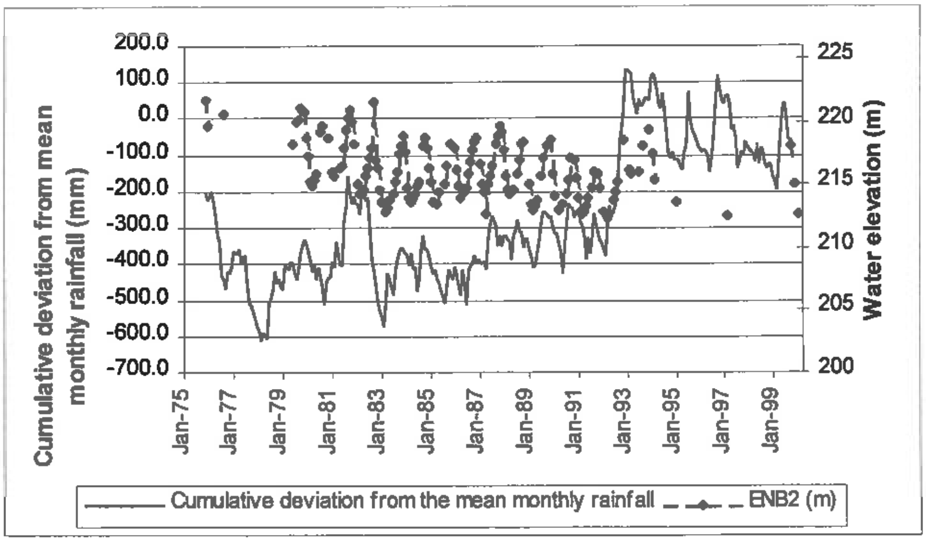


Figure 22 shows a different water level trend in relation to the cumulative deviation from the monthly mean for observation bore ENB15. This same trend was similar for ENB17 and ENB19. For these observation bores there has been a trend to increasing water elevations which would appear to indicate that recharge for these bores is independent of precipitation events. This may indicate that the recharge for these bores comes from vertical or horizontal recharge from the other geological formations in the area.

Figure 22. Fernbrook rain gauge station cumulative deviations from the mean monthly rainfall and water elevations at ENB15.

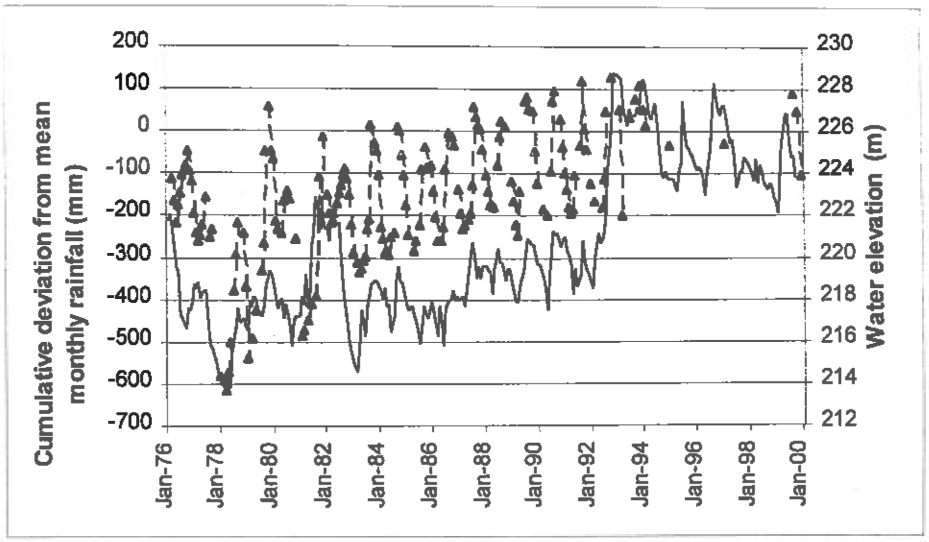
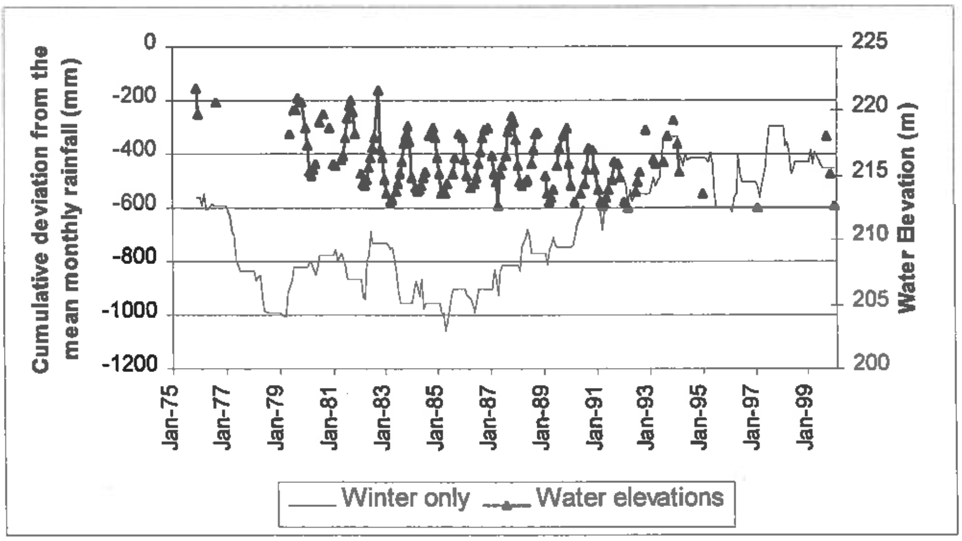


Figure 23 shows another way of seeking out relationships between water elevations and rainfall events. Using only the winter rainfall (April to October) the relationships between rainfall and water levels can be examined. It can be seen from this graph that the water level trends are more closely related to the total year's rainfall than to the winter rainfall.

Figure 23. Cumulative deviations from mean monthly rainfall for the whole year, winter only and water elevations for ENB2.

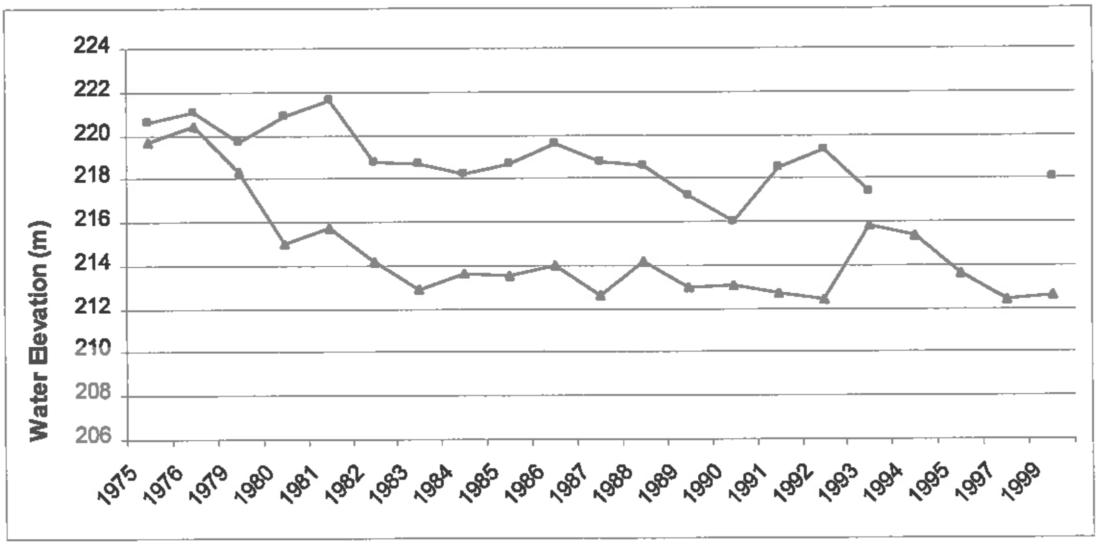


6.2.2 Drawdowns

Another way of analysing water level trends is to look at the drawdowns or the highest and lowest water elevation for each year. Maximum and minimum annual water elevations were estimated for each bore by taking the highest value measured during the winter and the lowest value measured during the summer. These estimations could only be calculated for the years where there was a seasonal component. Appendix 6 shows graphs for each observation bore showing the maximum and minimum water elevations for each year. Regression lines and equations have been calculated and are also shown on the graphs.

Some interesting features of these graphs are that in 1993 when there was a surplus of rainfall, there was a sharp response to this event evident in the minimum elevations. A fairly consistent pattern, as shown in Figure 24, for 10 of the observation bores as shown but there are different response patterns for the rest of the observation bores. From 1983 to 1993 the water levels in these 10 bores appears to be fairly consistent. After the rise in response to the rainfall event in 1993, there appears to be a steady decline in water elevations. Most likely this response is due to the decreasing amount of rainfall in the catchment.

Figure 24. Maximum and minimum water elevations for observation bore ENB2.



ENB15 and ENB13 have very consistent maximum water level elevations over the monitoring period with the exception of the 1993 rainfall event. ENB15 shows a trend to a steady increase in water levels over the years. Since 1983 this response has been fairly smooth and consistent. The minimum water levels in ENB14 appear to be fairly consistent over the years. The graph shows that the maximum water elevation can change but only by at most 0.6 m. The water elevations in ENB19 have been steadily increasing since 1983 but there appears to be a dramatic change in this trend in recent years. Both the minimum and maximum water elevations have changed by 2m since 1992. This is in part due to the lower rainfall in the area but also could be attributed to increased irrigation in this part of the catchment.

ENB16 has a different water elevation pattern than the other observation bores as shown in Figure 25. The maximum drawdown for this bore was 31 m in 1987. The average drawdown for this bore is 20 m. The minimum water elevation appears to be fairly consistent but the maximum water elevation is very erratic. In 1993, the drawdown for this bore was only 8 metres which indicates that the maximum drawdown was strongly influenced by the rain event in that year.

Figure 25. Maximum and minimum water elevations for observation bore ENB16.

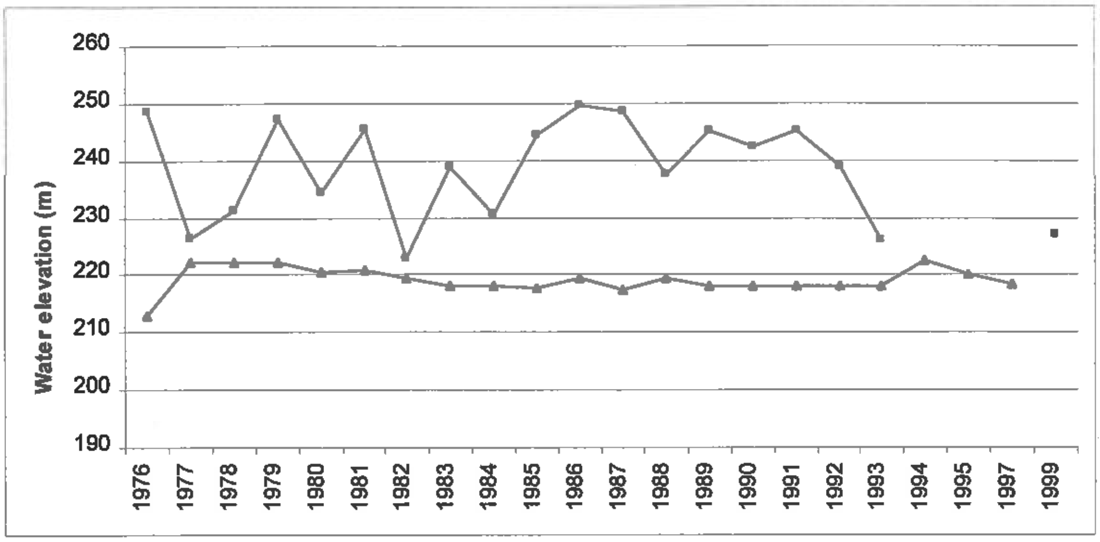


Figure 26 shows that for ENB2, ENB4-6, ENB8-12, ENB15 and ENB20 there was a similar pattern observed for drawdowns. Except for ENB20, the average drawdowns were calculated to be around 5 metres (7 m for ENB20) and the ranges of drawdown values from about 2m to 6m (5-8m for ENB20).

A different drawdown pattern was observed for ENB13-14, ENB17 and ENB19 as shown in Figure 27. For these observation bores there was about half the amount of drawdown as observed for the above mentioned wells and also a smaller range of drawdowns. ENB14 and ENB 17 are completed into the quartz arenite aquifer. All bores are located on the western side of the Hindmarsh Tiers Basin.

Figure 26. Drawdowns for observation bores ENB2, ENB4-6, ENB8-12 and ENB20.

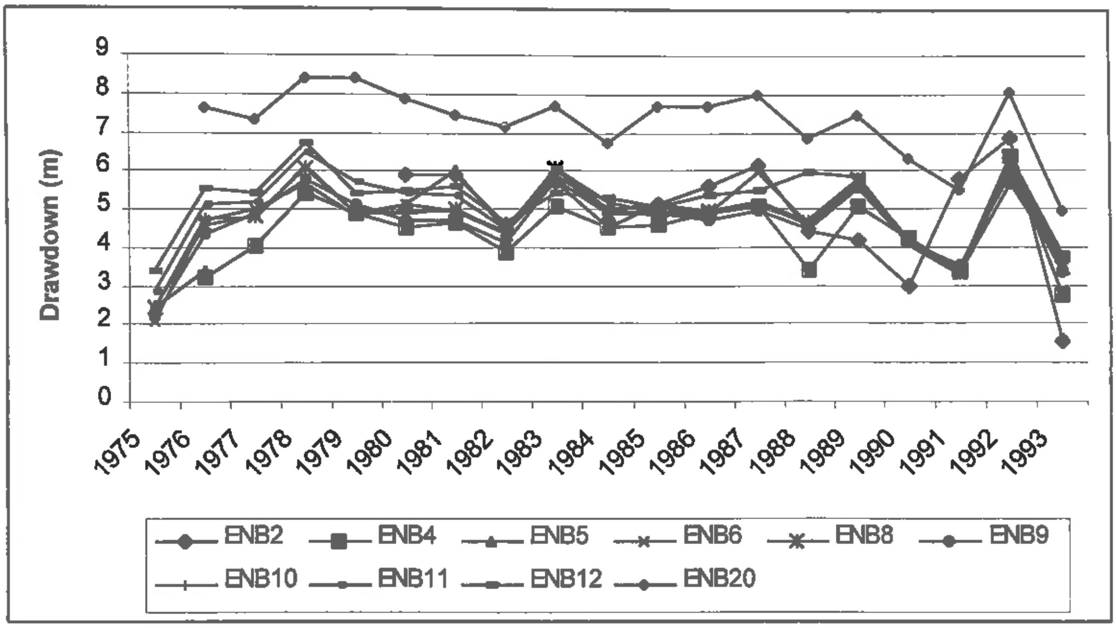
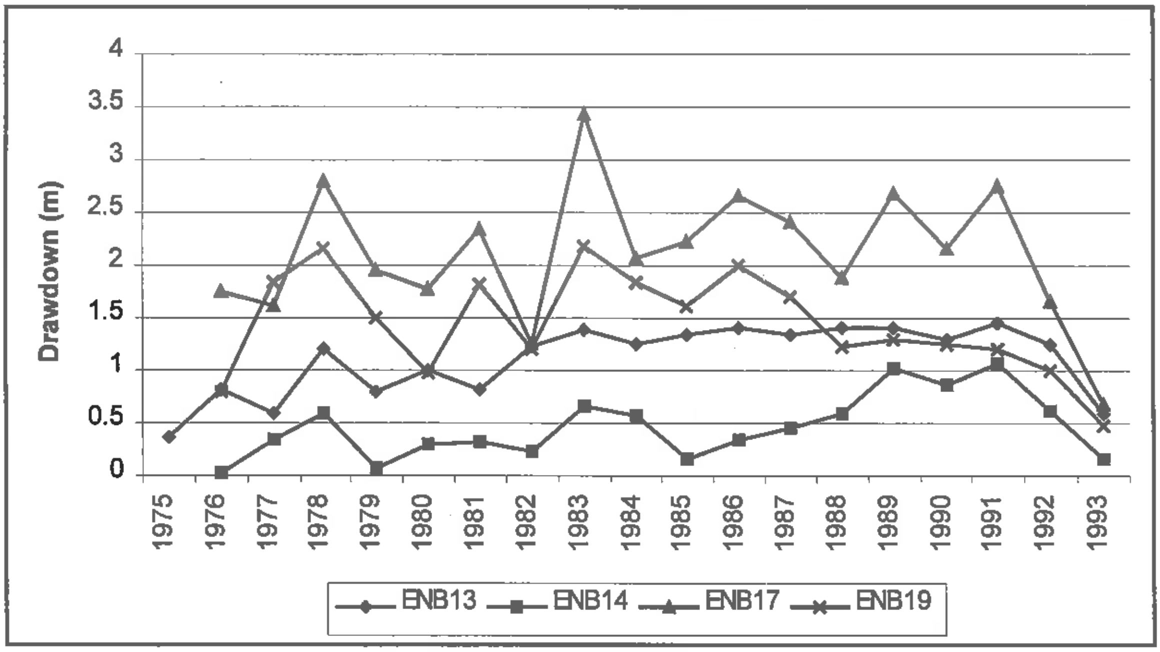


Figure 27. Calculated drawdowns for ENB13-14, ENB17 and ENB19.



6.3 Groundwater Quality Trends

Groundwater salinity data (TDS - Total Dissolved Solids) are collected and stored in SA-GEODATA. All salinity results for each of the study catchments were downloaded from the database and analysed according to geological formations that the bores were completed in. There were several bores in each catchment that did not have bore lithologies and therefore no analysis was done: Hindmarsh River (31 results), Inman River (28 results) and Currency Creek (6 results). SA-GEODATA also stores data on the bore depth from which the sample was taken. In instances where no bore depth was recorded, the previous sample depth or the maximum depth of the bore was used. Plots of groundwater salinity concentrations have been done for each catchment and only bores with samples depths have been plotted. All salinity results have been used in the following analyses ie, some bores had more than one salinity result.

Appendix 7 shows the depth and TDS or salinity values for bores completed into the different geological formations in each catchment. In addition, Appendix 7 has the summary statistics for all the salinity concentrations and geological formations. Appendix 8 describes the impacts of different concentrations of salinity to the land and salinity tolerances of livestock.

Boxplots have been used to graphically represent the different distributions of salinity concentrations for each of the geological formations. The horizontal line in the graphs indicates the minimum and maximum salinity concentrations. The boxes enclose the values that fall within the 25th and 75th percentiles and the line across the box represents the median or middle value for the dataset.

Salinity trends over time were examined for bores with salinity samples taken at different times. No apparent trends were apparent in different catchments or geological formations. However, in order establish a trend more than two results are required and there were very few bores with more than 2 salinity results.

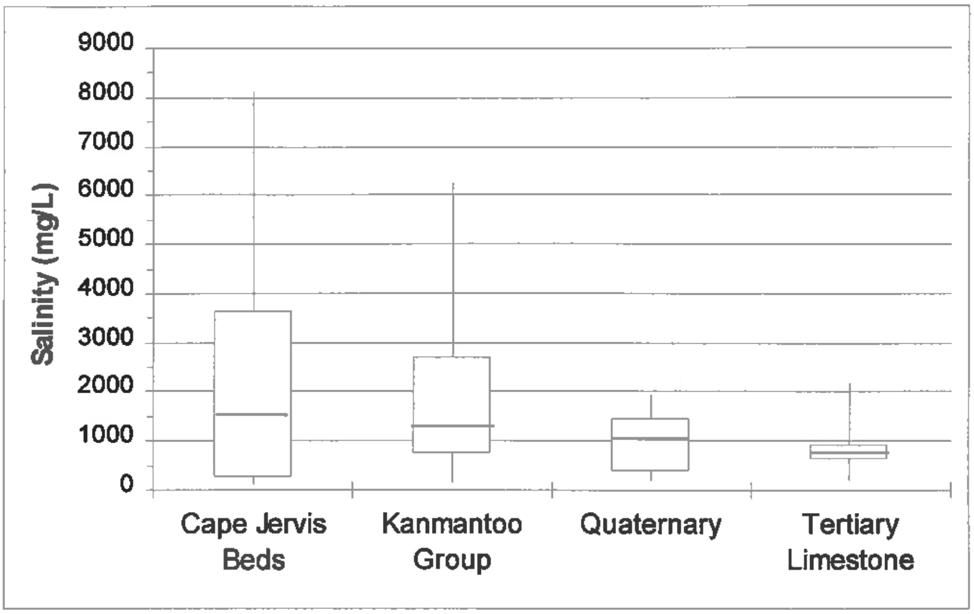
6.3.1 Hindmarsh River Catchment

In the Hindmarsh River Catchment there were a total of 172 salinity results that were used in the following analyses. Figure 28 shows the distribution of salinity concentrations in the different formations in the Hindmarsh River Catchment.

The highest salinity concentrations were found in the Cape Jervis Bed and the Kanmantoo Group formations. In the Cape Jervis Beds, the 31 results analysed indicated that the salinity concentration ranged from 127-8,098 mg/L with an average value of 1,995 mg/L and a median value of 1,470 mg/L. The average value is slightly higher than the median salinity concentration which would indicate that the average is influenced by the higher salinity concentrations.

The salinity concentrations in the Kanmantoo Group for the 31 results analysed ranged from 145-6,245 mg/L with an average concentration of 1,931 mg/L and a median concentration of 1,367 mg/L. The same conclusions can be drawn about this distribution as the Cape Jervis Beds distribution. Both the Kanmantoo Group and Cape Jervis Beds formations have similar salinity concentration distributions over the catchment. The majority of the Kanmantoo Group distribution is over a smaller range than the Kanmantoo group as shown in Figure 28 and the median and average salinity concentrations are slightly lower.

Figure 28. Boxplots for salinity concentrations for bores in the Hindmarsh River Catchment.



There were only 11 salinity results for the Quaternary formation. These results ranged from 200 - 1950 mg/L with an average and median value of 1002 and 1079 mg/L, respectively.

The lowest salinity concentrations were found in the Tertiary Limestone formations. The results from the 93 samples analysed showed that the concentrations ranged from 187-2174 mg/L and the average and median value of 787 and 715 mg/L, respectively.

Figure 29 shows the distributions for the different geological formations. For both the Cape Jervis Beds and the Kanmantoo Group, the salinity results are fairly evenly distributed throughout the different ranges. The salinity results from bores completed into the Tertiary Limestone formation have the highest distribution in the 500 - 1000 mg/L range (56 results) with a similar amount of results in the categories bracketing this range (16-20 results). Most of the Quaternary results were in the 1000-2000 mg/L range (6 results). The Kanmantoo Group had more values in the 1,000 to 3,000 mg/L range than the

Cape Jervis Beds but in the 3,000 to >5,000 mg/L range there was a slightly higher number of Cape Jervis Beds salinity results (9 vs 6).

Appendix 7 shows the graphs for the bore depths and salinity concentrations for the geological formations. For the all the geological formations, it appears that the higher salinity results are found at more shallow depths. Figure 30 shows that the salinity concentrations for bores completed into the Kanmantoo Group have higher concentrations at depths above 100 m. The same relationship is reproduced in the Cape Jervis Beds and Tertiary Limestone. However, as there are only a few results at lower depths, this conclusion may not be accurate. Categorised salinity concentrations for the entire catchment are shown in Figure 31. Most of the bores with low salinity concentrations are located in the Hindmarsh Tiers Basin.

Figure 29. Salinity distributions for different geological formations in the Hindmarsh River Catchment.

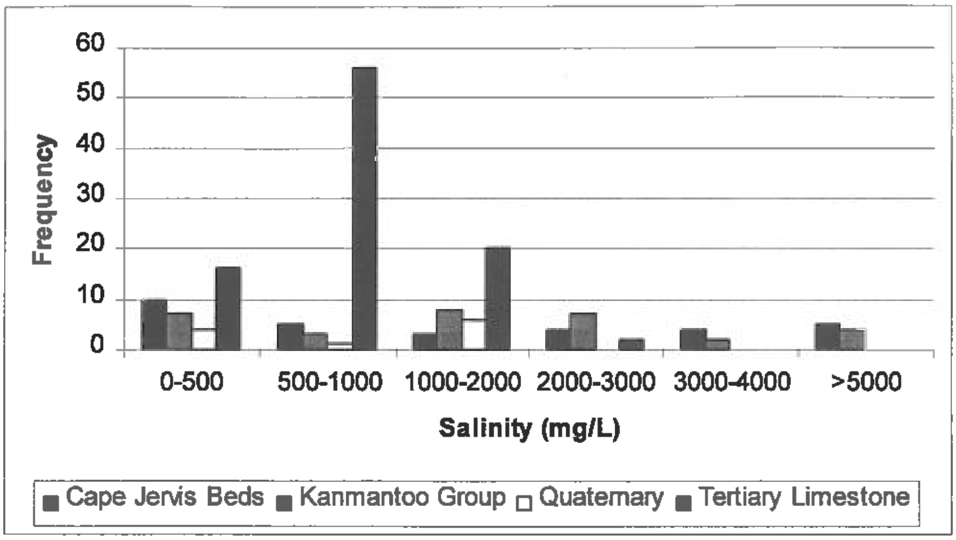
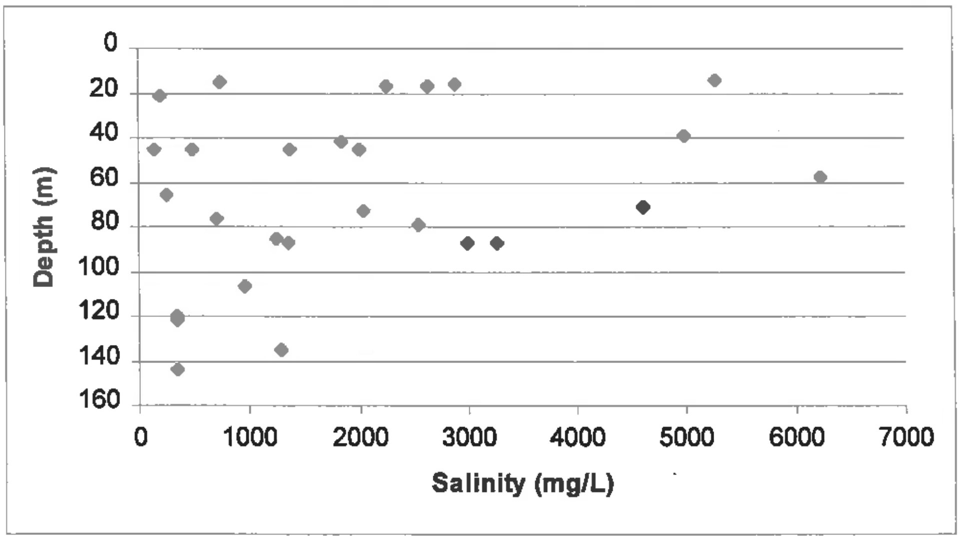


Figure 30. Bore depth and salinity concentration for bores completed into Kanmantoo Group in the Hindmarsh River Catchment.



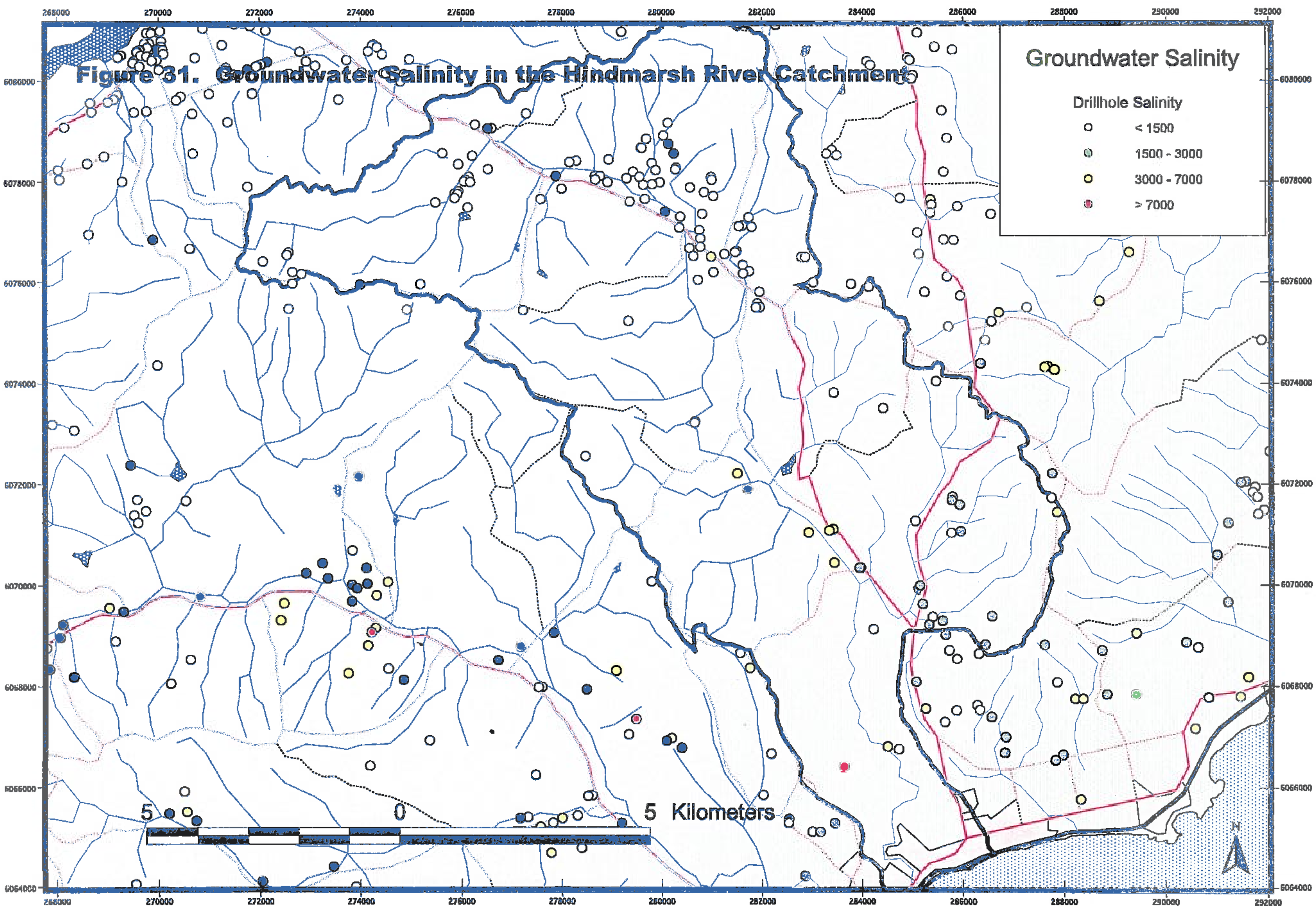


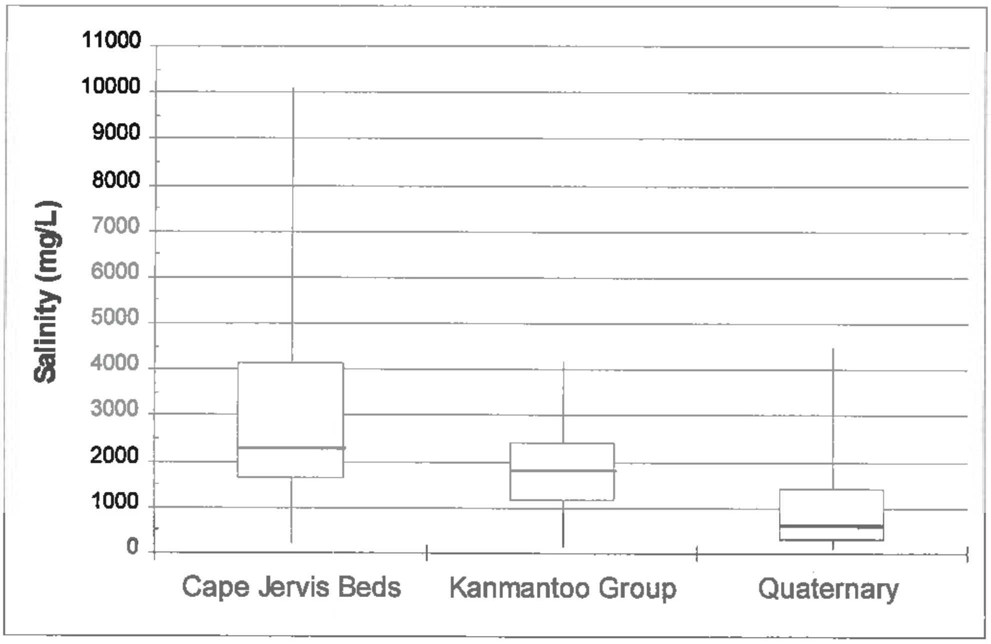
Figure 31. Groundwater Salinity in the Hindmarsh River Catchment
Groundwater Salinity
Drillhole Salinity
< 1500
1500 - 3000
3000 - 7000
> 7000
5
0
5 Kilometers
N
268000
270000
272000
274000
276000
278000
280000
282000
284000
286000
288000
290000
292000
6064000
6066000
6068000
6070000
6072000
6074000
6076000
6078000
6080000

6.3.2 Inman River Catchment

In the Inman River Catchment there were a total of 116 salinity results that were utilised in the following analyses. Figure 32 shows the distribution of salinity concentrations in the different formations in the Inman River Catchment.

The highest salinity concentrations were evident in the Cape Jervis Bed formation. In the Cape Jervis Beds, the 59 results analysed indicated that the salinity concentration ranged from 207-10,103 mg/L with an average value of 3,496 mg/L and a median value of 2,308 mg/L. The discrepancy between the median and average salinity values indicates that the average value is influenced by the several high values.

Figure 32. Boxplots for salinity concentrations for bores in the Inman River Catchment.

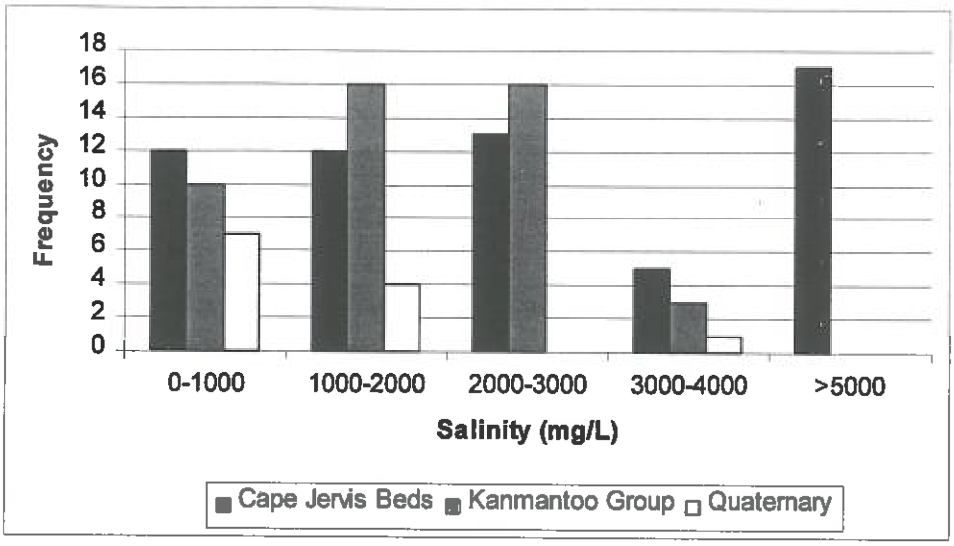


The salinity concentrations in the Kanmantoo Group for the 45 samples analysed ranged from 114-4,164 mg/L with an average concentration of 1,737 mg/L and a median concentration of 1,870 mg/L. Unlike the Hindmarsh River Catchment, the Kanmantoo Group appears to have a lower overall salinity than the Cape Jervis Bed formation.

There were only 12 salinity results for the Quaternary formation. These results ranged from 67-4,465 mg/L with an average and median value of 1,023 and 524 mg/L, respectively. There were no bores completed into the Tertiary Limestone formation in the Inman River Catchment.

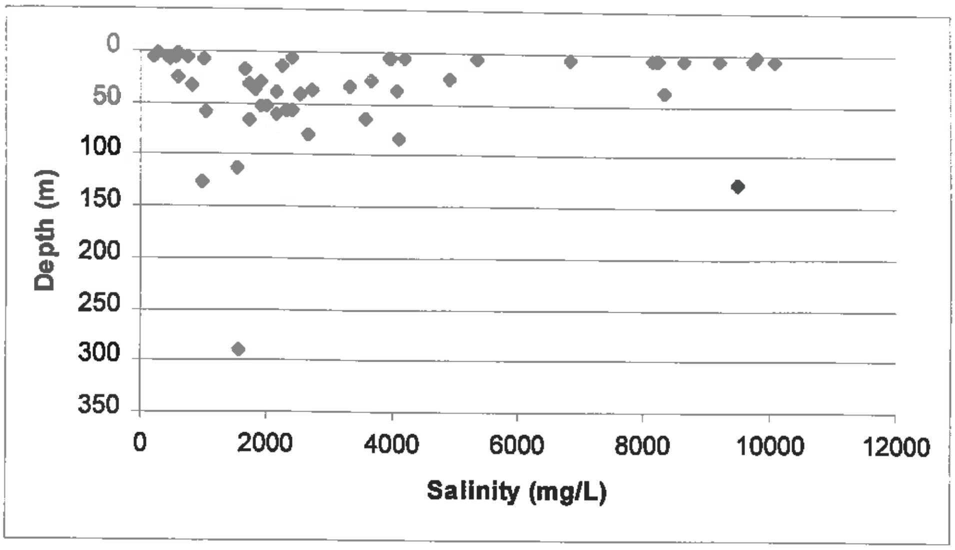
Figure 33 shows the distributions for the different geological formations. For both the Cape Jervis Beds and the Kanmantoo Group, the salinity results are fairly evenly distributed throughout the first three ranges with the Kanmantoo Group bores showing a higher frequency in the 1,000-3,000 mg/L range. However, there are no salinity results in the Kanmantoo Group in the > 5,000 mg/L which is in contrast to the Cape Jervis Beds where this category had a higher number of salinity results than all the other categories.

Figure 33. Salinity distributions for different geological formations in the Inman River Catchment.



Appendix 7 and Figure 34 shows the graphs for the bore depths and salinity results for all the geological formations. Unlike the Hindmarsh River Catchment results, there does not appear to be a clear trend with respect to salinity results and depth of the bore. Most of the bores completed into the Cape Jervis Beds formation were less than 150 metres in depth and the salinity concentrations were not distributed in any clear pattern. The same is true for the bores completed into the Kanmantoo Group formation. Figure 35 shows the categorised salinity concentrations for the entire catchment. Most of the bores located along Inman River and Back Valley Creek have salinity concentrations >1,500 mg/L.

Figure 34. Bore depth and salinity results for bores completed into the Cape Jervis Beds in the Inman River Catchment.



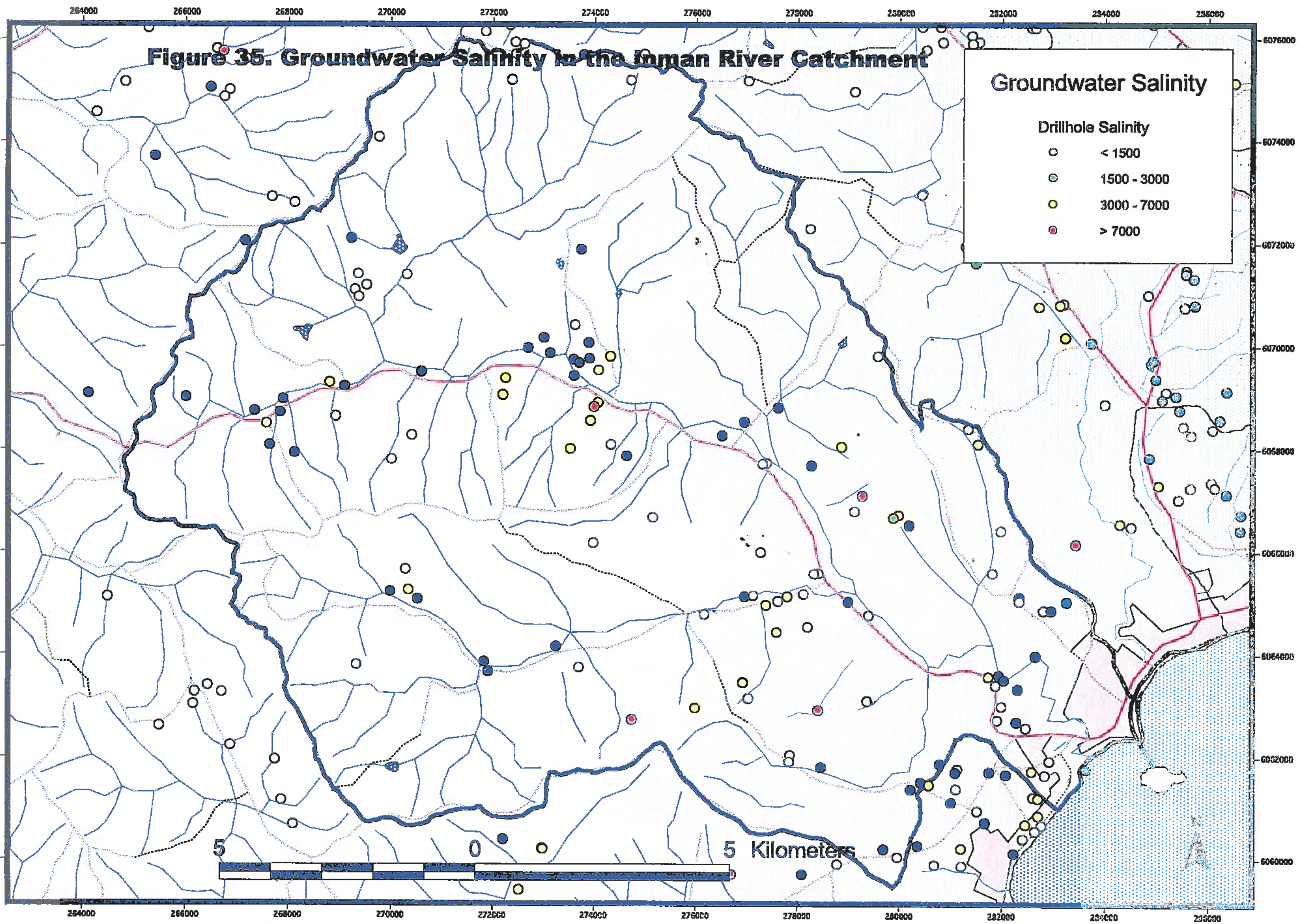


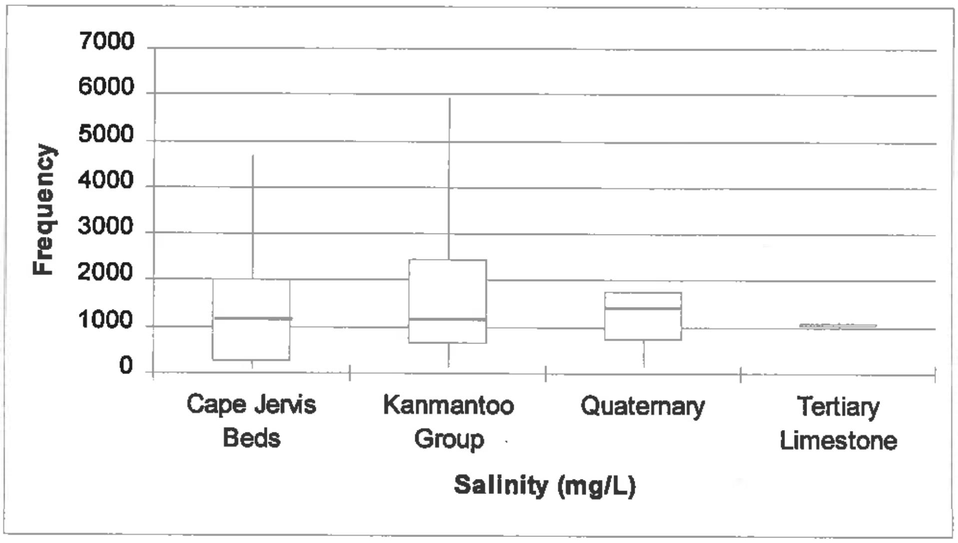
Figure 35. Groundwater Salinity in the Inman River Catchment
Groundwater Salinity
Drillhole Salinity
< 1500
1500 - 3000
3000 - 7000
> 7000
5
0
5 Kilometers
264000
266000
268000
270000
272000
274000
276000
278000
280000
282000
284000
286000
6076000
6074000
6072000
6070000
6068000
6066000
6064000
6062000
6060000

6.3.3 Currency Creek Catchment

In the Currency Creek Catchment there were a total of 169 salinity results that were utilised in the following analyses. Figure 36 shows boxplots of salinity concentrations in the different formations in the Currency Creek Catchment.

The highest salinity concentrations were evident in the Quaternary formation but there were only 5 results available so this may not be an accurate assessment. In the Kanmantoo Group, the 110 results analysed indicated that the salinity concentration ranged from 99-5,920 mg/L with an average value of 1,645 mg/L and a median value of 1,281 mg/L. The discrepancy between the median and average salinity values indicates that the average value is influenced by several high values

Figure 36. Boxplots for salinity concentrations for bores in the Currency Creek Catchment.



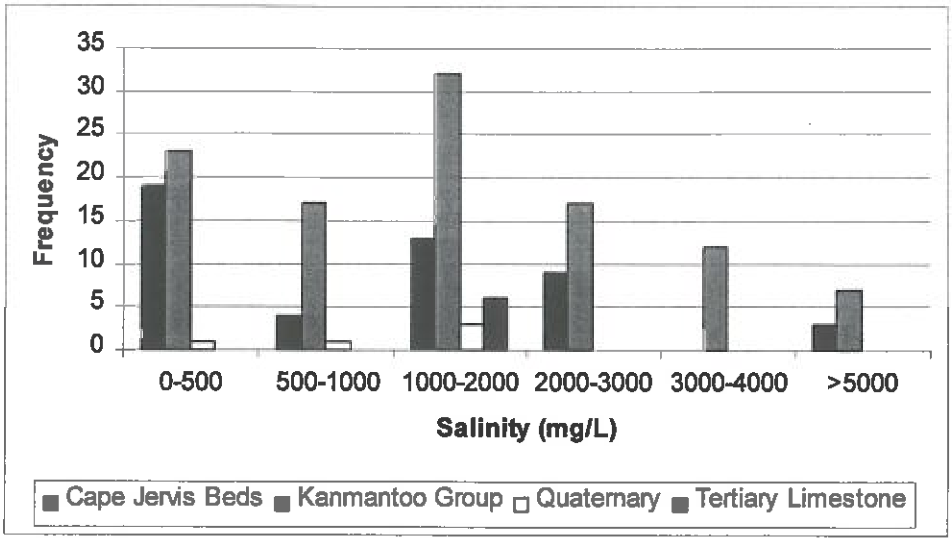
The salinity concentrations in the Cape Jervis Beds for the 48 samples analysed ranged from 98-4,676 mg/L with an average concentration of 1,326 mg/L and a median concentration of 1,198 mg/L. If the median values are compared, the Kanmantoo Group has a slightly higher median than the Cape Jervis formations.

There were only 5 salinity results for the Quaternary Alluvium formation. These results ranged from 115-1775 mg/L with an average and median value of 1,247 and 1,316 mg/L, respectively.

There were 6 salinity results for the 2 bores completed into the Tertiary Limestone formation in the Currency Creek Catchment. The results for these bores ranged from 1,002-1,118 mg/L with a median value of 1,016 mg/L and an average value of 1,039 mg/L.

Figure 37 shows the distributions for the different geological formations. For the Kanmantoo Group formation the distribution of salinity concentrations is highest in the 1,000-2,000 mg/L category with fairly similar results in the bracketing categories and lower frequencies in the higher two categories. The Cape Jervis Bed formation has the highest frequency of results in the lowest category (0-500 mg/L).

Figure 37. Salinity distributions for different geological formations in the Currency Creek Catchment.



Appendix 7 and Figure 38 shows the graphs for the bore depths and salinity results for all the geological formations. There does not appear to be any clear pattern for the salinity results for bores completed into the Kanmantoo Group formation. Bores completed into the Cape Jervis Bed formation appear to have higher concentrations at lower depths, however, as there are only a handful of deeper bores, this may not be true.

Figure 38. Bore depth and salinity results for bores completed into the Cape Jervis Beds in the Currency Creek Catchment.

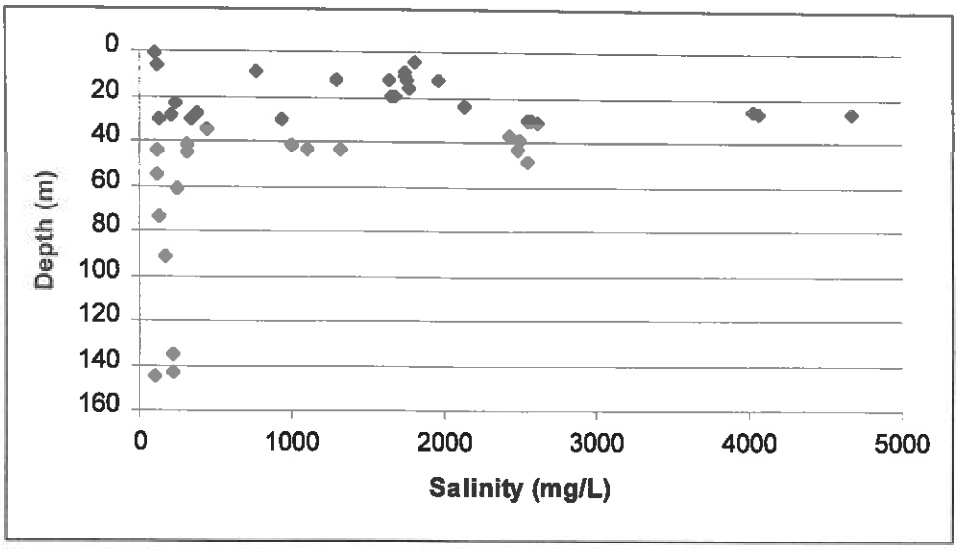
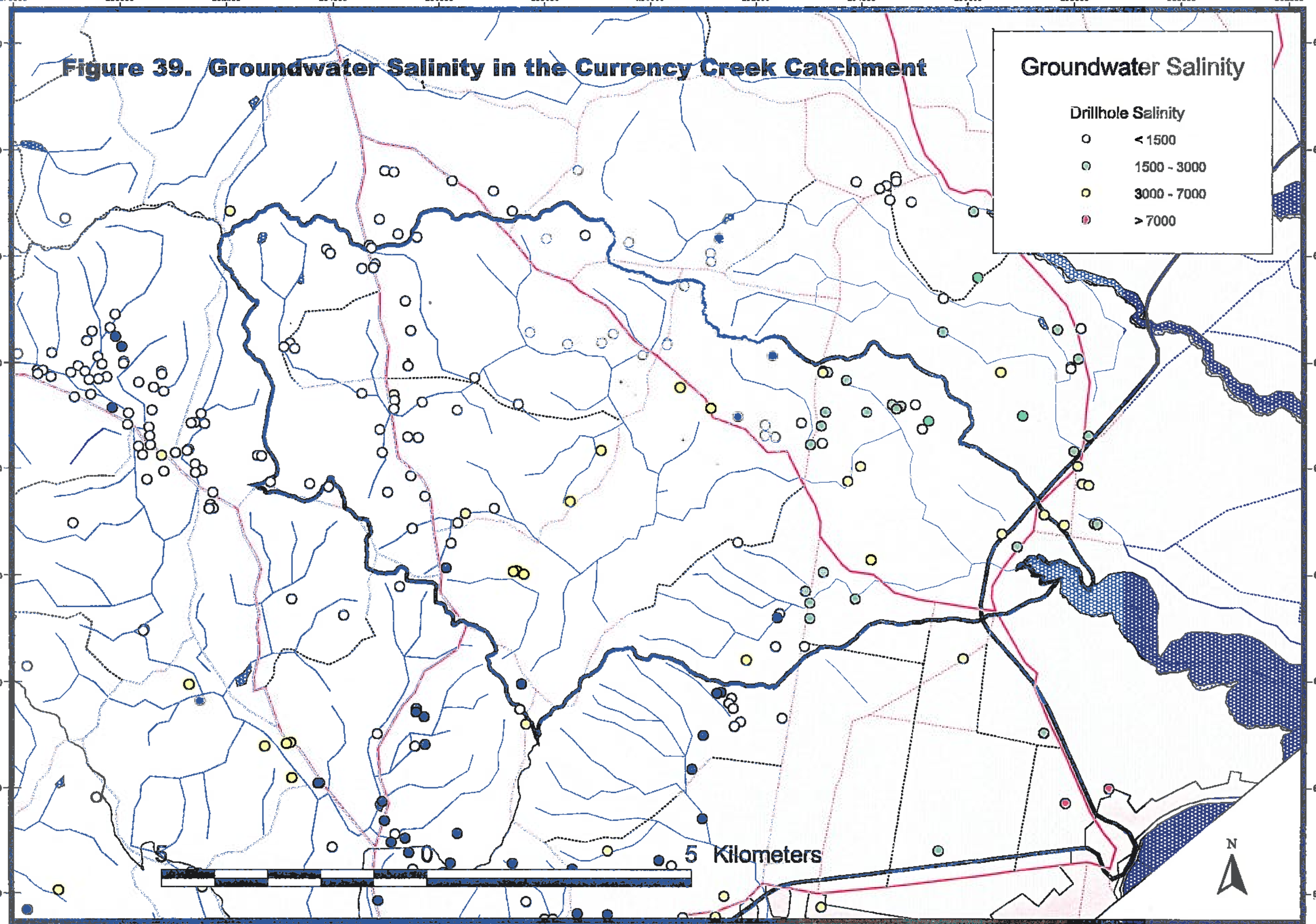


Figure 39 shows the categorised salinity concentrations for the entire catchment. There appears to be good quality groundwater in the upper portion of the Currency Creek Catchment. Bores completed into both Cape Jervis Beds and the Kanmantoo Group have very low salinity concentrations. The particular lithology of the Kanmantoo Group in this area may contribute to this phenomena in that the fractures in the rock may allow ready access for rainfall. In addition, there may be enhanced recharge in this area due to higher rainfall.

Figure 39. Groundwater Salinity in the Currency Creek Catchment



6.4 Land Use

Land use can have a significant impact on the withdrawal of groundwater and surface water from a catchment. It is important to examine the present groundwater status in catchments in the context of their previous histories. Unfortunately, in the study catchments there is not much information readily available on the historical groundwater development and use. There is some information on past irrigation practices in the Hindmarsh Tiers that will be discussed in the Section 6.7.2.1.

Land use spatial mapping has been done by PIRSA (Sustainable Resources) and resides on the corporate GIS system (ArcView and ArcInfo). In 1993 GIS coverage of land use in the Mount Lofty Ranges was done using aerial photographs and groundtruthing. From March to July 1999 land use mapping work was repeated. In 1999, the land use classifications were expanded to be consistent with the Australia New Zealand Land Use Codes (ANZLUC). In this report the 1999 land use data has been used for all water balance components and estimations. The 1993 land use data has been used for comparative purposes.

In land use classification there are several sources of error that should be noted. The Digital Cadastral Database (DCDB) may have spatial data inaccuracies which in turn impacts on the spatial data accuracy of the final classified land use polygons. It has been estimated with 85% confidence that the final land use polygons will have spatial errors along any give side or vertex with approximately +/- metres (Circular Error) relative to the DCDB (Flavel, 2000).

Polygons were validated with both an interpreted land use and a field checked land use which were compiled for each land use for each Local Government Area (LGA). The accuracy for each land use in the whole LGA is assumed to be the accuracy for the sampled land use in that LGA (Flavel, personal communication). Due to the time of the year of the field work (March to July 1999) the classification of the category 'crops' has a low degree of confidence - 57% (Flavel, 2000). In addition, due to the changes in land use (crop rotation, etc.) that are ongoing and to the elapsed time between aerial photography and field validations, dairy, pastures and vegetables have a lower degree of confidence - 67%, 57%, 49%, respectively (Flavel, 2000). Urban areas also had a low degree of confidence (45%) due to the refinement of this classification into more subcategories and a more focussed interpretation of the differences between urban and rural living (Flavel, 2000). Vines, parks, orchards, native vegetation, forest plantations and cultural features all had high levels of confidence with respect to their accuracy.

The changes made to the 1999 land use classifications made comparisons between the 1993 and 1999 land uses difficult. In order to attempt a reasonable comparison the following modifications were made to the 1999 land use data:

- dairy = dairy + irrigation pasture
- grazing = grazing + pastures + rural living + horses + crops
- vegetation = plantation forests + National Parks and Wildlife Service (NPWS) + native vegetation
- other = recreation + aquaculture + cultural + mine/quarry + effluent ponds + education

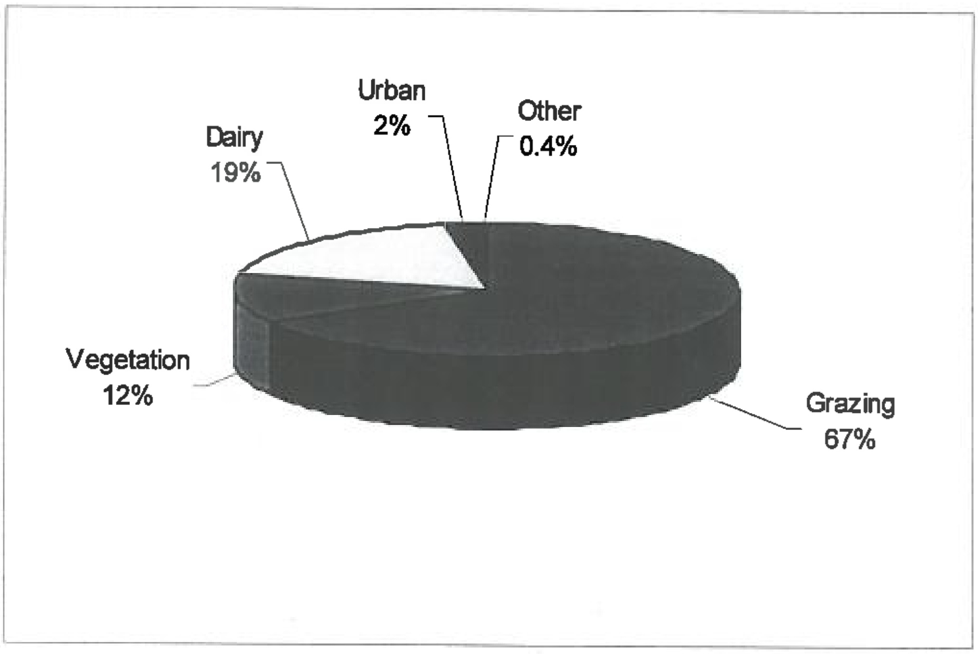
6.4.1 Hindmarsh River Catchment

In 1993, the major dryland use in the Hindmarsh River Catchment was grazing, as shown in Table 17 and Figure 40, followed by dairy. An interesting feature of the 1993 land use is a chain of plantation forests on the western boundary which appeared to be boundary fence revegetation. Small scale plantation forests occurred across the catchment. The coastline was urbanised with grazing occurring on either side of the Hindmarsh River where it discharges to the sea. Native vegetation occurred in the headwaters around Mount Cone, Strangway Hill and Peeralilla Hill and through the centre of the catchment.

Table 17. Land Use in the Hindmarsh River Catchment for 1993.

Land Use	Area (ha)	Percent of Total Area
Grazing	7,476	67%
Dairy	2,170	19%
Native vegetation	1,310	12%
Urban	261	2%
Other	42	0.4%

Figure 40. 1993 Simplified land use classifications for Hindmarsh River Catchment.



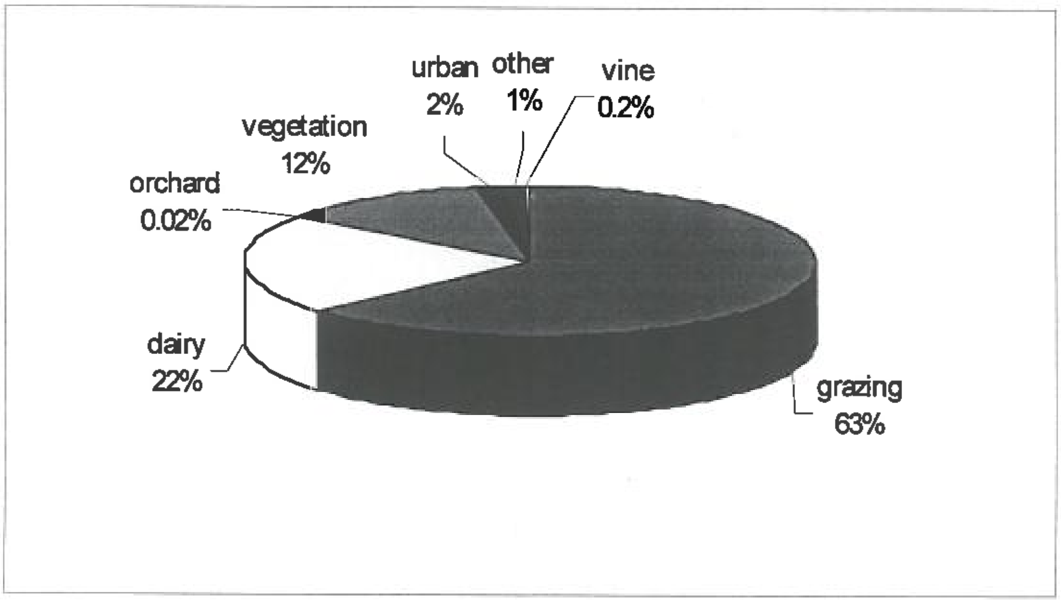
The 1993 land use codes were translated up to the ANZLUC 1999 codes and this translation has been used to compare the two datasets. Table 18 and Figures 41 and 42 shows the 1999 land use. There has been little change in the land use in the Hindmarsh River Catchment in the past 6 years other than an addition of 2 ha of orchards (most likely olive trees) and 23 ha of vines in the lower part of the catchment. The difference in the amount of grazing and dairy in this catchment could be due to the change in land use codes as opposed to an actual change in land use as there is no difference in the percentage of land that these land uses cover (both 85%). Figures 40 and 41 graphically show the different land uses for 1993 and 1999 as a percentage of total area in each catchment.

Table 18. Land use in the Hindmarsh River catchment for 1999.

Land Use	Area (ha)	Percent of Total Area
Grazing	5961	53%
Dairy	2453	22%
Native vegetation	1274	11%
Pastures	1000	9%
Urban	191	2%
Rural living	114	1%
Plantation forest	78	0.7%
Recreational	77	0.7%
Horses	63	0.6%
Cultural	34	0.3%
Vine	23	0.2%
Dam	9	0.1%
Education	9	0.1%
Coast	10	0.1%
NPWS	5	0.04%
Orchards	2	0.02%

Figure 42 shows the 1999 land use for the Hindmarsh River Catchment. The majority of the dairy operations are in the top portion of the catchment but there are some farms in the lower portion. Patches of native vegetation are interspersed throughout the catchment.

Figure 41. 1999 modified land use classifications for the Hindmarsh River Catchment.



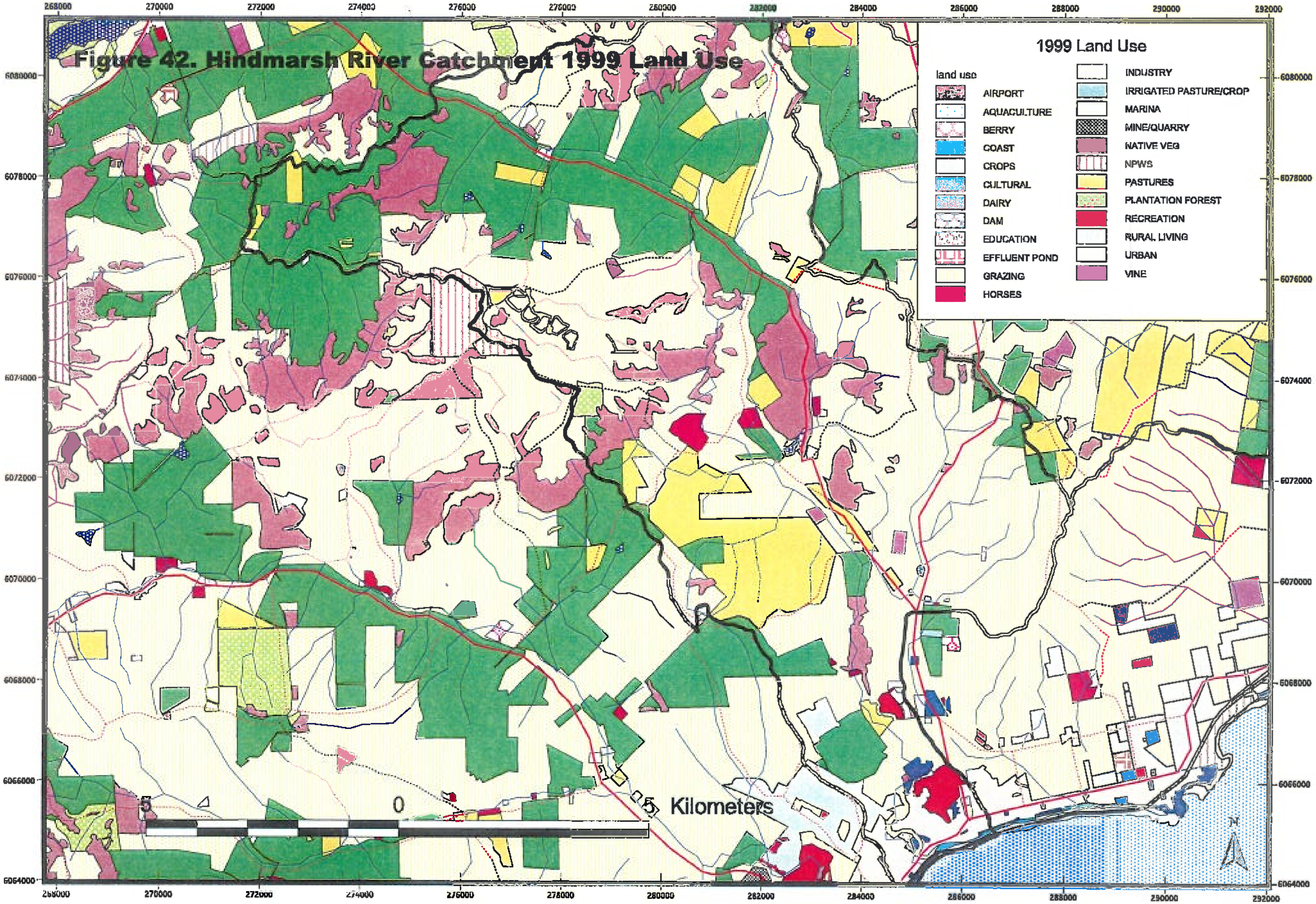


Figure 42. Hindmarsh River Catchment 1999 Land Use
1999 Land Use
land use
AIRPORT
AQUACULTURE
BERRY
COAST
CROPS
CULTURAL
DAIRY
DAM
EDUCATION
EFFLUENT POND
GRAZING
HORSES
INDUSTRY
IRRIGATED PASTURE/CROP
MARINA
MINE/QUARRY
NATIVE VEG
NPWS
PASTURES
PLANTATION FOREST
RECREATION
RURAL LIVING
URBAN
VINE
5 0 5 Kilometers
N

6.4.2 Inman River Catchment

The lands of the Inman River catchment were home to the Ramindjeri, a local group of Nagarrindjeri people (Burston and Good, 1995). The Aboriginal names for the Inman River are “Moo-oola” and “Moogoora”. The Inman Valley was first discovered by European settlers in 1831 as Captain Collet Barker travelled overland across the Fleurieu Peninsula (Burston and Good, 1995). The district was settled in 1837 and the river named Inman after the first Superintendent of Police in the colony of South Australia (Lush, 1971). Many of the watercourses in this catchment were marshy wetlands with no defined channel.

Heavy stands of blue gum and red gum were cut down to provide railway sleepers, building and fence materials. Timber was also used to fire the boilers of the Amscol milk factory located on the outskirts of Victor Harbour, use in the mines and for construction of the wharves and causeway at Victor Harbour (Burston and Good, 1995). By the 1950s the valley had already been cut over three times.

The English farmers initially took up land in the region known as Bald Hills and cropping and pastoral activities were the main enterprises (Burston and Good, 1995) However, as phosphate and nitrogen reserves declined, so did the productivity of the region and many farmers left in the 1870s and 1880s for the better soils of the Mid North. In the early years, livestock grazing was centred around the major watercourses and numerous freshwater springs (200-300) located across the catchment (Burston and Good, 1995). Grazing pressure was intense at these sites in the summer and many springs dried up after being dug out and enlarged for livestock and today only a handful exist (Burston and Good, 1995). Livestock grazing and dairy have been the mainstay of the valley for the past 120 years.

In 1993, the major dryland land use within the Currency Creek Catchment was grazing followed by dairy as shown in Table 19 and Figure 43. There were large sections of dairy land located throughout the upper and central regions of the catchment. Cropping occurred in the lower reaches of the catchment and on the shores of Lake Alexandrina and plantation forests were planted in the northwest.

Table 19. 1993 Simplified Land Use Classifications for the Inman River Catchment.

1993 Land Use	Area (ha)	Percent of Total Area
Grazing	12,391	64%
Dairy	4,483	23%
Native Vegetation	2,164	11%
Urban	334	2%
Other	129	0.7%
Orchard	8	0.04%

The coastal region of this catchment, like Hindmarsh River was urbanised and rural living occurs inland. Native vegetation was found mainly in the headwaters of this catchment and in a band along the western boundary of the catchment. The Spring Mount Conservation Park was located in the northern corner of the catchment. Horse keeping occurred inland and there was a small area of orchards in the centre of the catchment.

Figure 43. 1993 land use classifications for the Inman River Catchment.

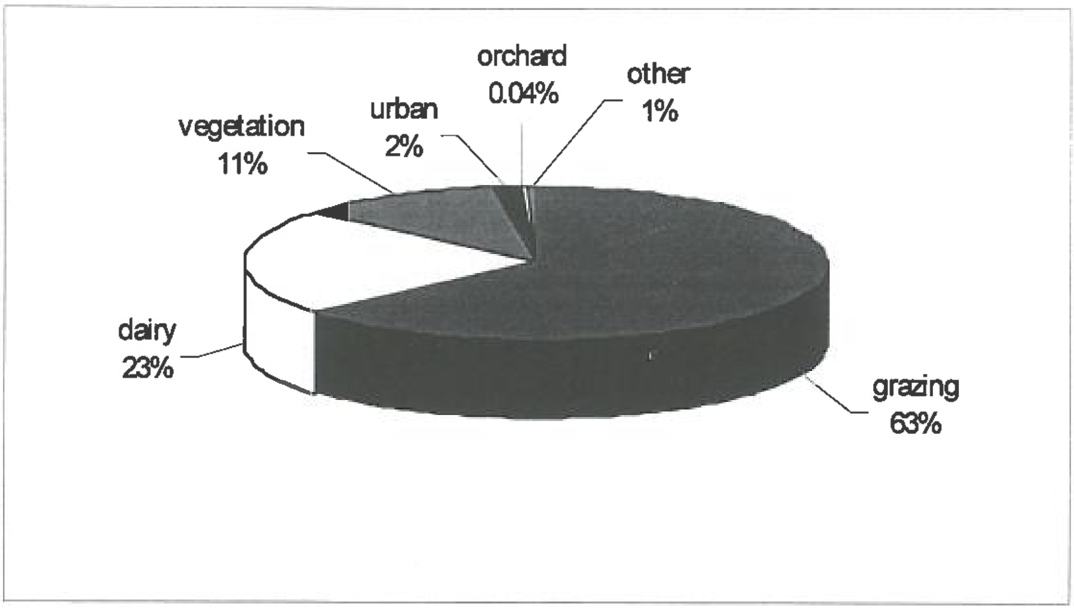


Table 20 and Figures 44 and 45 shows the 1999 land use classifications. There does not appear to be any significant change in land use in the Inman River Catchment in the last six years. The slight changes in percentage of the total catchment area for dairy and grazing could be due to the changes in the land use classification methods used in 1993 and 1999. However when the total area cover by these two land uses area compared there is about the same percentage of land use in both 1993 and 1999. Grazing continues to be the predominant land use in this catchment, followed by dairy. There appears to be a slight increase in the size of the orchards in the Inman River Catchment but this is not a significant change. Dairy operations occur mainly along the Inman River and Back Valley Creek.

Table 20. 1999 land use classifications for the Inman River Catchment.

Land Use	Area (ha)	Percent of Total Area
Grazing	10813	55%
Dairy	5140	26%
Native vegetation	1754	9%
Rural living	496	2.5%
Plantation forest	307	1.6%
Urban	310	1.6%
Pastures	206	1.1%
NPWS	195	1.0%
Recreation	127	0.7%
Horses	74	0.4%
Cultural	33	0.2%
Berry	13	0.1%
Mine/quarry	25	0.1%
Coast	8	0.04%
Aquaculture	3	0.02%
Education	3	0.02%
Effluent pond	2	0.01%
Crops	0.03	0.0001%

Figure 44. 1999 modified land use classifications for the Inman River Catchment.

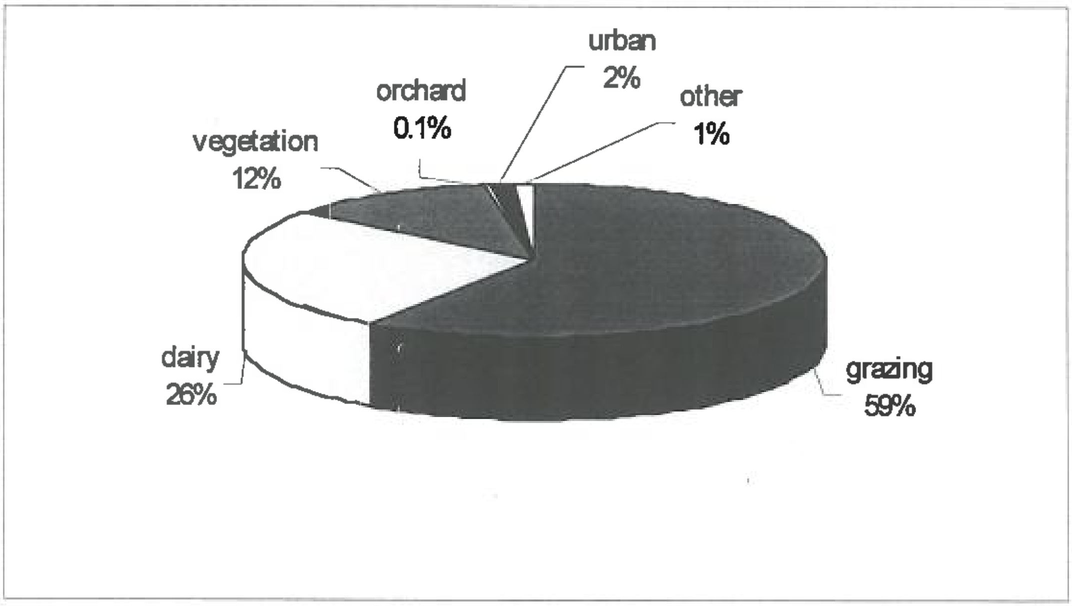
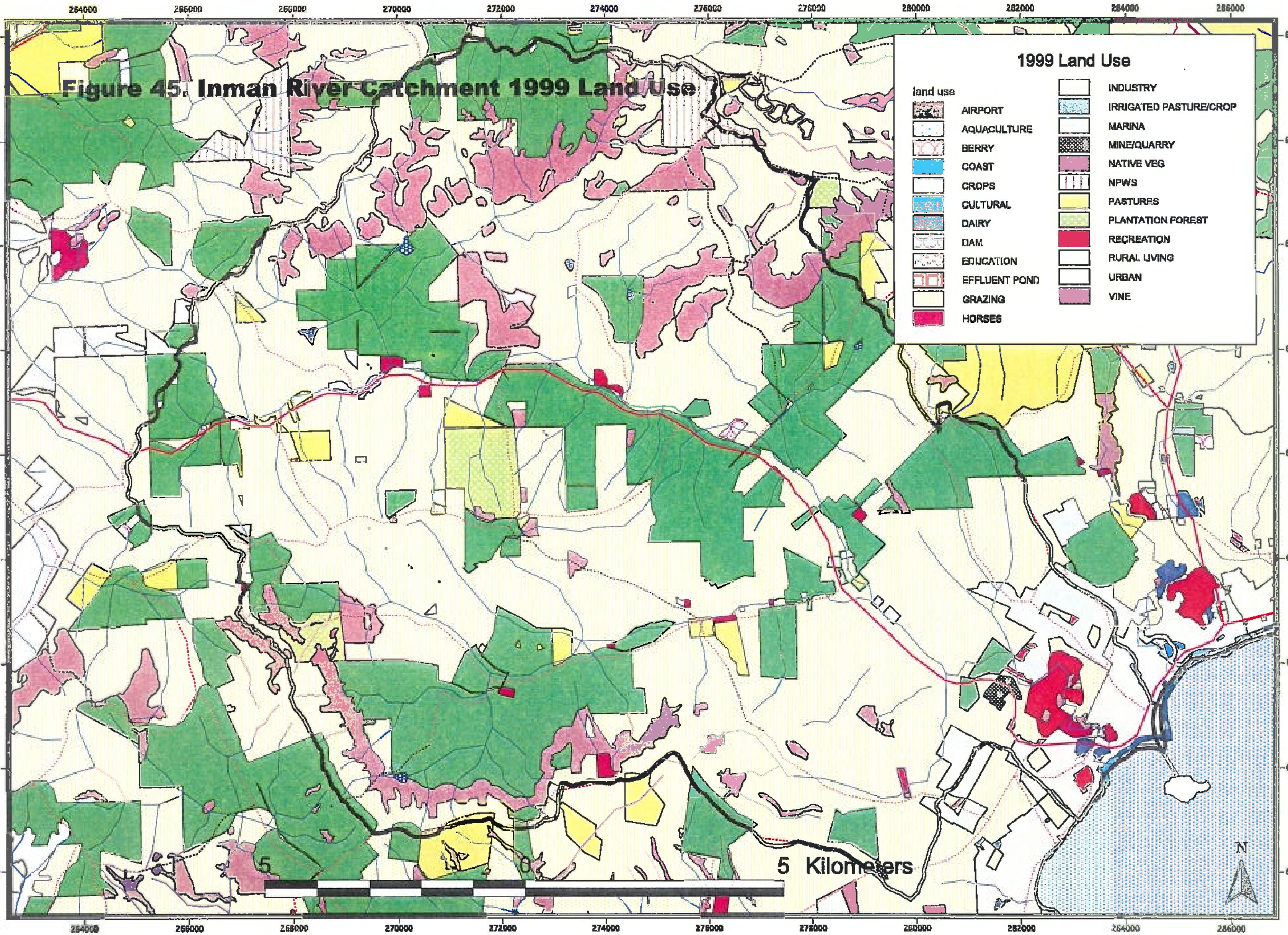


Figure 45. Inman River Catchment 1999 Land Use



6.4.3 Currency Creek Catchment

The dominant land use in the Currency Creek Catchment in the 1993 land use classification was grazing as shown in Table 21 and Figure 46. Dairy is the next largest land use and occurred across the catchment. Native vegetation is found throughout the catchment also. In 1993 horse keeping and plantation forests occurred in the upper catchment while cropping and vines occurred in the lower reaches of the catchment.

Table 21. 1993 Land use classifications for the Currency Creek Catchment.

Land Use	Area (ha)	Percent of Total Area
Grazing	7,632	83%
Dairy	1,103	12%
Native vegetation	382	4%
Vineyard	106	1%

The Currency Creek Catchment has had more changes in land use in the past six years than the other two study catchments. Table 22 and Figures 47 and 48 shows the 1999 land use classifications. The land area used for vines has tripled in size in the last six years as several new vineyards have been established across the catchment. There have also been several areas where olive trees are being planted - in general, the same area where the new vineyards are. Land used for dairy production decreased in area covered from 1993 to 1999 (95% to 92%). This most likely is land that was converted into vine production.

Table 22. 1999 land use classifications for the Currency Creek Catchment

Land Use	Area (ha)	Percent of Total Area
Grazing	5,129	56%
Dairy	1,331	14%
Pastures	1,298	14%
Native vegetation	414	5%
Crops	361	4%
Vine	317	3%
Horses	193	2%
Rural living	95	1%
NPWS	70	0.8%
Orchard	9	0.1%
Plantation forest	4	0.04%
Irrigated pasture/crop	2	0.02%
Dam	0.5	0.005%

Figure 46. 1993 land use classifications for the Currency Creek Catchment.

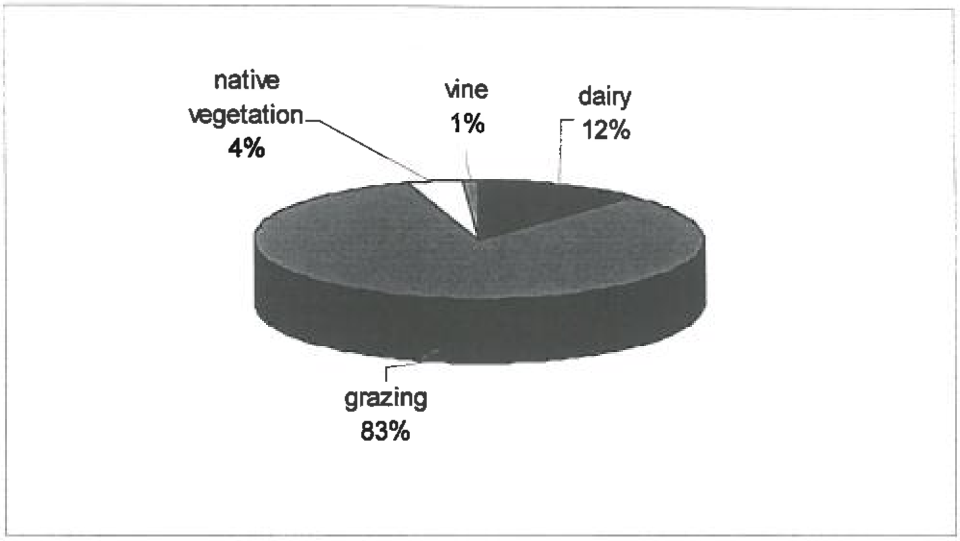


Figure 47. 1999 modified land use classifications for the Currency Creek Catchment.

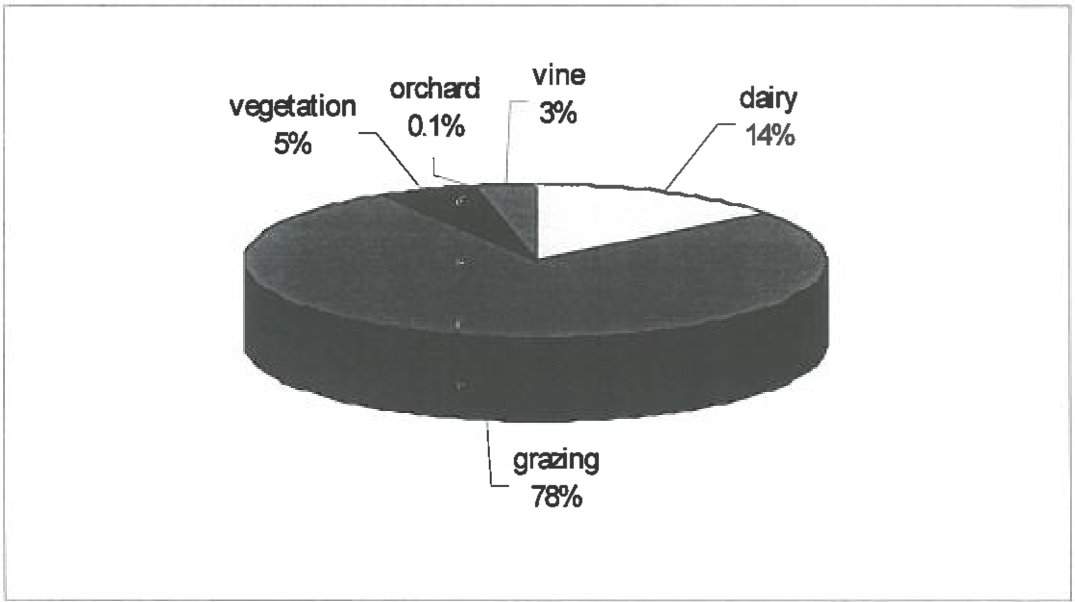
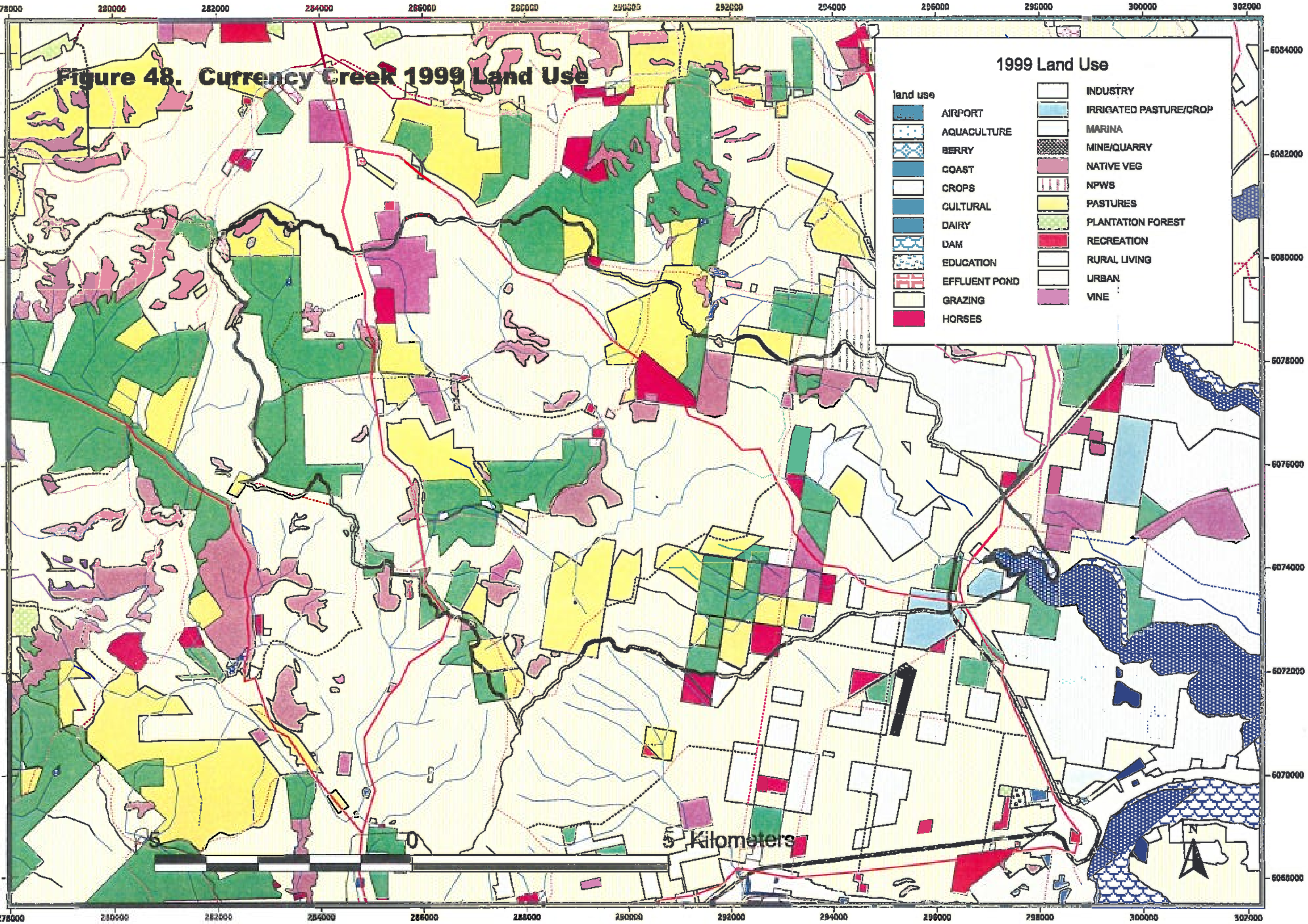


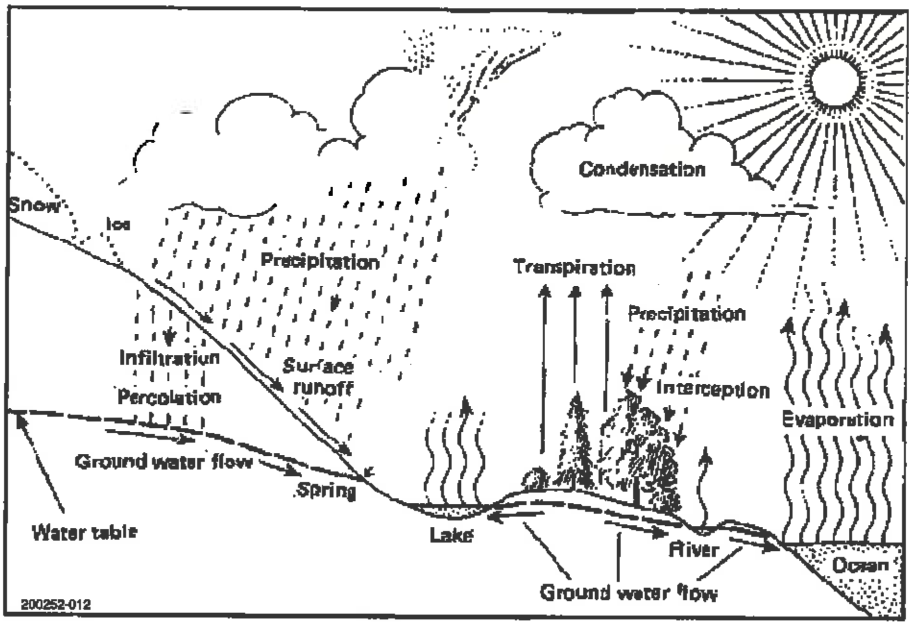
Figure 48. Currency Creek 1999 Land Use



6.5 Water Balance

The hydrological cycle as shown in Figure 49 describes the movement of water on earth and the atmosphere. Water is evaporated from the ocean and carried over the land masses in the form of vapour. Mountain ranges cause the air masses to rise which cools and causes the water vapour to condense resulting in precipitation. The precipitation falls on the land and has several pathways: evaporation, infiltration, overland flow, runoff in streams, transpiration by plants and recharge to groundwater after penetrating below the root zone. Water flowing in a stream can come from overland flow or from groundwater that has seeped into the streambed, known as baseflow.

Figure 49. Hydrological cycle. (ref)



The basic equation for a water balance is:

Inflow = Outflow ± Change in Storage (ΔS)

Where for the purposes of this report:
Inflow = Rainfall
Outflow = Runoff + Evapotranspiration + Farm Dam Storage + Recharge
ΔS assumed to be zero for the purposes of this investigation

In order to assess the groundwater sustainability of each of the catchments in this study, water balances are determined using available and modelled data. The water balance components used in this study were measured or estimated with varying degrees of rigour and accuracy. Geographical Information Systems (GIS) utilised existing datasets and facilitated the estimation of some of the various water balance components.

6.5.1 Rainfall

Precipitation is the large term in the water balance equation and is a parameter for which direct measurements in a number of locations in each of the study catchments are available. Rain gauge stations used in this assessment are shown in Figures 50-52. Only rain gauge stations with more than 10 years of data were analysed. Monitoring data ranging to a few months to several years was missing for most of the rain gauge stations. Patching of these rainfall datasets was done to maximise the number of data available. Missing data was "patched" using correlations with existing stations to fill in the monitoring gaps. Appendix 9 shows the average monthly rainfall results for all the study catchments.

There are two estimations of total annual rainfall for each catchment presented - one using a triangulated irregular network (TIN) method and the other using the isohyet method. The TIN method data has been used in all subsequent rainfall estimates in the water balance for input.

In South Australia the predominant rainfall occurs in the winter months and most of the summer rainfall is lost by evaporation before it has a chance to percolate down to the plant root zone or the water table. Only the winter rainfall (rain events from April to October) is considered to be effective in contributing to the water balance and has been used in the water balance equations. However, assuming that effective rainfall is from April to October may not be a correct assumption for different locations.

Boxplots were drawn for each rain gauge station to graphically represent the data. The vertical lines in the boxplot indicate the range of values in the dataset and the "boxes" enclose the 25^{th} and 75^{th} percentile values with the median value (middle value of the dataset) shown as the horizontal line drawn across the box.

Appendix 10 shows graphs of the cumulative deviation from the mean monthly rainfall for all the rain gauge stations in the study catchments. A steep downward decline on these graphs indicates a period of below average rainfall or a dry period. In contrast rising slopes indicate periods of above average rainfall or wet periods. These graphs provide a means of interpreting rainfall over the years and assist in interpreting groundwater level trends.

Rainfall interception by vegetation is an important hydrological process, especially in forested catchments. The intercepted water may be retained on leaves, flow down the plant stems to become stemflow, or drop off the leaves to become part of the throughfall, or be evaporated from wet canopy surface during the period of storm (Zhang et al, 1999). Rainfall interception varies considerably between species and on average forests intercept more rainfall than grass and crops (Zhang et al, 1999). The difference in rainfall interception between forests and short grass has important implications for catchment water balances because most of the intercepted rainfall is evaporated directly into the atmosphere.

Rainfall interception by vegetation has not been calculated for this study. However, rainfall interception has in part be accounted for in the use of effective rainfall (April to October) in the water balance equations. The land use classification data available does not provide adequate data on the amount of forested areas in each catchment, other than the classification for plantation forests. Areas classified as native vegetation and National Parks and Wildlife Services contain forested areas but the exact area of forest is not known. In future, capture of this data and use of the models developed could provide a simple and quick means of evaluating the impact of vegetation changes on catchment water balance and recharge.

6.5.1.1 Hindmarsh River Catchment

The Hindmarsh River Catchment has 2 active rain gauge stations and one inactive one (see Table 23). Both the Fernbrook and Springmount rain gauge stations are located in the headwaters of the catchment (see Figure 50) on either side of the Hindmarsh River. The closed station was located in the lower part of the catchment. There are two other stations located on Figure 50 - 23851 and 23850 - which were established in 1989 but no rainfall data was collected.

Table 23. Rain gauge stations located in the Hindmarsh River Catchment.

Station Name	Bureau of Meteorology Station	Station Elevation (m)	Years of data collection
Fernbrook	23823	245	1936-present (64 years)
Springmount	23824	410	1952-present* (45 years)
Hindmarsh Valley	23760	N/A	1887-1944+ (43 years)

* Missing years of data 1963, 1965, 1966
+ missing years of data 1906-1920

Figure 51 shows the distribution of rainfall at all three gauging stations as boxplots. The vertical line begins at the lowest monthly rainfall recorded and ends at the highest. Monthly rainfall data at the Fernbrook and Springmount rainfall gauging stations have similar median rainfall results (59 mm and 60mm, respectively). The median rainfall for the Hindmarsh Valley station is slightly lower (48 mm) which could be the result of either measurements being taken during a different time frame ie, no overlapping years or topographical conditions in the lower valley portion of the catchment.

One way to examine rainfall data to calculate the cumulative deviation from the mean monthly rainfall. Figure 52 shows the cumulative deviation from the mean monthly rainfall for the Fernbrook rain gauge station. The most significant feature of this graph is that since 1959 the rainfall in this area has been in a deficit situation. This has a major impact on the annual recharge for groundwater in the area as precipitation is the key source of recharge to the geological formations. From June till December 1992, above average rainfall occurred as shown in the sharp rise in the graph. However, this rainfall did not have a significant impact on the deficit situation and since 1992 the recorded rainfall has been below average on the whole.

Figure 50. Location of Rain Gauge Stations in the Hindmarsh River Catchment

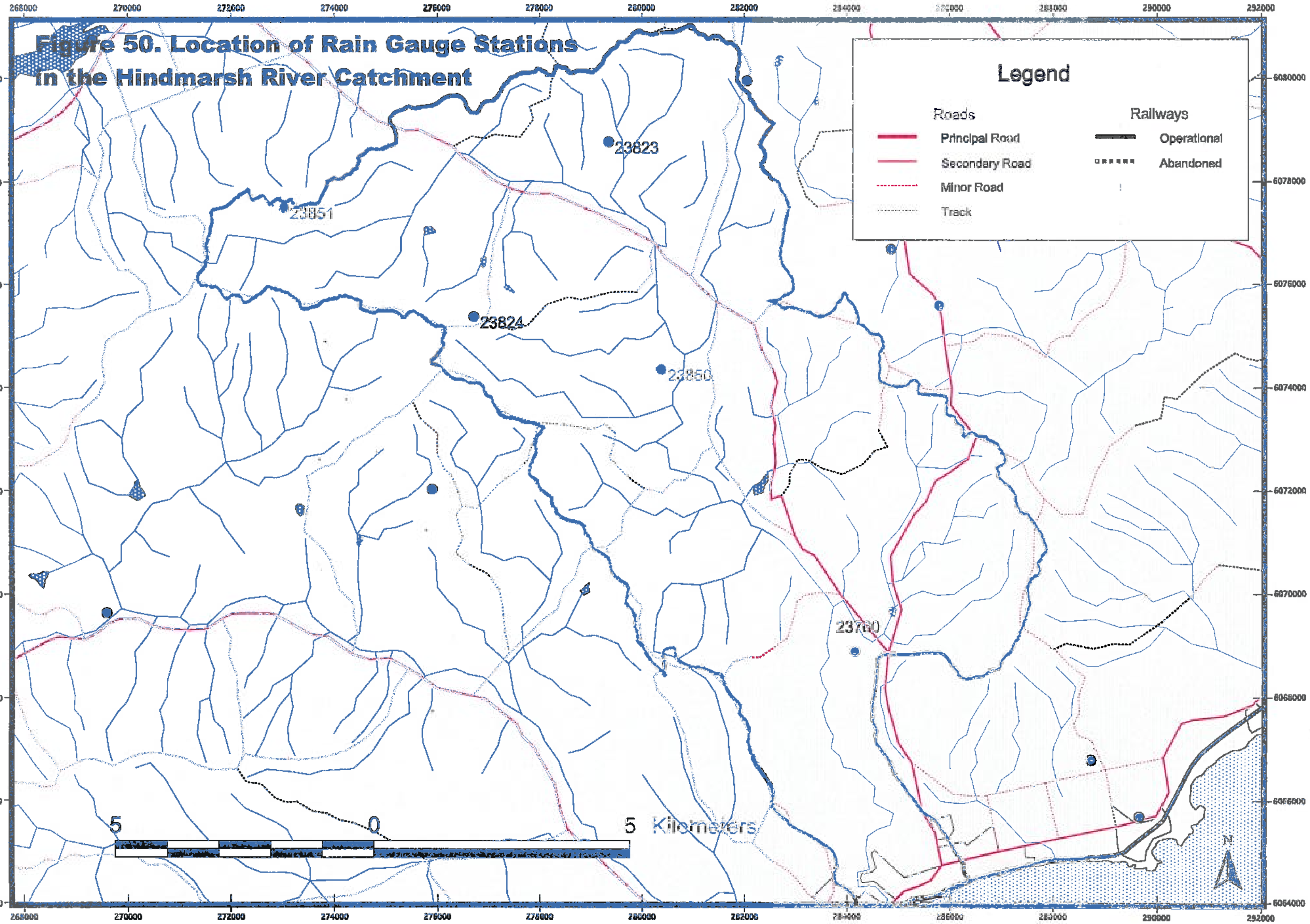


Figure 51. Boxplots for the rain gauge stations in the Hindmarsh River Catchment.

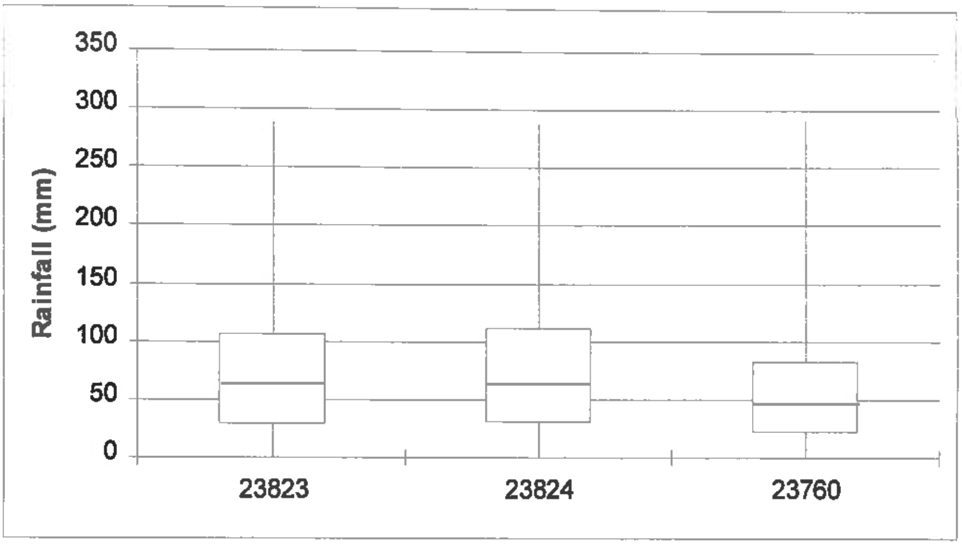
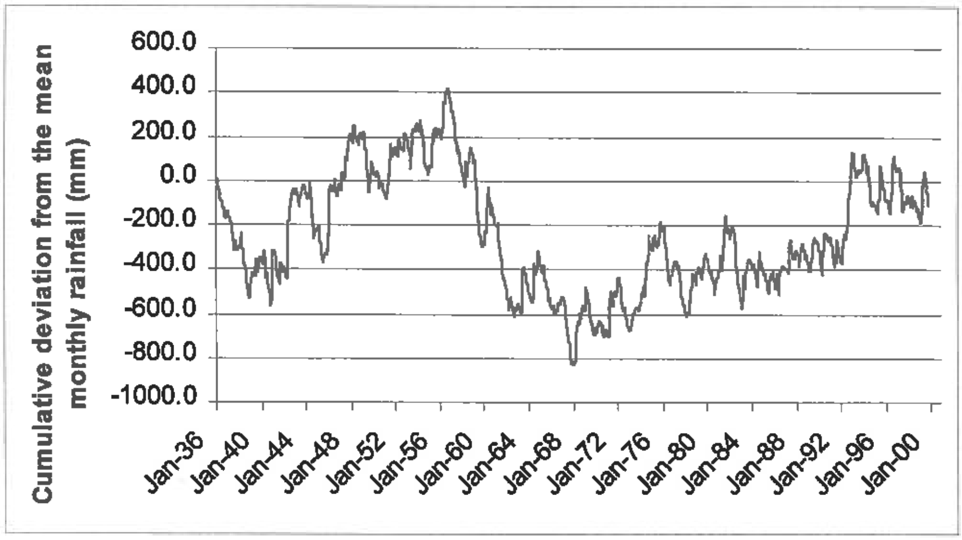


Figure 52. Cumulative deviation from the mean monthly rainfall (mm) for the Fernbrook rain gauge station in the Hindmarsh River Catchment.



Data from these rain gauge stations were used in the estimation of total and effective rainfall for the Hindmarsh River Catchment using the TIN methodology and the isohyet method. Table 24 shows the results of the rainfall estimations from the TIN method that have been used in the subsequent determination of the water balance and recharge.

Table 24. Average total and effective annual rainfall for the Hindmarsh River Catchment (TIN method).

Unit	Total Rainfall	Effective Rainfall
ML	87,040	70,260
Mm	770	622

Rainfall data was also calculated using an isohyet method by DEHAA and reported by percentiles in Table 25. According to this method the median annual rainfall was 742 mm which is in good agreement with the total average annual rainfall of 770 mm calculated by the TIN method. In the following water balance equations the effective rainfall value of 622 mm has been used.

Table 25. Annual rainfall estimations using the isohyet method for the Hindmarsh River Catchment (SCRN et al, 2000).

Catchment	10th Percentile (Dry) (mm)	Median (Normal) (mm)	90th Percentile (Wet) (mm)
Hindmarsh River	540	742	918

6.5.1.2 Inman River Catchment

The Inman River Catchment has three active rain gauge stations and two inactive stations (see Table 26). Yankalilla station is located in the headwaters of the Inman River (see Figure 53). Rivington Grange and Willow Creek are located in the southern portion of the catchment and the Victor Harbour station is located right on the coast, and Mount Alma located in the most northern portion of the catchment.

Table 26. Rain gauge stations located in the Inman River Catchment.

Station Name	Bureau of Meteorology Station	Station Elevation (m)	Years of data collection
Yankalilla	23723	100	1933-present (67 years)
Rivington Grange	23743	87	1910-present (90 years)
Willow Creek	23762	210	1954-1987 (33 years)
Mount Alma	23827	365	1972-1978 (6 years)
Victor Harbour	23751	5	1882-present (118 years)

Boxplots for each of the rain gauge stations have been calculated and are shown in Figure 54. The median monthly rainfall values for both the Yankalilla and Rivington Range station are very similar (52 and 50 mm respectively). The median value for the Victor Harbour station is lower at 38 mm and indicates there is less rainfall in the lower part of the catchment. The highest median monthly rainfall was recorded at the Willow Creek station.

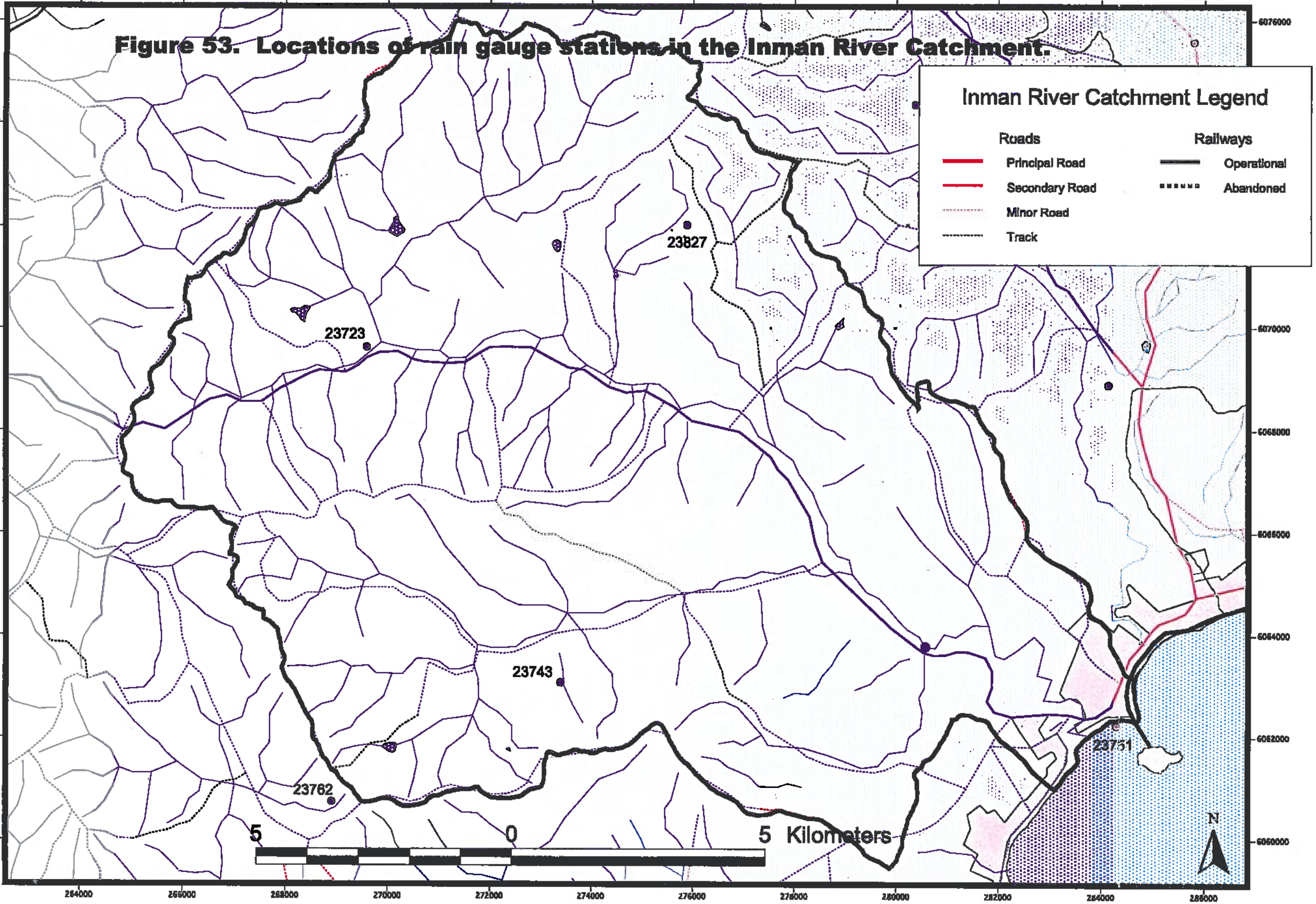
The cumulative deviation from the mean monthly rainfall for the Rivington Grange rain gauge station is shown in Figure 55. It is apparent from this plot that the rainfall deficit situation as seen in the Hindmarsh River Catchment is not reproduced here. In general, there was a rainfall surplus until 1956 and then a sharp decline until 1968. Rainfall was above average again until 1981 and since this time there has been a steady downward trend or deficit pattern with intermittent periods of above average rainfall and the same above average rainfall in 1993. Since 1993 monthly rainfall has steadily been less than the mean monthly rainfall.

Data from these rain gauge stations were used in the estimation of total and effective rainfall for the Inman River Catchment. Table 27 shows the results of the rainfall estimations from the TIN method that have been used in the subsequent determination of the water balance and recharge.

Table 27. Average total and effective annual rainfall for the Inman River Catchment.

Unit	Total Rainfall	Effective Rainfall
ML	142,731	114,395
mm	732	586

Figure 53. Locations of rain gauge stations in the Inman River Catchment.



Rainfall data was also calculated using an isohyet method by DEHAA and reported by percentiles in Table 28. According to this method the median annual rainfall was 712 mm which is in good agreement with the average annual rainfall of 732 mm calculated by the TIN method. In the following water balance equations the annual average effective rainfall of 586 mm has been used.

Table 28. Annual rainfall estimation for the Inman River Catchment using the isohyet method (SCRN et al, 2000).

Catchment	10th Percentile (Dry) (mm)	Median (Normal) (mm)	90th Percentile (Wet) (mm)
Inman River	546	712	887

Figure 54. Boxplots for the rain gauge stations in the Inman River Catchment.

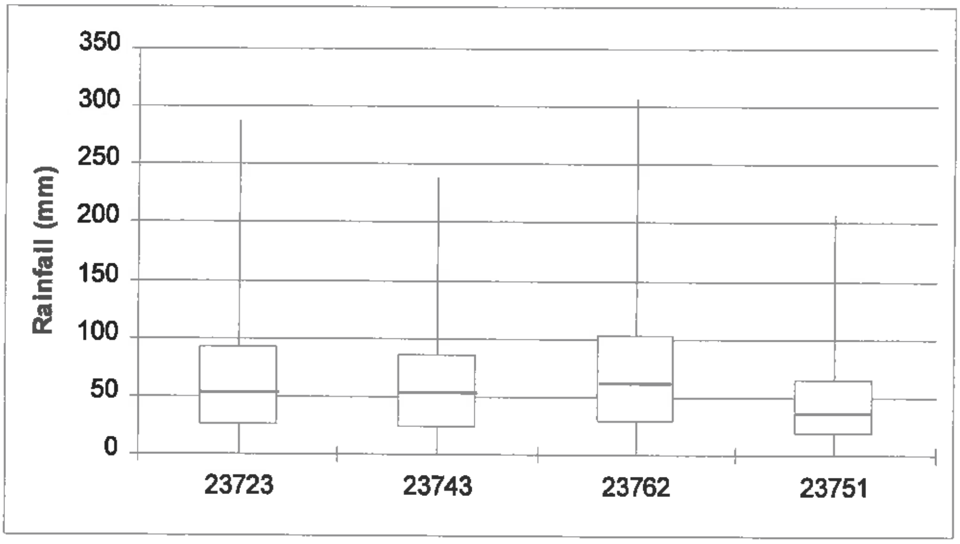
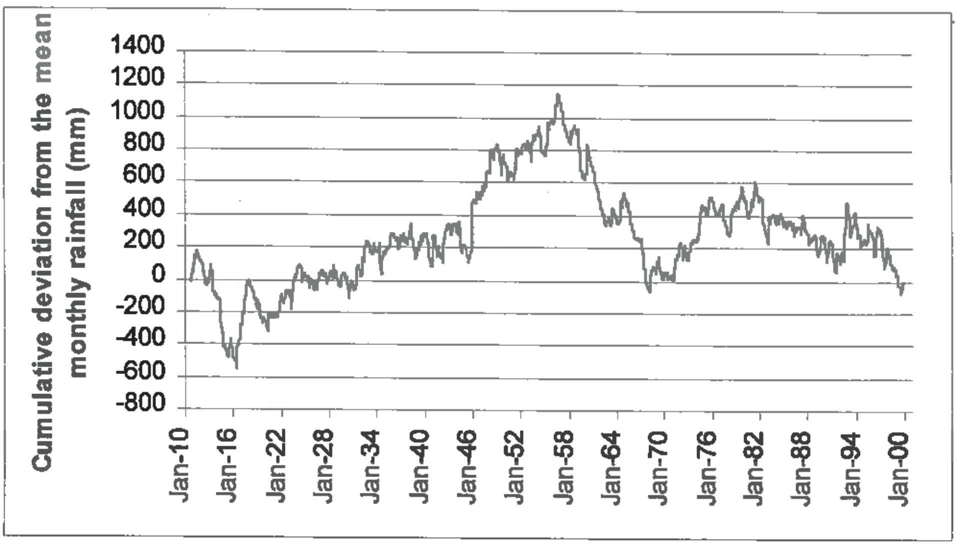


Figure 55. Cumulative deviation from the mean monthly rainfall for the Rivington Grange rain gauge station in the Inman River Catchment.



6.5.1.3 Currency Creek Catchment

The Currency Creek Catchment has one active Bureau of Meteorology rain gauge station and two closed stations as shown in Table 29. The Department of the Environment and Aboriginal Resources (DEHAA) station had a rain gauge station in the central part of the catchment which was closed in 1993. Locations of these rain gauge stations is shown in Figure 56.

Table 29. Rain gauge stations located in the Currency Creek Catchment.

Station Name	Bureau of Meteorology Station	Station Elevation (m)	Years of data collection
Berrima	23834	265	1973-present (25 years)
Mount Compass-Marshall Brae	23838	192	1979-1997 (18 years)
Mount Jagged	23777	N/A	1898-1917 (18 years)
Dalenka Downs	AW426647 (DEHAA)	255	1988-1993 (5 years)

The rainfall records for the active stations in this catchment are not as long as in the other catchments which limits the interpretation of any trends. Boxplots for the three Bureau of Meteorology rain gauge stations are shown in Figure 57. It is difficult to compare the rainfall between these stations because of the limited amount of data that was collected simultaneously. The rainfall for the Mount Jagged station appears to be higher but that could be more a result of the time in which the data was recorded and that this time was a period of higher rainfall than the last 20-30 years. There is a difference in the medians between the Berrima and the Mount Compass rain gauge stations (47 and 54 mm, respectively) indicating that there is more rainfall at the Mount Compass site which is at a higher elevation than the Berrima station.

A cumulative deviation from the mean monthly rainfall plot is shown in Figure 58 for the Berrima rain gauge station. There is only a limited amount of data to calculate average values from and this impacts on any interpretation of general trends at this site. It appears that from 1973 till 1996 was a high rainfall period relative to the average, however since 1996 the monthly rainfall has been decreasing which has resulted in a downward slope to the graph. This downward trend has been seen in the results from rain gauge stations in the other study catchments. The rainfall trend is different at Mount Compass station where the levels appear to have remained fairly constant from 1983 - 1992. The 1993 above average rainfall event is more pronounced at this station but the same below average trend since 1993 is apparent.

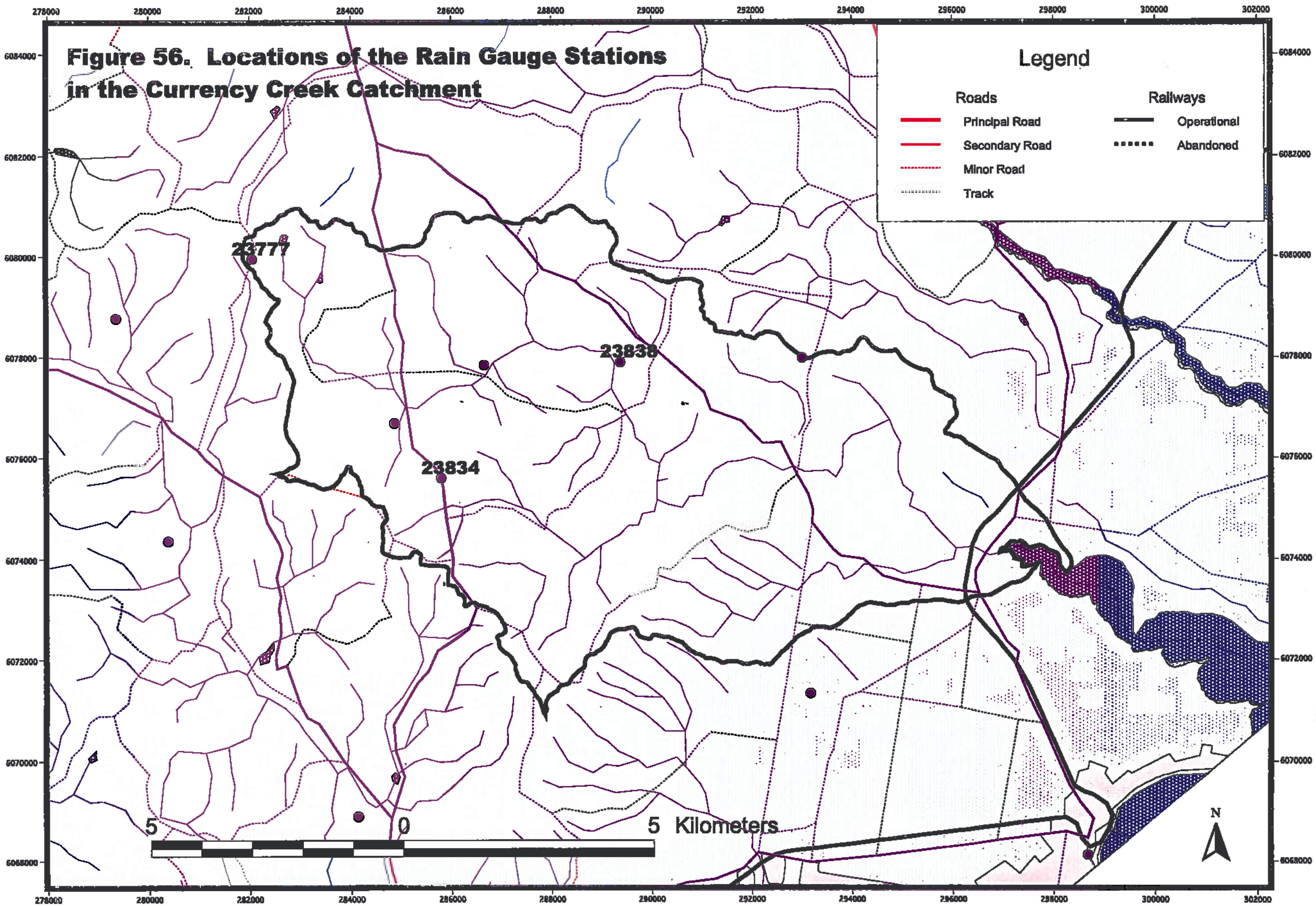


Figure 56. Locations of the Rain Gauge Stations in the Currency Creek Catchment
Legend
Roads
Principal Road
Secondary Road
Minor Road
Track
Railways
Operational
Abandoned
23777
23838
23834
5
0
5 Kilometers
N
278000
280000
282000
284000
286000
288000
290000
292000
294000
296000
298000
300000
302000
6084000
6082000
6080000
6078000
6076000
6074000
6072000
6070000
6068000

Figure 57. Boxplots for Bureau of Meteorology rain gauge stations in the Currency Creek Catchment.

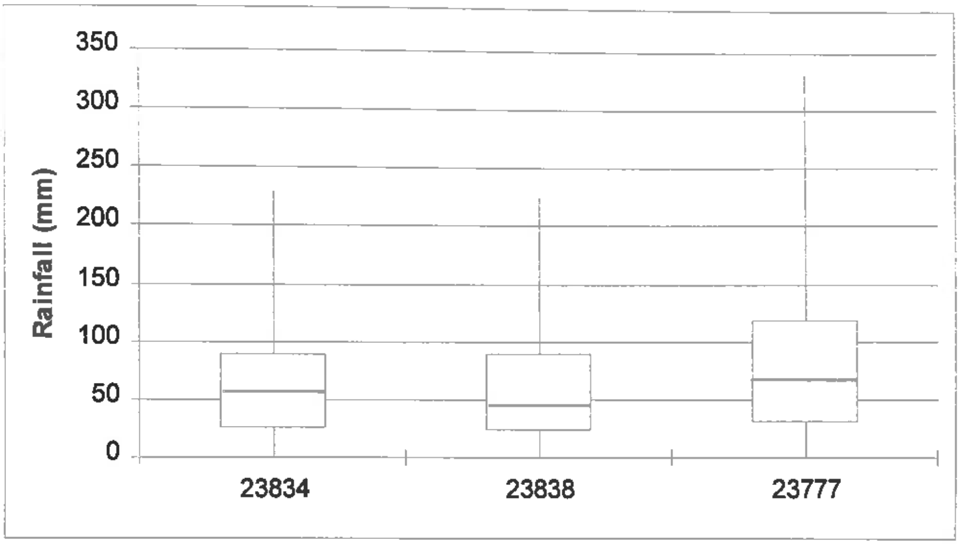
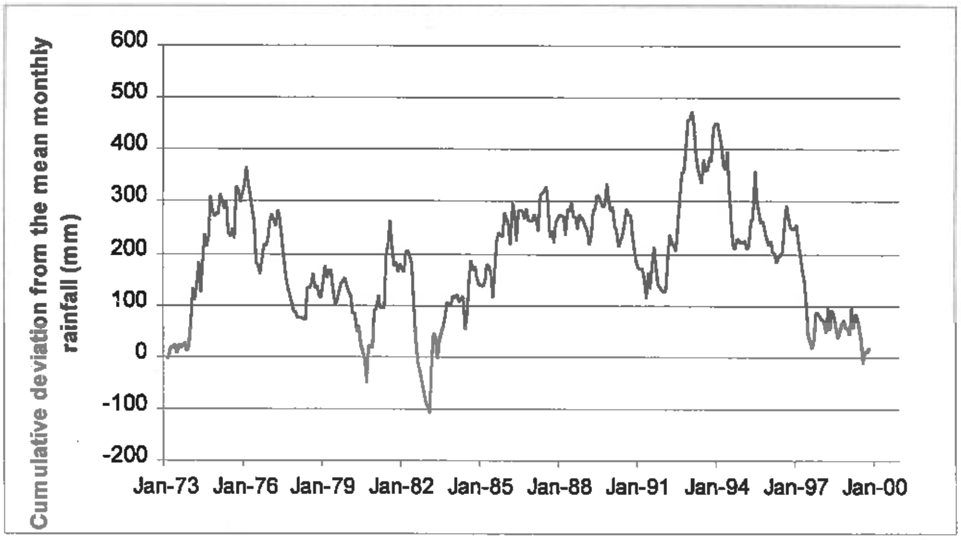


Figure 58. Cumulative deviation from the mean monthly rainfall at the Berrima rain gauge station 23834 in the Currency Creek Catchment.



Data from these rain gauge stations were used in the estimation of total and effective rainfall for the Currency Creek Catchment. Table 30 shows the results of the rainfall estimations from the TIN method that have been used in the subsequent determination of the water balance and recharge.

Table 30. Average total and effective annual rainfall for the Currency Creek Catchment.

Unit	Total Rainfall	Effective Rainfall
ML	59,618	46,991
mm	646	509

Rainfall data was also calculated using an isohyet method by DEHAA and reported by percentiles as shown in Table 31. According to this method the median annual rainfall was 670 mm which is in close agreement with the average annual total rainfall of 646 mm estimated by the TIN method. In the following water balance equations the annual average effective rainfall of 509 mm has been used.

Table 31. Annual rainfall estimation for the Currency Creek Catchment using the isohyet method (SCRN et al, 2000).

Catchment	10th Percentile (Dry) (mm)	Median (Normal) (mm)	90th Percentile (Wet) (mm)
Currency Creek	480	670	810

6.5.2 Runoff

Estimating total streamflows, runoff and baseflows for catchments without long continuous consistent data records is difficult. Gauging stations should have a minimum of five years of data to be useful to estimate total streamflow for a catchment. Missing data was patched in order to maximise the value of the entire dataset. Another problem encountered in the estimation of streamflow for a catchment is that impacts of development can influence natural flows. Flows measured at gauging stations are not natural because of water storages such as farm dams, reservoirs and water use. This study has used both the stream gauge station data and modelled streamflow results to estimate both runoff and baseflow for each of the study catchments. Summary statistics on the streamflow data are shown in Appendix 11.

Streamflow data from gauging stations (see Figures 59-61) were available for each of the study catchments and will be discussed in more detail in the following sections. The quality and quantity of this data varied greatly and therefore all of these stream gauge stations presented challenges in the estimation of total streamflow. One of the limitations of the current streamflow datasets for Hindmarsh River and Currency Creek in generating streamflow results on a catchment basis is that the gauging stations do not cover the entire catchment and therefore monitoring results must be extrapolated to the whole catchment. The regression modelling provides this function but validating these calculated streamflows with recorded streamflow for the catchment would be beneficial.

In order to estimate runoff and baseflow, the streamflow data needs to be analysed. As mentioned in Section 6.4.2, HYBASE was used to separate out baseflow from total streamflow. HYBASE has a default filter value of 0.925 which was developed primarily for eastern flowing streams. Using this filter resulted in poor separation of baseflow from streamflow. After analysing the streamflow data for each of the study catchments using different filter values and filtering intervals, the following combinations were found to produce good baseflow separation results:

- Hindmarsh River Catchment - filter 0.97 and filter interval 60 minutes;
- Inman River Catchment - filter 0.985 and filter interval 45 minutes; and
- Currency Creek Catchment - filter 0.99 and filter interval 30 minutes.

These setting were experimented on both wet and dry periods in the data record to check their robustness and were found to be reasonable. These values were used to produce an average baseflow index for each catchment. It is recognised that a single baseflow index is not truly representative of the different baseflow conditions throughout the catchment but it does give a reasonable estimation and was used in the water balance calculations. This exercise provides a lesson in not simply trusting in a program generated result without checking to see if the result is reasonable or not.

6.5.2.1 Hindmarsh River Catchment

The Hindmarsh Reservoir is located in the lower part of the Hindmarsh River Catchment and since 1994/1995 has been used as a storage tank for filtered water supplies transferred from the Myponga Filtration Plant for domestic supplies around the Victor Harbour area. There has been a cut-off drain constructed around the perimeter of this reservoir to stop any catchment or stormwater drainage into the reservoir. The reservoir is managed by the Country Division of SA Water.

Before 1994/1995, the Hindmarsh Reservoir received inputs of raw water from Myponga Reservoir, diversions from the Hindmarsh River and catchment inflows directly from Mount Billy Creek. Overflows from the reservoir were drained back into the Hindmarsh River which eventually drains into Encounter Bay. Overflow discharges from this weir occurred generally between June and October.

There is a gauging station at the spill from the Hindmarsh Valley Reservoir Intake Weir (station number 501500) which has recorded streamflows since 1969 - see Figure 60. This gauging station monitors the releases or flows over this diversion weir into the Hindmarsh River. Unfortunately there was no data collected on the actual volume of the diversions at the spill into the reservoir over the years and therefore the streamflow data, prior to the last diversion, is not useful in estimating actual flows of the Hindmarsh River. This entire dataset would have been of value if the diversion volumes had been recorded.

The total data record for this station provided by DEHAA was from March 7, 1969 to December 10, 1999. The flow data was closely examined and SA Water was contacted to provide information on the last diversion made to the Hindmarsh Reservoir. May 15th, 1992 appears to have seen the last diversion and data from this date onward was used in the following analyses. The area of the catchment that the gauging station covers is 5,600 ha or 50% of the total catchment area.

The mean annual flow was 6,741 NL and the median was 6,098 ML. Figure 59 shows the monthly ranges and median values for the Hindmarsh stream gauge station from June 1992 to present. In this period, the highest annual total flow was 11,428 ML in 1996. The highest monthly flow was 6068 ML in July 1995 and the lowest was 6 ML in February 1999. Higher flows are evident from June to November. There is a high maximum streamflow recorded in December which corresponds to the above average rainfall event for that month.

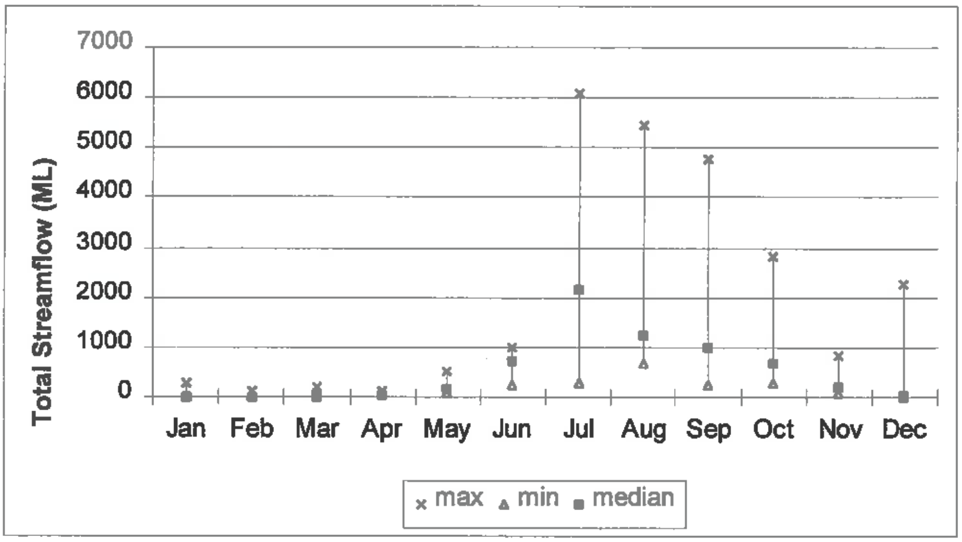
Table 32 shows the results from the analysis (50% of the catchment) and from the modelling (total catchment) for streamflow in the catchment. The modelled streamflow result for the Hindmarsh River catchment was 164 mm (SCRN et al, 2000). After the preliminary analysis of the shorter data record (1992 to present) and a comparison with the surrounding catchments this modelled streamflow results appeared to be too high. After consultation with staff at DEHAA there was agreement that the total streamflow range was from 100 to 115 mm. The value selected for the purposes of this study was 110 mm which appears to be a more reasonable estimate and consistent with the surrounding catchments. The median streamflow was chosen over the average streamflow because the median value is not as influenced by both high and low streamflow events as is the average streamflow.

Table 32. Calculated and modelled total streamflow (mm) for the Hindmarsh River Catchment (June 1992 to November 1999).

Catchment	Proportion of Catchment	Average Streamflow (mm)	Median Streamflow (mm)	Modelled Streamflow Median (mm)*
Hindmarsh River	50%	120	109	164

* SCRN et al, 2000

Figure 59. Monthly total flows recorded at stream gauge station 501500 (only values from 1992 - 1995 are included).



After the appropriate filter and filter interval were selected, the results from the baseflow separation analysis produced an average baseflow index of 0.34 using the data from June 1992 to November 1999. The same baseflow separation procedure was done on the entire dataset producing a baseflow index of 0.33. This would indicate that the diversions did not influence this baseflow separation greatly. Using this baseflow index the total streamflow can be partitioned into runoff and baseflow:

- **38 mm for baseflow (4,272 ML) and**
- **72 mm for runoff (8160 ML).**

These estimations have been used in the following calculations for recharge. It is recognised that this is just an estimate and at present there is no means of validating the accuracy of these numbers.

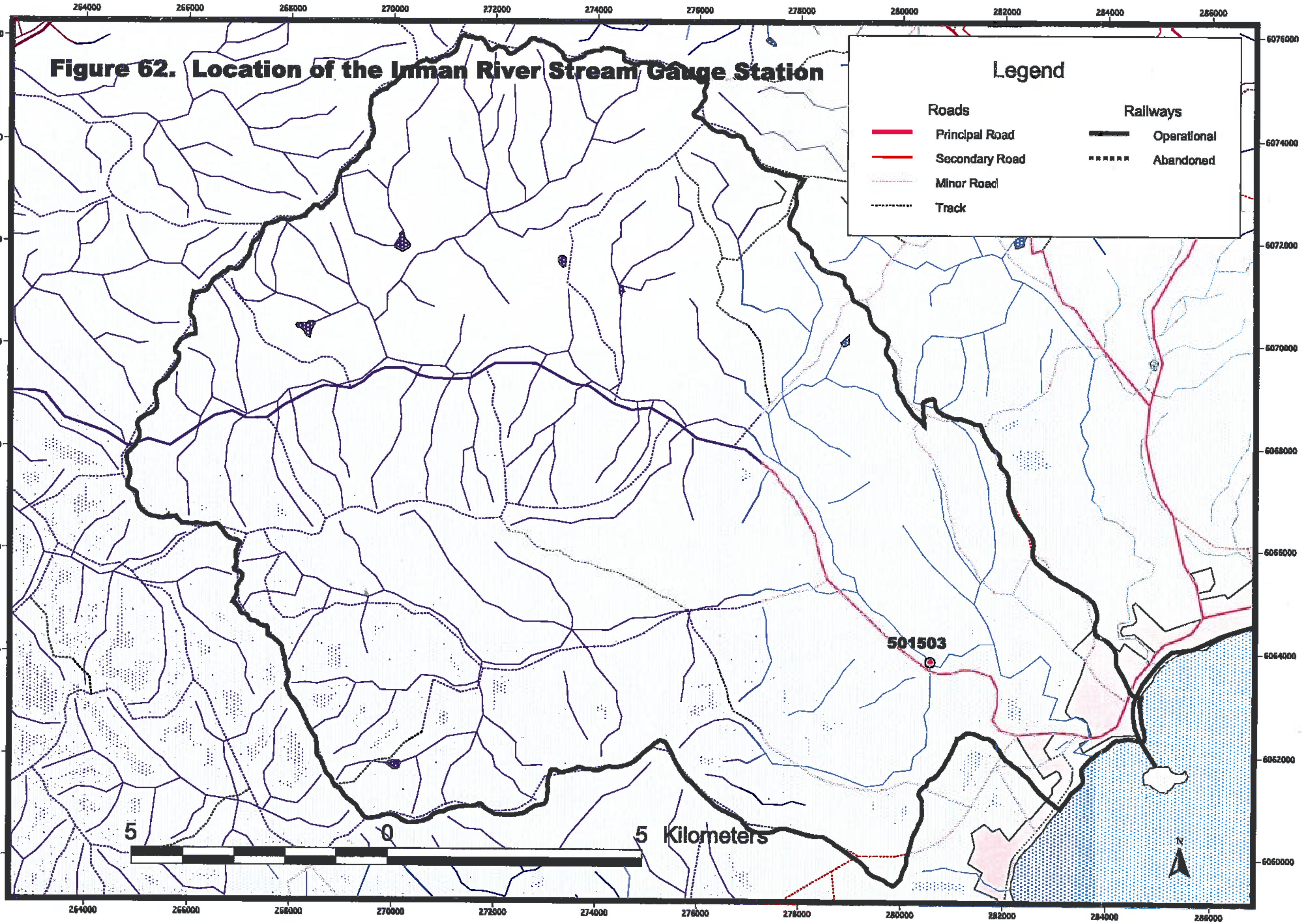


Figure 62. Location of the Inman River Stream Gauge Station

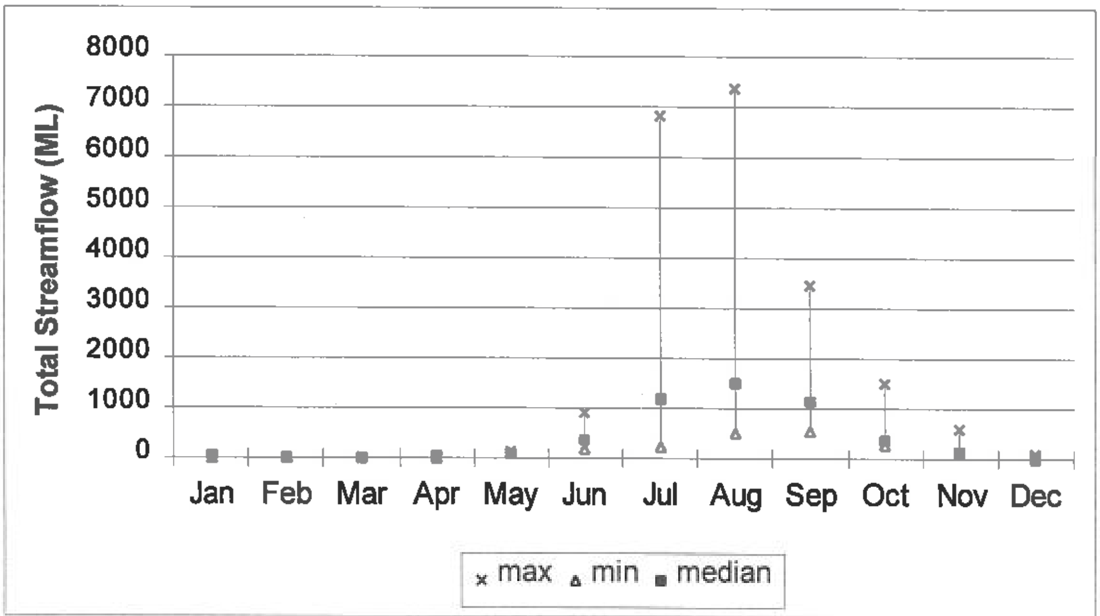
6.5.2.2 Inman River Catchment

Historically, the Inman River never existed and a defined incised channel only became evident when clearing occurred. The Inman River Catchment does not have any major instream water control structures. The Inman River receives discharges from the Victor Harbour Sewage Treatment Works and drains to Encounter Bay.

There is a stream gauge station at the lower end of the river - stream gauge station 501503 - see Figure 62. The streamflow record provided by DEHAA was from January 24, 1995 to January 14, 1999. The data for this station is classified as Provisional as the station is relatively new and the theoretical rating for the weir has not been verified by manual discharge measurements. This stream gauge station monitors the flow from 16,300 ha or 84% of the Inman River Catchment.

The mean annual flow was 6,961 ML and the median annual flow was 4,206 ML. There is a large difference between the median and mean annual flows but this is most likely due to the shortness of the data record and the period of record. The ranges and median monthly total flows recorded at this gauging station is shown in Figure 61. The highest monthly flow was 7,380 ML recorded in August 1996 and the lowest monthly flow was 10 ML in February 1999. For this short record the highest total annual flow was 15,975 ML in 1996 and the lowest annual flow was 4,000 ML in 1998. Low annual total flows were also recorded in 1999 - 4,412 ML. In general flows commence in May/June and continue through until November.

Figure 61. Monthly total flows recorded at the Inman River stream gauge station 501503.



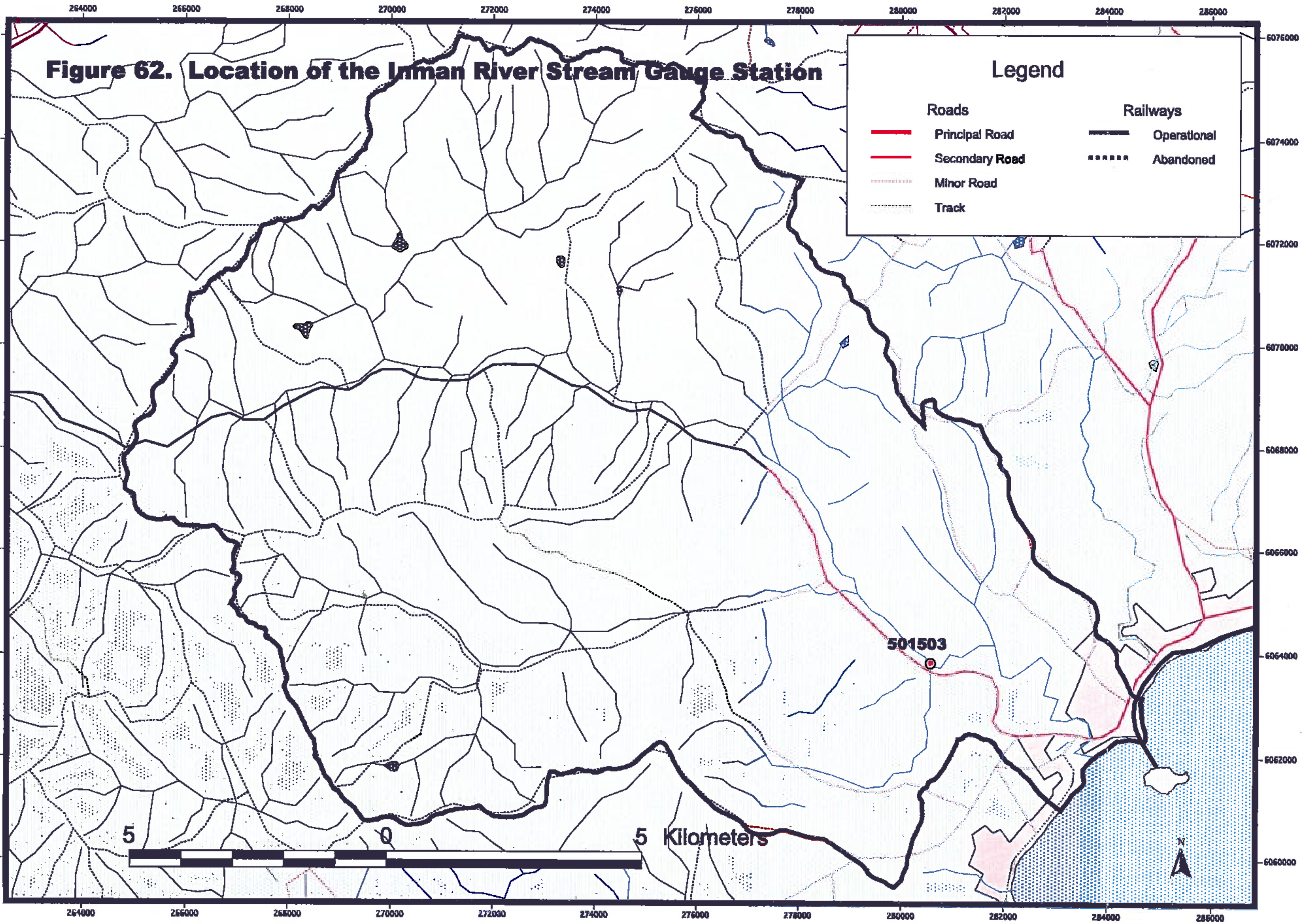


Figure 62. Location of the Inman River Stream Gauge Station

This stream flow record for the Inman River is relatively short and, in addition, the flow data that has been recorded is during a period of relatively low flows and low precipitation events. Therefore the streamflow data recorded for the Inman River Catchment only provides a limited estimation of the flow for this catchment and should be considered with caution.

Table 33 shows the results from the analysis (84% of the catchment) and from the modelling (total catchment) for streamflow in the catchment. The total streamflow for the Inman River Catchment most likely is between 100 to 115 mm and in the following water balance analyses the modelled streamflow results has been used.

Table 33. Calculated and modelled total streamflow (mm) for the Inman River Catchment (January 1995 to January 1999).

Catchment	Proportion of Catchment	Average Streamflow (mm)	Median Streamflow (mm)	Modelled Streamflow Median (mm)*
Inman River	84%	43	26	113

* SCRN et al, 2000

There is a large discrepancy between the total streamflow estimated and the recorded streamflows at the gauging station. An analysis was done to examine the average and median rainfall for the period of the streamflow record and the whole data record for both the Yankalilla (23723) and Rivington Grange (23743) rain gauge stations with the following results:

- Yankalilla station - 61 mm average from 1995-1999 (42 mm median) and 63 mm average for the whole rainfall record (52 mm median) and
- Rivington Grange station - 53 mm average from 1995-1999 (39 mm median) and 59 mm average for the whole rainfall record (50 mm median).

The rainfall data demonstrates that the period over which the streamflow record was collected was a below average rainfall period by about 10 mm. This in part explains the difference but there is still 77 mm to account for. There are several factors that should be considered when trying to explain this phenomena:

- the period of streamflow record was a dry period of reduced flows;
- there are a large number of farm dams in the Inman River Catchment (216) and 27 of these dams have estimated volumes of over 5 ML; and
- the Inman Valley is an area with sandy soils and not much substrate.

In this dry period, there was most likely interception by the farm dams which substantially reduced the streamflow in the river. The same effect was not observed in the Hindmarsh River and Currency Creek Catchments where there is more likely to be a high carry over in these catchments, especially where there are spring fed dams. However, this theory cannot be proved as the stream gauge data for the Inman River is limited and the stream gauge data for Currency Creek for this same period is non-existent (only patched data is available). As more streamflow data is collected at the Inman River stream gauge station, especially over wet periods, there will be a better indication of how much of the Inman River flow is being intercepted by farm dams and what affect this is having on the streamflow regime of the River.

After the appropriate filter and filter interval were determined, the results from the baseflow separation analysis produced an average baseflow index of 0.41. This result was produced from using the data from January 1995 to January 1999. In order to check whether this baseflow index was appropriate for times of high and low flow, baseflow indices were calculated for 1996 (high flow) and 1998 (low flow). The 1996 baseflow index was 0.41 and for 1998 was 0.40. These results are in good agreement with the average baseflow index and tends to suggest that the average is not influenced greatly by wetter and drier periods. Using this baseflow index the total streamflow can be partitioned into runoff and baseflow:

- **46 mm for baseflow (9,005 ML) and**
- **67 mm for runoff (13,040 ML)**.

These estimations have been used in the following estimations for recharge. It is recognised that this is just an estimate and, at present, there is no means of validating the accuracy of these numbers.

6.5.2.3 Currency Creek Catchment

Currency Creek drains into Lake Alexandrina and stream gauging station 426530 is located near Higgens, just downstream from the Junction of Currency Creek and a minor tributary (see Figure 64). The streamflow data provided by DEHAA was from June 6, 1972 to August 23, 1993. There were a number of missing data and a patched dataset was provided by DEHAA. This stream gauging station monitors flow from the upper half of the catchment which includes 5,700 ha or 62% of the Currency Creek Catchment.

The ranges and median monthly total flows recorded at this gauging station are shown in Figure 63. The median annual flow recorded for this station was 5,868 ML and the average annual flow was 5,908 ML. The highest annual flow recorded at this site was 14,424 ML in 1992 which is almost three times higher than the mean and median annual flows. The lowest annual flow was 1,003 ML in 1982. The highest monthly flow recorded at this station was 4,220 ML in July 1974 and the lowest recorded monthly flow was 3 ML in January 1972.

Figure 63. Summary of monthly flow data collected at the gauging station 426530 in Currency Creek near Higgens.

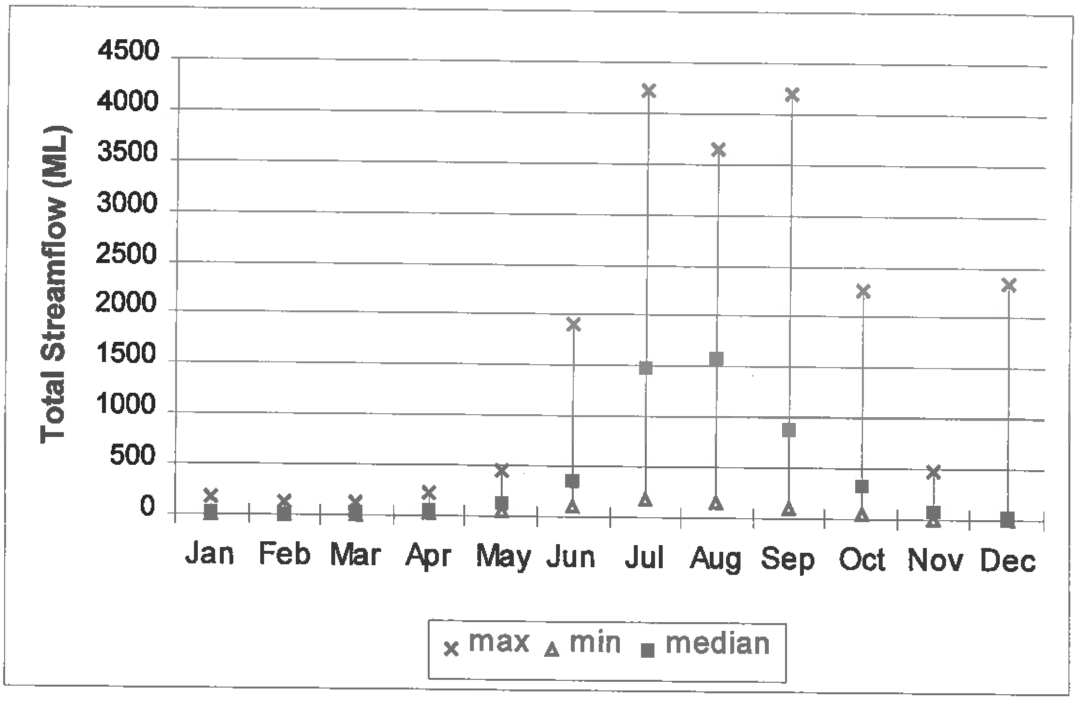


Table 34 shows the results from the analysis (62% of the catchment) and from the modelling (total catchment) for streamflow in the catchment. There is a difference between the modelled and the stream gauge station results. The stream gauge station is located in an elevated area. Currency Creek flows from this elevated area down to a valley where it becomes a losing stream and there is ongoing losses to recharge. Therefore, the modelled streamflow median value of 79 mm is a reasonable estimate of the streamflow for this catchment.

Table 34. Calculated and modelled total streamflow (mm) for the Currency Creek Catchment (June 1972 to August 1973).

Catchment	Proportion of Catchment	Average Streamflow (mm)	Median Streamflow (mm)	Modelled Streamflow Median (mm)*
Inman River	62%	107	106	79

* SCRN et al, 2000

After the appropriate filter and filter interval were selected, the results from the baseflow separation analysis produced an average baseflow index of 0.27. This result was produced using the data from June 1972 to August 1993. Using this baseflow index the total streamflow can be partitioned into runoff and baseflow:

- **23 mm for baseflow (2,087 ML) and**
- **56 mm for runoff (5,199 ML).**

These estimations have been used in the following estimations for recharge. It is recognised that this is just an estimate and, at present, there is no means of validating the accuracy of these numbers.

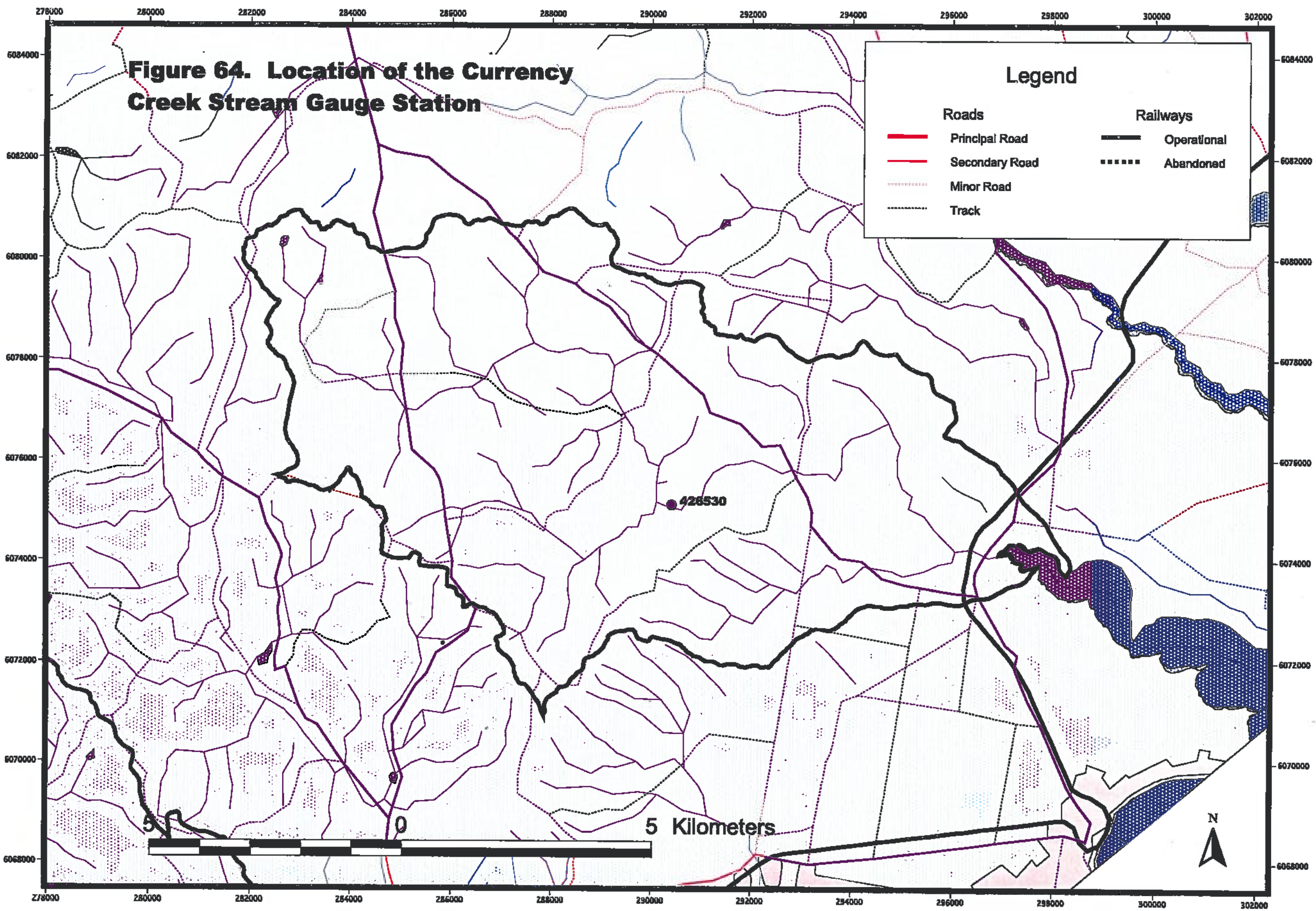


Figure 64. Location of the Currency Creek Stream Gauge Station

6.5.3 Evapotranspiration

Growing plants are continuously pumping water from the ground into the atmosphere through transpiration (Hendricks & Hansen, 1962). Water is drawn into a plant rootlet from the soil moisture and moves through the plant to the leaves where it is passed into the atmosphere. The process of transpiration accounts for most of the vapour losses from a land-dominated catchment. The amount of transpiration is a function of the density and size of the vegetation.

To calculate the total water loss in a catchment evapotranspiration is required and includes the transpired water, free water evaporation and soil-moisture evaporation. Evapotranspiration is the major use of water in all but extremely humid, cool climates (Fetter, 1994). If evapotranspiration was reduced, such as through cutting down forests, both infiltration to groundwater and runoff would increase, thereby increasing the available water supply. However, reducing the amount of forested lands has other adverse consequences such as erosion and sedimentation in surface waters.

The amount of evapotranspiration in a catchment is determined by the interaction of supply of water (total rainfall) and atmospheric demand (potential evapotranspiration), balanced by plants. The most important factors in determining annual evapotranspiration are the amount of annual rainfall, potential evapotranspiration and the available plant water capacity.

Potential evapotranspiration was estimated through the use of crop factors (see Appendix 1 and 2) which vary as the year progresses. The effects of wind and relative humidity are not accounted for. Monthly crop evapotranspiration was estimated for each of the study catchments by multiplying monthly bird-guarded class A pan evaporation data by monthly bird-guarded crop factors.

The 1999 land use classifications were grouped into three broad categories for the evapotranspiration analysis:

- Grasslands - dairy, pastures, grazing, recreation(30%),cultural (30%), education(40%), urban (30%), rural living, horses, crops- using crop factor for pastures;
- Vines- using the crop factor for wine grapes; and
- Orchards - using the crop factor for apples.

The percentages referred to above are estimates of the proportion of land that be covered in vegetative matter that could transpire water. For instance, it is estimated that 30% of the land mass for recreation is covered in grass or other vegetation. For all other categories without a percentage indicated, it is assumed that 100% of the land mass is available for evapotranspiration.

There are substantial inherent sources of error associated with the estimation of evapotranspiration due to the data available. For instance, the evaporation data for the whole of Australia is based on only 40 evaporation pans. From this data extrapolations are made and the evaporation is mapped for the country. Recent work soon to be published has reexamined and enhanced this dataset and should be used in future studies of this type. Another source of error is the use of crop factors. The crop factors used were initially proposed for the whole of South Australia and now are being used on a site specific basis which wasn't the original intent of developing these numbers. There is an estimated ±30% error factor in the evapotranspiration results.

6.5.3.1 Native Vegetation and Plantation Forests Evapotranspiration

It has been found that there is a strong relationship between recharge and rainfall for annuals on sandy soils (Petheram et al, 1999). In the study catchments, the predominant surface soil type was sand to loamy sand which in general can be groups as sandy soils. Research has shown that there is a strong regression for herbaceous plants grown in sandy soils and average annual rainfall, where the regression equation derived from experimental data is:

$y = 0.2357x - 63.096$ ($R^2 = 0.8075$) (Petheram et al, 1999)

Where y = recharge (mm) and x = rainfall (mm)

A similar relationship was not reproduced between trees grown in sandy soil and average annual rainfall ($R^2 = 0.0299$) (Petheram et al, 1999). Both regression equations were used to estimate recharge for native vegetation and plantation forests. Estimates of recharge were calculated using both the effective and total annual rainfall and the results are shown in Table 35.

Table 35. Estimations of recharge and evapotranspiration from lands covered with native vegetation in the catchment areas.

Catchment	Rainfall		Recharge		Evapotranspiration	
	Effective (mm)	Total (mm)	Effective (mm)	Total (mm)	Effective (mm)	Total (mm)
Hindmarsh River	622	770	83	118	538	652
Inman River	586	732	75	109	511	622
Currency Creek	509	646	57	89	452	557

For the purposes of the following calculations native vegetation includes lands classified under native vegetation and National Park and Wildlife Services (NPWS). Plantation forests in the study catchments are mainly pine plantation forests.

As effective rainfall has been used for the other evapotranspiration estimations, it has also been used in the estimation of evapotranspiration for native vegetation. Table 36 shows the results for evapotranspiration estimates for the study catchments. It is recognised there are broad assumptions made in these estimations, such as the catchment being predominantly composed of sandy soils and the vegetation in the native vegetation land use classification being mainly herbaceous. These assumptions are not entirely accurate as the geological cross sections show many different layers of sand, clay and rock types beneath the surface. In addition, areas of native vegetation are a mixture of trees and annual and perennial shrubs and grasses. Revisions to these values should be made as better information becomes available.

The calculate evapotranspiration estimations for native vegetation are considered to be reasonable. In other groundwater assessments in other Mount Lofty Ranges catchments, it has been assumed that 50 mm is available for recharge in areas of native vegetation (Barnett and Zulfic, 1999a, 1999b). The above calculated recharge values are higher than this estimate and in fact may be slightly lower depending on the amount of trees within the classified native vegetation areas. However, this information is not available.

Use of the regression equation to calculate recharge under trees indicated that there would be no recharge. Therefore, it has been assumed that the trees transpire all the effective rainfall and no water is available for recharge. This is an assumption that has been used in other studies (Barnett and Zulfic, 1999a, 1999b). However, this assumption would only be valid up to a certain rainfall. For large rainfall events, there most likely would be recharge and runoff occurring under these tree areas.

Table 36. Total annual recharge and evapotranspiration for plantation forests and native vegetation in the study catchments.

	# ha	Estimated Recharge (mm/yr)	Effective Annual Rainfall (mm)	Evapotranspiration Rate (mm/yr)	Water Loss (ML/yr)
Hindmarsh River					
Native Vegetation	1,279	83	622	538	6,882
Plantation Forests	77	0	622	622	482
Total	**1,356**				**7,364**
Inman River					
Native Vegetation	1,948	75	586	511	9,962
Plantation Forests	306	0	586	586	1,796
Total	**2,255**				**11,757**
Currency Creek					
Native Vegetation	484	57	509	452	2,191
Plantation Forests	4	0	509	509	21
Total	**488**				**2,212**

The largest area of native vegetation and plantation forests is in the Inman River and Hindmarsh River Catchments (12% of the total catchment) followed by the Currency Creek Catchment (5% of the total catchment).

Most of the plantation forests in these catchments are pine. It should be noted that in the Hindmarsh Tiers area a new plantation (34 ha) of Tasmanian blue gum trees was planted in July 1998. These trees are now 18 months old and at present do not transpire all the effective rainfall and have not been included in the evapotranspiration for plantation forests. There is a new development program for a farm forestry industry in the Adelaide Hills and on the Fleurieu Peninsula. The vision of this program is to plant 1000 ha of plantation each year for the next 15 years (PIRSA, 1999). The establishment of plantation forests will alter the water balance and less water will be available for recharge. The evapotranspiration component of the water balances for these study catchments should be revised over the years as new plantation forests are established.

6.5.3.2 Total Evapotranspiration

The evapotranspiration values in Mega Litres (ML) for each of the broad classifications of land use for the study catchments are shown in Tables 37-39. As expected the largest water loss in this catchment is from the largest land use grouping - grasslands.

Table 37. Evapotranspiration for the Hindmarsh River Catchment.

Land Use	Area (ha)	Evapotranspiration (mm/yr)	Water Loss (ML/yr)
Grassland	9,762	381	37,214
Native Vegetation	1,279	538	6,882
Plantation Forest	77	622	482
Vines	23	123	28
Orchard	2	196	5
		Total	**44,610 (395 mm)**

Table 38. Evapotranspiration for the Inman River Catchment.

Land Use	Area (ha)	Evapotranspiration (mm/yr)	Water Loss (ML/yr)
Grassland	16,998	377	64,094
Native Vegetation	1,948	511	9,962
Plantation Forest	306	586	1,796
Orchard	13	200	26
		Total	**75,878 (389 mm)**

Table 39. Evapotranspiration for the Currency Creek Catchment.

Land Use	Area (ha)	Evapotranspiration (mm/yr)	Water Loss (ML/yr)
Grassland	8,409	387	32,519
Native Vegetation	484	452	2,191
Vines	317	13	41
Plantation Forest	4	509	21
Orchard	9	197	18
		Total	**34,789 (377 mm)**

Most of the areas in all three catchments has been broadly categorised as grasslands: for Hindmarsh and Inman River Catchments about 86% and Currency Creek about 91%. The Hindmarsh River Catchment has a slightly higher weighted evapotranspiration than Inman River. The crop factors for pastures have been used in the above calculations and it was felt that this crop factor best represented the broad classification of grasslands. As more accurate information becomes available as to area, crop factors and type of ground cover, this estimation of evapotranspiration can be refined.

Evapotranspiration is a complex process and is closely associated with characteristics of vegetation. The most important factors affecting the mean annual evapotranspiration appear to be annual rainfall and vegetation type (Zhang et al, 1999). Evapotranspiration is affected by interception of rainfall and energy, advection, turbulent transport, canopy resistance, leaf area, and plant available water capacity (Zhang et al, 1999).

A number of studies have shown that mean annual evapotranspiration is strongly correlated with mean annual rainfall (Zhang et al, 1999). For a given amount of annual rainfall, total evapotranspiration from forested catchment areas is greater than for non-forested catchments (Zhang et al, 1999). The difference is larger in high rainfall areas and it diminishes in areas with annual rainfall less than 500 mm. This implies that tree plantation in low rainfall areas are not likely to alter the water balance very much and hence control the amount of non-transpired water (the difference between rainfall and evapotranspiration). However, this depends on the variability of the rainfall. If the rainfall events are highly variable, there will be pulses of recharge as the available water is much greater than the evapotranspiration (Daniell, personal communication).

Catchments with mixed cover have annual evapotranspiration between that observed for fully forested and fully cleared catchments. Work has been done to quantify the relationship between mean annual rainfall and fraction of forest cover and this model could be used in the future to evaluate the impact of vegetation changes on catchment water balance (Zhang et al, 1999). Use of this model should be further examined in the study catchments as a means to estimate annual evapotranspiration volumes.

6.5.4 Farm Dams

Farm dams are prevalent within much of the South Central Region and play an important role in water resource management as they influence the total flow of water throughout a catchment and have an impact on catchment yield, water allocation, water for stock and domestic purposes and environmental flows.

A farm dam project was completed in 1996 to determine the volume of water in farm dams at the time of the aerial photographs (December 1995 and January 1996) (McMurray, 1996). It was recognised that there would be large errors in detecting and estimating the volume of smaller dams but this was not considered to be a serious problem as the majority of water in farm dams is stored in larger dams - on average 69% of the total volume in farm dams in the Mount Lofty Ranges catchments was contained in dams over 5 ML (McMurray, 1996). An investigation carried out by the author of the report indicated that for the Marne catchment, the results of the 1996 farm dams project are a reasonable representation of the volume of water stored in farm dams at the time of the air photography, that the errors are within the expected limits and that the correction factors used in the study were supportable (McMurray, 1996).

Distributions and volumes for farm dams in the study catchments are shown in Appendix 12. Figure 65 shows the distribution of the farm dams for each size-class. In all three catchments, farm dams over 5 ML make the largest contribution to total stored surface water. In the Hindmarsh River Catchment farms dams over 5 ML comprise 53% of the total volume, in the Inman River Catchment, 75% of the total volume and in Currency Creek, 69% of the total volume. Except for Hindmarsh River, these results confirm that the farm dam volume assessment is reasonable as the majority of the volume for the farm dams is associated with dams over 5 ML in size.

The percentage of total dams less than 5 ML was fairly consistent across each catchment: 89% of the farm dams were less than 5 ML in Hindmarsh River, 88% in Inman River and 88% in Currency Creek. A larger volume was estimated in the Hindmarsh River Catchment for these smaller dams and if these volumes were underestimated, due to the potential error in estimating the volume of these smaller sized dams, the total volume for Hindmarsh River Catchment could be slightly higher than the volume reported below in Table 40.

The farm dam volumes in Table 40 below represent the estimated number and volume of water stored in the farm dams at the time the aerial photography was captured, ie December 1995 and January 1996. Since 1996, there may have been more farm dams constructed in all of the study catchments.

In addition to the above catchment storage volumes, the Hindmarsh River Catchment has a reservoir with a capacity of 475 ML. This volume has not been used in the water balance equations as the water stored in this reservoir is piped water from the Myponga reservoir, as discussed earlier, and is not part of the Hindmarsh River water budget.

Figure 65. Total farm dam volumes for different size classes after correction factors have been applied.

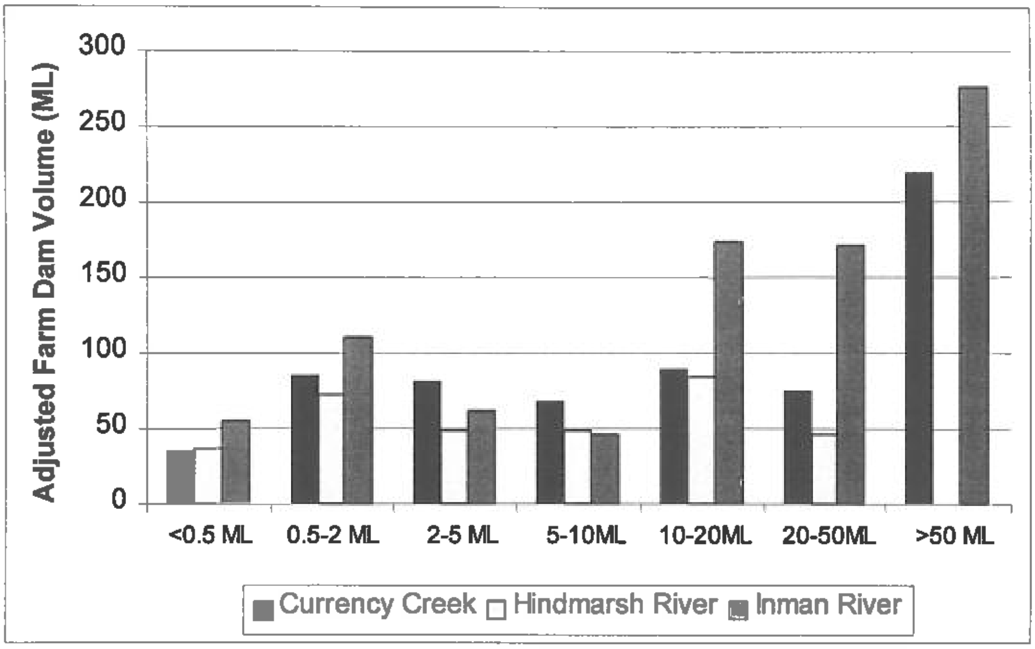


Table 40. Summary of Totals for each of the catchments in the study area after correction factors were applied (McMurray, 1996).

Catchment	All Dams Total Volume (ML)
Hindmarsh River	338
Inman River	896
Currency Creek	656

One of the basic assumptions of the methodology that generated the above results is that the farm dams are full at the end of winter/spring and receive no more inflows during summer. This assumption, however, is not totally valid for all farm dams. In the field survey component of this study, it was discovered that several of the dams that are used for irrigation purposes are spring fed. This type of dam violates the above assumption. In calculating recharge, spring fed dams, at present are not taken into account. Springs are a discharge point for groundwater systems and this water should be accounted for in water budgets. However, this is beyond the scope of this study and may warrant further investigation in the future.

Farm dams collect and retain stream runoff and alter the flow regime and quantity of water to downstream users and to the environment. The estimation of farm dam volumes for catchment in the Mount Lofty Ranges need to be revised and a robust methodology developed. Aerial photographs should be taken in the late spring to ensure that the water storage is at a maximum and accurate registration of aerial photographs should be done so that dams are correctly located within the GIS and match appropriate land tenure (SCRN et al, 2000). In future farm dam surveys, the farm dam outline should be determined from scanned air photography by manually digitising on-screen which should assist in the determination of the maximum dam capacity. There still will be sources of error in this method but the largest error is likely to be in the estimation of volume by using a formula based only on surface area.

Farm dam surface evaporation volumes were estimated using the surface area of the farm dams as reported in the McMurray 1996 study. The results of this analysis are not included in the water balance equations in the results section of this report as the volumes were considered to be low and insignificant in comparison to the evapotranspiration volumes. The following are the calculated evaporation annual volumes from farm dams:

- Hindmarsh River - 2.8 to 3.2 ML per year;
- Inman River - 5.1 to 5.8 ML per year; and
- Currency Creek - 5.6 to 6.3 ML per year.

6.5.5 Water Balance Components for Recharge Calculation

Tables 41 to 43 summarise the water balance components discussed in the previous sections. As discussed in each of the individual section, there are limitations and sources of error associated with each of these estimations:

- Streamflow, runoff and baseflow have been generated through both monitoring and modelled data which have potential sources of error;
- Evapotranspiration for grasslands has broadly grouped a number of land uses that may have different evapotranspiration rates; and
- Farm dam volumes are those estimated for 1996 and the number and volume of smaller sized dams (<5 ML) may be underestimated.

However, the results below are based on best available information at this present time. These numbers should be revised as more current and accurate information becomes available.

Table 41. Estimated water balance data for Hindmarsh River Catchment.

	Inputs		Outputs	
	Type	Amount(ML)	Type	Amount (ML)
	Effective Rainfall	70,260	Evapotranspiration	44,610
			Runoff	8,160
			Farm Dams	338
Total		**70,260**		**53,108**

Table 42. Estimated water balance data for Inman River Catchment.

	Inputs		Outputs	
	Type	Amount(ML)	Type	Amount (ML)
	Effective Rainfall	114,395	Evapotranspiration	75,878
			Runoff	13,040
			Farm Dams	896
Total		**114,395**		**89,813**

Table 43. Estimated water balance data for Currency Creek Catchment.

	Inputs		Outputs	
	Type	Amount(ML)	Type	Amount (ML)
	Effective Rainfall	46,991	Evapotranspiration	34,789
			Runoff	5,199
			Farm Dams	656
Total		**46,991**		**40,644**

6.6 Groundwater Recharge

Groundwater recharge is a challenging component of the water budget to estimate. Recharge can be variable over a catchment due to its relationship with and dependence on factors such as soil type and vegetation cover. Three different methods have been used in this study to calculate recharge: water balance methods, chloride method and groundwater balance method.

6.6.1 Water Balance Method

In the water balance method all other components of the water balance are calculated with the outstanding quantity attributed to recharge. Recharge is measured indirectly:

$$D = P - (ET + R + \Delta S)$$

Where:
P = precipitation
ET = evapotranspiration
R = surface runoff
D = recharge to groundwater
ΔS = change in soil water storage

In this equation only the winter rainfall (April to October) has been used as it is considered to be effective in contributing to the water balance. For the purposes of this study, it is assumed that the change in soil water storage is zero. As farm dams (FD) divert volumes of surface runoff they must also be taken into account in the recharge estimation and the equation then becomes:

$$D = P - (ET + R + FD)$$

Table 44 shows the estimations of recharge for each of the study catchments. The largest volume of water available for recharge is in the Inman River Catchment, followed by the Hindmarsh River and Currency Creek Catchments.

Table 44. Water balance and recharge estimates for the study catchments.

	Hindmarsh River	Inman River	Currency Creek
Inflow (Rainfall) ML	70,260	114,395	46,991
Outflow ML	53,108	89,813	40,644
Recharge ML	**17,152**	**24,581**	**6,347**

There are many sources of error associated with the above estimation that should be noted and a total error calculated. The total error for this method is ±40% assuming the following error factors for each component of the water balance: ±5% for rainfall, ±30 for evapotranspiration, ±20% for runoff and ±20 for farm storage.

6.6.2 Chloride Method

The chloride method for estimating recharge produced very different results than were calculated in the water balance method. This may be due to the small number of chloride results that were available for analysis:

- Hindmarsh River - 54 results;
- Inman River - 31 results; and
- Currency Creek - 15 results.

No attempt was done to partition the chloride concentrations into geological formations as there were not enough chloride results in each formation to make this a meaningful exercise.

Table 45 shows the results from the analysis. Average and median values are presented below to give a indication of the chloride distributions. The chloride values in the Hindmarsh River Catchment are close to normally distributed, as seen by the similarity in the average and median values but the distributions in both the Inman River and Currency Creek Catchments are not.

The average chloride values varied for each catchment:

- Hindmarsh River - 350 mg/L;
- Inman River - 1,482 mg/L; and
- Currency Creek - 1,633 mg/L.

Recharge estimates using Hutton's method are closer to the values calculated in the water balance method than Kayaalp's values. However both values are out by over an order of magnitude. The results are in the same relative magnitude, ie. If the average values for Hutton's method are used, Inman River has a greater recharge than Hindmarsh River which has a greater recharge than Currency Creek.

Table 45. Recharge estimates for the study catchments using the chloride method.

Catchment	recharge	Hutton mm	Kayaalp mm	Hutton ML	Kayaalp ML
Hindmarsh River	average	29	13	3,327	1,434
	median	21	10	2,427	1,124
Inman River	average	29	12	5,714	2,284
	median	6	2	1,081	434
Currency Creek	average	11	5	1,045	438
	median	5	2	496	175

This method has been used in other catchments in the Mount Lofty Ranges with the results showing similar low values when compared to other methods of recharge (Barnett and Zulfic, 1999a, 1999b). However, the results in the other studies were not as divergent as the ones calculated in this study. In other studies, the difference was explained as the new chloride equilibrium not being reached since land clearing and that the values reflect pre-clearing recharge rates.

In order to further investigate this discrepancy, the salt balances for the study catchments were estimated. In the chloride method, the chloride ion is used to estimate recharge provided that it is not dissolved from rocks or minerals. Average conductivity readings were obtained for the stream gauging stations in the Hindmarsh River and Currency Creek catchments (SCRN et al, 2000 and SCRN et al, 2000). Data for the Inman River Catchment was not available. It has been assumed that 40% of the salinity concentration is attributed to chloride. Table 48 shows the results of the salt balance. There are ranges of chloride in rainwater presented based on the average chloride concentrations in rainfall calculated through the Hutton and Kayaalp methods (see Section 6.6.2). As shown in this rough salt balance, there is more chloride leaving the catchments than there is entering. There is a large error factor associated in calculating the chloride concentration in streamflow but even if the calculated concentration of streamflow chloride concentration is doubled or halved there is still an inbalance.

It is clear that the chloride concentrations in each of the study catchments are not in a steady state. Other work done in the Mount Lofty Ranges has shown that there is a net export of salt in this region (Kayaalp, 1998). Therefore, the results from the chloride method of estimating recharge are not applicable and should not be used.

Table 46. Salt water balance for Hindmarsh River and Currency Creek Catchments.

Catchment	TDS (mg/L)	Chloride (mg/L)	Stream-flow (ML)	Chloride out (Mg)	Chloride in rainfall (mg/L)	Rainfall (ML)	Chloride in Rainfall (Mg)	Difference (Out - In) (Mg)
Hindmarsh River	574	230	6,781	1,556,895	3.5 to 8.1	43,520	153,196 to 352,306	1,204,589 to 1,403,699
Currency Creek	1,478	591	6,119	3,617,476	3.7 to 9.8	36,963	136,764 to 362,239	3,255,237 to 3,480,712

6.6.3 Groundwater Balance Method

The groundwater balance method is the third method used to determine groundwater recharge and has been used in other studies to assess groundwater sustainability in the Mount Lofty Ranges (Barnett and Zulfic, 1999a, 1999b). In the groundwater balance method recharge is calculated as follows:

Recharge = Baseflow + Groundwater extraction

Baseflow estimates were made in Section 6.5.2 and groundwater extraction estimates were made for domestic use, stock use and irrigation - Section 6.7.2. The results of this method are shown in Table 46. Groundwater extraction volumes have been calculated from the field survey results and estimated amounts for other irrigation uses and domestic and stock water.

Table 47. Recharge estimations from the groundwater balance method.

Catchment	Baseflow (ML)	Field and Theoretical Groundwater Extraction (ML)	Recharge (ML)
Hindmarsh River	4,272	5,464	9,736 (86 mm)
Inman River	9,005	109	9,114 (47 mm)
Currency Creek	2,087	634	2,721 (29 mm)

There are many sources of error associated with the above estimation that should be noted and a total error calculated. The total error for this method is ±42% assuming the following error factors for each component of the groundwater balance: ±30% for baseflow and ±30 for groundwater extraction.

6.6.4 Recharge Summary

The results from the three different methods of calculating recharge are presented in Table 47. The results are very divergent and there does not appear to be any consistency in the magnitude or order of recharge for the study catchments. In the water balance and chloride methods the Inman River Catchment has the highest recharge but in the groundwater balance method the Hindmarsh River Catchment is highest. This is in part due to the low use of groundwater in the Inman River Catchment.

Table 48. Summary of recharge methods for study catchments.

Catchment	Water Balance	Chloride Method	Groundwater Balance
Hindmarsh River	17,152 ML 152 mm	3,327 ML 29 mm	9,736 86 mm
Inman River	24,581 ML 126 mm	5,714 ML 29 mm	9,114 47 mm
Currency Creek	6,347 ML 69 mm	1,045 ML 11 mm	2,721 29 mm

The chloride method's recharge results are 4-6 times less than the water balance method. One possible explanation for this is that the water balance method estimates recharge over the whole catchment whereas the chloride method is dependent on the locations of the bores with chloride values and therefore does not provide a catchment perspective. But as discussed earlier, the method is not valid in the study catchments as there is a net export of salt from these areas.

Another way to check if the recharge results are reasonable is to determine what the percentage of total annual rainfall that the recharge comprises. Table 49 shows this analysis. The rainfall percentages for the water balance method appear to be reasonable for a high rainfall area which in the upper portions of the catchment are 300-400 metres above sea level. The percentage of recharge for Hindmarsh River for the groundwater balance method appears to be reasonable but those for Inman River and Currency Creek appear to be low. Therefore, the water balance method most likely gives a more accurate estimation of the recharge for the study catchments.

Table 49. Percentages of the total annual rainfall attributed to calculated recharge values.

	% Recharge (Water Balance Method)	% Recharge (Groundwater Balance Method)
Hindmarsh River	20%	14%
Inman River	17%	8%
Currency Creek	11%	6%

6.7 Water Use

The main water use in all of the study catchments is irrigation. Other water uses include domestic and stock water. None of the bores in the study catchments have metres installed to accurately assess the volume of water extracted on an annual basis. Two methods have been used to estimate irrigation volumes in each of the study catchments: field survey and estimations using percentages of land use classifications and target irrigation needs.

It is difficult to estimate the annual volume attributed to irrigation as pumping is varied to suit antecedent rainfall, soil moisture and temperatures. The volumes estimated are very conservative and should be revised as more current and accurate information becomes available. Attempts have been made to partition the groundwater and surface water components of water use. However, these are approximations only and should be revised as more accurate information becomes available.

6.7.1 Irrigation Volumes (Theoretical)

Target irrigation needs were generated from estimated annual application rates and proportions of land uses irrigated in the study catchments. This was not an easy task as data in the 1999 GIS land use classifications were not collected and collated for the purposes of estimating the amount of land irrigated in each catchment. As discussed in Section 6.5.3, land use classifications were broadly grouped into one category called "grasslands" in order to calculate the evapotranspiration volumes. However, in estimating target irrigation needs this broad grouping is not applicable and a "best guess" at the percentages of land irrigated for each land use in each catchment and an application rate needs to be determined. These estimations were first reviewed by an irrigation professional and were considered to be reasonable for the purposes of this theoretical estimation (Cole, personal communication).

The application rates in the attached tables were generated using a standard reference crop and multiplying this by a crop coefficient to obtain the water use for a particular crop (see Appendix 1 and 2). For the broad grouping of grasslands the standard reference crop used was pasture to generate the application rates used in these estimations. The crop factor for wine grapes (full irrigation) was used for vines and the crop factor for apples was used for orchards. The GIS uses grid arithmetic functions to then calculate this reference crop water use on a monthly basis and posts the results against known rainfall sites. These crop water requirements were also reviewed and considered reasonable (Cole, personal communication). This method of determining irrigation volumes is only to be used to provide a general idea of irrigation volumes. In the study catchments for extensive land use categories such as grazing the actual volume is likely to be below the theoretical.

6.7.1.1 Hindmarsh River Catchment

It has been estimated that approximately 2% of the catchment was irrigated in 1993 (SCRN et al, 2000). Table 50 indicates that dairy was the major irrigated land use in the Hindmarsh River Catchment. There were large tracts of land dedicated to dairy throughout the catchment, noticeably on the lower slopes and floor of the Hindmarsh Tiers Basin. Recreation was a land use that used irrigation within the urban areas and horse keeping occurred in the headwaters of the catchment. The average application rate was estimated to be 5.5 ML/ha. It was estimated that approximately 75% of water used for irrigation was sourced from groundwater (SCRN et al, 2000).

Table 50. Estimated volumes of water used for irrigated land in the Hindmarsh River Catchment (1993) (SCRN et al, 2000).

Catchment	Land Use	Application Rate (ML/ha)	Area Irrigated (ha)	Total Volume (ML)
Hindmarsh River	Dairy	4.2	217	912
	Recreation	12.5	42	525
	Horse keeping	4.0	4	14
	Total		**263**	**1.451**

Table 51 shows the theoretical estimations of the amount of water used for irrigation purposes in the Hindmarsh River Catchment in 1999. The total number of hectares were taken from the 1999 land use GIS using the 1993 land use codes translated up to the ANZLUC 1999 codes. According to these theoretical estimations 12% of the total Hindmarsh River Catchment was irrigated. The application rate is estimated to be 8.1 ML/ha (for pastures) which is double the estimated value of 4.0-4.2 ML/ha in 1993.

Table 51. Theoretical estimations of total amount of water used for irrigation in the Hindmarsh River Catchment in 1999.

Land Use +	Area ha	Proportion Irrigated	Area Irrigated (ha)	Application Rate (ML/ha)*	Water Use (ML)
Grazing	5,961	0.1	298	8.1	2,426
Dairy	2,453	0.3	736	8.1	5,990
Berry (Orchards)	2	1.0	2	6.7	15
Rural living	114	0.1	11	8.1	93
Pastures	1,000	0.1	100	8.1	814
Horses	63	0.1	6	8.1	51
Urban	23	0.3	7	8.1	56
Recreation	190	0.8	152	8.1	1,237
Cultural	77	0.3	23	8.1	188
Education	34	0.4	14	8.1	111
Vine	9	1.0	9	3.6	33
		Total	**1,359**		**11,015**

+ 1993 land use codes translated up to the ANZLUC 1999 codes
*derived from Target Irrigation Needed calculations performed by GIS for orchard (apples), wine grapes (full irrigation) and pasture

6.7.1.2 Inman River Catchment

In 1993, it was estimated that approximately 3% of the Inman River Catchment was irrigated as shown in Table 52. Dairy operations were the main irrigation users and were located throughout the upper and central regions of the catchment. It was estimated that 10% of the water used for irrigation was sourced from groundwater (SCRN et al, 2000). The report speculated that the Inman River Catchment had the highest irrigation water use compared to the rest of the Fleurieu catchments (SCRN et al, 2000).

Table 52. Estimated volume of water used for irrigated land in the Inman River Catchment (1993) (SCRN et al, 2000).

Catchment	Land Use	Application Rate (ML/ha)	Area Irrigated (ha)	Total Volume (ML)
Inman River	Dairy	4.0	448	18028
	Recreation	11.7	119	1389
	Orchard	4.0	7	29
	Horse keeping	4.9	7	33
	Total		**580**	**3252**

Table 53 shows the theoretical estimations of the amount of water used for irrigation purposes in the Inman River Catchment in 1999. The total number of hectares were taken from the 1999 land use GIS using the 1993 land use codes translated up to the ANZLUC 1999 codes. According to these theoretical estimations 7% of the Inman River Catchment was irrigated. The estimated irrigation rate is 8.2 ML/ha for pastures (double the 1993 application rate). The1999 theoretical estimations are higher than the 1993 estimates due in part to the total estimated area and application rates.

Table 53. Theoretical estimations of total amount of water used for irrigation in the Inman River Catchment.

Land Use+	Area ha	Proportion Irrigated	Area Irrigated (ha)	Application Rate (ML/ha)*	Water Use (ML)
Pastures	206	0.1	21	8.2	169
Grazing	10,812	0.05	541	8.2	4,433
Dairy	5,139	0.1	514	8.2	4,214
Rural Living	496	0.1	50	8.2	407
Crops	0.03	0.2	0.006	8.2	0.05
Horses	74	0.1	7	8.2	61
Recreation	127	0.8	102	8.2	833
Orchard	13	1	13	6.7	87
Urban	310	0.3	93	8.2	763
Cultural	33	0.3	10	8.2	81
Education	3	0.4	1	8.2	10
		Total	**1351**		**11,057**

+ 1993 land use codes translated up to the ANZLUC 1999 codes
*derived from Target Irrigation Needed calculations performed by GIS for orchard (apples) and pasture

6.7.1.3 Currency Creek Catchment

In 1993, it was estimated that approximately 2.3% of the Currency Creek Catchment was irrigated (SCRN et al, 2000). The average application rate was estimated to be 3.3 ML/ha and the total area irrigated 212 ha (SCRN et al, 2000). In 1993, the irrigated land uses in the catchment were dairy, horse keeping and vines (SCRN et al, 2000). The majority of the irrigation in Currency Creek was thought to occur in the upper catchment where large dams occurred. It was estimated that 20% of the irrigation water was sourced from groundwater (SCRN et al, 2000).

Table 54 shows the theoretical estimations of the amount of water used for irrigation purposes in the Currency Creek Catchment. The total number of hectares were taken from the 1999 land use GIS using the 1993 land use codes translated up to the ANZLUC 1999 codes. According to these theoretical estimations 12% of the Currency Creek Catchment was irrigated.

These theoretical estimations for the Currency Creek Catchment are again higher than the 1993 irrigation estimates due in part to the total amount of area estimated to be irrigated. Since 1993, there has been some land use changes in the Currency Creek Catchment (more vines) which in part explains this difference in irrigated areas. The estimated irrigation rate for 1999 is 8.9 ML/ha for pastures which is over double the rate estimated in 1993.

Table 54. Theoretical estimations of total amount of water used for irrigation in the Currency Creek Catchment.

Land Use+	Area ha	Proportion Irrigated	Area Irrigated (ha)	Application Rate (ML/ha)*	Water Use (ML)
Dairy	1,331	0.25	333	8.9	2,958
Grazing	5,129	0.05	257	8.9	2,280
Pastures	1,298	0.1	130	8.9	1,154
Orchards	9	1	9	7.3	65
Vine	317	1	317	3.9	1,239
Horses	193	0.1	19	8.9	172
Rural Living	95	0.1	9.5	8.9	84
Crops	361	0.2	72	8.9	642
Irrigated Pasture/Crops	2	0.8	1.5	8.9	14
		Total	**1,148**		**8,608**

6.7.2 Irrigation Volumes (Field Investigation)

Field investigations were carried out in November 1999 and January 2000. Areas of irrigation were first identified through infrared aerial photographs that were obtained from DEHAA and mapped out on 1:10,000 scale bore location maps. Some of these "irrigated" areas proved to be areas of vegetation, bracken or high groundwater tables. In general, however, the majority of irrigated areas identified during the field work component of this study were found through this mapping exercise. Visual inspection of irrigation equipment was another means of finding properties that were irrigated. Another very useful method of obtaining the names of irrigators was by asking known irrigators to identify other irrigators in the area. Although the dataset collected in this study may not be totally complete, it is felt that the majority of significant irrigators in the study catchments were identified and interviewed in this field investigation.

If a property was identified through one of the methods described above the owner of the property was sought out and an interview took place. Appendix 3 shows the bore survey form that was used during this interview. In addition, a irrigation log form was provided to the groundwater irrigators for them to record their actual water use over the 1999/2000 season. These forms will be collected at the end of the season and the data analysed to estimate the actual groundwater irrigation use.

The data provided on water use for irrigation purposes were rough estimates. Water use is dependent on many factors, such as temperature, rainfall, type of crop grown, and the volumes presented in this report should be used as a guide to the actual irrigation usage in the study catchments. If groundwater was being used to irrigate, a water sample was taken from one or more of the irrigation bores for a salinity analysis at the PIRSA Core Library. Results of this analysis were sent back to the irrigator when completed.

The response rate for this field survey was very good. In general, the irrigators were very generous with their time and provision of information about their operations. There were only two vineyards, a golf course and one orchard where no detailed information was collected on irrigation practices. Application rates were assumed for these operations. The results of the field survey can be seen in Appendix 13 and the salinity results in Appendix 14. Irrigators that used SA Water's mains water were not included in this survey as this water is not sourced from the study catchments.

6.7.2.1 Hindmarsh River Catchment

Currently, as in the past, the majority of irrigation in the Hindmarsh River Catchment occurs in the Hindmarsh Tiers Basin. In the past it was noted that some of the irrigation in the valley was wasteful with water running off pastures into Hindmarsh River changing the river from an ephemeral to a perennial stream (Furness et al, 1981). However, in speaking with irrigators in the area, changes in past practices have taken place and less water is wasted.

Appendix 13 and Table 55 shows the results from the field investigation in the Hindmarsh River Catchment. There were a total of 15 irrigators identified in the field investigation and of these 15, a total of 9 irrigators were identified in the Hindmarsh Tiers Basin. The remaining 6 irrigators were located in the lower Hindmarsh River Catchment and the lower southern boundary of the Hindmarsh Tiers Catchment. Estimations were made for the volume of water used on one of the vineyards and the golf course. Theoretical application rates were used for these properties and the area of the golf course was estimated based on the length of the golf area (7.5 km), assuming a width of 300 metres and estimating that 33% of this area is irrigated.

Table 55. Summary data on irrigation practices in the Hindmarsh River Catchment.

Number of Irrigators	Water Source	Type of Crop Irrigated	Total Number of hectares	Estimated Annual Volume (ML)	Overall Application Rate (ML/ha)
13	26 bores	Pasture (dairy and golf course)	548	4,784	8.7
2	2 dams and 1 bore	vines	22	70	3.2
		Total	**570**	**4,854**	

In total, the 1999 field survey identified that 5% of the Hindmarsh River Catchment is regularly irrigated. A total volume of 4,854 ML of water is used. In comparison to the irrigation volumes estimated in Section 6.7.1, this volume is about three times greater than the volume estimated for 1993 and about two times less than the theoretical volume. The field survey volume only takes into account significant irrigation use which could explain some of the difference between the theoretical and field survey irrigation volume results. It should be noted, however, that only the major irrigators have been included in this assessment. There are several horse operations in the catchment that may also irrigate but through a quick inspection in passing these area it did not appear that any appreciable irrigation took place on these properties.

The overall application rate was 8.7 ML/ha for pastures and 3.2 ML/ha for vines. The range of application rates for pasture irrigators was 1.7 to 14.7 ML/ha and for vines the range was 1.0 to 3.6 ML/ha (3.6 ML/ha was used as a theoretical rate as the actual rate was not provided by the irrigator). These application rates are fairly consistent with the theoretical rates calculated in Section 6.7.1.1 and double the application rates estimated for 1993.

The pastures were irrigated for dairy purposes and a golf course. Ten of the irrigation bores were also used for stock purposes and 7 of these bores were also used for domestic purposes. Most of the dairy operations visited processed the milk on the farms and for these operations bore water was used for washing down and the processing of the milk.

Table 56 shows that the field survey estimates that 0.2% of the catchment is used for growing vines. Both these vineyards are located in the lower portion of the catchment close to the Hindmarsh River. The field investigation indicates that 4.9% of the catchment is regularly irrigated for pasture purposes and these areas are associated with dairy operations and golf course. Most of the irrigation, except for two dairy farms and the golf course in the lower Hindmarsh catchment are located in the Hindmarsh Tiers Basin.

Table 56. Percentages of bore and surface water used to irrigate in the Hindmarsh River Catchment.

	Vines	Pasture	% of Total
% of catchment (ha)	0.2%	4.9%	5.1%
Type of Water Used to Irrigate			
Bore	33 ML	4,554 ML	99.2%
Surface	37 ML*	240+	0.8%

*speculated use - vineyard irrigator unwilling to respond to survey
+ volume of water that golf course is licenced to withdraw out of Hindmarsh River

A study done in 1973-4 estimated that the water used for irrigation in the Hindmarsh Tiers was 2 x 10^6 m^3/yr (2000 ML/yr) (Williams and Dennis, 1975). Since 1973-4, the groundwater extraction volume has risen to 4,096 ML/yr in the Hindmarsh Tier Basin. The results of this survey indicate this is over double the previous annual rate of extraction and could in part have contributed to the decline in the water levels as seen in the observation bores. The total amount of land that was estimated to be irrigated in 1976 was 1.75 km^2 (175 ha) (Furness et al, 1981). The number of hectares identified in the field survey that are currently being irrigated in the Hindmarsh Tiers was 448 ha. This represents an increase of 273 ha. The land use in this basin appears to have changed considerably over the past 25 years. There is a good groundwater supply in the Tertiary Limestone aquifer and this supply should be closely monitored to ensure that it remains sustainable level.

The predominant source of irrigation water in the Hindmarsh River catchment is groundwater (99% of the irrigated water used). There were two irrigators (vineyard and golf course) in the lower Hindmarsh River catchment that used a combination of a dam and bore water to irrigate. In order to separate the surface water from the groundwater it was assumed for the vineyard that half the water on this property came from the dam and half from the bore. For the golf course, the volume of water on the surface water licence was used to partition the groundwater and surface water components.

The results from the 11 irrigation bores that were sampled are shown in Appendix 14. Five of the irrigation bores sampled had been sampled since the bore was drilled. There were no sources of contamination identified and no problems with salinity. Some of the water quality problems identified were: hard water, iron oxides in water and some scaling - calcium buildup on stainless steel equipment.

Most of the field salinity sampling were comparable to samples taken during drilling of the well. However there were three bores with very different salinity results:

- Bore 6626 255 had a salinity of 3001 mg/L in 1989 and the recent results were 1429 mg/L and
- Bore 6627 8040 had a salinity of 1049 mg/L in 1987 and the recent results were 3270 mg/L.

The month when the samples for bore 6626 255 were taken may explain the different results. The first sample was taken at the end of summer in April and the second sample was taken at the end of winter in November. This bore is located in the lower part of the Hindmarsh River Catchment and there could be a salt build up over the summer months in the groundwater in this area. The lower salinity result at the end of winter implies that the groundwater supply Is "freshened" by the winter rainfall.

The months when the sample for bore 6627 8040 were March for the first sample and November for the second sample. This bore is also located in the lower part of the Hindmarsh River catchment adjacent to the Hindmarsh River. It is not possible to explain the difference in these as there are only two results for this bore and more results would be needed to establish a trend.

One of the irrigators in the lower Hindmarsh River Catchment (HR5) was experiencing salinity problems and had recently purchased a desalinizer to address this problem. It was decided that a sample would be taken before and after the desalinizer to measure the effectiveness of this device. It is interesting to note that the water sampled before the desalinizer had a lower salinity concentration (3270 mg/L) than the sample taken after the water had passed through the desalinizer (3373 mg/L).

In the Hindmarsh Tiers Basin there were several irrigation bores that have not been properly located. It is assumed that these bores are completed into the Tertiary Limestone formation. These bores should be properly located and the data on these bores should be updated in SA-GEODATA and the 1:10,000 scale bore location maps.

6.7.2.2 Inman River Catchment

There were very few properties in the Inman River Catchment that were irrigated. Along Back Valley Creek Road there were a few properties that were irrigating pastures. Discussions with property owners indicated that irrigation water was provided through either spring-fed dams and/or Back Valley Creek. Smaller pastures where minor irrigation took place were not included in the following analysis.

Appendix 13 and Table 57 shows the results from the field investigation in the Inman River Catchment. There were a total of 3 irrigators identified in the field investigation. Two of the irrigators have dairy operations - one in the upper northwestern edge of the catchment and the other on Back Valley Creek road. The other irrigator has an orchard in the central part of the catchment. The estimated annual volume for the Inman River Catchment is 156 ML for 35 ha.

It was not possible to obtain water irrigation estimates for the orchard in the Inman Valley Catchment as the ownership had recently changed and the new owner was not aware of the volume of water for irrigation. This orchard uses bore water and water from two dams to irrigate. The bore is artesian and no pumps are needed to apply the water to the orchard. For this property, an estimation has been made using the calculated application rates (see Section 6.7.1.2).

Table 57. Summary data on irrigation practices in the Inman River Catchment.

Number of Irrigators	Water Source	Type of Crop Irrigated	Total Number of hectares	Estimated Annual Volume (ML)	Overall Application Rate (ML/ha)
1	bore (also dams used)	Orchard	8.9	59.7	6.7
2	dams	Pasture	26.0	95.8	3.7
		Total	**35**	**156**	

*estimated volume and application rate - no data available from irrigator

Table 58 shows the percentages of types of water that was used to irrigate. In this estimation it was assumed that 33% of the water used to irrigate the orchard was sourced from the bore and the rest from the dams. Only a very small percentage of the total land area in the Inman River Catchment is regularly irrigated (0.2%). One of the reasons for this low use of irrigation in this catchment is most likely due to the poorer water quality from both surface and groundwater sources.

These results are very different from both the 1993 estimations and the theoretical areas and volumes. In 1993, it was estimated that 3% of the catchment was irrigated with 3252 ML/yr and that 10% of this irrigation was sourced from groundwater. These results are very high in comparison to the field survey results. The theoretical estimations were not even close to what was indicated in the field survey. According to the theoretical calculations 11,057 ML/yr is used for irrigation purpose. This volume is two orders or magnitude higher than the field survey results. It is acknowledged it is possible that not all the Inman Valley irrigators were contacted in this catchment and that there could be other minor irrigation occurring but the total volume used for irrigation is most likely to be less than 500 ML/yr.

In the Inman River an additional source of water use was discovered when inquiring about irrigation practices. One farm in the area has a yabby pond that is emptied once a year. The volume of this pond is 0.54 ML. This has not been included in the water use estimations.

Table 58. Percentages of bore and surface water used to irrigate in the Inman River Catchment.

	Orchard	**Pasture**	**% of Total**
% of catchment (ha)	0.05%	0.13%	0.18%
Type of Water Used to Irrigate			
Bore	20 ML		12.7%
Surface	40 ML	96 ML	87.3%

Only the artesian bore for the orchard was sampled. The salinity results from this recent sampling (2618 mg/L) were comparable with the previous sampling that was done in 1989 (2278 mg/L).

Broad acre vegetation clearance can result in a higher rate of groundwater recharge and rising water tables (Burston and Good, 1995). Most of the water used to irrigate land and for stock water purposes in the Inman River Catchment is sourced from dams or the Inman River. Irrigation does not appear to be widely practised in the catchment largely due to the saline nature of the groundwater and surface water during summer. Every summer the water of the Inman River becomes saline (Burston and Good, 1995) and all the watercourses that drain the Permian glacial sediments become brackish. A combination of the rising water tables and incision (bed-deepening) has resulted in saline groundwater draining directly into the river (Burston and Good, 1995). None of the irrigators interviewed indicated any problems with water quality or quantity.

6.7.2.3 Currency Creek Catchment

Land use in the Currency Creek Catchment is undergoing more changes than the other two catchments in this study. More vineyards are being established and olive trees are being planted (often on the same property and on land that was formerly used for grazing or pasture). The upper part of the Currency Creek Catchment has several large vineyards and there is also a large vineyard in the lower portion of the catchment on Flagstaff Hill Road. There was one vineyard on Mosquito Hill Road where no information was collected and estimations have been made for application rates.

Table 59 shows the summary results from the field investigation in the Currency Creek Catchment. There were a total of 12 irrigators surveyed in this catchment - 7 irrigators associated with vines and olive trees and 5 irrigators linked with pasture. The dairy operations in this catchment are in the upper and middle portions of the catchment. One of the vineyards uses a mixture of bore and dam water. It has been assumed for this irrigator that 20% of the irrigation water is sourced from groundwater and the rest from surface water (dam). The field survey indicates that there are 225 ha of land regularly irrigated in the Currency Creek Catchment using a total volume of 909 ML. The largest use of water for irrigation purposes is for vines followed by pasture and then by olives.

Table 59. Summary data on irrigation practices in the Currency Creek Catchment.

Number of Irrigators	Water Source	Type of Crop Irrigated	Total Number of hectares	Estimated Annual Volume (ML)	Overall Application Rate (ML/ha)
7	7 bores and 5 dams	vines	141	581	4.1
5	5 bores and 2 dams and 1 Currency Creek	pasture	58	303	5.2
2	3 bores and 1 dam	olives	26	25	1.0
		Total	**225**	**909**	

Table 60 shows the portions and sources of the water used to irrigate in this catchment. It is estimated that 2.4% of the catchment is regularly irrigated. This is in agreement with the estimated 1993 amount of 2.3%. However, since 1993 there have been several additional vineyards established in this catchment which have added to the volume of water used for irrigation purposes which would make the 1993 percentage high.

It appears that a slightly higher percentage of water is sourced from dams or Currency Creek in this catchment (55%) than from groundwater sources

(45%). Some of the irrigators interviewed said that their dams were spring fed. These dams provided good quality and quantity of water to the irrigators and were located in the upper end of the catchment. One irrigator (CC6) utilises 3 spring fed dams to irrigate his property and does not require pumps as the dam water has enough pressure to operate his sprinkler systems. On another property in this same area, one large vineyard operation has a very large dam which is spring fed. The level of this dam does not decrease significantly throughout the season. The manager of the vineyard told of the dam recently being emptied into the nearby creek and filling up within several days. This is a good source of water for this vineyard operation.

Table 60. Percentages of bore and surface water used to irrigate in the Currency Creek Catchment.

	Vines	Olives	Pasture	% Total
% catchment	1.5%	0.3%	0.6%	2.4%
	Type of Water Used to Irrigate			
Surface water	369 ML	0.0	133 ML	55.3%
Groundwater	212 ML	25 ML	170 ML	44.7%

Application rates varied from 0.3 to 10.4 ML/ha for vines in this catchment with an overall average application rate of 4.1 ML/ha. Application rates for pasture ranged from 0.7 to 9.2 ML/ha with an overall average of 5.2 ML/ha. The application rate for olives was 1.0 ML/ha. The overall application rate is comparable with the theoretical rate for vines but is much lower for pastures. A consideration for application rates is the age of the crop. For vines, the newly established vines require considerably more water than well established vines. Most of the vineyards surveyed had a mixture of new and older plants and their irrigation patterns varied greatly. The volumes presented in this report give a conservative estimate of the total volumes.

The sampling results for the irrigation bores sampled can be seen in Appendix 14. The results for bore unit number 6627 9975 are surprising. Since 1998, the salinity has decreased from 220 mg/L to 99 mg/L. This bore is completed into the Kanmantoo Group and the low salinity concentration is unusual for this formation. The other bore in close proximity also had a low salinity concentration 253 mg/L and another bore across the road had a salinity of 143 mg/L. These salinity concentrations are well below the concentrations of other bores completed into the same geological formation in this catchment and other catchments. Bores in this area also appear to have relatively high well yields. This is the same area where there is a large spring fed dam. This information implies that there is enhanced recharge to the groundwater from the high rainfall in this area.

This situation of decreased salinity concentrations in the groundwater is most likely the result of increased recharge to the system since native vegetation was cleared 100 years ago. Pre-clearing recharge to the system was low and the dissolved ion concentrations were in equilibrium between matrix and fractures in the basement rock (Love et al, 1999). Since clearing, recharge may have increased by an order of magnitude which has resulted in lower salinity groundwater which is currently flushing the fracture systems and has established a concentration gradient between matrix and fracture components (Love et al, 1999). Dissolved ions can now diffuse back from the matrix into the fractures. The higher salinity concentrations in bores completed into the Kanmantoo Group are most likely in a lower flow system where there is a greater contribution of salt from water/rock interactions due to the longer contact times.

Some irrigators interviewed indicated that their water source was a bit saline. The vineyard irrigator in the lower part of the catchment pumps groundwater from a recently drilled bore into a large dam on his property. This area is a new area of vines that was a pasture area in the past. One vineyard operator in the lower part of the catchment uses a "shandy" of dam water and groundwater as the groundwater water is too saline to apply directly to his vines. There have been 3 bores drilled on this property but only one is operational.

6.7.2.4 Summary of Irrigation Use

The results of the field survey provide an insight into the irrigation water use in the study catchments. Estimated irrigation volumes were considerably less than the theoretical estimations. This is most likely due to the fact that there are extensive land uses in these catchments, such as grazing, that do not require that much water being used on the entire landscape as is theorectically estimated. Caution should be taken when estimating irrigation volumes without groundtruthing.

Irrigation use in the Hindmarsh Valley Catchment appears to have increased over the years, as shown by the two-fold increase in the irrigation use in the Hindmarsh Tiers Basin. In the Inman Valley Catchment, there does not appear to be much irrigation which is mainly due to the quality of the groundwater and surface water in the area. In the Currency Creek Catchment, there is no historical irrigation data for comparison but it is assumed that there is increasing irrigation in this catchment due to the changing land uses and the development of vines and olive orchards.

The results of the field survey should not be considered to be precise, as the rates of use provided by the irrigators were approximations only. There are many variables that need to be taken into account when estimating irrigation volumes such as rainfall, temperature, type and age of crop and type of irrigation system. More accurate estimates of actual usage for dairy farms are presently being recorded by 20 dairy farmers in the Myponga, Mount Jagged, Goolwa and Parawa districts. This study will provide a measured, objective record of the participants irrigation practices and will be compared against best irrigation practices. The data, when compiled, should be used to validate the data collected in this study. This study was initiated by Dairy SA because the farmers have recognised opportunities to improve the profitability of their irrigated pasture production.

Over the last 5 years, on-farm monitoring has identified strong associations between pasture utilisation and farm gross margins (Mitchell, 1998) and between stocking rates and gross margins (Mitchell et al, 1999). However, similar monitoring work has not identified a relationship between the percentage of farm area irrigated and the farm gross margins in 1997/1998 (Mitchell et al, 1998). It appears that irrigation is not a key driver of profitability on Mount Lofty Ranges dairy farms. It is recognised that there are some highly profitable irrigated farms but irrigation efficiency is deficient on many farms and is not driving pasture production or utilisation (Mitchell, personal communication). The lesson here is that dairy farmers should irrigate in a controlled manner or not at all.

6.7.3 Domestic Use

Obtaining accurate estimations of number of households in each catchment is not a trivial exercise. This type of data is not collected and stored in spatial datasets and boundaries used to group this type of data do not coincide with catchment boundaries.

SA Water provides mains water to homes and commercial operations in Victor Harbour. All the sports ovals, reserves and park areas in Victor Harbour are irrigated with mains water. The Victor Harbour Golf Course irrigates with recycled effluent water and the Greenhill Adventure Park and other commercial operations in the Victor Harbour area irrigate with mains water.

Another source of domestic water in the study catchment is rainwater. During the field work component of this study, many rain tanks of varying size were seen at the home sites. Rainwater is a good quality water source, especially for areas where the groundwater and surface water is too saline for domestic use.

Estimates for number of households for each catchment were made using the Rapid Number system database which is used by the District Councils to record locations of primary dwellings on properties for fire fighting purposes. The District Council of Victor Harbour manages this database and provided the estimates of number of households for the study catchments as shown in Table 61. These numbers may be a good estimate of approximately 90% of the households in the study catchments. Estimated number of households in Table 61 does not include households supplied with SA Water mains water.

In Adelaide, water consumption is estimated to be 350 L/person/day (Van der Wel and McIntosh, 1998). For the purposes of calculating domestic water use in the study catchments, the Adelaide's water consumption rate has been used which is 0.38 ML/yr per household. It has been assumed that an average household is composed of three persons.

Table 61. Estimations of annual domestic water use for the study catchments.

Catchment	Estimated Number of Households	Estimated Annual Water Use (ML/yr)	Total Catchment Domestic Water Use (ML/yr)
Hindmarsh River	217	0.38	83
Inman River	268	0.38	103
Currency Creek	133	0.38	51

The source of this water is more difficult to determine. SA-GEODATA has indicated the following number of domestic bores for each catchment:

- Hindmarsh River - 11 bores;
- Inman River - 11 bores; and
- Currency Creek - 29 bores.

The number of households do not even come close to matching the number of domestic bores. One possible explanation is that bores reported only for irrigation use are also being used for domestic purposes. Discussion with a local resident indicated that in the Inman River Catchment very few of the landholders in this catchment use groundwater for domestic purposes (Burston, personal communication). Generally, the groundwater in this catchment is too salty for drinking water purposes. The landholders on the northern side of the catchment near Springmount would be using groundwater but they could possibly be using rainwater for drinking water purposes.

In the Hindmarsh River Catchment, there would be few landholders that would use groundwater for drinking water purposes. The landholders in the Hindmarsh Tiers area would be using groundwater as the quality of this source of groundwater is good. However, for the lower part of the catchment, most of the domestic water would be coming from the river, farm dams or rainwater tanks (Burston, personal communication).

In Currency Creek, the upper end of the catchment appears to have good quality groundwater and most likely there is a greater number of households that use groundwater for domestic purposes. However, the groundwater quality in the lower end of the catchment is more saline and this source would have limited use for domestic purposes.

The following estimates have been made for the annual volume of domestic water that is sourced from groundwater:

- Hindmarsh River - 42 ML (50%);
- Inman River - 5 ML (5%); and
- Currency Creek - 31 ML (60%).

These volumes are approximations only. If more accurate information becomes available these volumes should be updated.

6.7.4 Stock Use

Water is an essential component of an animal's diet and can impact production if an inadequate quantity and quality of water are used. There are many factors to take into account when determining the amount of water an animal consumes such as weather, distance to feed, type of feed, quality of water, activities and type of housing. Salinity is important, particularly in summer, when the animals need to drink more. Maximum tolerated concentrations of salinity range from 3500 mg/L (poultry) to 10,000 mg/L (sheep) - see Appendix 8 (Solomon and Ashton, 1997).

Tables 62 to 64 show the estimated number of stock and annual water consumption for each of the study catchments. Dairy cows and other cows were estimated through information provided by Steve Rice, Executive Officer of the Dairy Authority. In the Central Region which includes the Adelaide Hill and Fleurieu Peninsula, there are 291 dairy farms and a total of 37,471 milking cows (DASA, 1999). This works out to an average density of 129 dairy cows per farm. Maps prepared by the Department of Environment and Natural Resources Group based on licensed data were examined and dairy farms were identified and counted for each catchment. The number of dairy farms in each catchment were:

- 22 dairy farms in the Hindmarsh River Catchment;
- 29 dairy farms in the Inman River Catchment; and
- 21 dairy farms in the Currency Creek Catchment.

The estimated numbers for dairy cows in the tables below were generated by multiplying the average number of cows per farm by the number of farms in each catchment. The "other cow" category in the tables below refers to an estimated 40% of the dairy herd that are either calves, heifers and dry cows (Prance, T. personal communication). Recommended daily water intakes have been used and the same daily water use for beef cows has been used for "other cows" (Solomon and Ashton, 1997).

The largest annual water use for stock is in the Inman River Catchment (145 ML) followed by the Hindmarsh River Catchment (128 ML) and the Currency Creek Catchment (115 ML). These annual use volumes are to be considered only estimations and should be revised if more accurate information becomes available.

Attempting to partition this stock water into surface and groundwater sources is again a challenge. SA-GEODATA has recorded the following number of bores listed for stock water purposes:

- Hindmarsh River - 37 bores;
- Inman River - 47 bores; and
- Currency Creek - 33 bores.

Smaller farm dams are a potential source of stock water and should also be examined when attempting to partition the water source. The following number of farm dams have been estimated in each catchment that are less than 10 ML in total volume (McMurray, 1996):

- Hindmarsh River - 133 farm dams;
- Inman River - 196 farm dams; and
- Currency Creek - 144 farm dams.

In addition to stock use, dairy farms use water to process milk and for washing down purposes. As mentioned in the methodology section, it is estimated that 1000 kL/year of water per dairy is used for processing milk. For the purposes of this study it will be assumed each of the dairy farms identified process milk. The total amount for each study catchment is estimated to be:

- Hindmarsh River - 22 ML/yr;
- Inman River - 29 ML/yr; and
- Currency Creek - 21 ML/yr.

Another difficulty in partitioning the stock water source is to determine the number of animals on each property. The only information on this is the number of dairy farms in each catchment. Given the all of the above information, the following estimates have been made with respect to the total annual volume of groundwater used for stock purposes:

- Hindmarsh River - 105 ML (70%)
- Inman River - 35 ML (20%)
- Currency Creek - 81 ML (60%)

These volumes are approximations only and should be revised if more accurate information becomes available.

Table 62. Estimated number and type of stock and annual water use for the Hindmarsh River Catchment.

Animal	Approximate Number	Normal Water Intake (daily consumption in litres)*	Annual Water Use (ML)
Sheep	100	1.6 (average over year)	0.1
Beef cow	3,000	35 (average over year)	38.3
Dairy cow	2,833	70	72.4
Other cow	1,133	35 (average over year)	14.5
Horses	150	45	2.5
Processing	22 farms	1000 kL/year	22
		Total Water Use	**150**

- Solomon A and Ashton B, 1997

Table 63. Estimated number and type of stock and annual water use for the Inman River Catchment.

Animal	Approximate Number	Normal Water Intake (daily consumption in litres)*	Annual Water Use (ML)
Sheep	2,000	1.6 (average over year)	1.2
Beef cow	2,000	35 (average over year)	25.6
Dairy cow	3,735	70	95.4
Other cow	1,494	35 (average over year)	19.1
Horses	200	45	3.3
Processing	29 farms	1000 kL/yr	29
		Total Water Use	**174**

- Solomon A and Ashton B, 1997

Table 64. Estimated number and type of stock and annual water use for the Currency Creek Catchment.

Animal	Approximate Number	Normal Water Intake (daily consumption in litres)*	Annual Water Use (ML)
Sheep	2000	1.6 (average over year)	1.2
Beef cow	2000	35 (average over year)	25.6
Dairy cow	2705	70	69.1
Other cow	1082	35 (average over year)	13.8
Horses	300	45	4.9
Processing	21 farms	1000 kL/yr	21
		Total Water Use	**136**

- Solomon A and Ashton B, 1997

6.7.5 Summary of Water Use

The theoretical irrigation water use for each catchment estimated the total amount of water used for irrigation purposes. However, some of this water was sourced from SA Water mains water and should not be included in the water budget calculations as this water does not come from the study catchments and comes from Myponga. Tables 65 and 66 show revised theoretical irrigation volumes removing the estimated volumes sourced from SA Water. No revisions were made to the Currency Creek Catchment theoretical volumes as it is assumed that there are no SA Water services in this catchment after discussion with SA Water staff.

Table 65. Revised theoretical irrigation volumes for the Hindmarsh River Catchment.

Land Use	Number ha	Proportion Irrigated	Area Irrigated (ha)	Application Rate (ML/ha)	Water Use
Grazing	5,961	0.1	298	8.1	2,426
Dairy	2,453	0.3	736	8.1	5,990
Orchards	2	1.0	2	6.7	15
Rural living	114	0.1	11	8.1	93
Pastures	1,000	0.1	100	8.1	814
Horses	63	0.1	6	8.1	51
Recreation	90	0.8	72	8.1	586
Cultural	35	0.3	11	8.1	85
Education	17	0.4	7	8.1	55
Vine	9	1.0	9	3.6	33
Totals			**1,252**		**10,149**

Table 66. Revised theoretical irrigation volumes for the Inman River Catchment.

Land Use	Number ha	Proportion Irrigated	Area Irrigated (ha)	Application Rate (ML/ha)	Water Use
Pastures	206	0.1	21	8.2	169
Grazing	10,812	0.05	541	8.2	4,433
Dairy	5,139	0.1	514	8.2	4,214
Rural Living	496	0.1	50	8.2	407
Crops	0	0.2	0.006	8.2	0
Horses	74	0.1	7.4	8.2	61
Recreation	70	0.8	56	8.2	459
Orchard	13	1	13	6.7	87
Cultural	20	0.3	6	8.2	49
Education	3	0.4	1.2	8.2	10
Total			**1,208**		**9,888**

The following Tables 67-69 have summarised the water use estimations calculated in the preceding sections. There have been three estimates provided in each table for total water use:

- "Field" includes the field survey results and the estimated domestic and stock water use for each catchment;
- "Field and Theoretical" includes the field survey results, estimated domestic and stock water use, and theoretical water uses including recreation, education, cultural, rural living and horses; and
- "Theoretical" includes the theoretical estimations for irrigation use and the estimated domestic and stock water use (not including SA Water).

Also included in each table is the estimated amount of groundwater. The estimated volume for theoretical has been estimated using the following:

- Hindmarsh River - 85% groundwater, 15% surface water;
- Inman River - 5% groundwater, 95% surface water; and
- Currency Creek - 45% groundwater, 55% surface water.

The large difference between the theoretical and both the field and field and theoretical implies that caution should be taken if only using theoretical estimations to calculate irrigation volumes. The theoretical results are considerably higher (2 - 23 times) than what is most likely actually occurring in each of these catchments. The most notable difference is in the Inman River Catchment where the theoretical results are 8-23 times higher than the field and field and theoretical results. In the Currency Creek Catchment the theoretical estimation is 6-8 times higher than the field and field and theoretical results.

The largest water use was in the Hindmarsh River Catchment where the total water use ranged from 5,087 to 10,382 ML per year. This catchment also had the highest groundwater use with the volumes ranging from 5,464 to 8,784 ML per year. The next highest water use was seen in the Currency Creek Catchment with the total water use ranging from 1,095 to 8,795 ML per year and the groundwater use ranging from 634 to 3,986 ML per year. The smallest water use was apparent in the Inman River Catchment with total water use ranging from 432 to 10,164 ML per year and groundwater use from 109 to 534 ML per year.

The percentages of groundwater used in each catchment is:

- Hindmarsh River - 85-92%;
- Inman River - 5-9%; and
- Currency Creek - 45-47%.

Clearly the largest use of groundwater is in the Hindmarsh River Catchment followed by Currency Creek. Inman River Catchment only uses a small amount of groundwater. Caution should be taken in the accuracy of all these estimations. As mentioned throughout this document, if more accurate data is made available, these numbers should be revised.

Table 67. Water use estimations using field and theoretical data for the Hindmarsh River Catchment.

Water Use	Field (ML)	Field and Theoretical (ML)	Theoretical (ML)	Groundwater	
				Field and Theoretical (ML)	Theoretical (ML)
Irrigation	4,854	5,725	10,149	5,318	8,627
Domestic	83	83	83	42	42
Stock	150	150	150	105	105
Total	**5,087**	**5,958**	**10,382**	**5,464**	**8,774**

Table 68. Water use estimations using field and theoretical data for the Inman River Catchment.

Water Use	Field (ML)	Field and Theoretical (ML)	Theoretical (ML)	Groundwater	
				Field and Theoretical (ML)	Theoretical (ML)
Irrigation	156	986	9,888	69	494
Domestic	103	103	103	5	5
Stock	174	174	174	35	35
Total	**432**	**1,262**	**10,164**	**109**	**534**

Table 69. Water use estimations using field and theoretical data for the Currency Catchment.

Water Use	Field (ML)	Field and Theoretical (ML)	Theoretical (ML)	Groundwater	
				Field and Theoretical (ML)	Theoretical (ML)
Irrigation	909	1,165	8,608	522	3,874
Domestic	51	51	51	31	31
Stock	136	136	136	81	81
Total	**1,095**	**1,351**	**8,795**	**634**	**3,986**

7.0 Sustainable Yield

A composite definition of safe or sustainable yield can be expressed as (Fetter, 1988):

"*Safe yield is the amount of naturally occurring groundwater that can be withdrawn from an aquifer on a sustainable basis, economically and legal, without impairing the native groundwater quality and creating an undesirable effect such as environmental damage.*"

A single value for the safe yield of an aquifer or catchment cannot be estimated in the same sense as total annual rainfall and relates to the variability of the climate.

Although the role that groundwater plays in controlling ecosystems is very poorly understood, it fundamentally controls the health of major ecosystems across Australia (Hatton and Evans, 1998). In recent years in Australia there has been an increasing awareness of the requirement for maintaining environmental flows. Environmental flows have been advocated to reduce the impacts of water extraction on rivers and wetlands and to protect the ecological and other values in the downstream rivers, riparian zones and floodplains (Cullen, 1994).

Surface water systems are reliant on natural groundwater discharge and groundwater development may reduce streamflow. Excess groundwater discharges to streams is considered to be baseflow. If groundwater extraction increased to equal the recharge rate, there may be no excess water to contribute to the baseflow to streams which in turn would impact the environmental flow. However, this is also dependent on the variability of flow in the catchment. If excessive pumping occurs near a river, groundwater discharge to the river could be eliminated and infiltration from the river to the aquifer could be induced (Fetter, 1988).

In other studies (Barnett and Zulfic, 1999a, 1999b), it has been proposed that the sustainable yield should not exceed 75% of the estimated recharge. The volumes for 50% (minimum estimate) and 75% (maximum estimate) of a range of recharge values are shown in Table 70. The low values in this table represent the recharge estimates calculated through the groundwater balance method and the high represents the recharge values calculated by the water balance method. Total water use in this table relates to the estimated field plus theoretical water use volumes calculated earlier. There is most likely an error factor of ± 30% associated with these numbers. The theoretical volumes have not been included as they appear to be excessive.

Table 70. Estimates of sustainable yield for the study catchments.

			50% Recharge		75% Recharge	
	Total Water Use (ML)	Groundwater Water Use (ML)	Low (ML)	High (ML)	Low (ML)	High (ML)
Hindmarsh River	5,958	5,464	4,868	8,576	7,302	12,864
Inman River	1,262	109	4,557	12,291	6,835	18,436
Currency Creek	1,351	634	1,360	3,174	2,040	4,760

In the Hindmarsh River Catchment, the current level of groundwater use is most likely around 50% of the recharge for the catchment. There is intensive groundwater irrigation in the Hindmarsh Tiers Basin which has more than doubled in the last 25 years. Although the groundwater use in this catchment is below the adopted 75% of recharge, the groundwater usage should be carefully monitored on a regular basis to ensure that the reduction of water levels in the Tertiary Limestone aquifer are not being impacted further from groundwater extraction. The total water use for this catchment is slightly higher and could be up to 60% of the annual recharge.

In the Inman River Catchment, the groundwater use is very low and well below any level of concern with respect to groundwater sustainability. There is not a lot of irrigation currently occurring in this catchment due in part to the high salinity levels found in both the groundwater and surface water in the summer. There is more concern in this catchment with the surface water resource and care should be taken to ensure that dams and water diversions are constructed and managed in such a way to protect the rights of the downstream users and to ensure that there are adequate environmental flows to protect catchment ecosystems.

In the Currency Creek Catchment, the estimated groundwater use is below the estimated 50% of recharge but the total water use is approximately 50% of the annual recharge. The low groundwater use has been estimated from the results of the field survey where it was found that surface water and groundwater were used in almost equal portions for irrigation. In addition, like the Inman River Catchment, the quality of the groundwater in parts of Currency Creek deters its use for irrigation, stock and domestic use. The level of development in the Currency Creek Catchment is in more of a dynamic state than the other two catchments and future developments should be closely monitored with respect to their impacts on the existing water resources in this catchment to ensure their sustainability. The construction and management of farm dams should be done to protect catchment ecosystems and the rights of downstream users.

The rate of recharge in the study catchments is dependent on the amount of rainfall. During times of below average rainfall or dry conditions, as seen in recent years, there has been less water available for recharge. The data record for the Hindmarsh Tiers observation network has provided an insight into the steady water level decline since 1975 for the majority of observation bores. This decline is most likely the result of the increased rate of groundwater extraction in the area combined with lower rainfall reducing the rate of recharge. The above average rainfall in 1992/1993 did not appear to "fill" the aquifer and return the watertable to its normal level. It will possibly take several years of continuous above average rainfall to reverse this trend of declining watertable. As the rainfall continues to be below average, the groundwater levels should be carefully monitored. Although water level data is not available for the other catchments, it can be inferred that a similar situation is occurring with respect to declining watertable due to the similar pattern of below average rainfall and in the Currency Creek Catchment increased irrigation due to changes in land use. Monitoring of selected bores in these catchments should be initiated to understand the groundwater level trends in these catchments and to ensure that water is being used sustainably.

8.0 Recommended Observation Networks

Observation networks provide an insight into the water level trends within an aquifer or an area and provide resource managers with an indication of whether the groundwater resource is under stress.

At present, the only observation network in the study catchments is in the Hindmarsh Tiers Basin. Other observation networks should be established in the lower portion of Hindmarsh Valley and in the Inman River and Currency Creek Catchments. Monitoring the water levels on these bores should be done 2-3 times a year and the results regularly reviewed.

Some suggested bores are shown in Figure 66. Each of these bores should be site inspected and the owner's consent sought. Bores that are used for irrigation purposes should not be monitored during production. Accessible abandoned bores near irrigated properties with good bore records would be the best candidates for observation bores. Selecting bores completed into different geological formations would also be useful in establishing trends and gaining insight into the groundwater in these catchments.

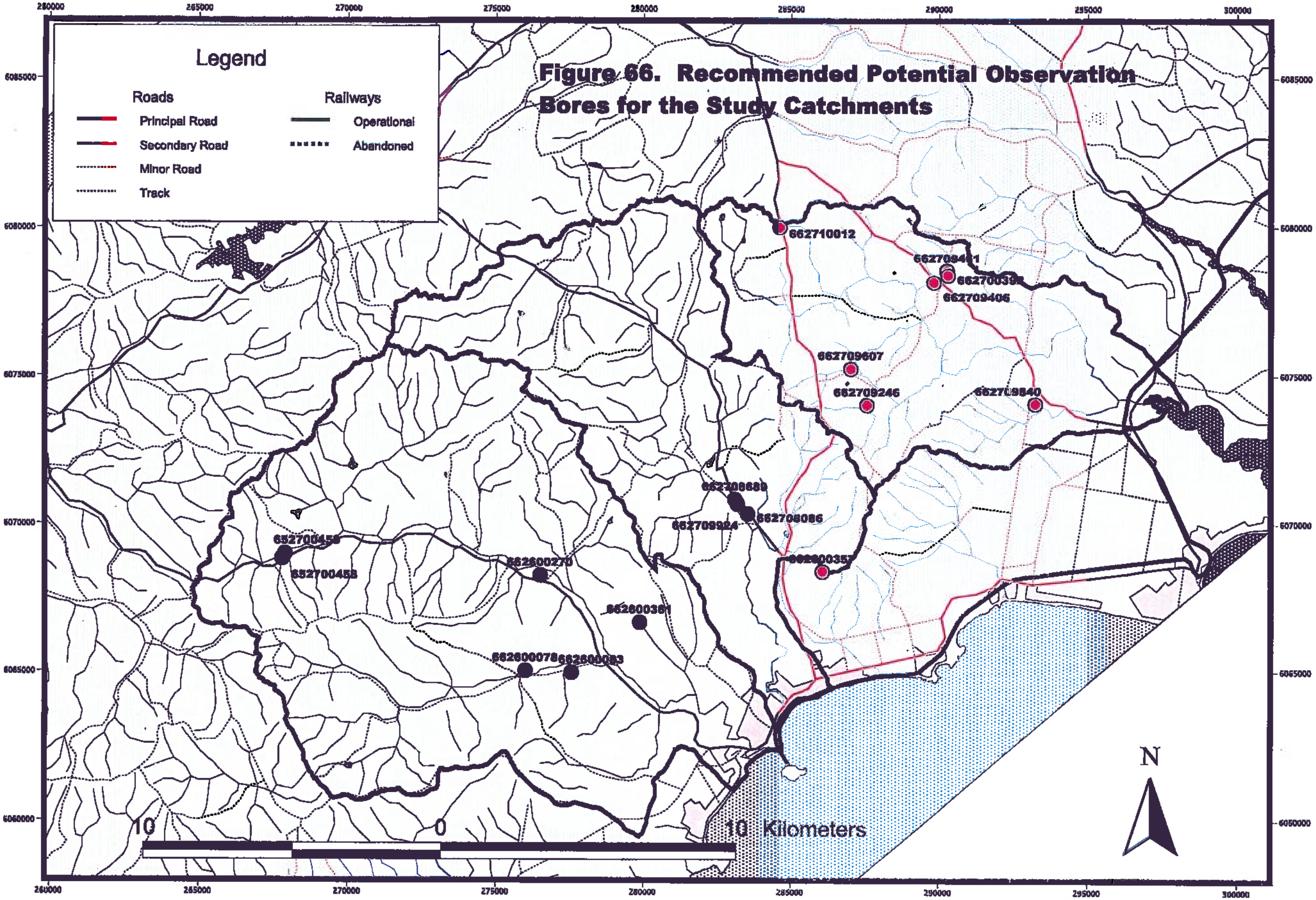


Figure 66. Recommended Potential Observation Bores for the Study Catchments

9.0 Conclusion

This study has analysed and used available and modelled data to indirectly determine the groundwater recharge in the Hindmarsh River, Inman River and Currency Creek Catchments. In addition, estimations on water use in these catchments has been determined through theoretical estimations and a field survey. The impact of the water use in these catchments on the sustainable yield has been estimated and reported. The assessments made in this report are the best estimate of the state of the resource based on available data and information. The following section on recommendations suggests some measures that could be taken to address these data gaps and therefore allow a more accurate estimation of both water use and water balances in the study catchments.

The data used in this study was variable with respect to quality and reliability. In addition, for some of the components of the water balance there was no existing information and estimations were made based on expert opinion, modelling and past studies. There were error ranges associated with each component of the water balance equations which should be taken into account when reviewing the results. The total error factor for all the components in the water balance equation is estimated to be ±40%. When more accurate estimates or data become available, components should be revised.

Water issues in the study catchment are complex and are a combination or the cumulative response to many issues including:

- land use;
- land clearances;
- over utilisation of existing land;
- riparian zone clearing;
- dams in creeks; and
- land management practices.

Evapotranspiration is the largest output component of the water balance. Annual evapotranspiration is generally greater for forested than for non-forested catchments and tree plantations will increase catchment evapotranspiration compared with pastures or crops. This has implications for catchment water balances in terms of multi-purpose land use management and rehabilitation strategies (Zhang et al, 1999).

There are some factors that limit the water resource development within the Hindmarsh River Catchment which include water quality (in the lower part of the catchment), groundwater extraction and decreasing water levels in the Hindmarsh Tiers, rising water tables in the lower part of the catchment, erosion of water courses through the lack of a sufficient riparian buffer and decline in native vegetation. All these issues have impacts on the water resources of the Hindmarsh River Catchment.

Factors that impact the water resource development in the Inman River Catchment are lack of a sufficient riparian zone buffer on the Inman River, surface and groundwater quality in the catchment and decline of native vegetation. Irrigation does not appear to be widely practised in the catchment largely due to the saline nature of the groundwater and surface water during summer.

Increasing number of vines in the Currency Creek Catchment is bound to impact both the surface water and groundwater resources in this catchment and will most likely continue due to fragmentation of larger properties with property owners wishing to use groundwater or surface water resources. Water quality appears to be variable across the catchment with low salinity concentrations in the top end of the catchment and higher concentrations in the lower end. There are a number of spring fed dams that provide irrigators in the upper portion of the catchment with abundant good quality water.

Management of water resources requires that current practices which contribute to identified problems be examined at and land owners encouraged and educated to make positive changes over both the short and long term for sustainability and their livelihood. There are a number of National Parks and Wildlife Service conservation areas within each of the study catchments. Preservation of these areas should continue as they provide a service to the catchments by ensuring that there are areas of native vegetation.

Recent changes in the *Water Resources Act* have placed the burden of water management on local governments and Catchment Boards. In areas that are not proclaimed waterways this burden is more pronounced as water management is an invasive issue and in some cases beyond the control and resources of local governments. This presents a challenge to all those involved and it is hoped that this report will in some way assist in the future management of the important water resources in the Hindmarsh River, Inman River and Currency Creek Catchments.

10.0 Recommendations

The following recommendations have been grouped into four categories: data gaps, policy, education and monitoring. These recommendations encompass all water resources of the study catchments as groundwater and surface water resources are strongly interrelated. It is recognised that some of these recommendations are not achievable in the short term, however, many could be integrated into long term planning and be developed as goals by both state and local governments.

Data Gaps

1. The water balance for each of the study catchments should be revised at regular intervals to take into account changes in land use and irrigation practices and estimated values for stock, number of households, number of dams and irrigation volumes. As well, the source of water use should be corrected as more accurate information becomes available.
2. Farm dam estimations should be amended to increase the spatial accuracy and volume estimations and a robust methodology developed. Aerial photographs should be taken in the late spring to ensure that water storage is at a maximum. Mapping should be repeated every five years to maintain a current coverage of this resource.
3. Future aerial photographs taken for GIS land use classification should be collected during the summer months in order to capture the appropriate data for irrigation use. This data should be collected to identify actual areas that are being irrigated and, if possible, the source of the irrigation water.
4. A survey of one or more catchments should be done to get an overview of the number of households, water uses, irrigation practices and stock water uses would be beneficial. These components of the water budget could be controlled through education and policy.
5. Provisions for water for environmental flows needs to be addressed and defined at a level sufficient to assist in the management of the water resources within each of these catchments.
6. Metering of groundwater is not a popular choice but for the larger irrigation bores that have been identified through this study, metering may be a option to get a more accurate idea of how much groundwater is being extracted.
7. The irrigation log forms handed out during the field survey should be collected and collated and compared with the estimated field survey volumes. Also, the results of the Dairy SA Irrigation Monitoring Program should be reviewed and used to validate or revise data collected in this study.
8. Irrigation bores in the Hindmarsh Tiers area should be properly located and mapped on 1:10,000 scale bore location maps and entered into SA-GEODATA.
9. The relationship between groundwater and surface water in the study catchments should be investigated, especially in areas with significant springs.

Policy

1. Consideration should be made to proclaiming the Inman and Hindmarsh River waterways under the *Water Resources Act.* This would facilitate the development of a water plan and allow for any remedial action to take place.
2. District Councils in the study catchments should consider policy development with respect to a mandatory requirement of rainwater tanks on any new homes or developments, a sustainable farm dam policy, guidelines on environmental flows and sustainable yields.
3. Land use mapping should be done consistently over time using standardised codes and methodologies to ensure that meaningful and accurate comparisons of land use changes can be made.
4. District Councils in the study catchment should consider the protection and/or rehabilitation of identified recharge areas in order to minimise rising water tables and stabilise areas susceptible to erosion.
5. Careful plans should be made to ensure land capability is not exceeded and water resources are utilised at sustainable rates. Water and soil conservation should be managed by matching land use with land capability.
6. Impacts of grazing in riparian areas can have a significant impact on surface water resources. There should be a riparian buffer zone determined and protected for all 1st to 3rd order streams to protect riparian ecosystems.
7. Areas of land that are covered in native vegetation should continue to be preserved.
8. Local governments should develop policies to ensure that dams and water diversions are constructed and managed in such a way to protect the rights of the downstream users and to ensure that there are adequate environmental flows to protect catchment ecosystems.

Education

1. There needs to be an increased perception by users of the water resources in each catchment of the issues in their areas. Ideally, it would be best if all major water users could sit down together and come to an agreement on how the water resource should be managed.
2. There is a need for education with respect to the use of crops that are tolerant to higher salinity concentrations in the groundwater found in the study catchments.
3. Standardised nomenclature for geological materials would enable a more consistent interpretation of geological formations. Courses could be offered to drillers to attempt to obtain a more standardised nomenclature.
4. Farmers and land owners should be encouraged to plant trees in riparian areas and on their properties, especially in areas where the water table is high, in order to reduce the level of the water table and at the same time reduce the salinity concentrations.
5. Irrigation efficiencies should be maximised by matching irrigation application rates with crop water requirements. Courses in effective

irrigation to refine irrigation practices should be made available to irrigators.

6. In the lower Hindmarsh River Catchment, irrigation practices should be reviewed and consideration made to storing surface water during peak flow periods in dams. This would have to be assessed carefully to ensure that the environmental flows would not be affected.

Monitoring

1. Regular water level monitoring should be resumed for the Hindmarsh Tiers observation network at a frequency of 2-3 times a year at a minimum at the end of winter and summer. The frequency should be reviewed every few years and the data should be regularly checked to monitor the water elevation trends in this area.
2. Groundwater salinities in each catchment should be periodically sampled to determine if any trends to increasing salinity are apparent.
3. Stream gauging stations in these catchments should be reviewed to increase representation within the catchments, especially for the Hindmarsh River Catchment. Gauging station flows should be adjusted wherever possible to remove the effects of farm dams. Re-establishment of a stream gauging station in the Currency Creek Catchment should be considered. A study to determine the natural flow records for these catchments would be beneficial.
4. There should be ongoing monitoring of these study catchments to determine recharge rates and pumping rates so that groundwater resources remain at a sustainable level.
5. Dairy farmers and other major irrigators in the study catchments should monitor evaporation rates on their farms to establish irrigation plans that objectively meet the water needs of their pastures.
6. A observation bore network should be established in Currency Creek and Inman River Catchments and the lower portion of the Hindmarsh River Catchment. Monitoring the water levels on these bores should be done 2-3 times a year and the results regularly reviewed at a minimum at the end of winter and summer.

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Appendix 1

Crop Factors

Bird-Guarded Crop Factors

Table 1. Bird-guarded crop factors, fg, for use with bird-guarded pan, Ep (Thomson, 2000)

Crop	Ref*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Almond NCC	FAO24	.512	.464	.465	.385	.336				.479	.560	.540	.512
Almond Drip	GS	.38	.21	.15	.24	.40	.50	.55	.65	.75	.65	.51	.47
Almond Spray	GS	.45	.25	.15	.24	.40	.50	.55	.65	.75	.75	.60	.55
Apple NCC	FAO24	.640	.551	.558	.467	.392				.435	.600	.684	.639
Carrot Apr					.440	.504	.550	.531	.616				
Cherry	FAO24	.640	.551	.558	.467	.392				.435	.600	.684	.639
Citrus	PB	.63	.62	.66	.72	.74	1.14	.92	.83	.90	.75	.72	.62
Lawn	CSIRO	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30	.30
Lucerne fodr	KDESTAT	.61	.55	.53	.41	.47	.47	.50	.68	.82	.88	.61	.61
Olive oil	DG	.416	.377	.403	.357	.364	.358	.383	.500	.566	.520	.468	.416
Olive table	DG	.480	.435	.465	.412	.420	.413	.442	.577	.653	.600	.540	.480
Onion	KDESTAT								.47	.78	.82	.71	.62
Pasture	H+W	.70	.62	.67	.50	.42	.44	.48	.78	.96	.81	.71	.67
Potato Dec	KDESTAT	.71	.84	.76	.53								.45
Sprouts Oct	FAO24	1.10									.90	1.00	1.10
Turf golf	H+W	.70	.62	.67	.50	.42	.44	.48	.78	.96	.81	.71	.67
WGrape full	IG	.500	.600	.400							.100	.250	.400
WGrape RDI	IG	.250	.300	.300	.200						.100	.250	.250

* references listed in Table 2.

Meaning of symbols used

NCC	No Cover Crop
Apr	April planting
full	full irrigation
RDI	Regulated Deficit Irrigation

Table 2. References used to determine the crop factors listed in Table 1.

No.	Reference	Ref
1	Burrows Pan and Rain data 1981	BUR
2	Holmes and Watson 1967	H+W
3	Holmes and Colville 1970	H+C
4	DuBois Monarto 1977-82	MONARTO
5	Solomon & Schrale Angas Bremer 1981	S+S
6	Kernich birdguard factors 1984	KERNICH
7	Desmier Tatiara 1988	DESTAT
8	Desmier Naracoorte Ranges 1989	DESNAR
9	Desmier Mallee 1991	DESMAL
10	Desmier Barossa 1991	DESBAROS
11	Desmier Padthaway 1992	DESPAD
12	FAO #24	FAO24
13	Jay Punthakey	JP
14	Max Till	MRT
15	Loxton ICMS	LOXT
16	Gerrit Schrale	GS
17	Michael McCarthy	MM
18	? Peter Buss	PB
19	Dave Goldhamer	DG
20	Ian Goodwin	IG
21	CSIRO	CSIRO

The full references used can be obtained from Tony Thomson, Conservation Irrigation Engineer, Sustainable Resources, Primary Industries and Resources of South Australia.

An estimate of the monthly crop water use (evapotranspiration, ETc) is calculated by multiplying the crop factor (f) by the pan evaporation (Ep) as calculated in table 3:

Table 3: Monthly crop water use, ETc = f * Ep

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
ETc Mm	193	153	125	63	35	28	29	55	94	117	146	173	1211

If it is assumed that the rate of rainfall does not exceed the soil infiltration rate then surface runoff can be ignored. For simplicity it is assumed that 15% rainfall interception losses caused by plant foliage and 85% of the rainfall is effective rainfall, which becomes useful water in the soil profile. In the Riverland 65% of the rainfall is effective.

Hence the monthly amount by which evapotranspiration exceeds the useful rainfall can be calculated from table 3 and table 1 using the formula I = ETc – (0.85 * R). The daily amount is calculated by dividing I by the number of days in each month.

Table 4: Monthly amount by which evapotranspiration exceeds effective rainfall

I = ETc – (0.85 * R)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
days/ mth	31	28	31	30	31	30	31	31	30	31	30	31	365
I mm	169	130	99	11	- 41	- 57	- 59	- 31	21	58	112	145	**+745** **-188**

Note that the negative values occur in the months where the effective rainfall exceeds the crop water requirements.

The annual amount by which winter rainfall exceeds winter evapotranspiration is:

188 mm

This excess rainfall can replace the last irrigation before winter.

The amount of this rainfall which can be used depends upon the moisture storing capacity of the soil. Assuming that your soil stores 60mm of Readily Available Water (RAW) per metre of soil depth, then the readily available water stored in 0.2m root depth of soil is

0.2 x 60 = 12 mm of water

We plan to have this amount of soil water deficit before the winter rains.

Hence the crop water needs which can be supplied by the excess Winter Rainfall, WR (millimeters) are:

Table 5: Crop water needs that can be supplied by winter rainfall

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
WR mm			1	11									12

The remaining winter rainfall

188 mm	minus 12 mm	=	176 mm

is lost as deep drainage (leaching) below the root zone.

The monthly irrigaton requirement, IRR(mm) in Table 6 is calculated by subtracting the crop water needs that can be supplied by winter rainfall, WR(mm) in Table 5 from the monthly amount by which crop water requirement exceeds the effective rainfall, I(mm) in Table 4.

Table 6: Monthly irrigation requirement
IRR (mm) = I (mm) – WR (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
IRR mm	169	130	98						21	58	112	145	733

The quantity of water applied **at each irrigation** and the dates of applications depend respectively upon the moisture holding capacity of the soil and the actual weather.

As no irrigation system distributes the water with 100% Distribution Uniformity, DU, to ensure that the least-well-watered area receives sufficient water, extra water must be supplied to the total area. The amount of additional water is included by dividing by DU.

As most irrigation water contains soluble salts additional irrigation water will be required to leach the accumulating salts below the root zone.

Hence the actual irrigation requirement becomes:

$$\text{IRR (actual) (mm)} = \frac{\text{IRR (mm)}}{(\text{DU} / 100)} * \frac{(100 + \text{leaching \%})}{(100)}$$

where:

$$\text{DU \%} = 100 * \frac{\text{avge depth in low quarter of cans (mm)}}{\text{avge depth in all cans (mm)}}$$

leaching % = % extra water needed to leach accumulated salts below the root zone.

As the water salinity increases the leaching fraction increases.

In this case:

$$IRR\ (actual) = \frac{IRR(mm) * (1.08)}{(0.75)}$$

Table 7: Irrigation requirement by month

For	PASTURE (HOLMES & WATSON)
at	MT. BARKER (SA)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
IRR act mm	243	187	141						30	84	161	209	1055

Assumptions:

Soil Readily Available Water (RAW) root depth	=	60	mm water per metre
Root depth of soil	=	0.2	metre
Distribution Uniformity (DU)	=	75	%
Salinity of irrigation water (ECiw) metre	=	1.6	deci-Siemen per
Leaching %	=	8	%

Appendix 2

Irrigation Needs

An estimate of the monthly crop water use (evapotranspiration, ETc) is calculated by multiplying the crop factor (f) by the pan evaporation (Ep) as calculated in table 3:

Table 3: Monthly crop water use, ETc = f * Ep

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
ETc Mm	193	153	125	63	35	28	29	55	94	117	146	173	1211

If it is assumed that the rate of rainfall does not exceed the soil infiltration rate then surface runoff can be ignored. For simplicity it is assumed that 15% rainfall interception losses caused by plant foliage and 85% of the rainfall is effective rainfall, which becomes useful water in the soil profile. In the Riverland 65% of the rainfall is effective.

Hence the monthly amount by which evapotranspiration exceeds the useful rainfall can be calculated from table 3 and table 1 using the formula I = ETc – (0.85 * R). The daily amount is calculated by dividing I by the number of days in each month.

Table 4: Monthly amount by which evapotranspiration exceeds effective rainfall

I = ETc – (0.85 * R)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
days/ mth	31	28	31	30	31	30	31	31	30	31	30	31	365
I mm	169	130	99	11	- 41	- 57	- 59	- 31	21	58	112	145	**+745 -188**

Note that the negative values occur in the months where the effective rainfall exceeds the crop water requirements.

The annual amount by which winter rainfall exceeds winter evapotranspiration is:

188 mm

This excess rainfall can replace the last irrigation before winter.

The amount of this rainfall which can be used depends upon the moisture storing capacity of the soil. Assuming that your soil stores 60mm of Readily Available Water (RAW) per metre of soil depth, then the readily available water stored in 0.2m root depth of soil is

0.2 x 60 = 12 mm of water

We plan to have this amount of soil water deficit before the winter rains.

Hence the crop water needs which can be supplied by the excess Winter Rainfall, WR (millimeters) are:

Table 5: Crop water needs that can be supplied by winter rainfall

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
WR mm			1	11									12

The remaining winter rainfall

188 mm	minus 12 mm	= 176 mm

is lost as deep drainage (leaching) below the root zone.

The monthly irrigaton requirement, IRR(mm) in Table 6 is calculated by subtracting the crop water needs that can be supplied by winter rainfall, WR(mm) in Table 5 from the monthly amount by which crop water requirement exceeds the effective rainfall, I(mm) in Table 4.

Table 6: Monthly irrigation requirement
IRR (mm) = I (mm) – WR (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
IRR mm	169	130	98						21	58	112	145	733

The quantity of water applied **at each irrigation** and the dates of applications depend respectively upon the moisture holding capacity of the soil and the actual weather.

As no irrigation system distributes the water with 100% Distribution Uniformity, DU, to ensure that the least-well-watered area receives sufficient water, extra water must be supplied to the total area. The amount of additional water is included by dividing by DU.

As most irrigation water contains soluble salts additional irrigation water will be required to leach the accumulating salts below the root zone.

Hence the actual irrigation requirement becomes:

$$\text{IRR (actual) (mm)} = \frac{\text{IRR (mm)}}{\text{(DU / 100)}} * \frac{\text{(100 + leaching \%)}}{\text{(100)}}$$

where:

$$\text{DU \%} = 100 * \frac{\text{avge depth in low quarter of cans (mm)}}{\text{avge depth in all cans (mm)}}$$

leaching % = % extra water needed to leach accumulated salts below the root zone.

As the water salinity increases the leaching fraction increases.

In this case:

$$\text{IRR (actual)} = \frac{\text{IRR(mm)} * (1.08)}{(0.75)}$$

Table 7: Irrigation requirement by month

For	PASTURE (HOLMES & WATSON)
at	MT. BARKER (SA)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
IRR act mm	243	187	141						30	84	161	209	1055

Assumptions:

Soil Readily Available Water (RAW) root depth	=	60	mm water per metre
Root depth of soil	=	0.2	metre
Distribution Uniformity (DU)	=	75	%
Salinity of irrigation water (ECiw)	=	1.6	deci-Siemen per metre
Leaching %	=	8	%

Appendix 3

Bore Survey Form

Bore Survey Form

IF THERE IS MORE THAN ONE IRRIGATION BORE ON YOUR PROPERTY, PLEASE FILL IN A SURVEY FORM FOR EACH IRRIGATION BORE.

1. General Information

Owner____
Owner's address____________________________________
Owner's phone number________________________________
Bore Identification # (Permit number-if known)________________________

Catchment Hindmarsh Inman River Currency Creek
Bore ground elevation (office use only): ________________________
Bore location (Hundred and Parcel No.): ________________________

2. Bore Use Information

Bore used for:
Irrigation Domestic Stock Other No bore used
(If irrigation bore go to 3. below)

Reasons for not using bore:________________________________

3. Irrigation bore use (annual)

Type of crop irrigated	# ha	No. of years crop grown	Approximate Bore Water Use (# days/hours)

Different crops grown in the past and number of years grown:______________________

Records kept on bore water use: Yes No
If Yes, would they be available to us: Yes No
Comments: ____

4. Pump Information

Pump extraction rate:____________________________________

5. Bore Problems

Water quantity problems ________________________________
If yes, when and how long was the bore dry? ________________________

Salinity problems?____

Other problems i.e. iron bacteria? ____

____

6. Bore Monitoring

Any sampling been done since bore was drilled? Yes No
If Yes, would the results be available to us? Yes No
Standing water depth (office use only)__________________________________
Water sample number (office use only)__________________________________

7. Potential sources of contamination

Septic tank near bore Yes No
Location of septic tank in relation to bore_________________________________

Pesticide use Yes No
Location of pesticide storage______________________________________

Proper surface seal Yes No
If no what is there____

8. Sketch of Bore and Surroundings

Date completed:____

Comments____

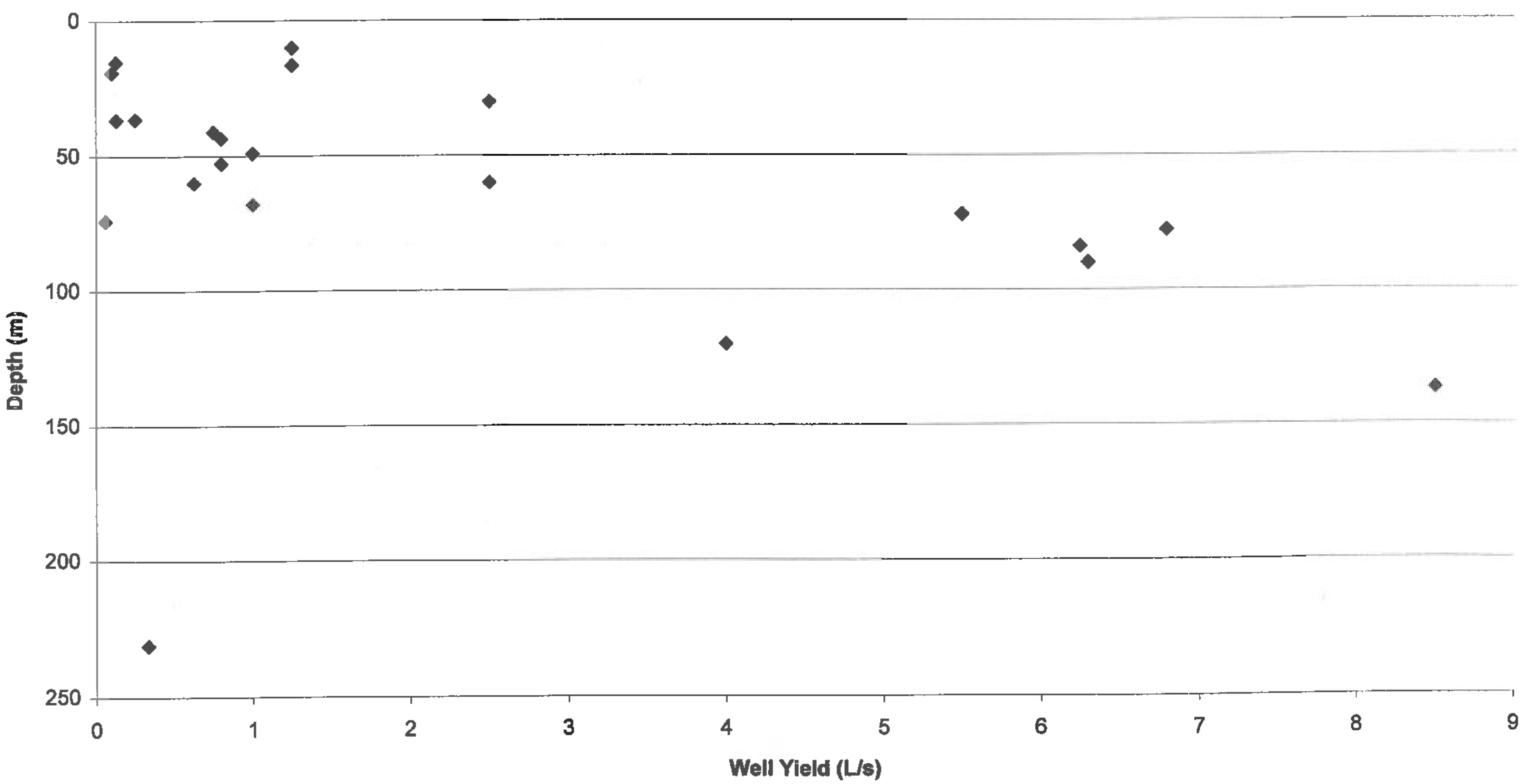
____

If you have any questions, please contact Vicki Carmichael at 8463 3158.
Thank you for your cooperation and assistance.

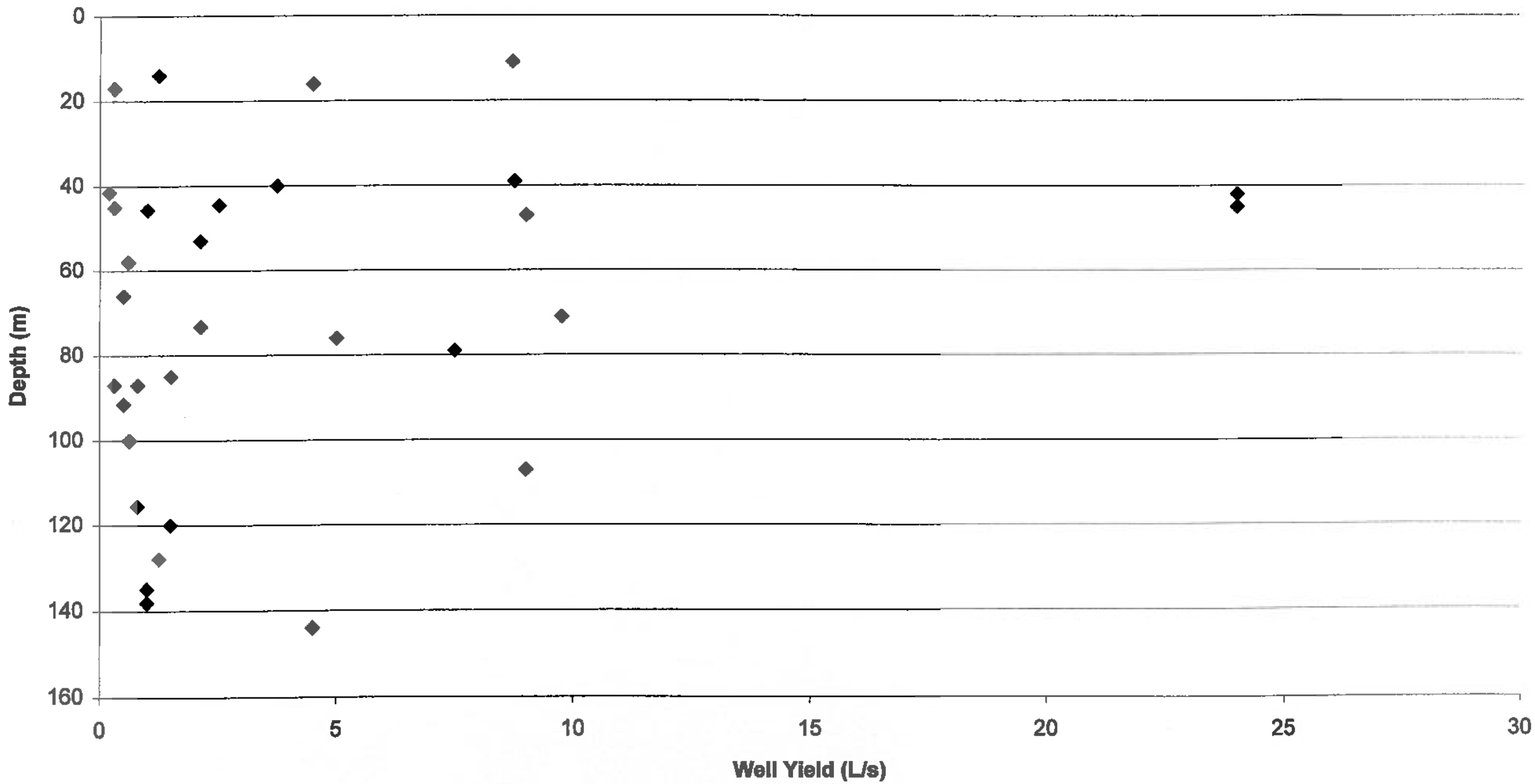
Appendix 4

Well Yields by Depth and Geological Formations

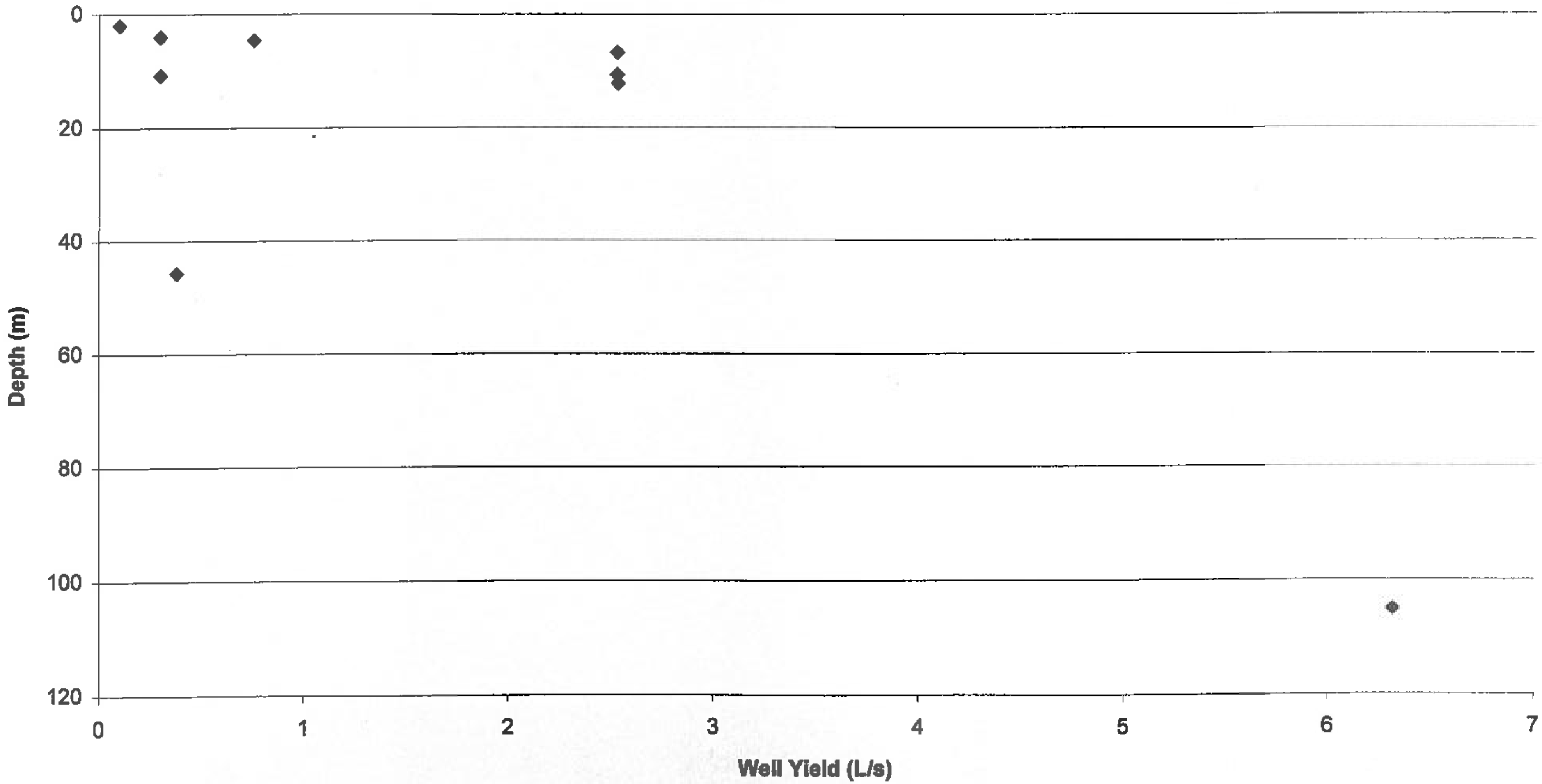
Hindmarsh River Catchment
Well Yield vs Depth (Cape Jervis Beds)



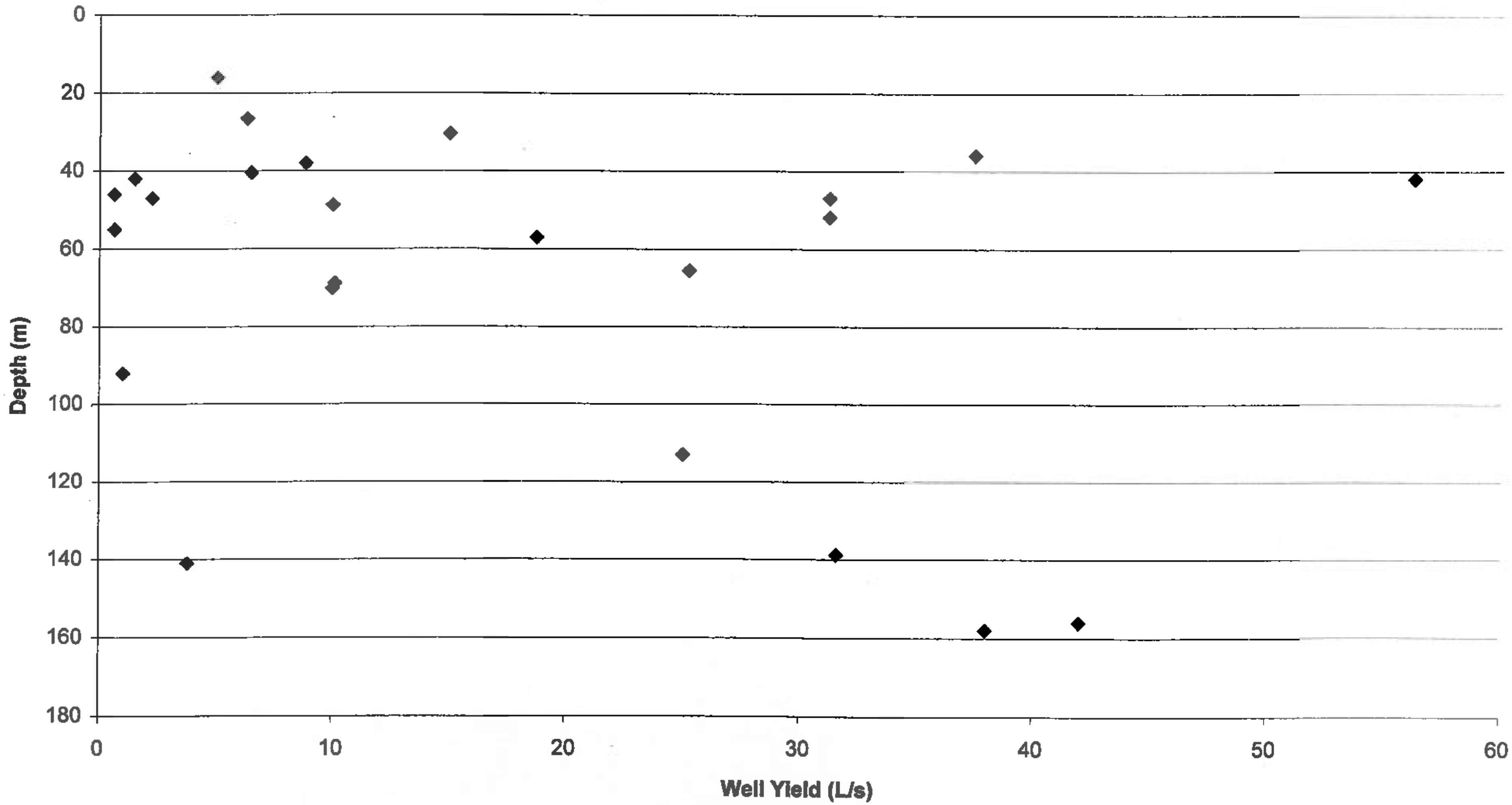
Hindmarsh River Catchment
Well Yield vs Depth (Kanmantoo Group)

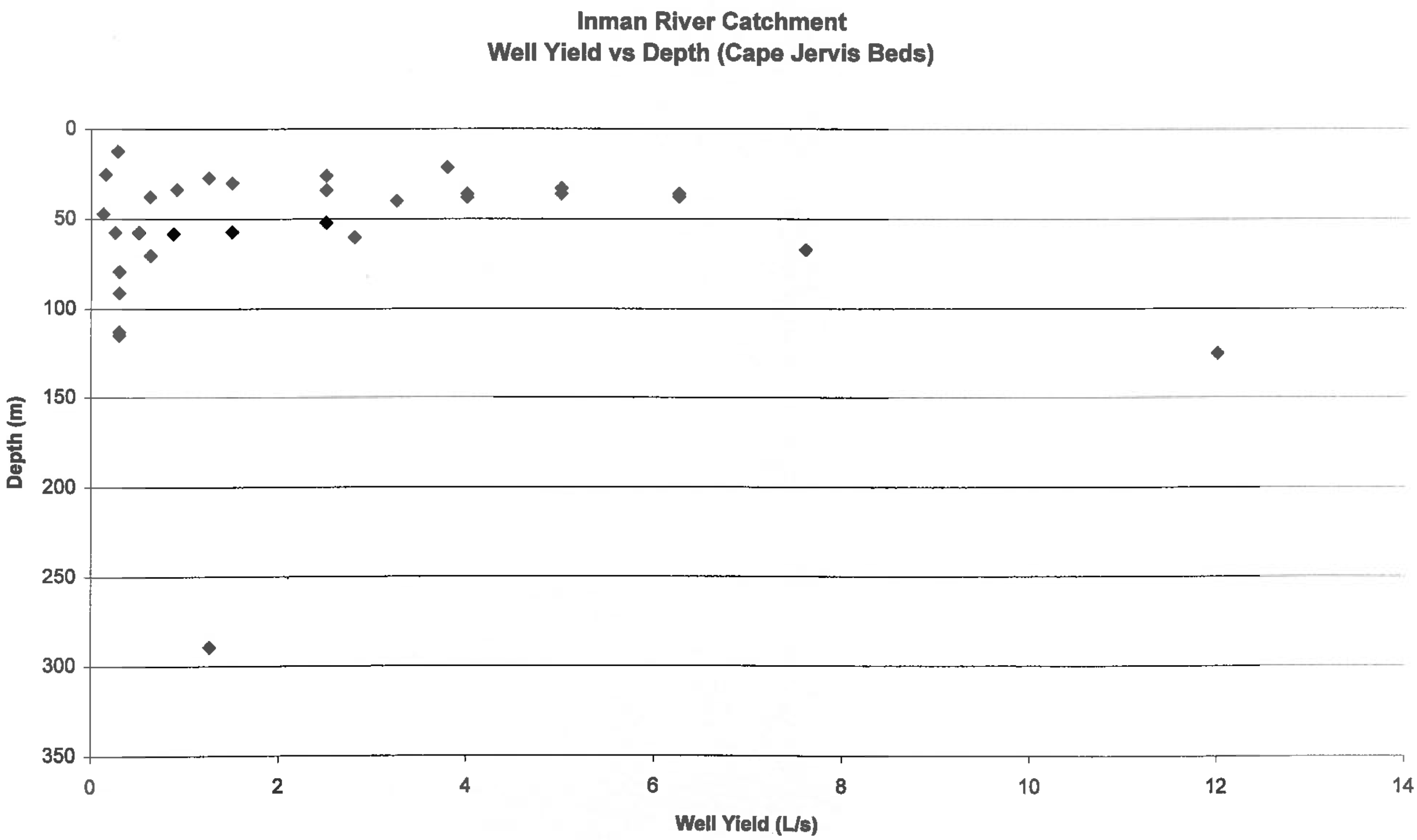


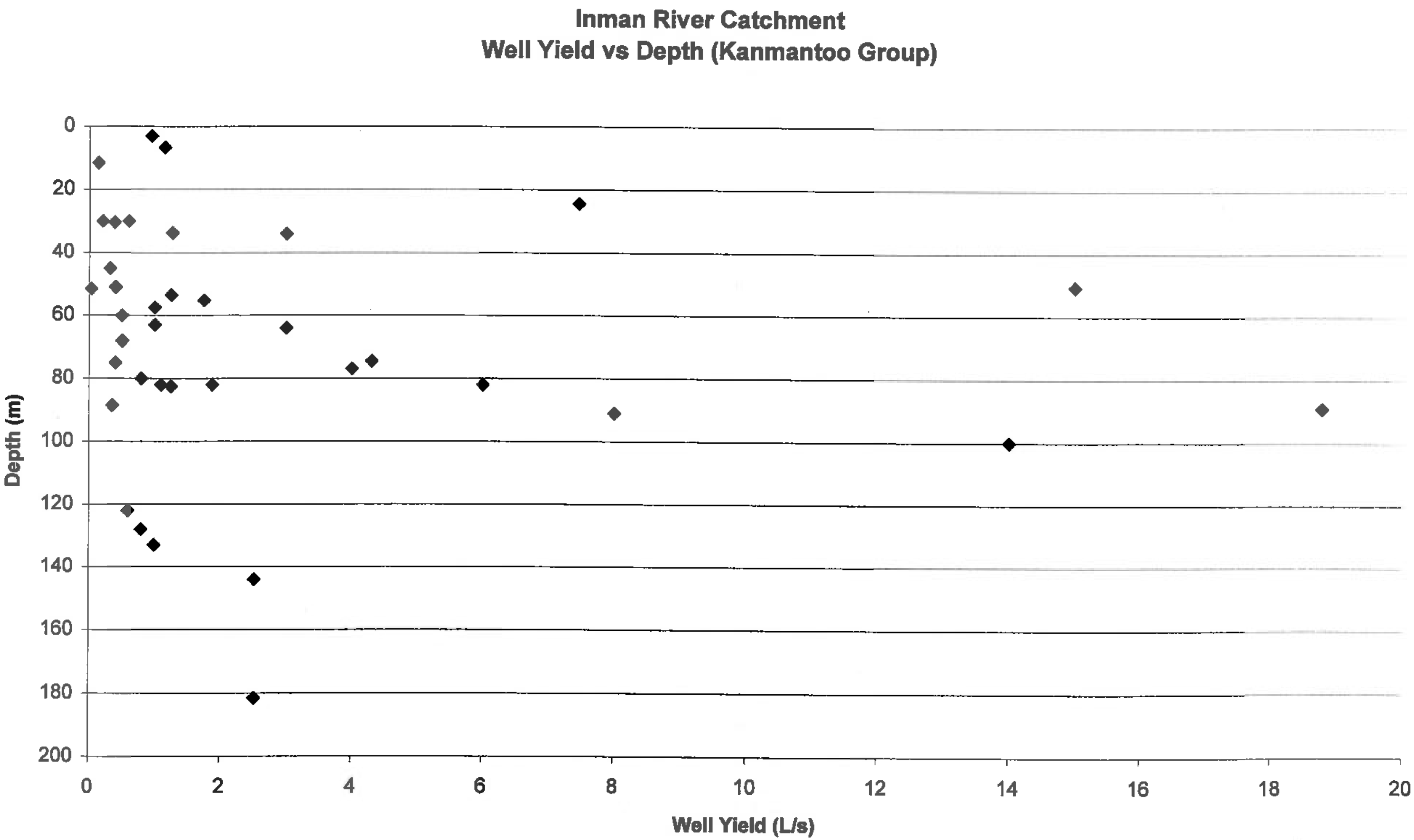
Hindmarsh River Catchment
Well Yield vs Depth (Quaternary Alluvium)



Hindmarsh River Well Yield vs Depth (Tertiary Limestone)

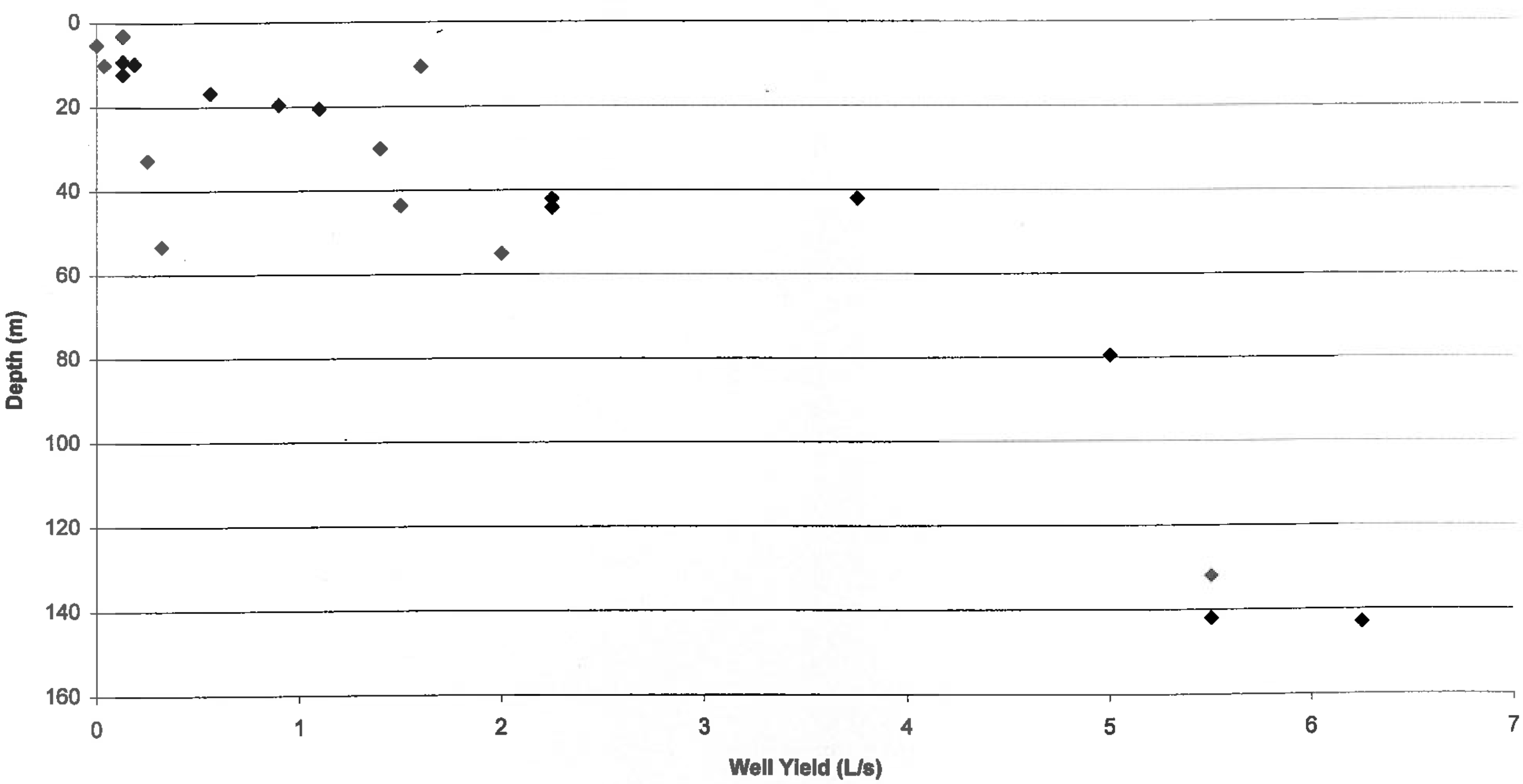



Inman River Catchment
Well Yield vs Depth (Cape Jervis Beds)
Depth (m)
0
50
100
150
200
250
300
350
0
2
4
6
8
10
12
14
Well Yield (L/s)

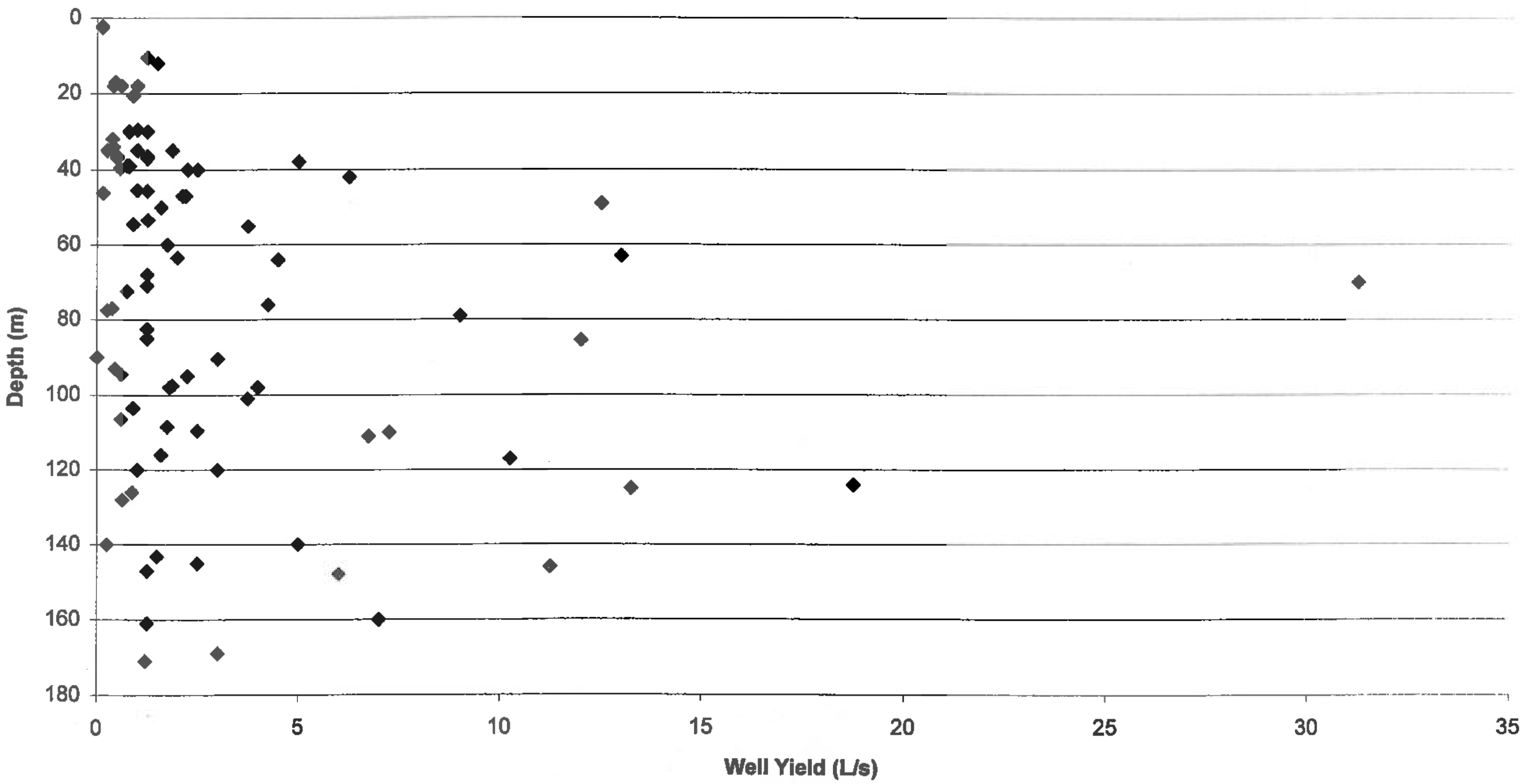


Inman River Catchment
Well Yield vs Depth (Kanmantoo Group)
Depth (m)
0
20
40
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
14
16
18
20
Well Yield (L/s)

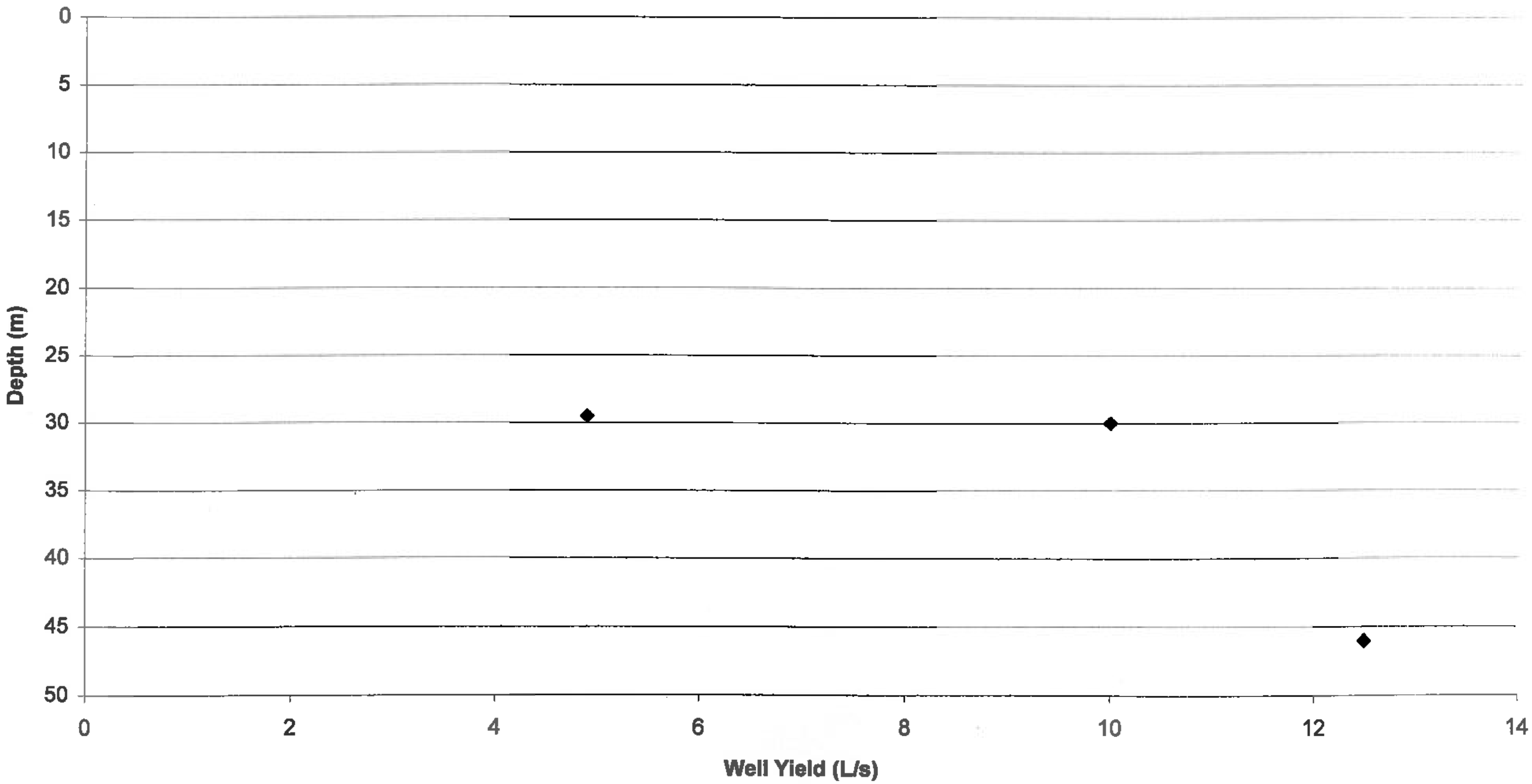
Currency Creek Catchment
Well Yield vs Depth (Cape Jervis Beds)



Currency Creek Catchment
Well Yield vs Depth (Kanmantoo Group)

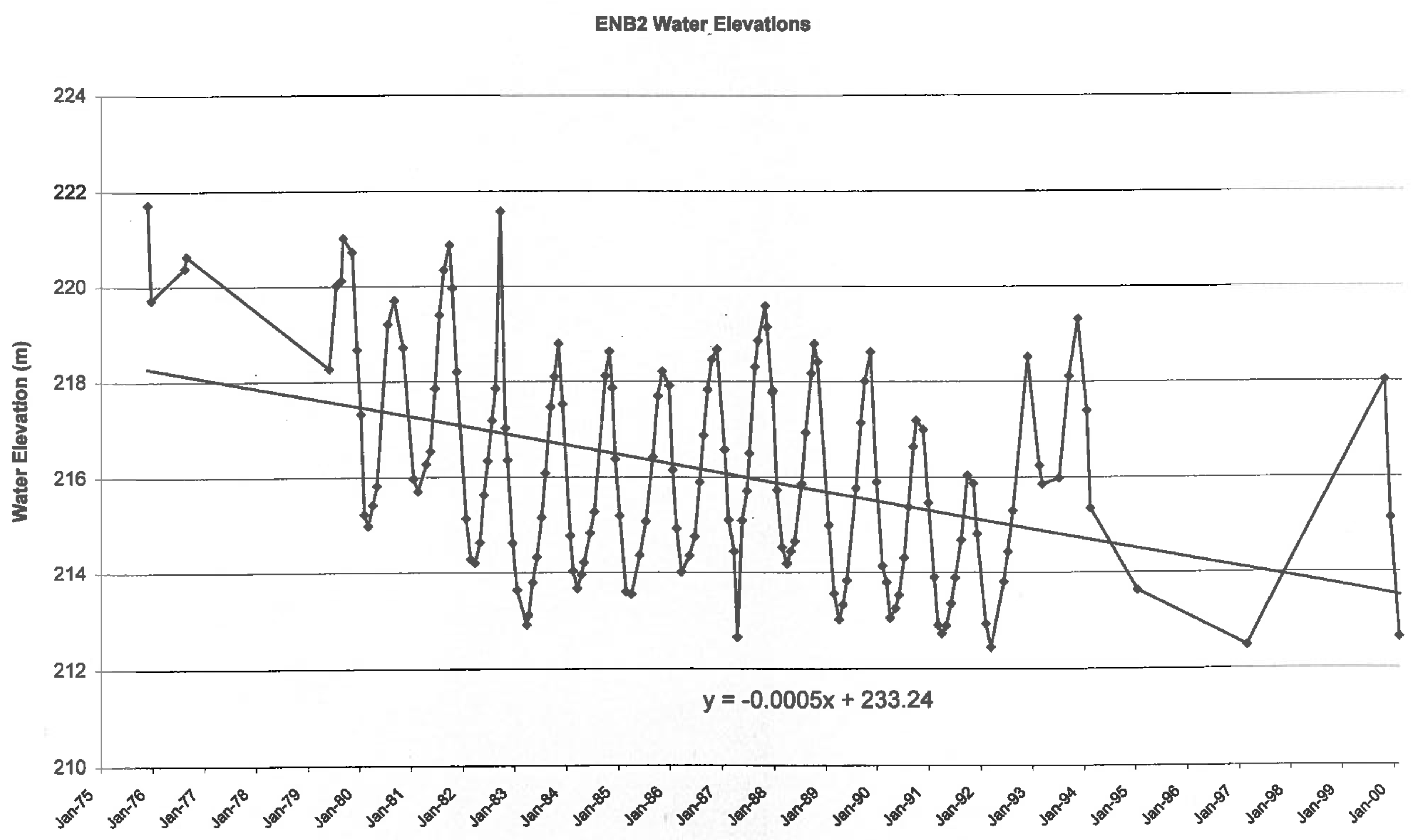


Currency Creek Catchment
Well Yield vs Depth (Tertiary Limestone)

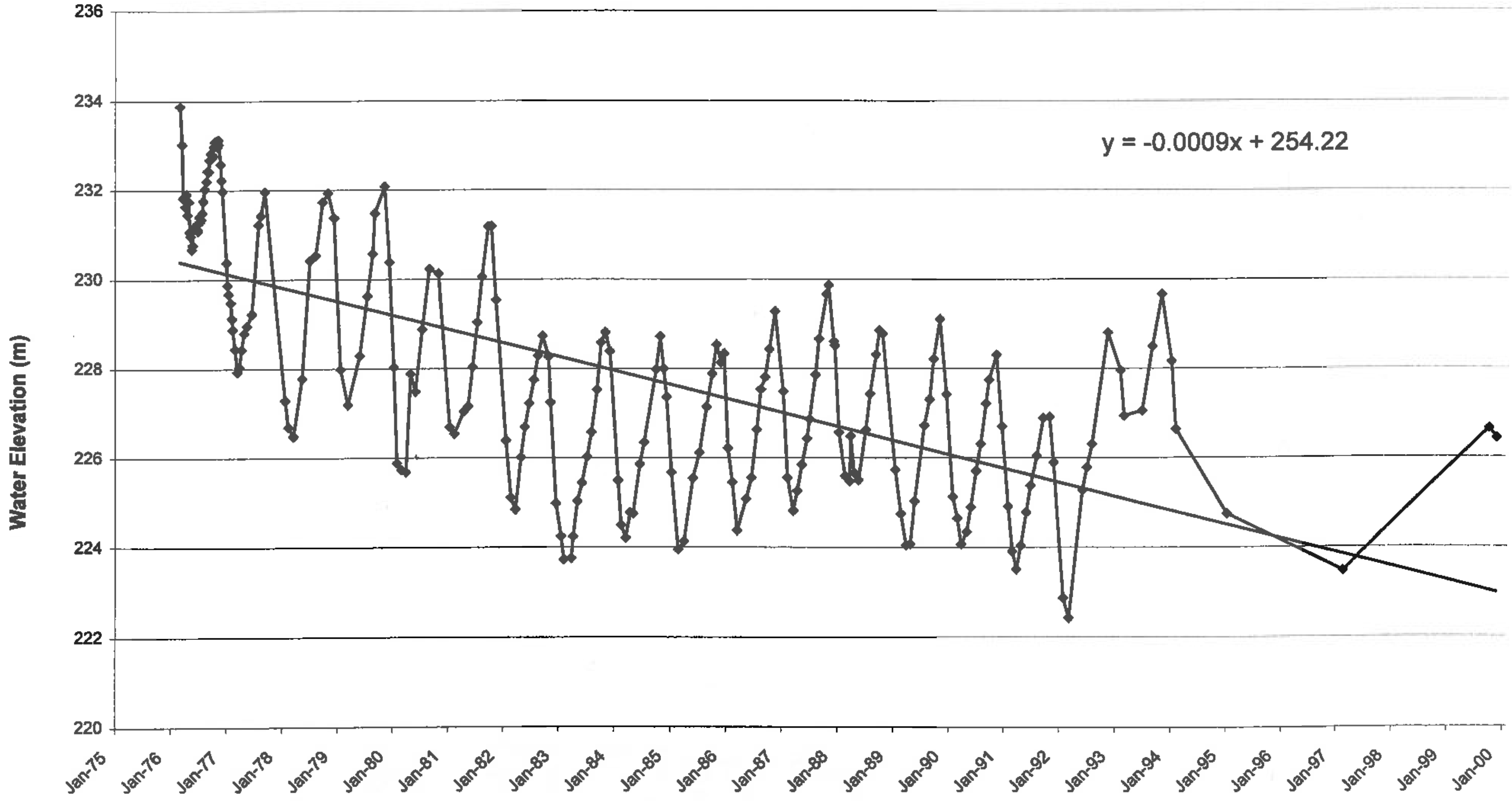


Appendix 5

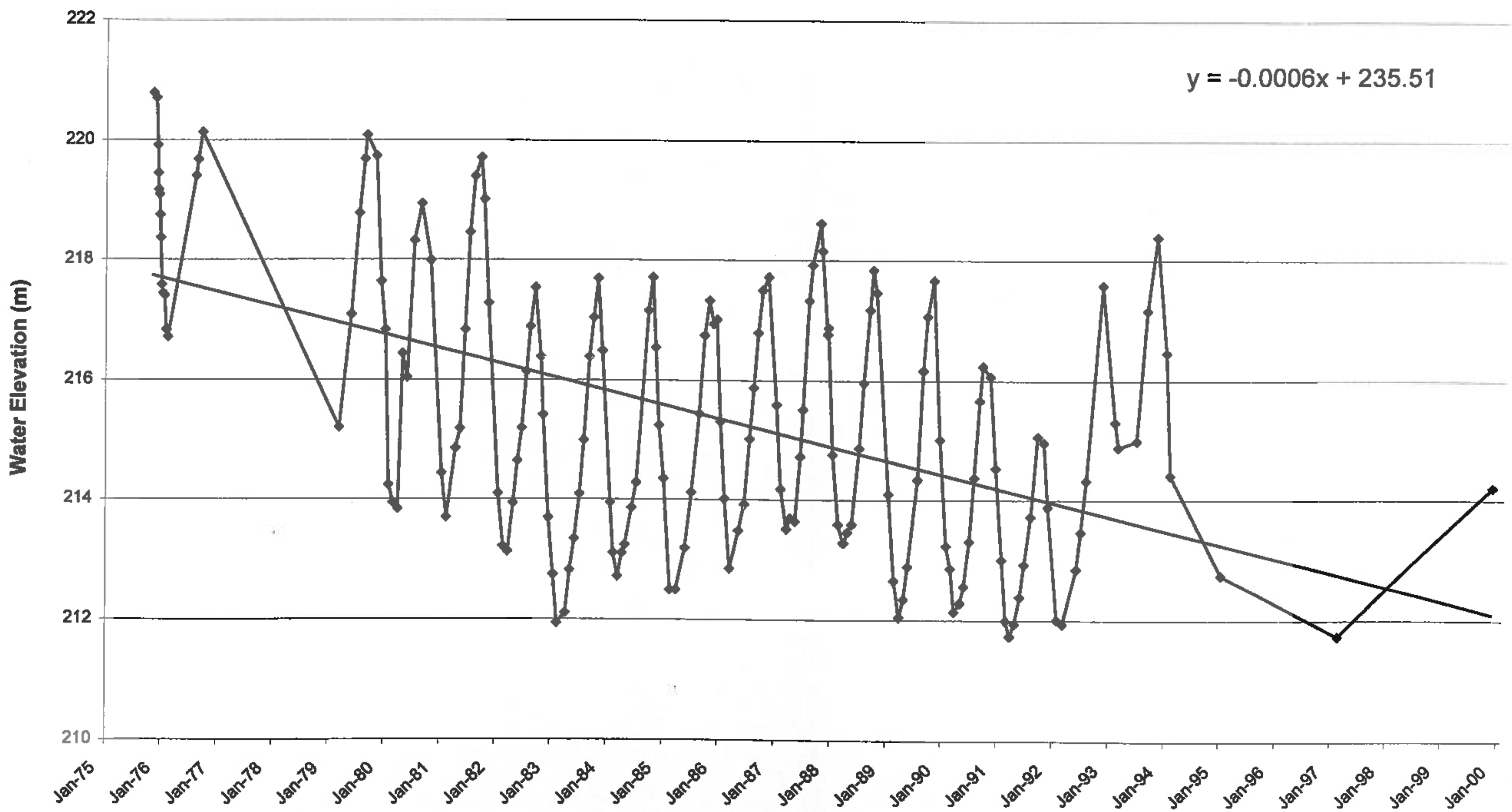
Water Level Elevations For Hindmarsh Tiers Observation Network

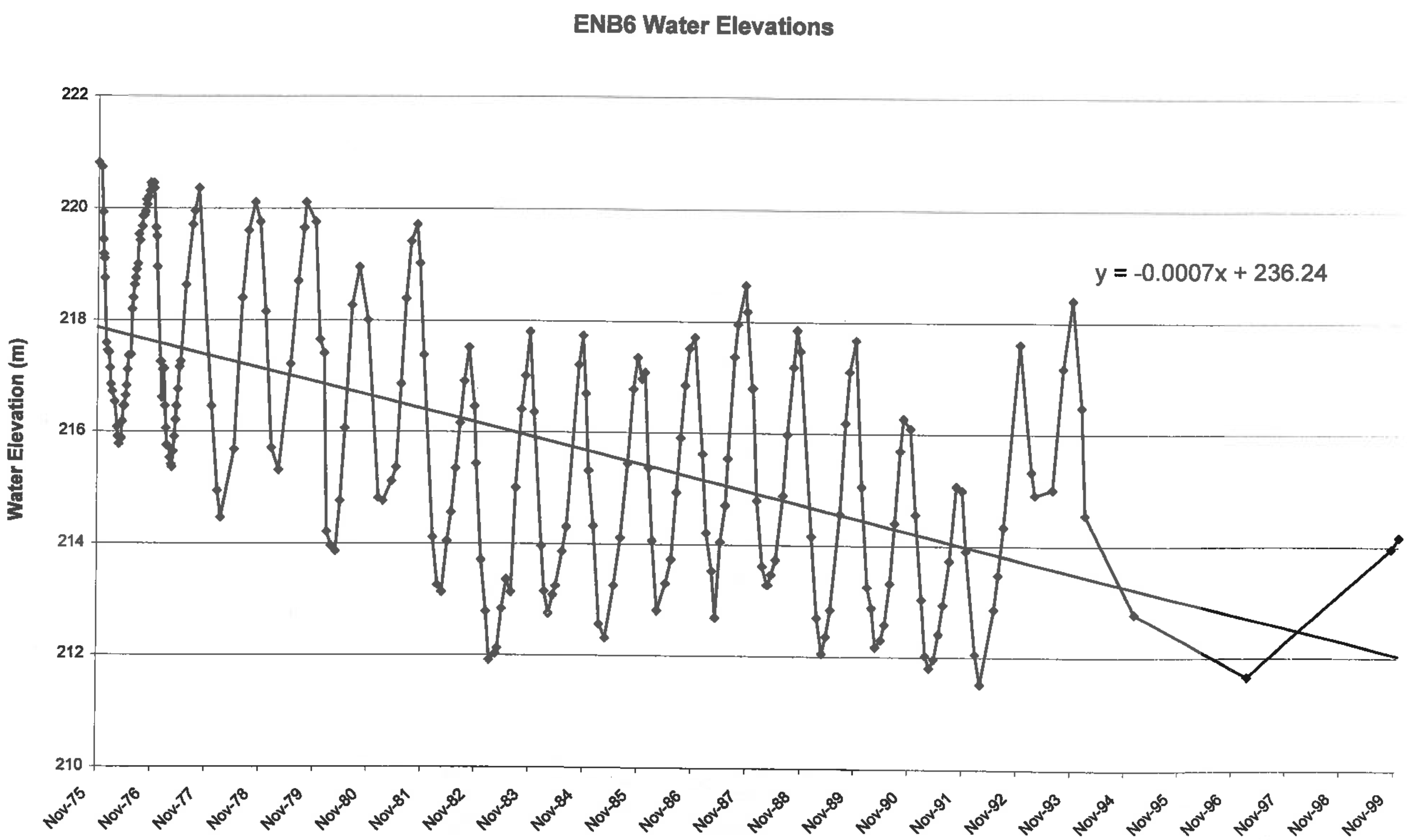

ENB2 Water Elevations
Water Elevation (m)
224
222
220
218
216
214
212
210
y = -0.0005x + 233.24
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00

ENB4 Water Elevations

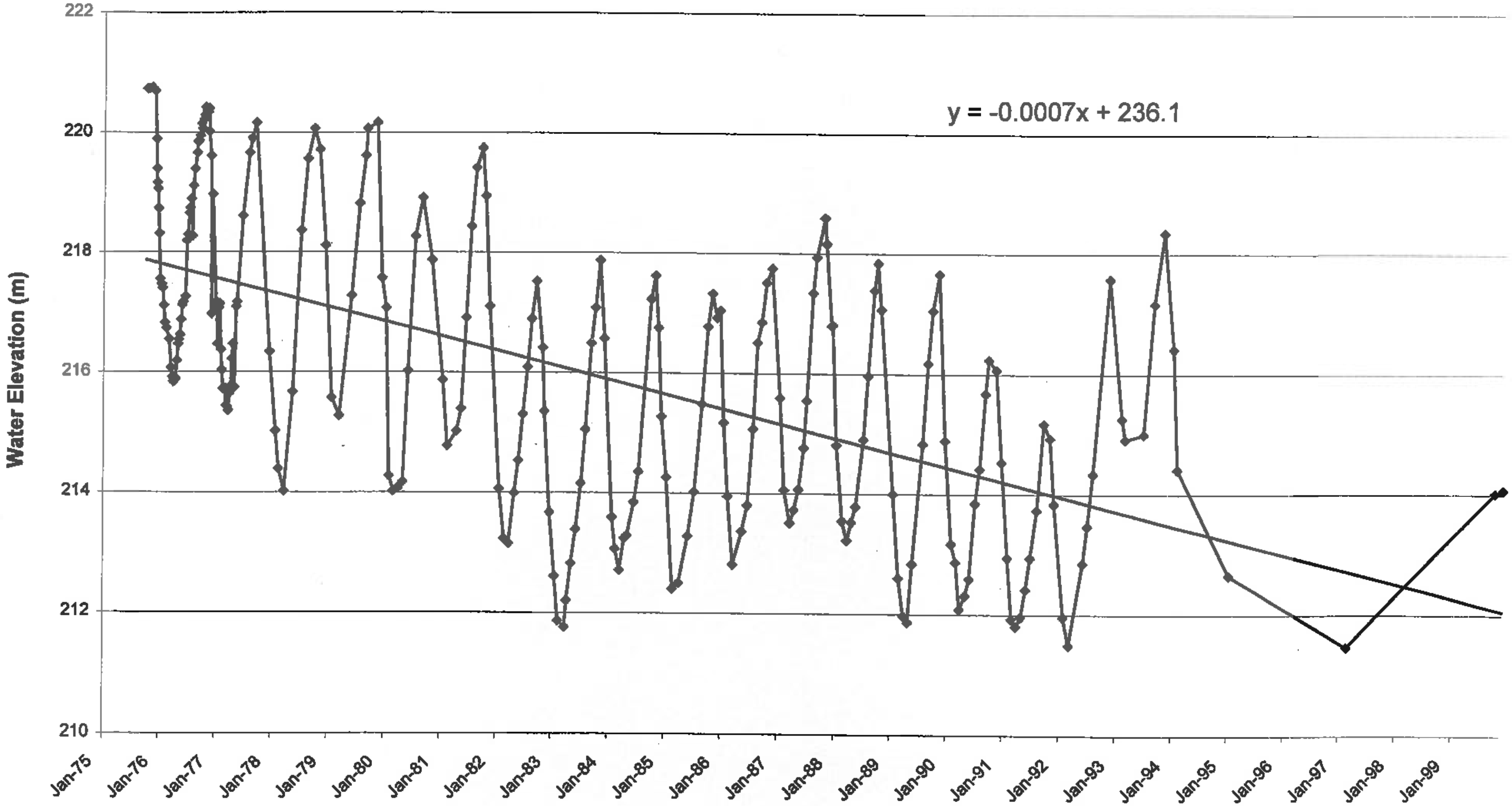


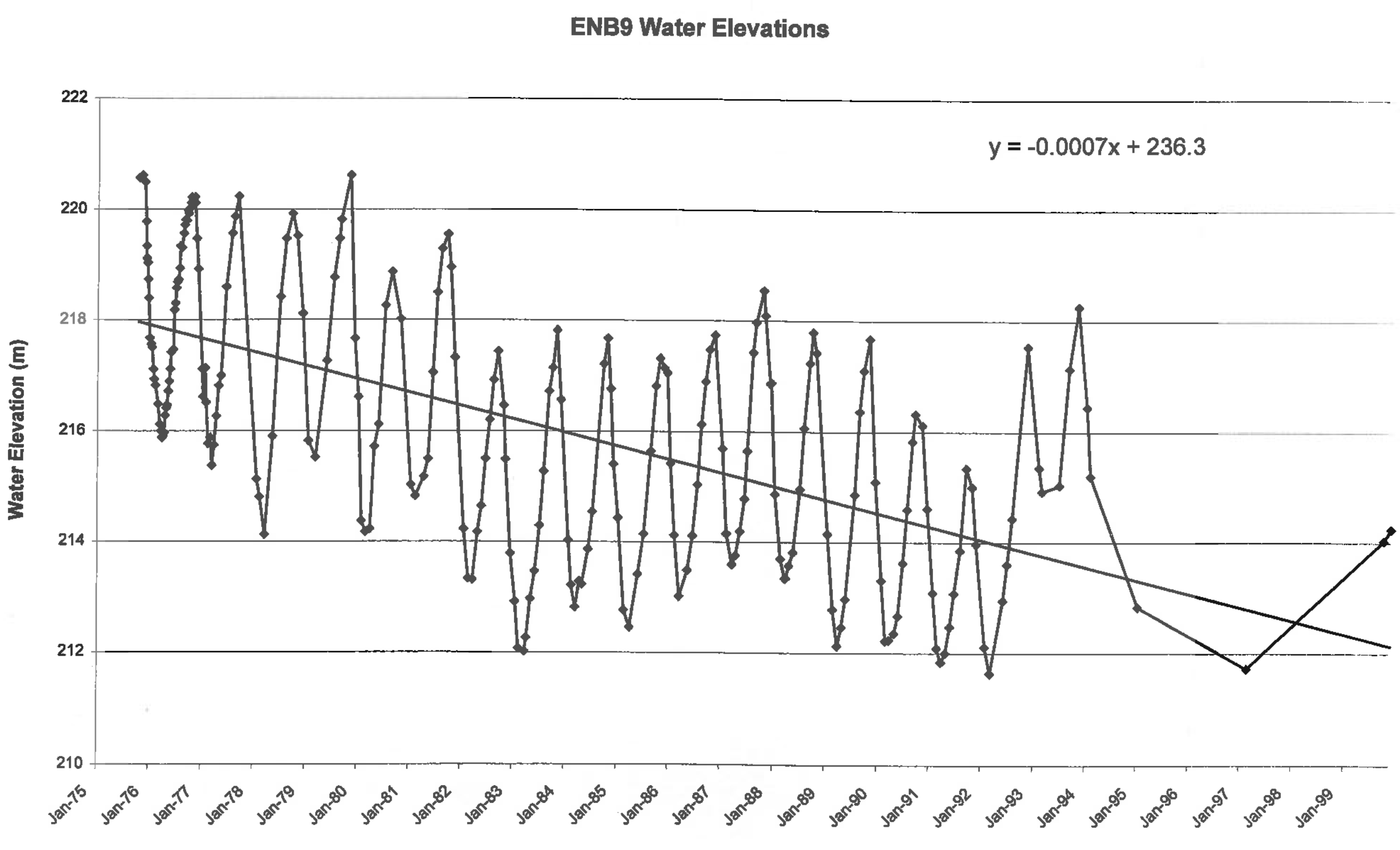
ENB5 Water Elevations



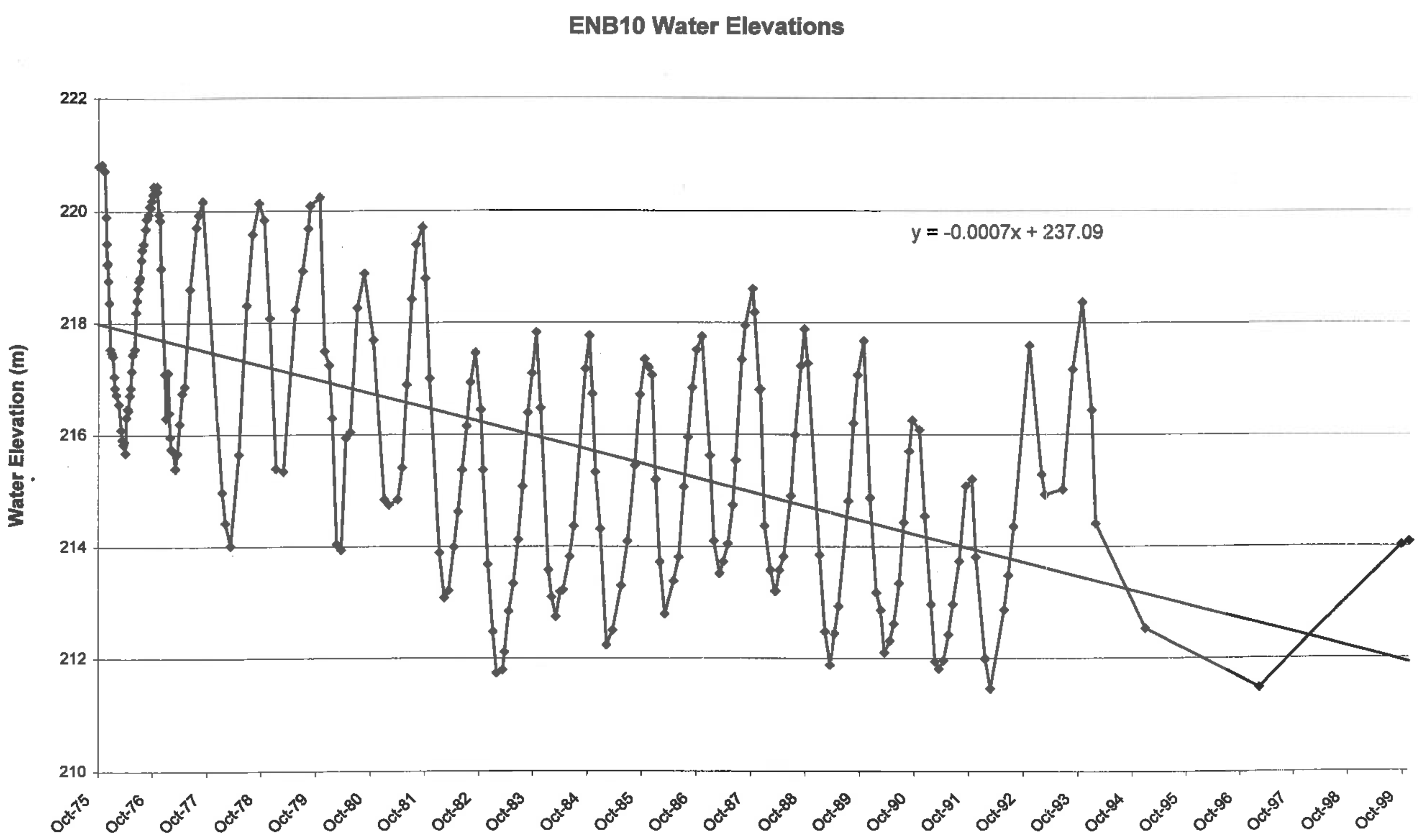

ENB6 Water Elevations
Water Elevation (m)
222
220
218
216
214
212
210
y = -0.0007x + 236.24
Nov-75
Nov-76
Nov-77
Nov-78
Nov-79
Nov-80
Nov-81
Nov-82
Nov-83
Nov-84
Nov-85
Nov-86
Nov-87
Nov-88
Nov-89
Nov-90
Nov-91
Nov-92
Nov-93
Nov-94
Nov-95
Nov-96
Nov-97
Nov-98
Nov-99

ENB8 Water Elevations

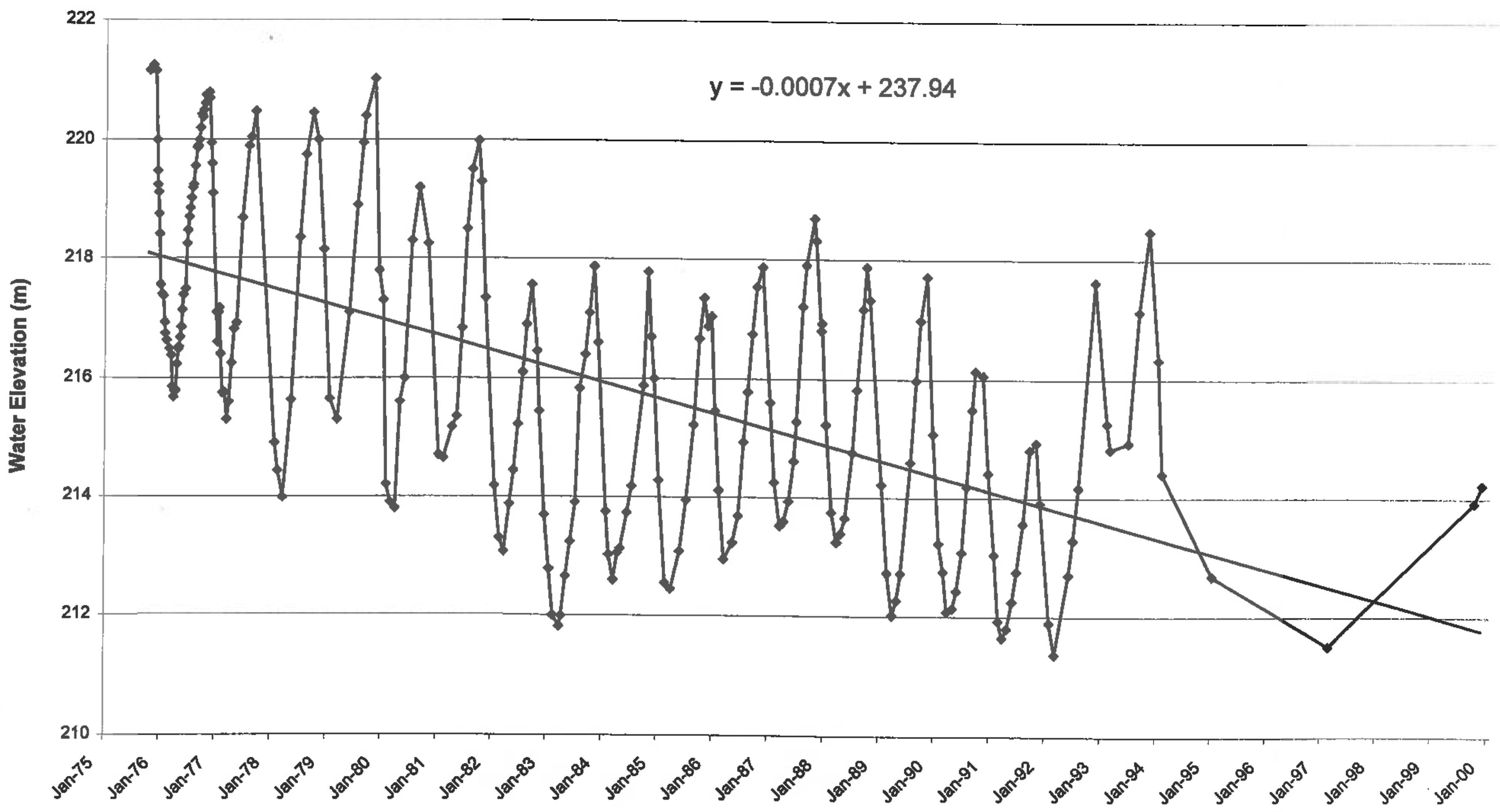




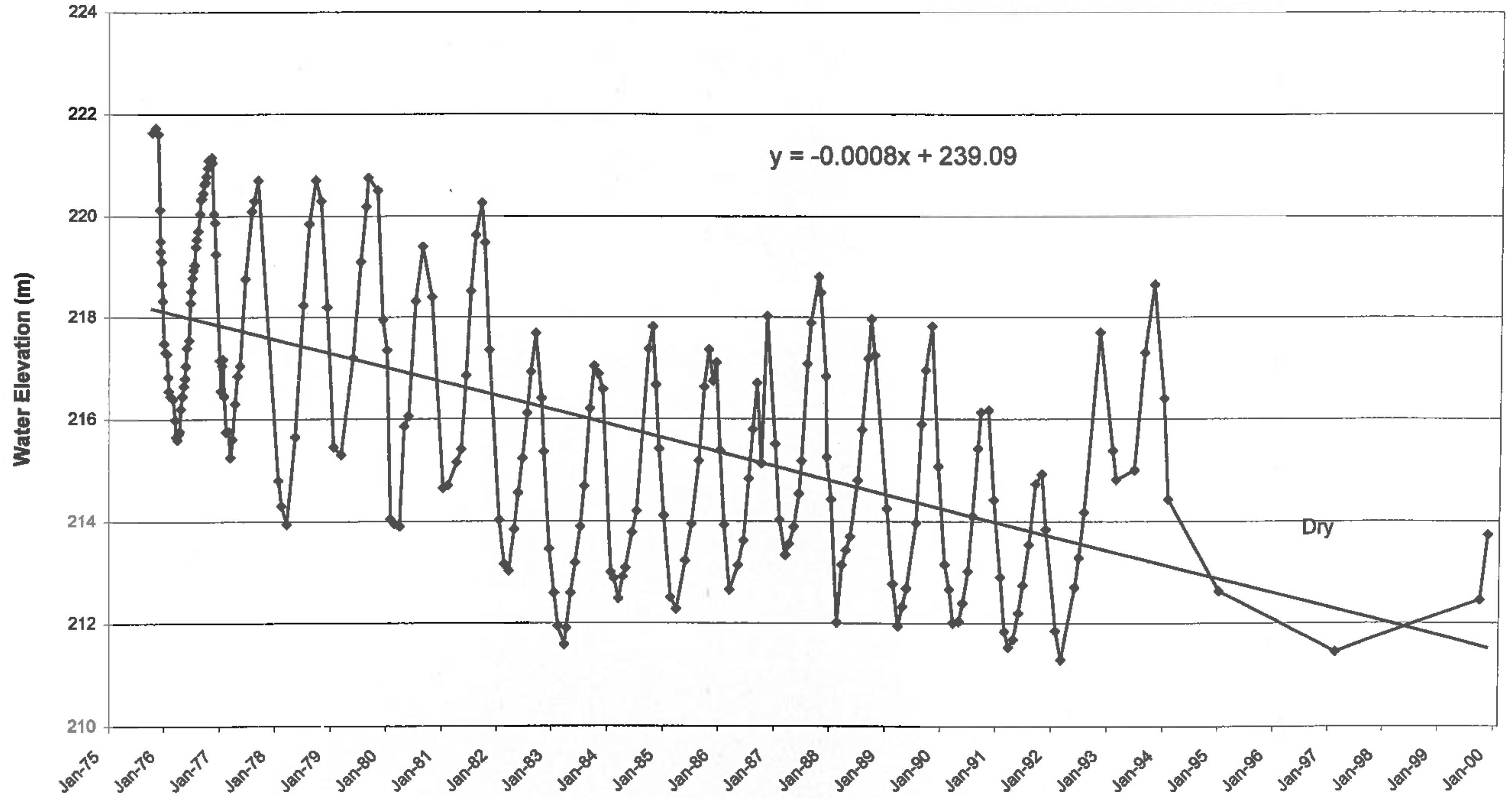
ENB9 Water Elevations
y = -0.0007x + 236.3
Water Elevation (m)
222
220
218
216
214
212
210
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99

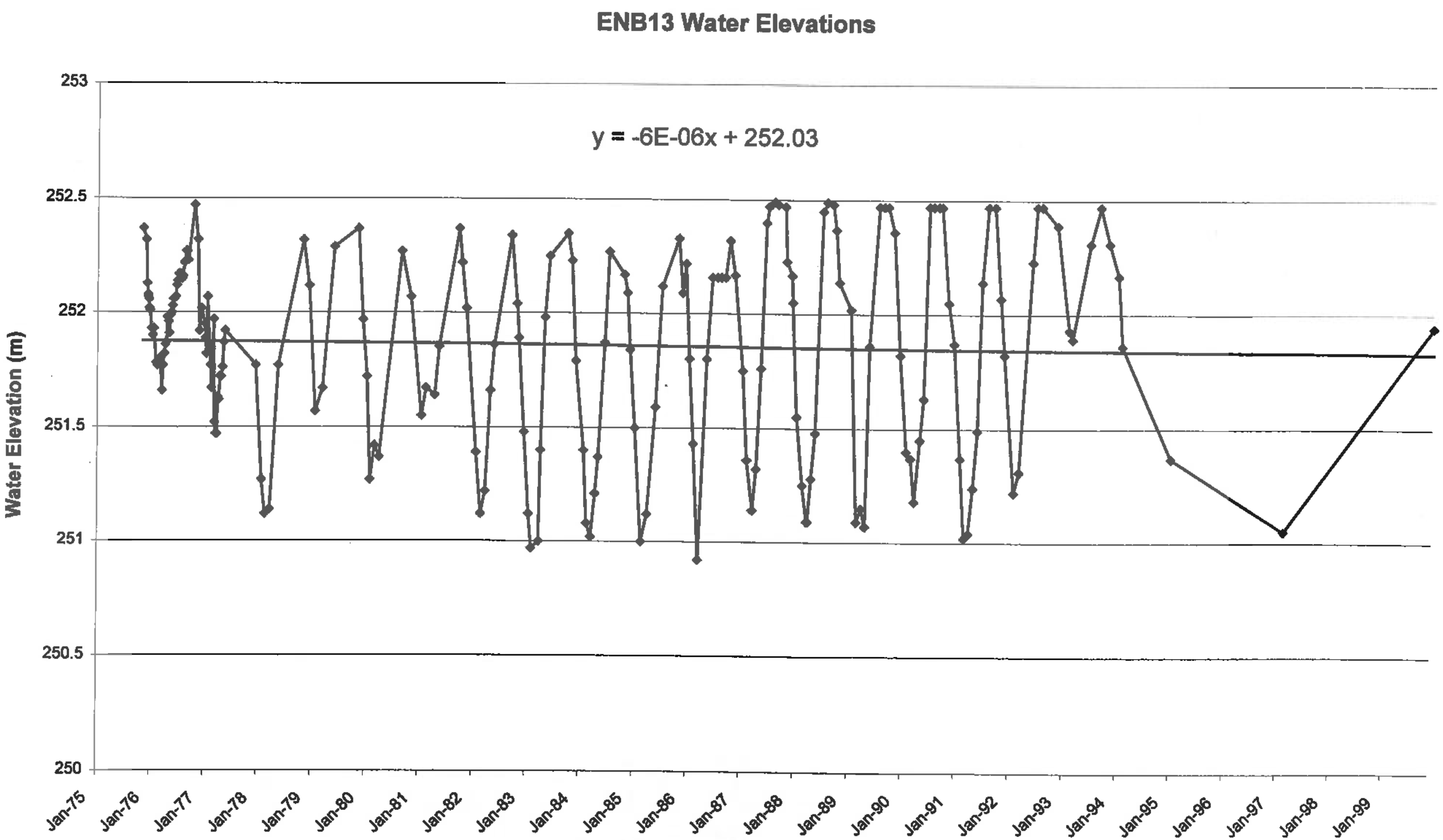

ENB10 Water Elevations
y = -0.0007x + 237.09
Water Elevation (m)
222
220
218
216
214
212
210
Oct-75
Oct-76
Oct-77
Oct-78
Oct-79
Oct-80
Oct-81
Oct-82
Oct-83
Oct-84
Oct-85
Oct-86
Oct-87
Oct-88
Oct-89
Oct-90
Oct-91
Oct-92
Oct-93
Oct-94
Oct-95
Oct-96
Oct-97
Oct-98
Oct-99

ENB11 Water Elevations

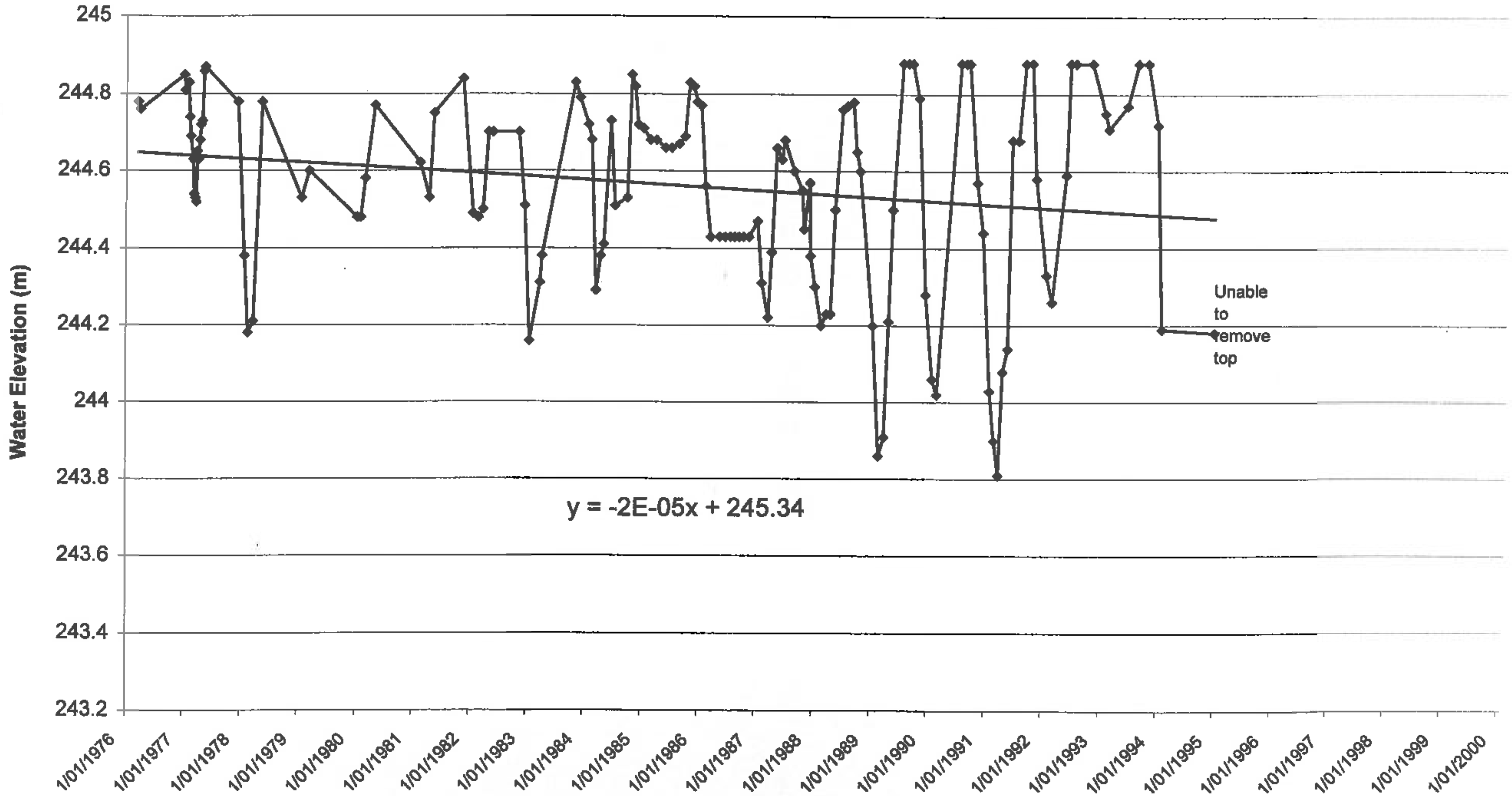


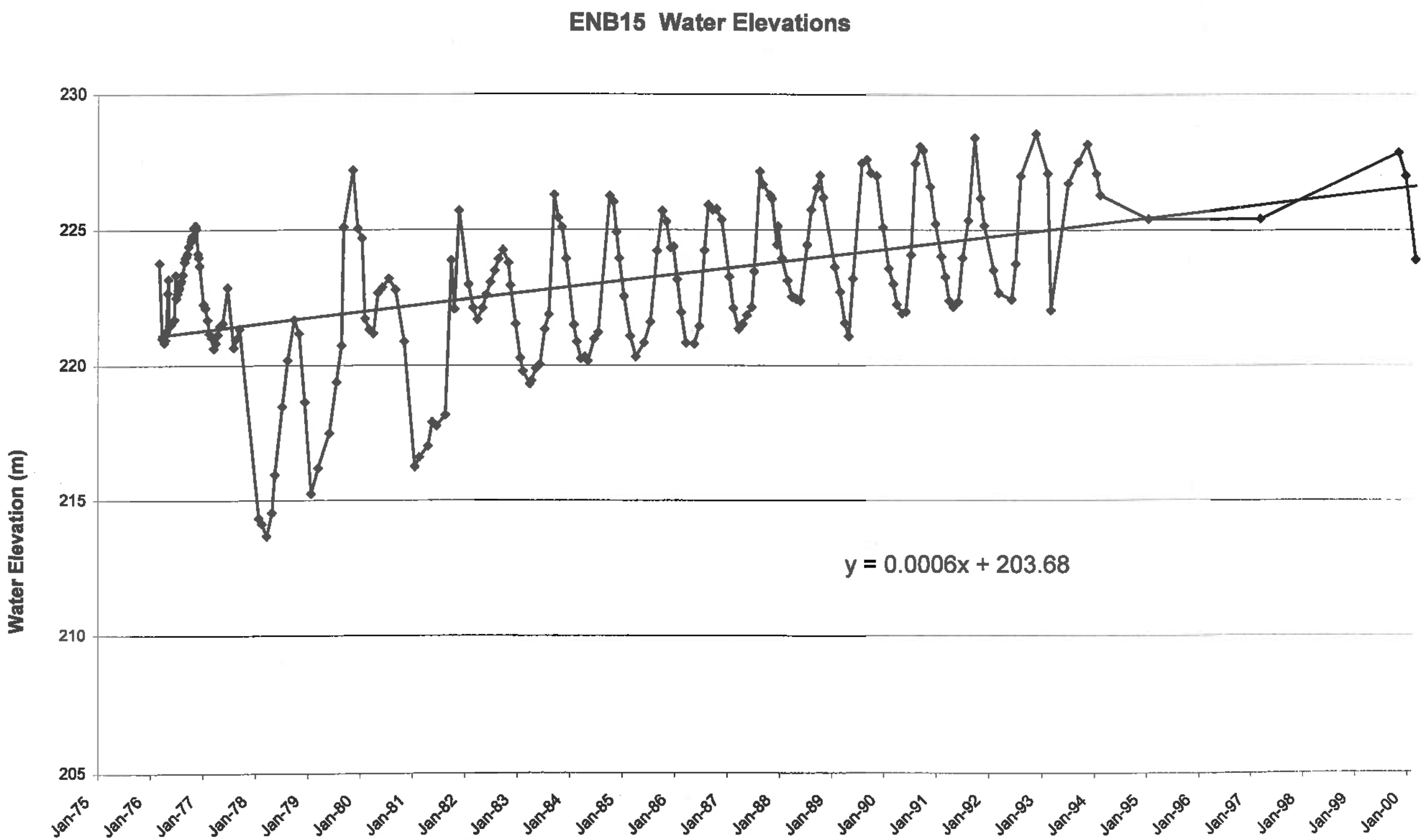
ENB12 Water Elevations

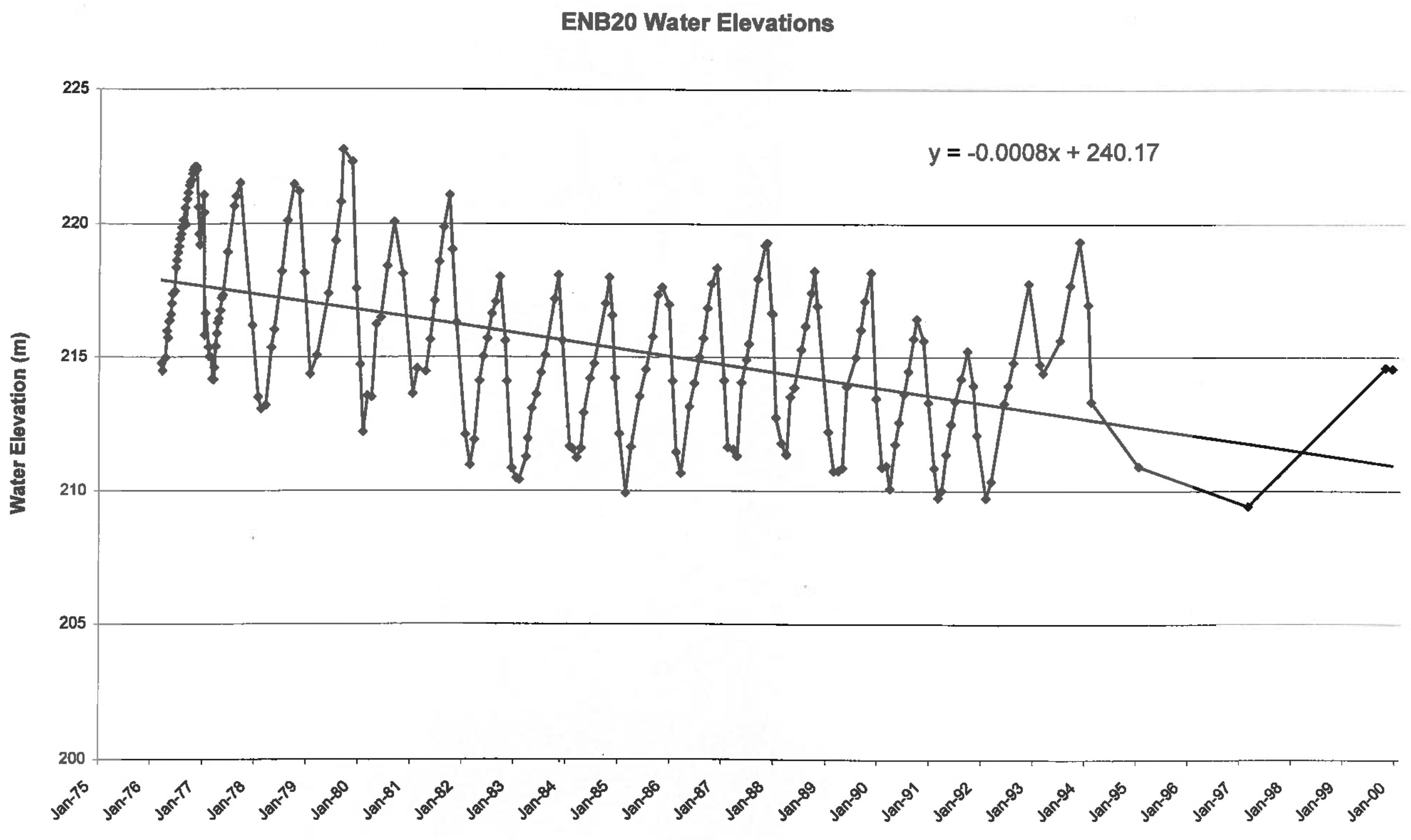



ENB13 Water Elevations
y = -6E-06x + 252.03
Water Elevation (m)
253
252.5
252
251.5
251
250.5
250
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99

ENB14 Water Elevations

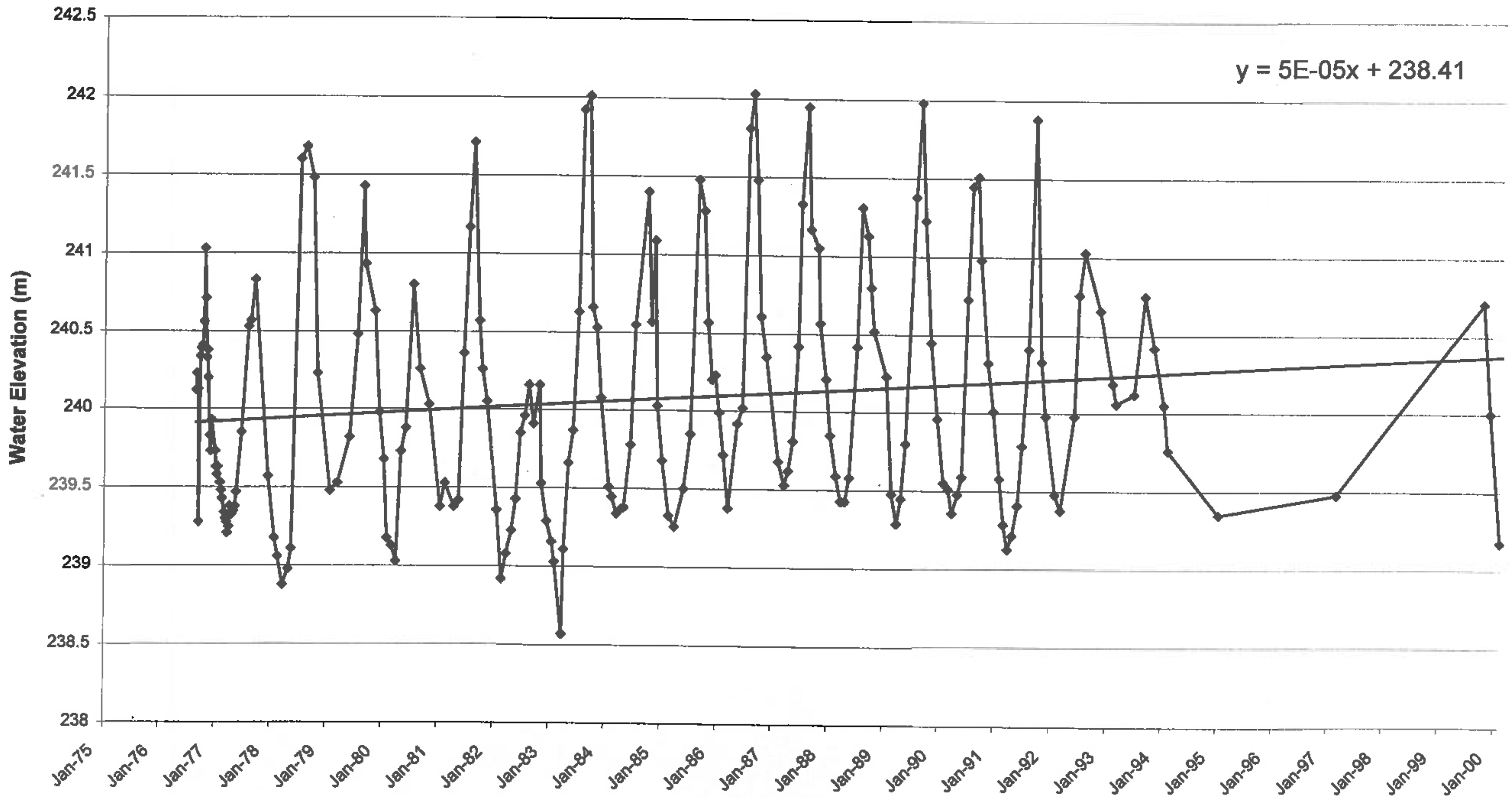



ENB15 Water Elevations
230
225
220
215
210
205
Water Elevation (m)
y = 0.0006x + 203.68
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00

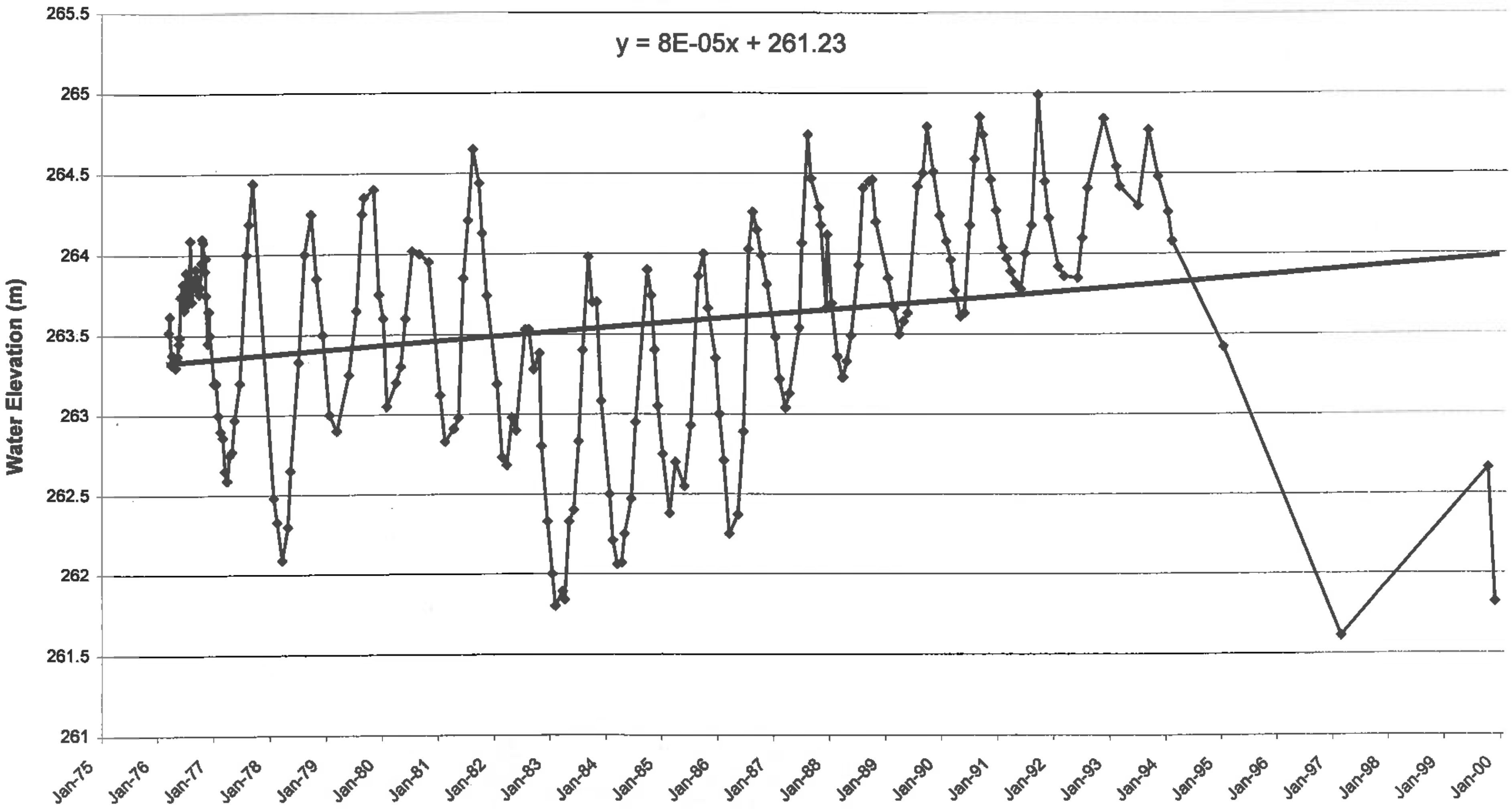


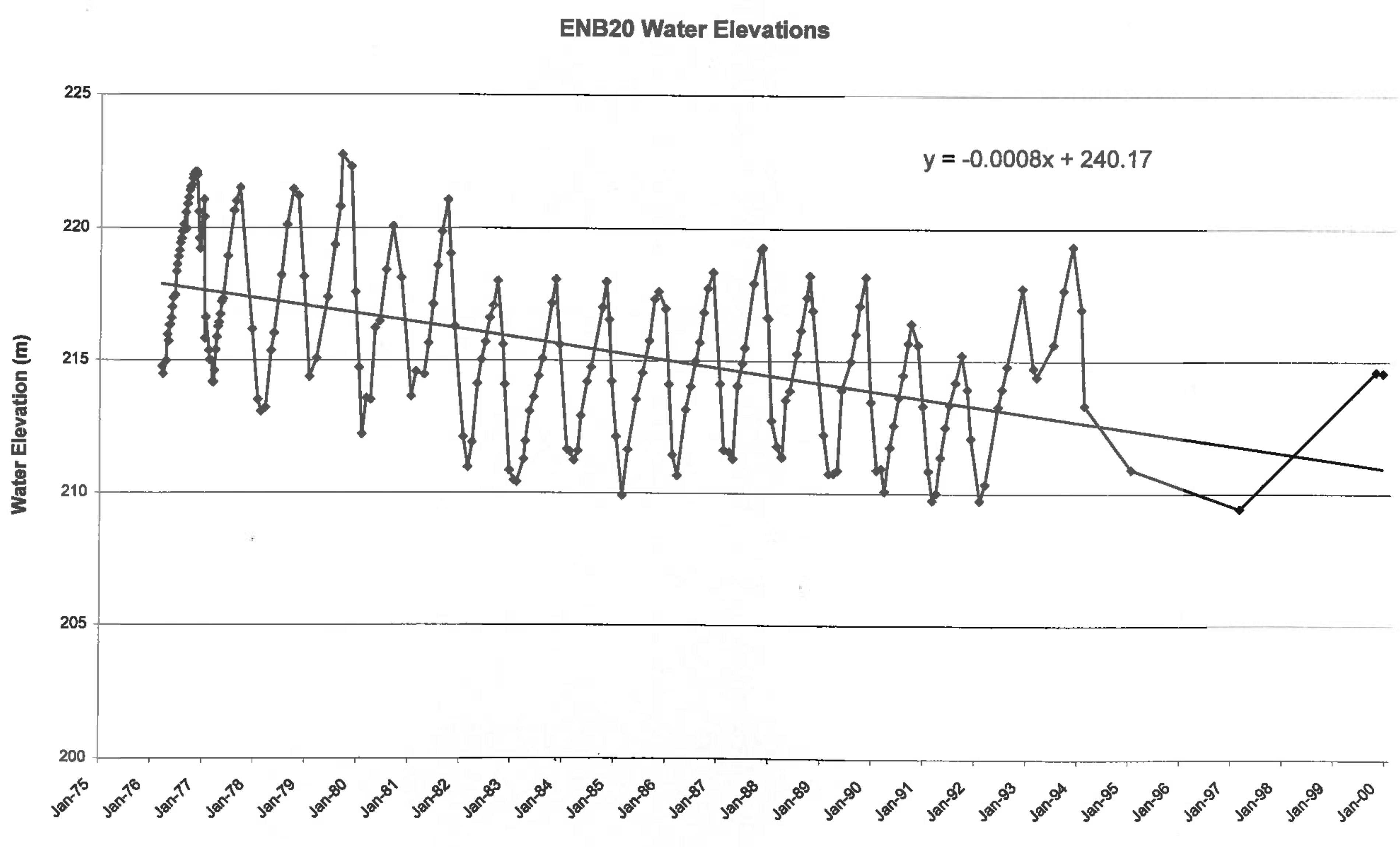
ENB20 Water Elevations
y = -0.0008x + 240.17
Water Elevation (m)
225
220
215
210
205
200
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00

ENB17 Water Elevations



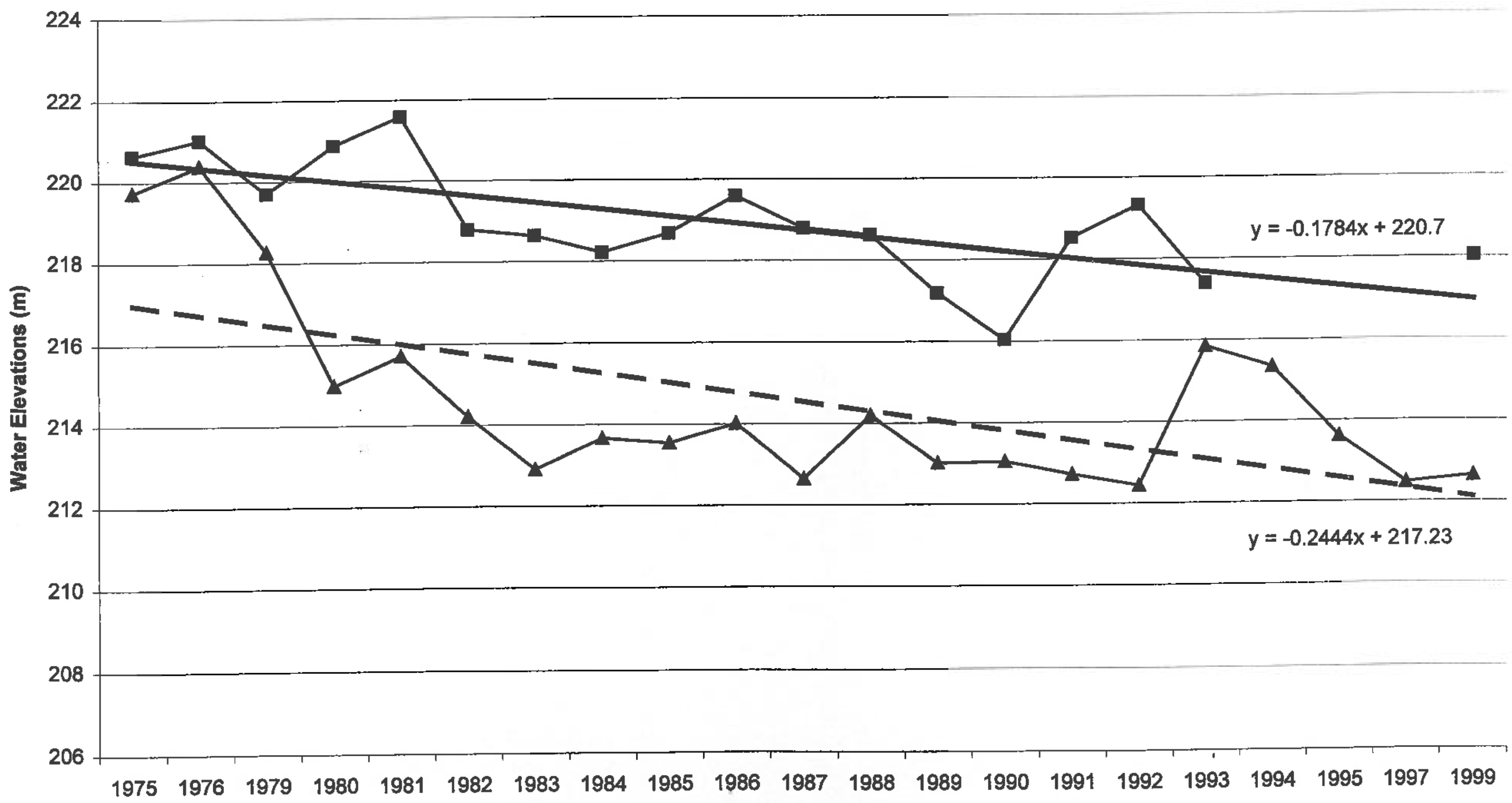
ENB19 Water Elevations



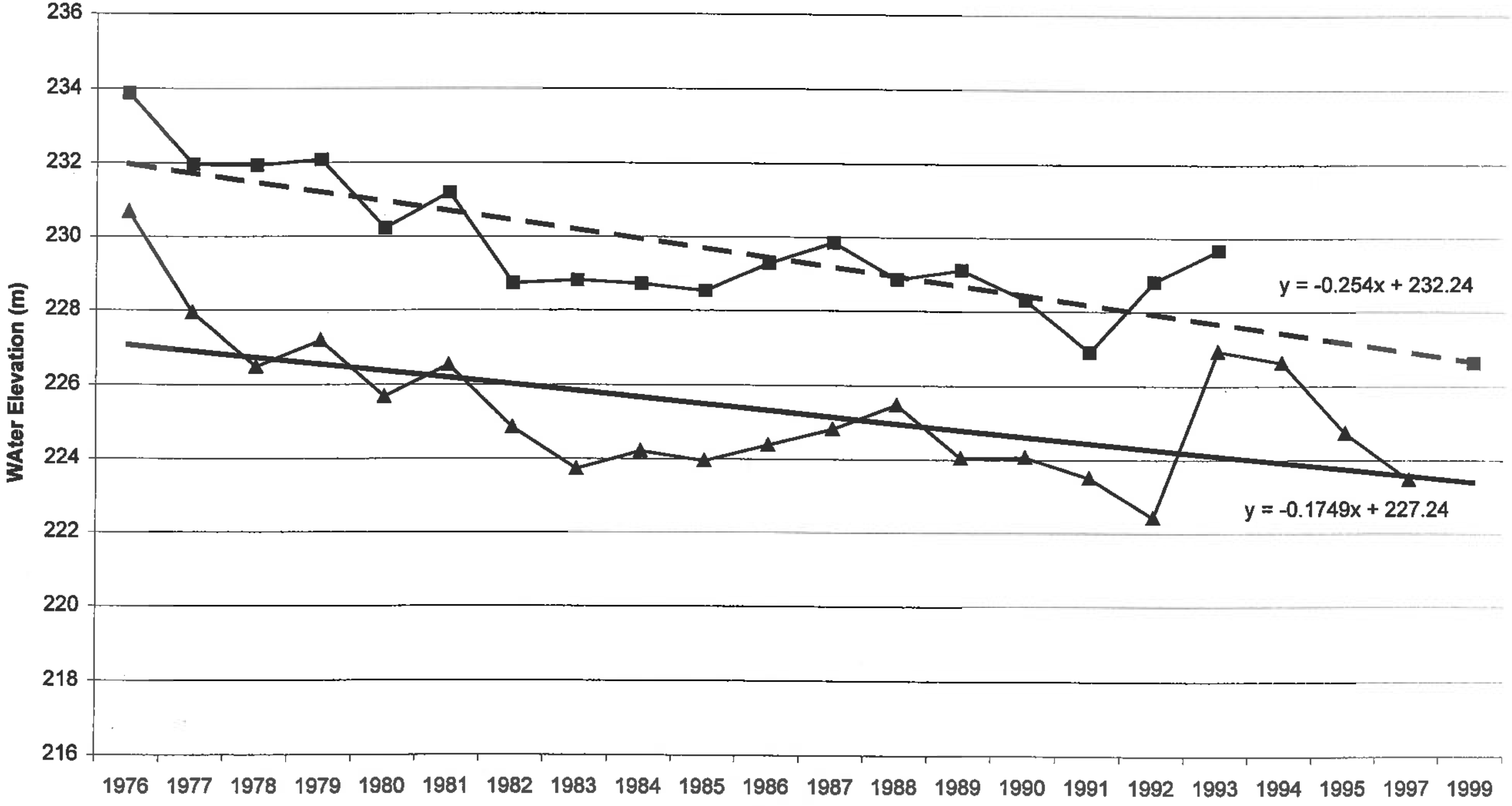

ENB20 Water Elevations
y = -0.0008x + 240.17
Water Elevation (m)
225
220
215
210
205
200
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00

Appendix 6
Maximum and Minimum Water Elevations
For the
Hindmarch Tiers Observation Bores

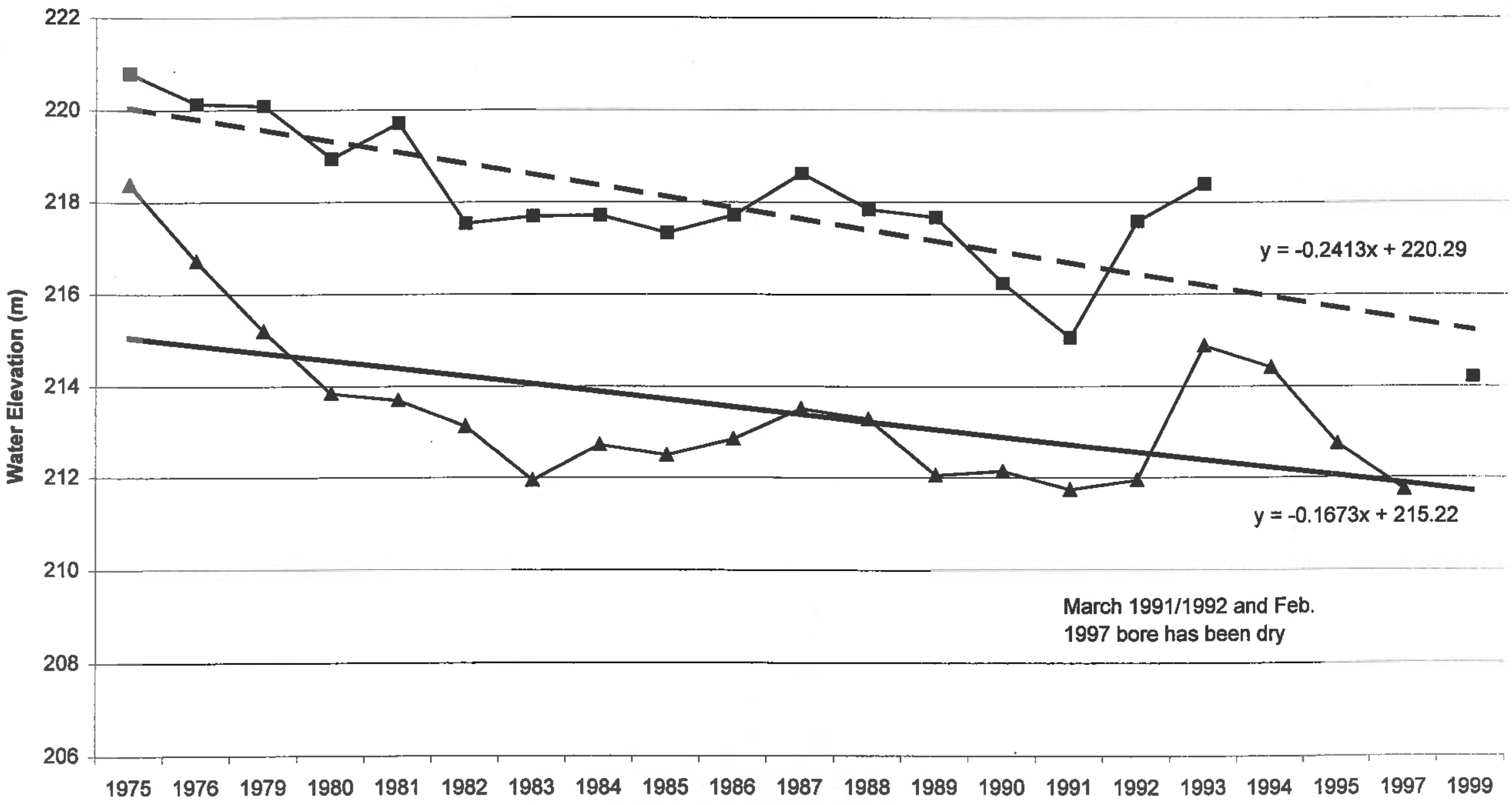
ENB2 Maximum and Minimum Water Elevations



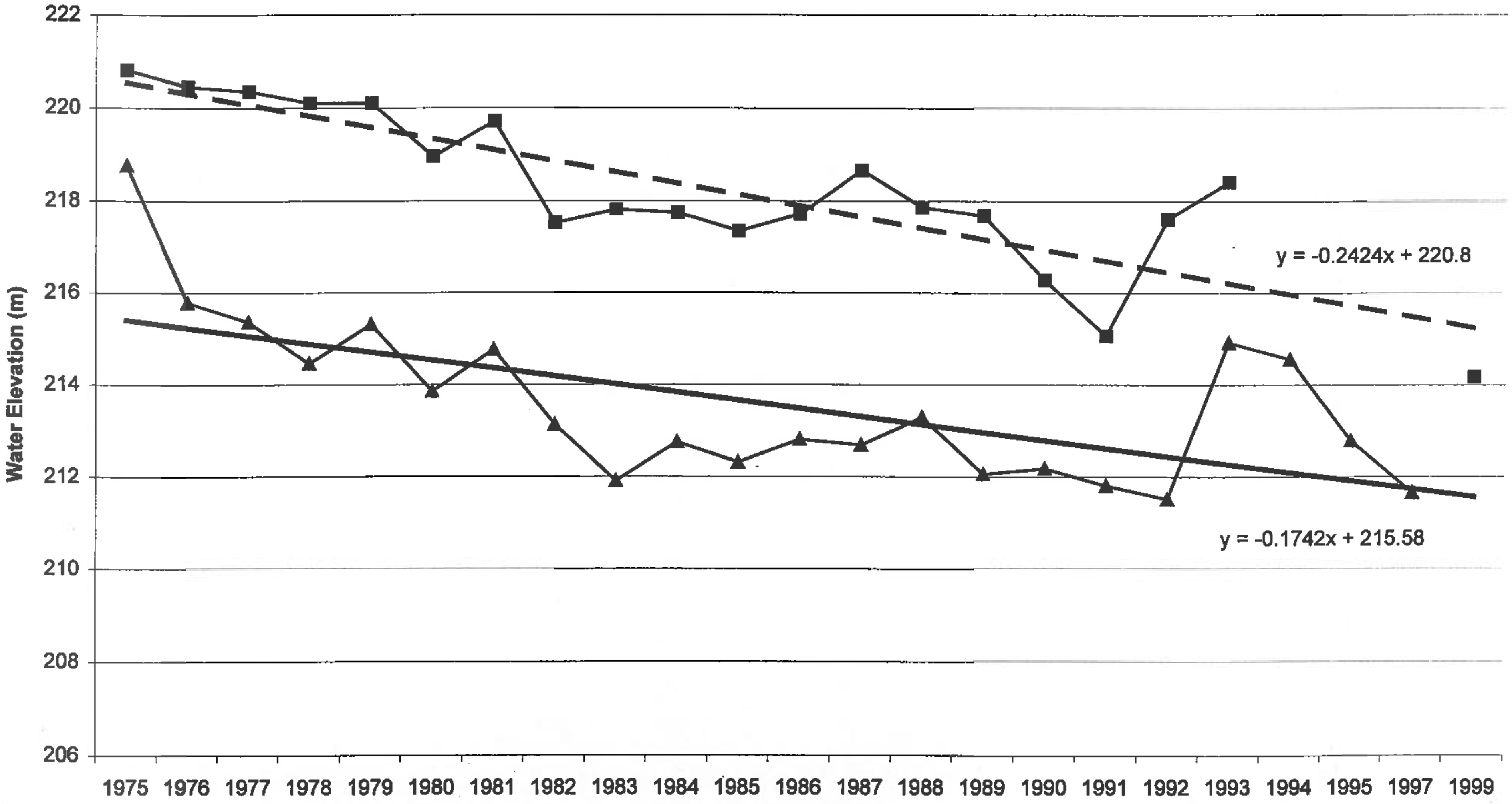
ENB4 Maximum and Minimum Water Elevations



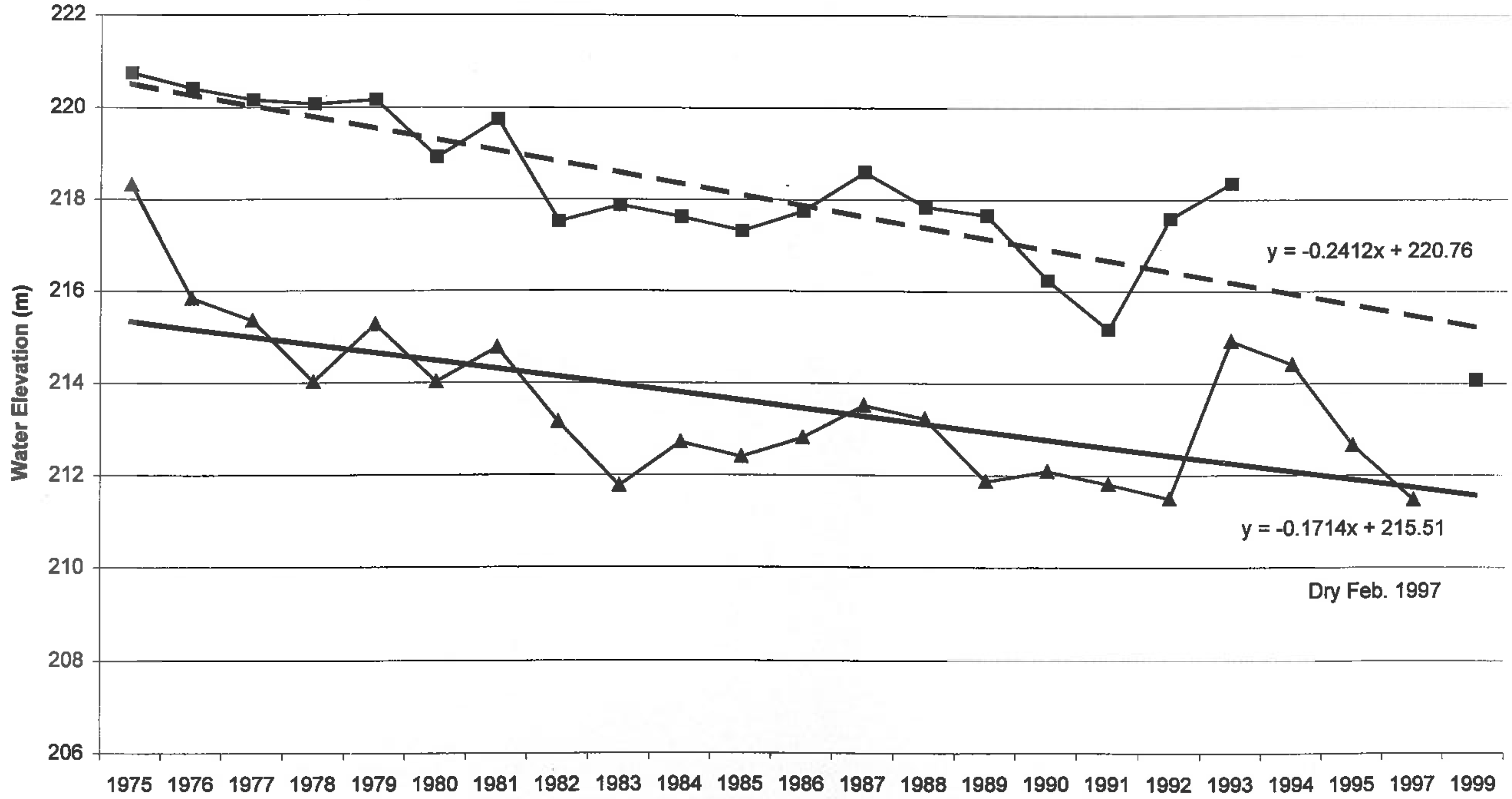
ENB5 Maximum and Minimum Yearly Elevations



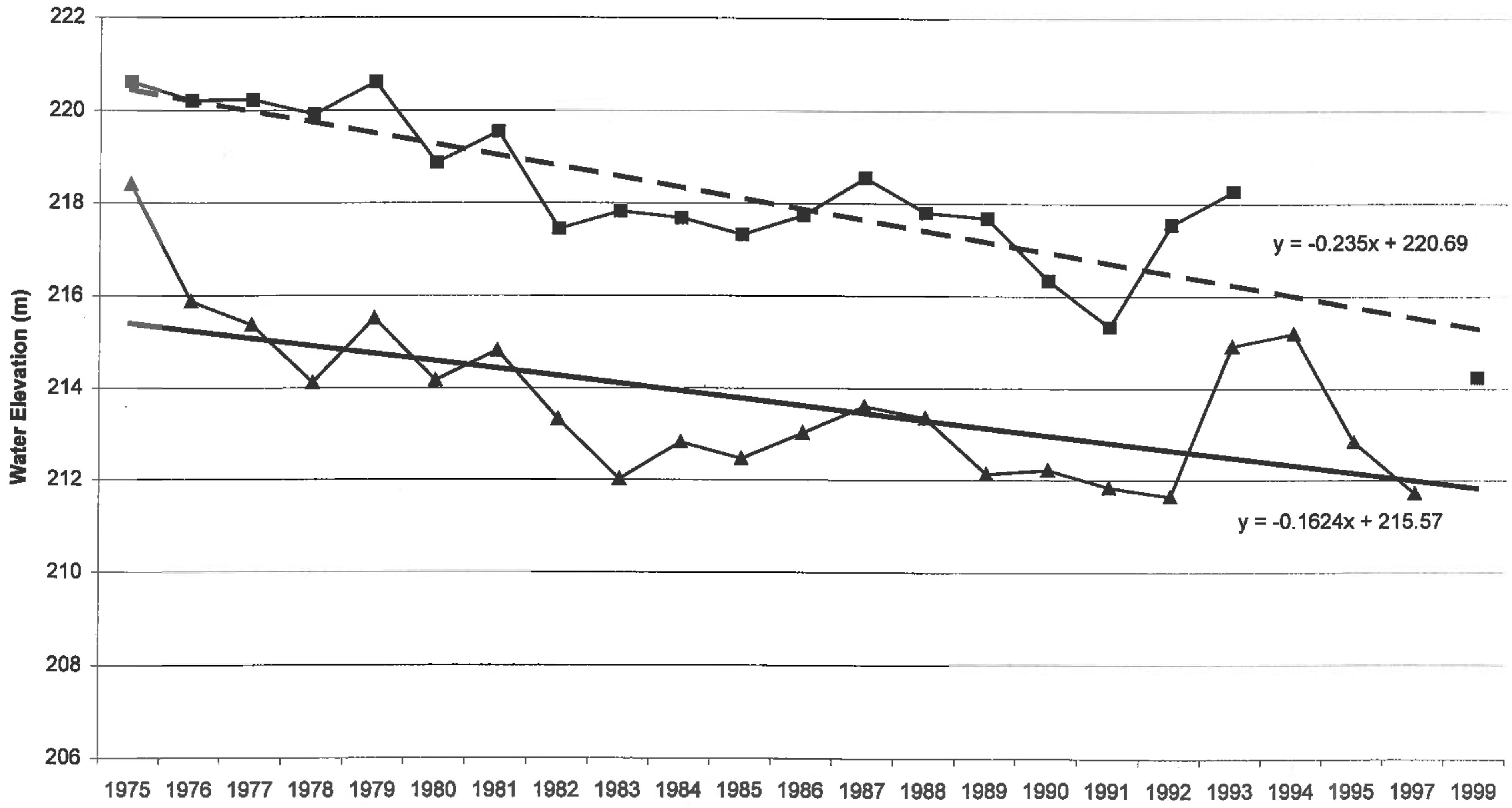
ENB6 Maximum and Minimum Yearly Elevations



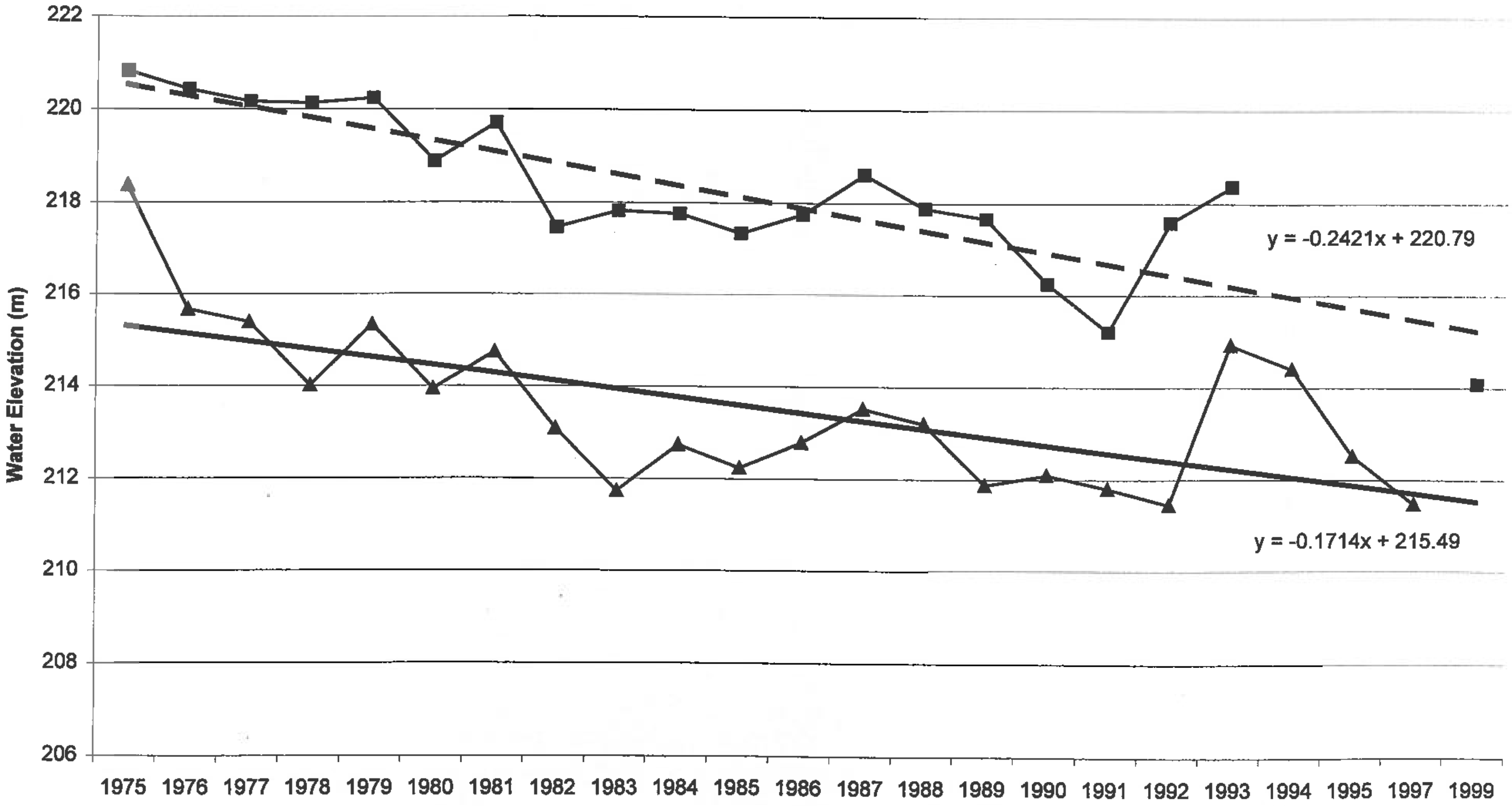
ENB8 Maximum and Minimum Yearly Elevations



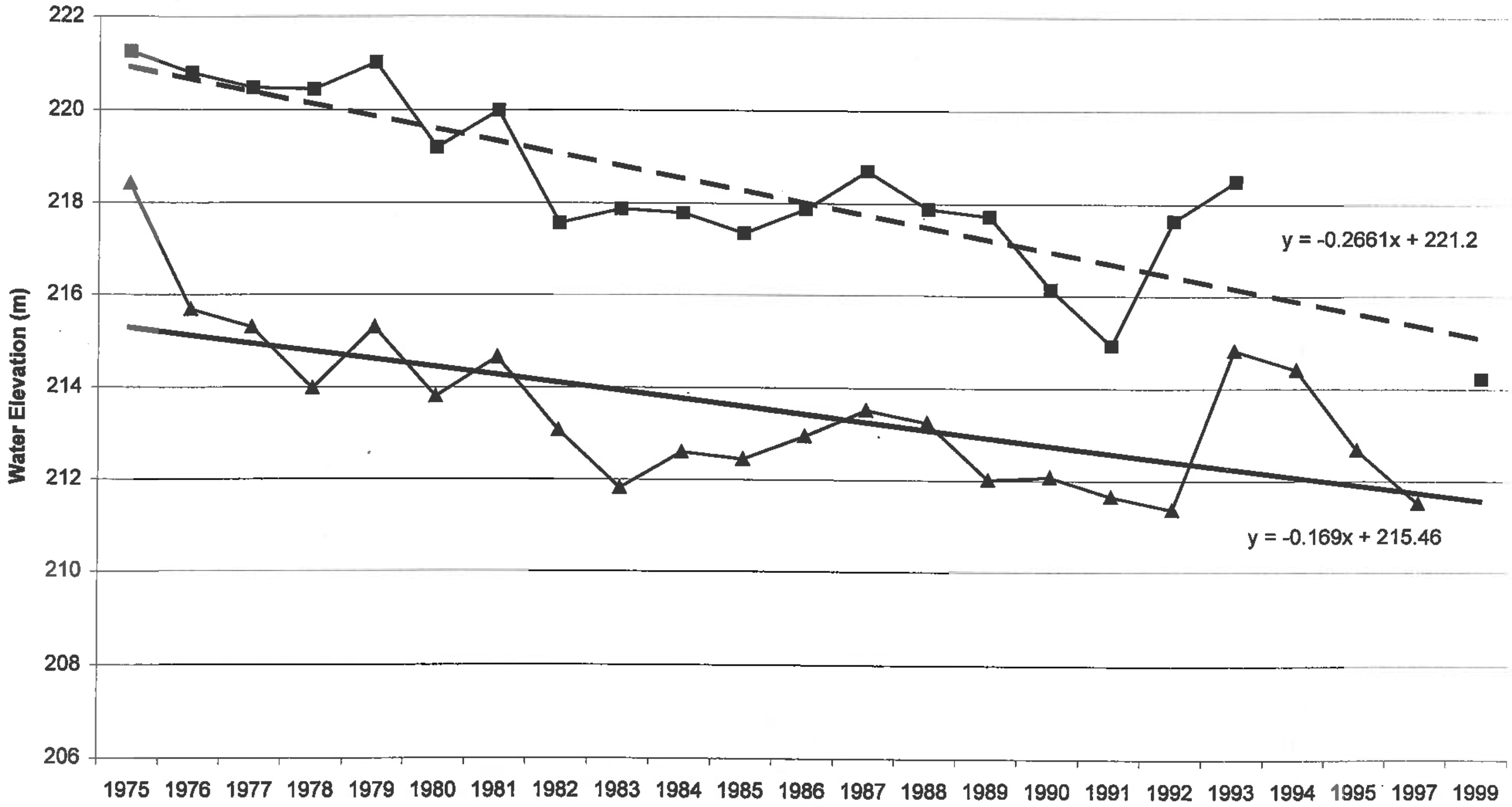
ENB9 Maximum and Minimum Yearly Elevations



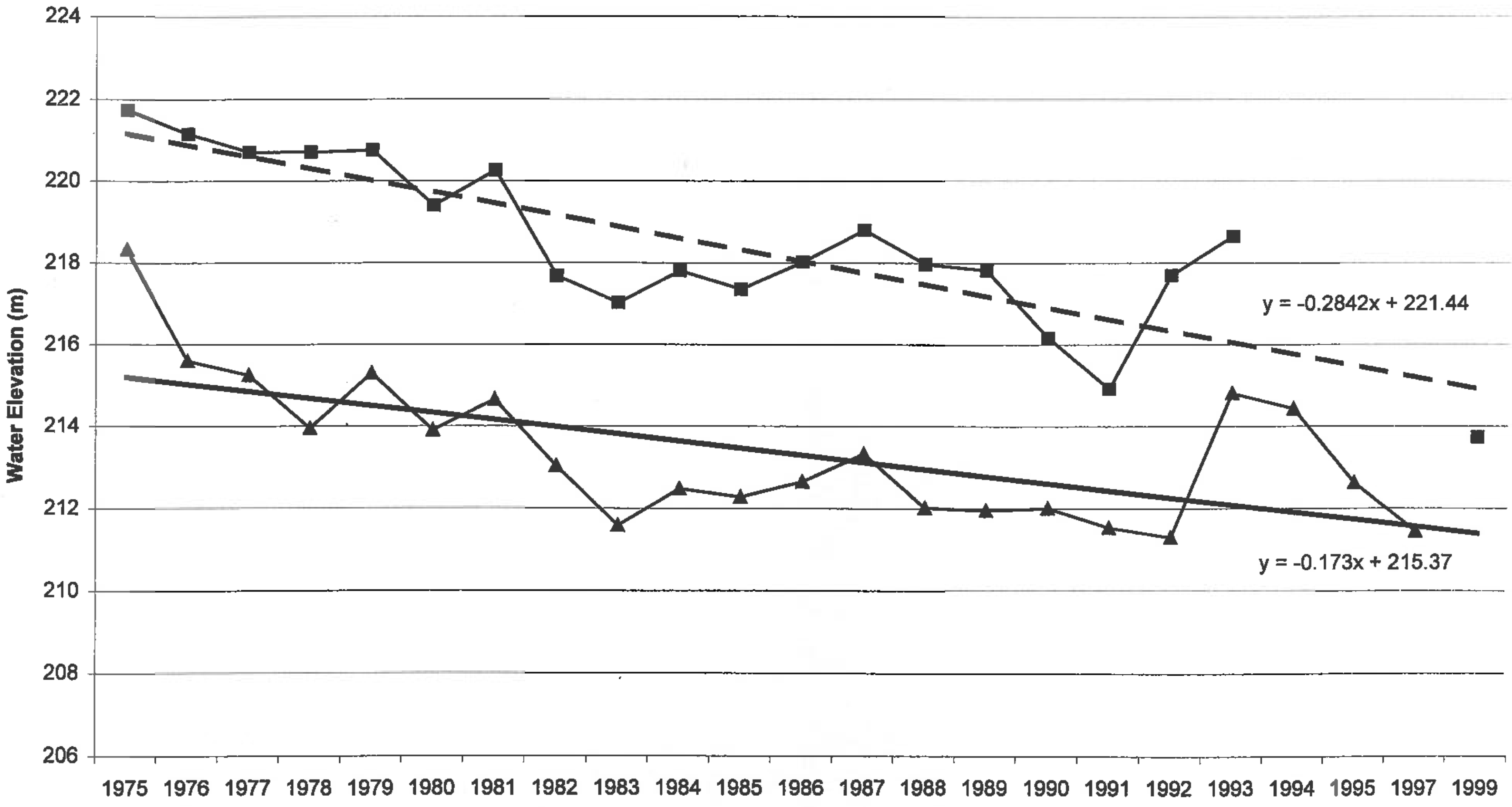
ENB10 Maximum and Minimum Yearly Elevations



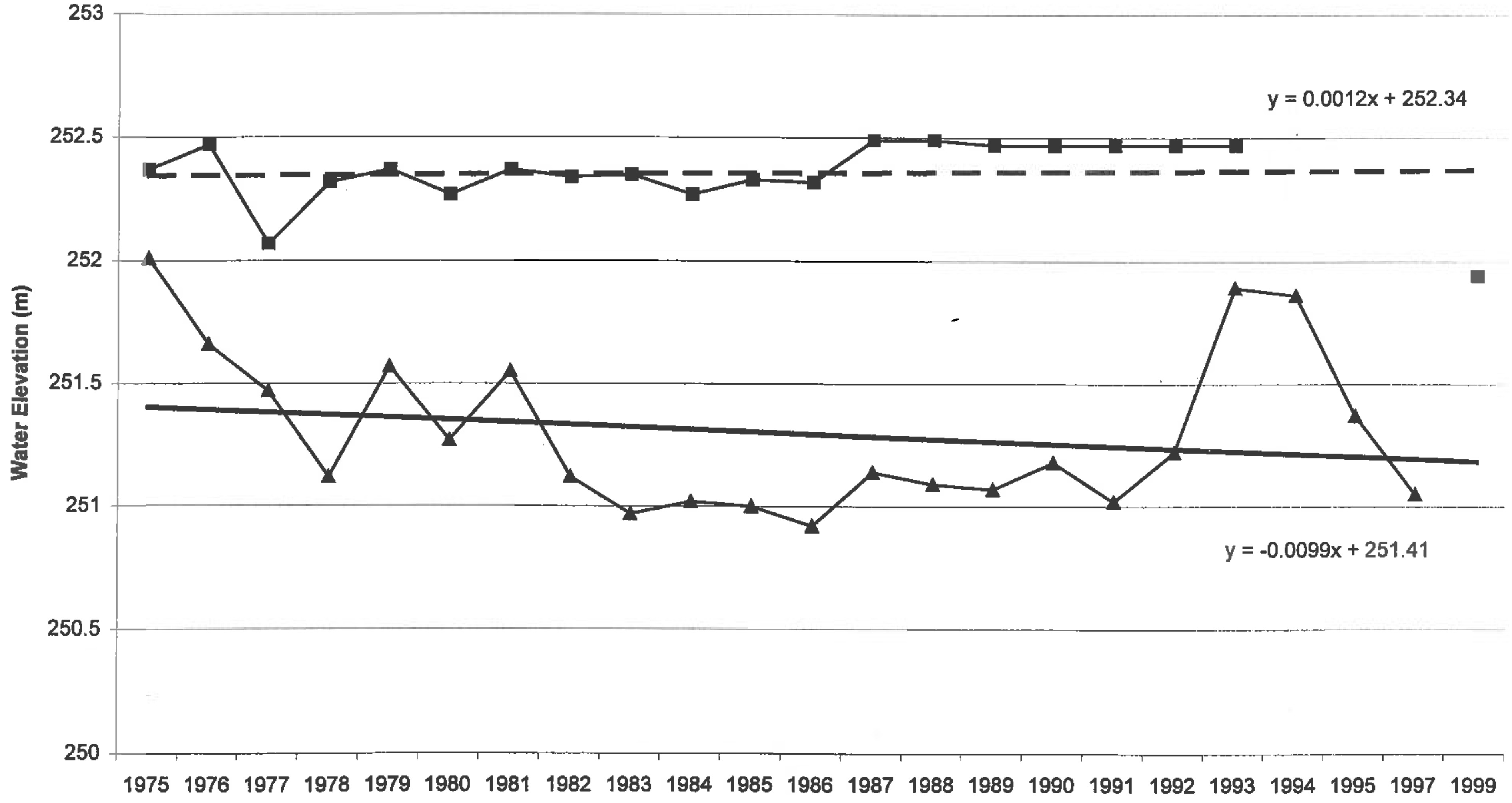
ENB11 Maximum and Minimum Yearly Elevations



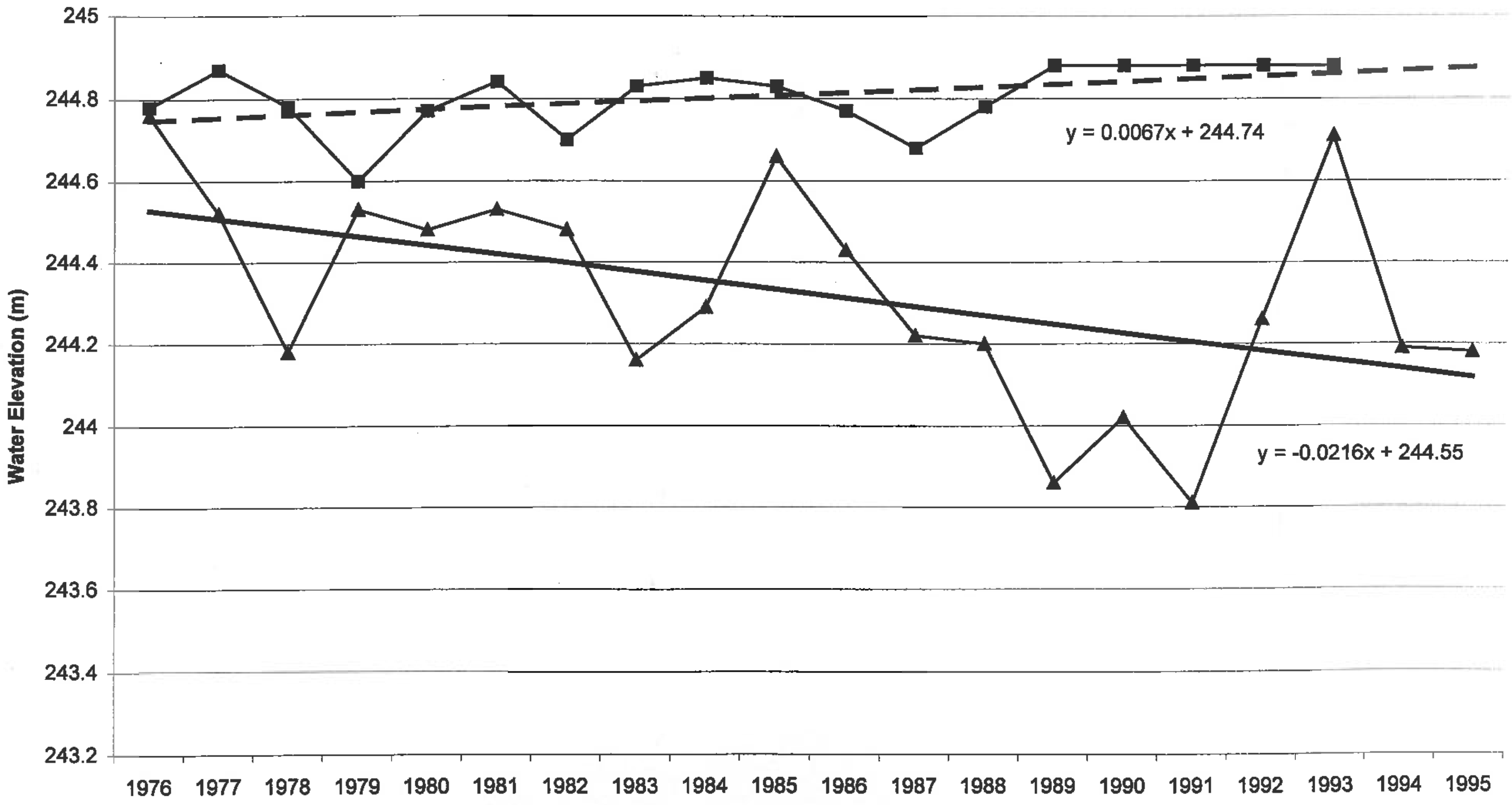
ENB12 Maximum and Minimum Water Elevations



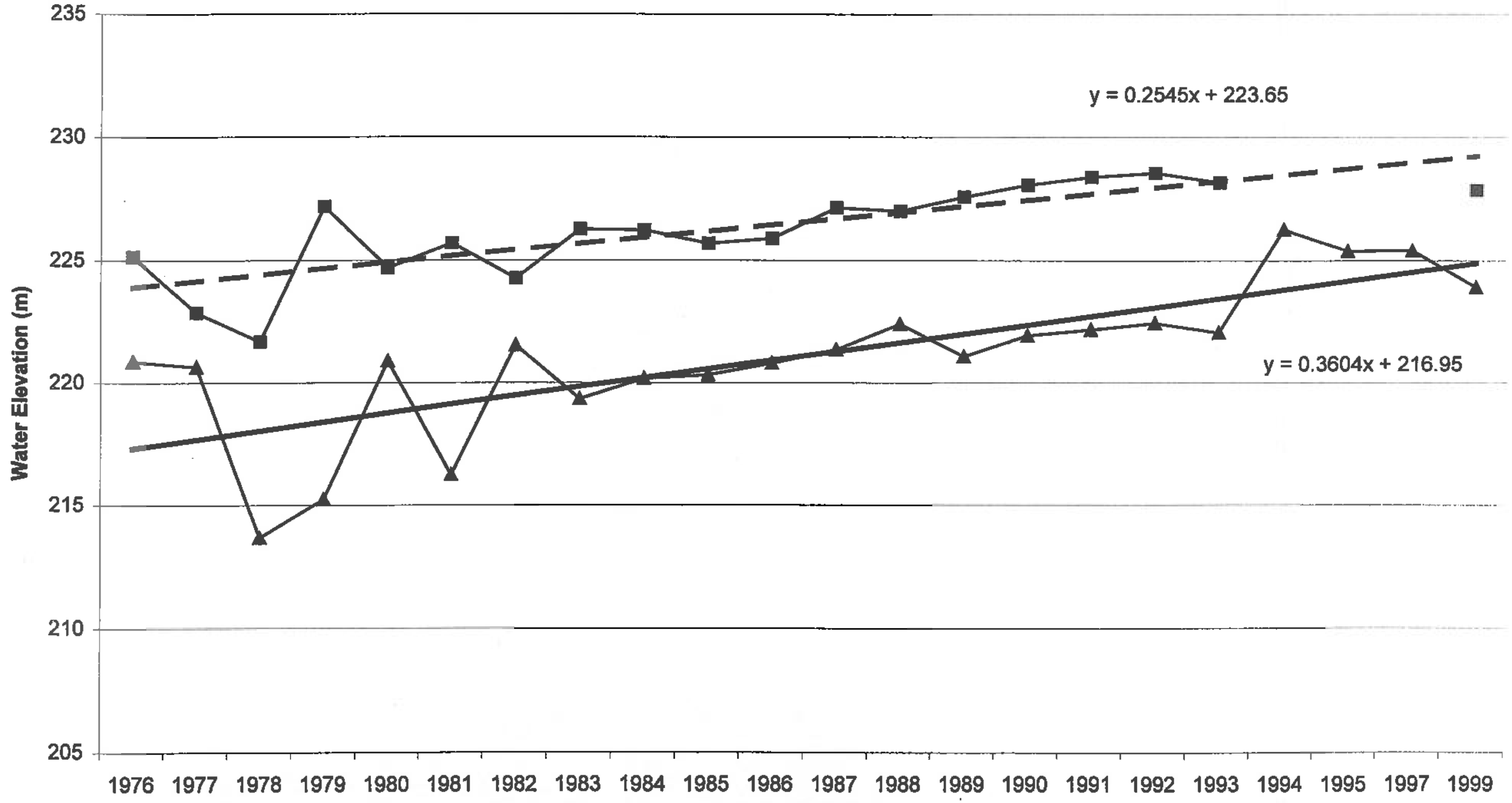
ENB13 Maximum and Minimum Yearly Elevations



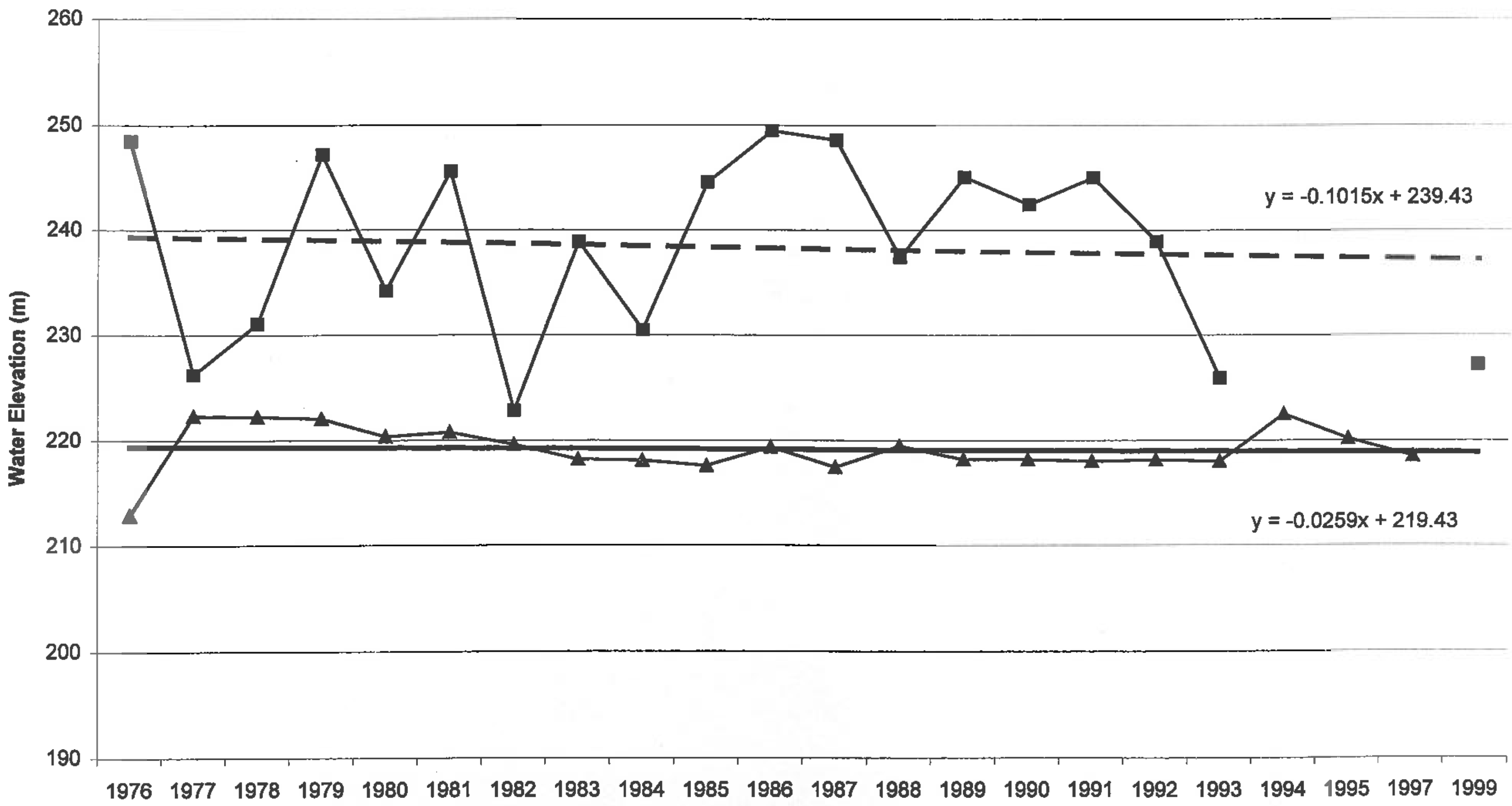
ENB14 Maximum and Minimum Yearly Elevations



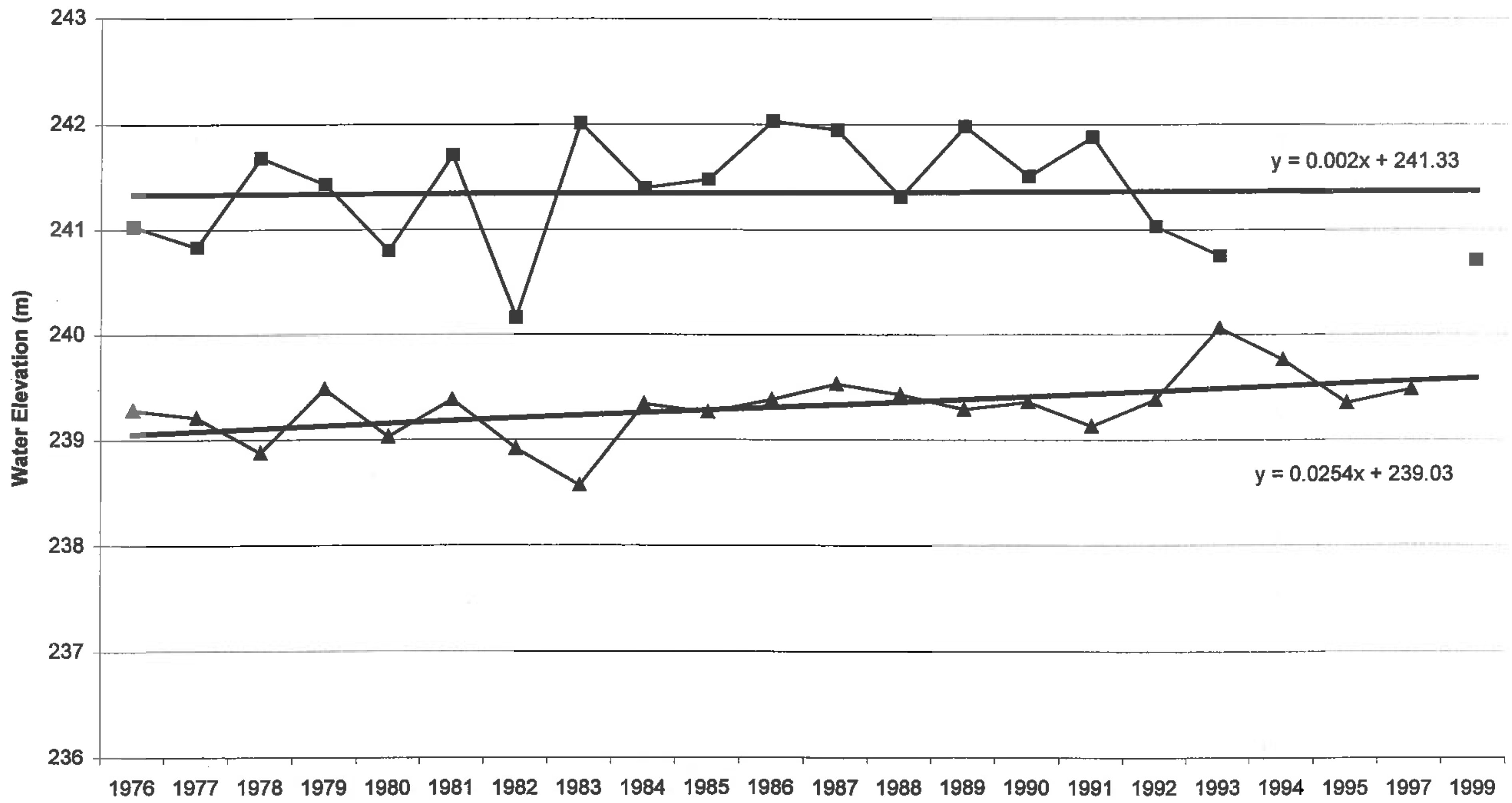
ENB15 Maximum and Minimum Yearly Elevations



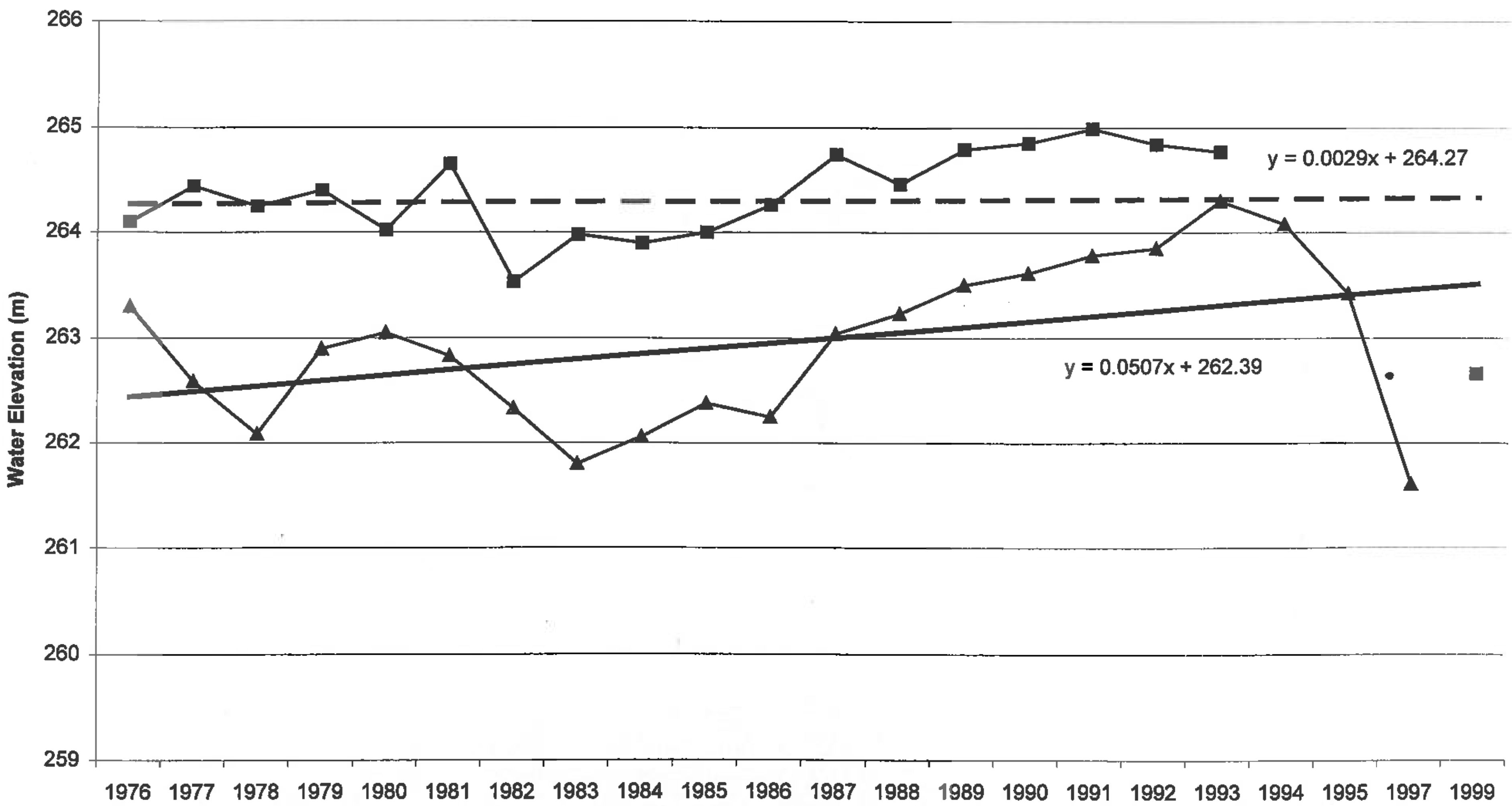
ENB16 Maximum and Minimum Yearly Elevations



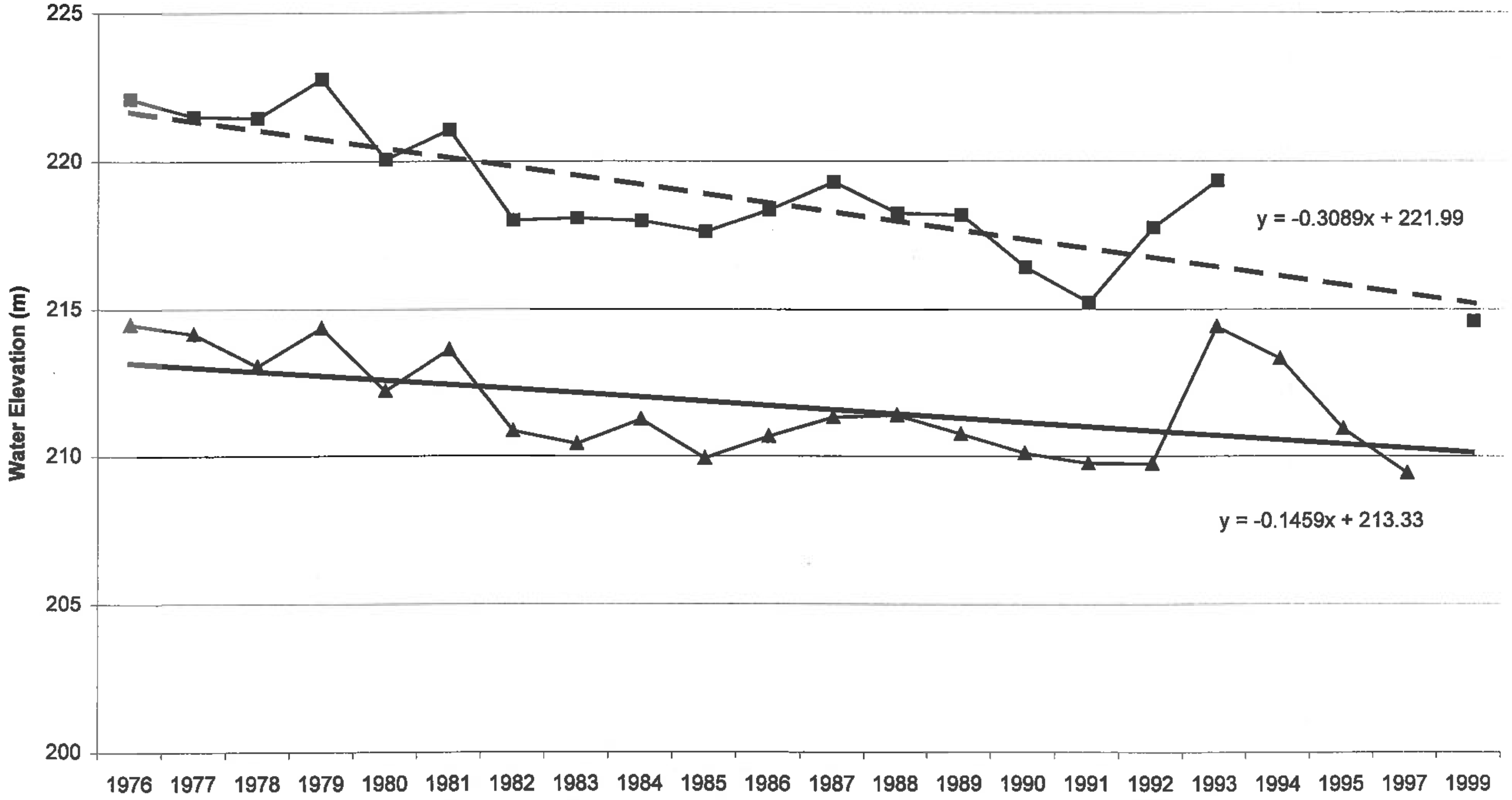
ENB17 Maximum and Minimum Yearly Elevations



ENB19 Maximum and Minimum Yearly Elevations



ENB20 Maximum and Minimum Yearly Elevations



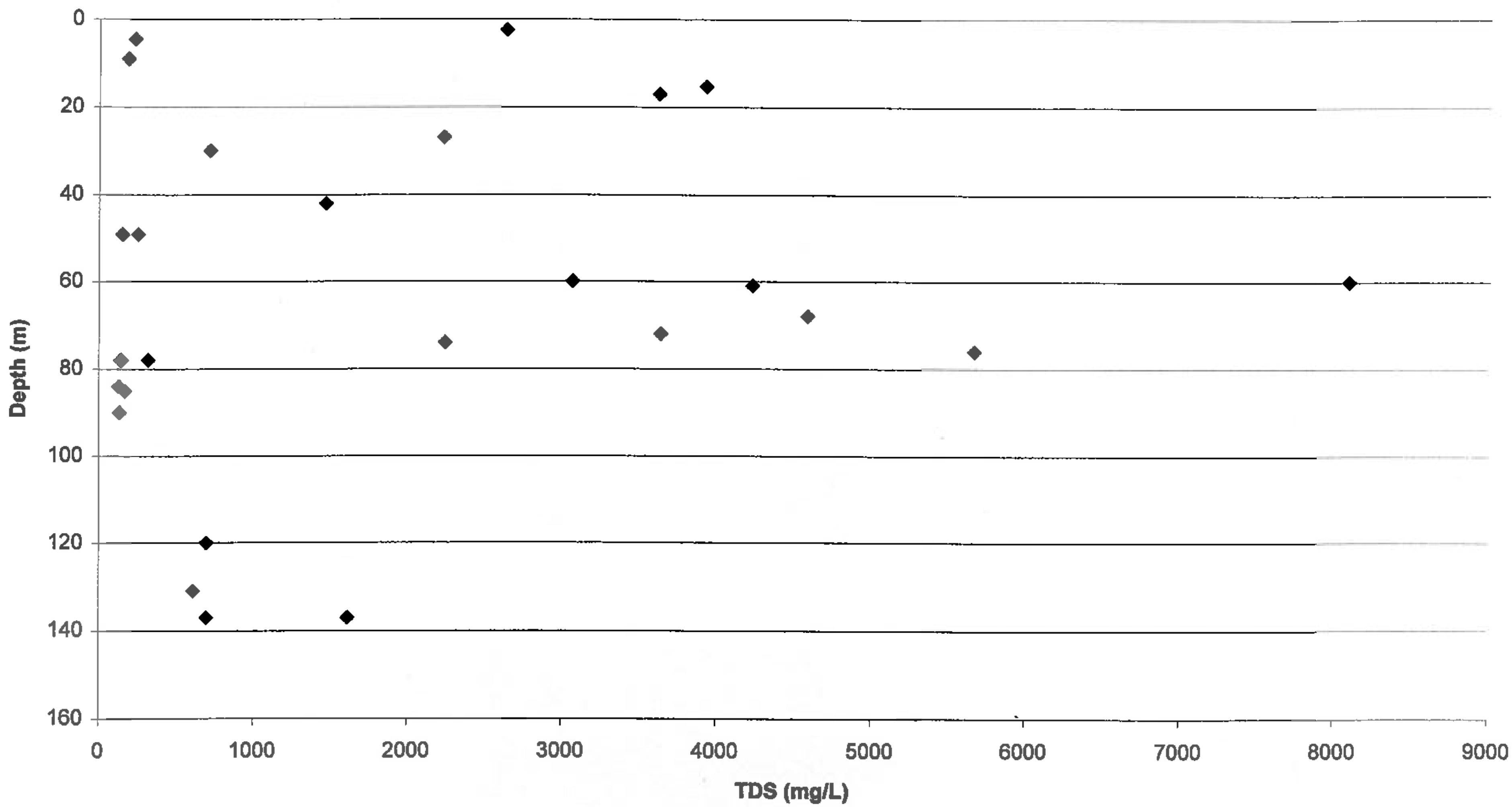
Appendix 7

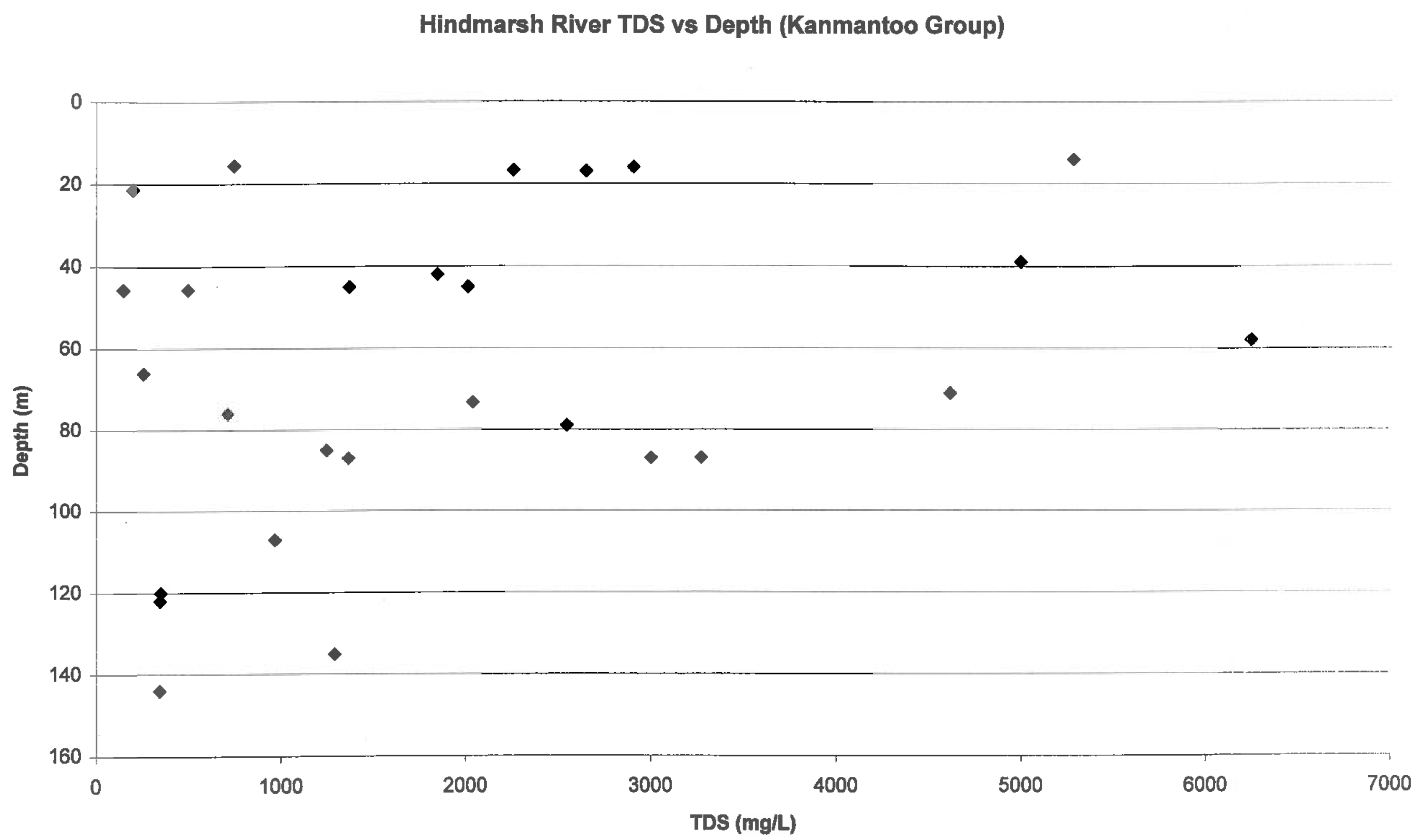
Salinity Concentrations by Depth And Geological Formation

Statistics on Salinity Concentrations on the Different Geological Formations for Each of the Study Catchments

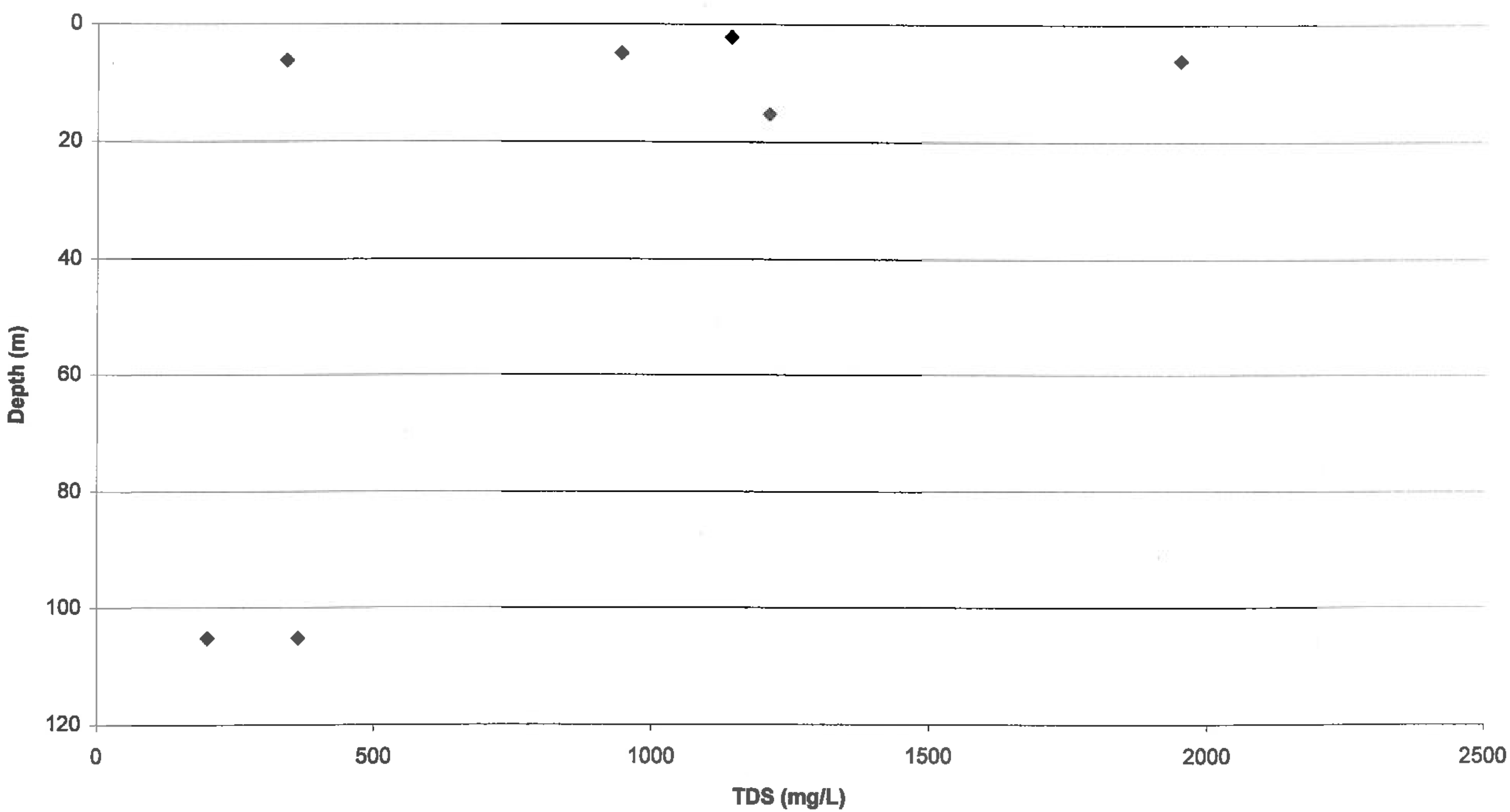
Catchment	Count of Concentrations	Minimum (mg/L)	25th Percentile (mg/L)	Median (mg/L)	75th Percentile (mg/L)	Maximum (mg/L)	Average (mg/L)
Hindmarsh River							
Cape Jervis Beds	31	127	239	1,470	3,348	8,098	1,995
Kanmantoo Group	31	145	727	1,367	2,596	6,245	1,931
Quaternary	11	200	353	1,079	1,460	1,950	1,002
Tertiary Limestone	93	187	592	715	938	2,174	787
Inman River							
Cape Jervis Beds	59	207	1,607	2,308	4,138	10,103	3,496
Kanmantoo Group	45	114	1,125	1,870	2,404	4,164	1,737
Quaternary	12	67	257	524	1,443	4,465	1,023
Currency Creek							
Cape Jervis Beds	48	98	228	1,198	2,004	4,676	1,326
Kanmantoo Group	110	99	581	1,281	2,437	5,920	1,654
Quaternary	5	115	672	1,316	1,775	1,775	1,247
Tertiary Limestone	6	1,002	1,005	1,016	1,088	1,118	1,039

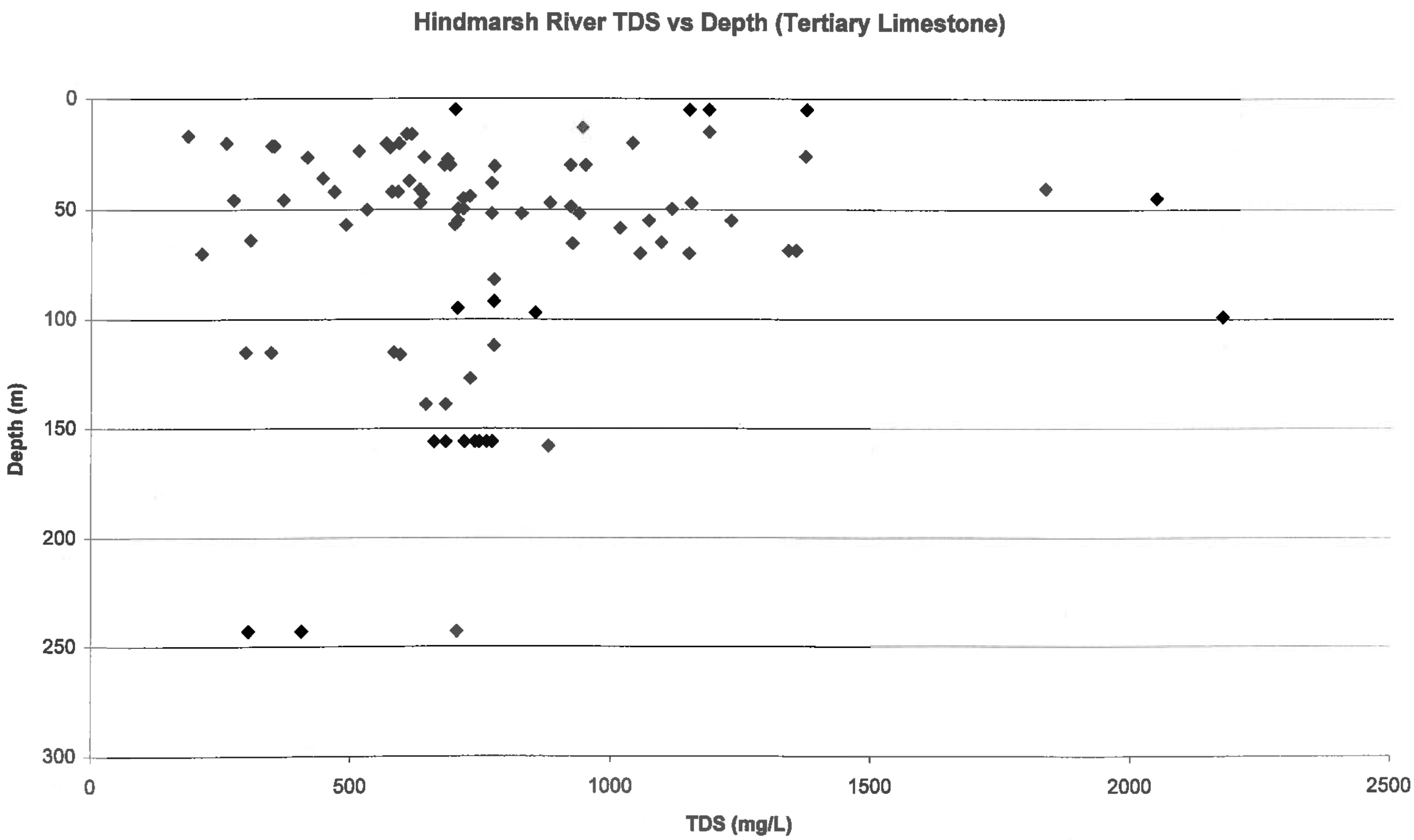
Hindmarsh River TDS vs Depth (Cape Jervis Beds)

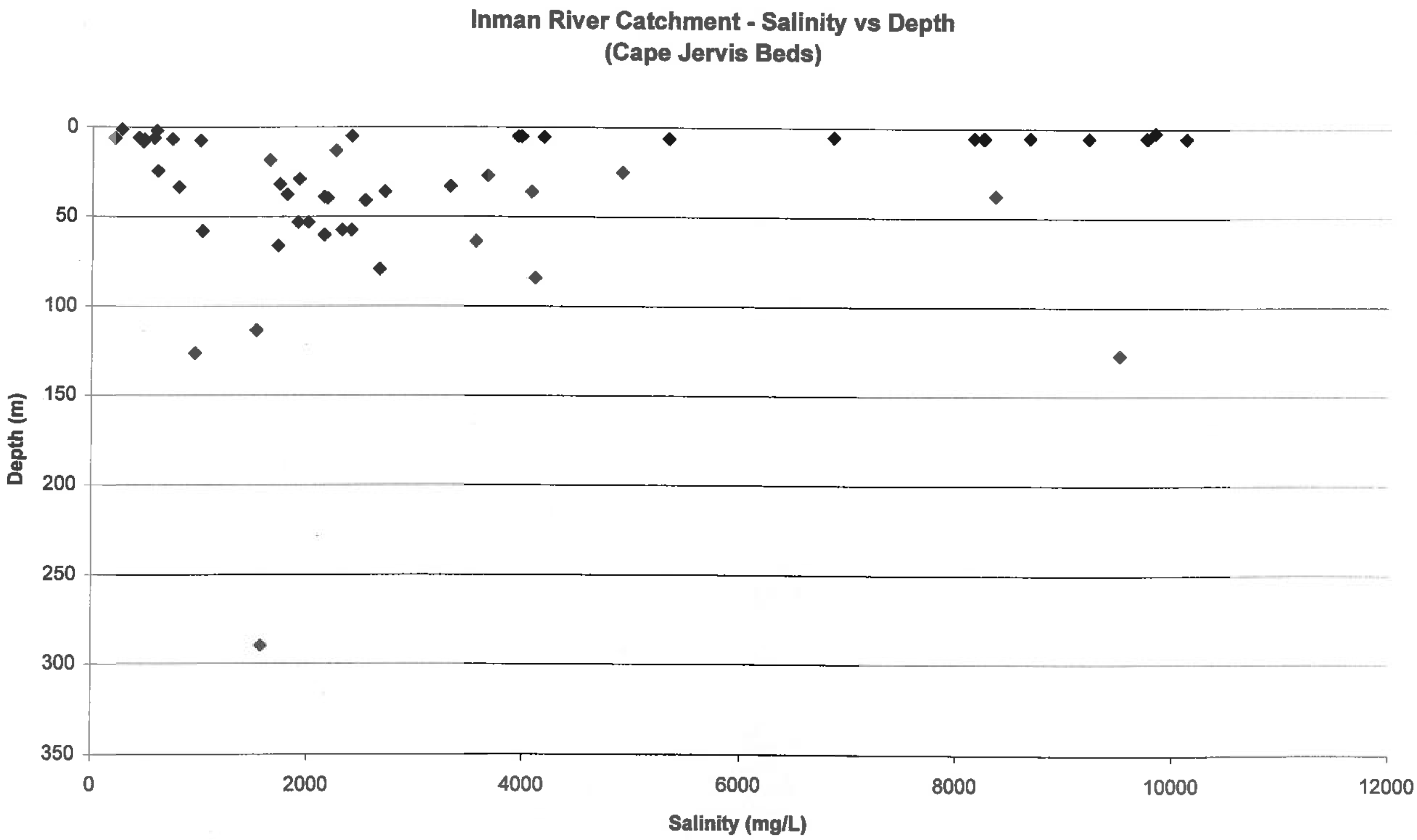



Hindmarsh River TDS vs Depth (Kanmantoo Group)
Depth (m)
0
20
40
60
80
100
120
140
160
0
1000
2000
3000
4000
5000
6000
7000
TDS (mg/L)

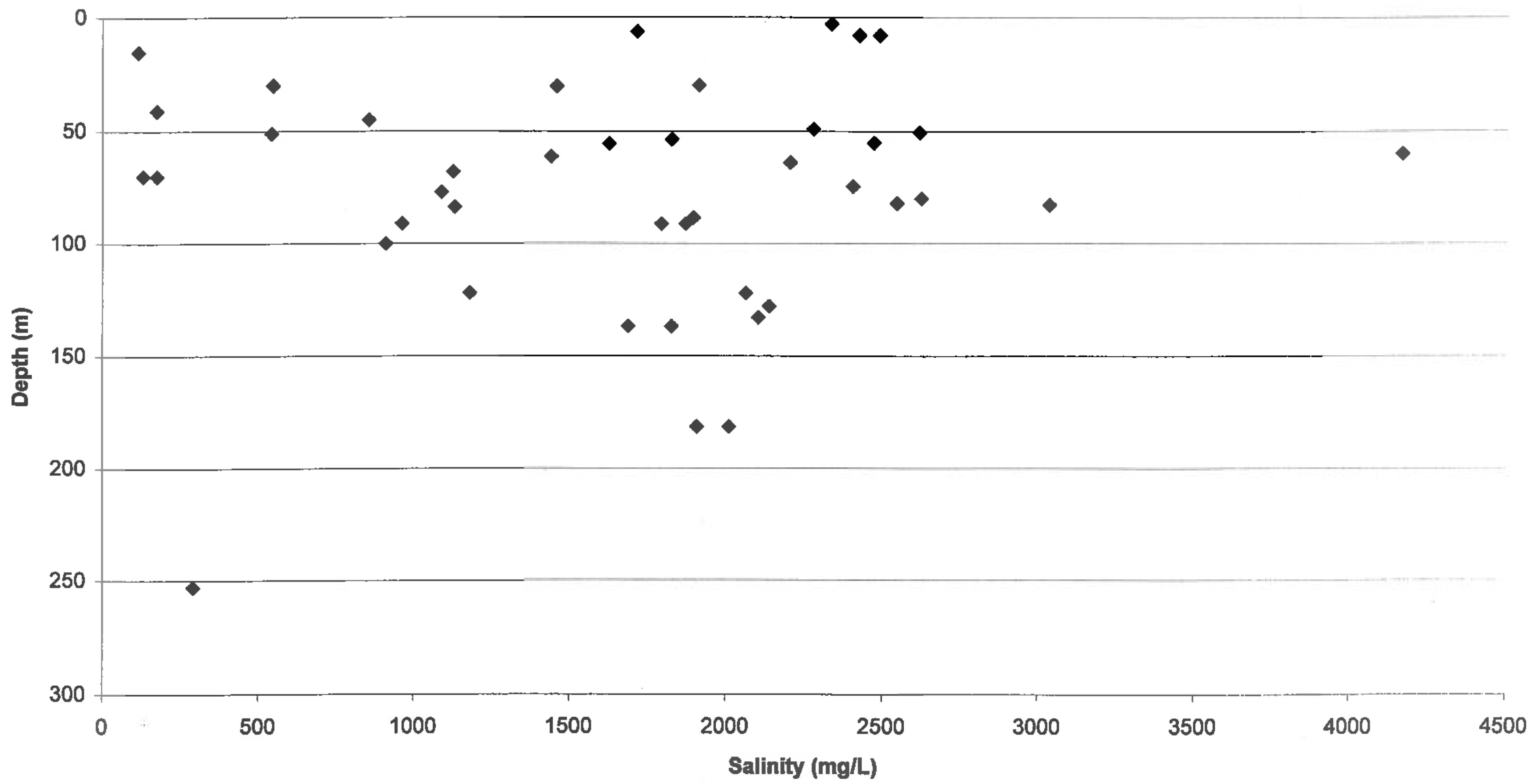
Hindmarsh River TDS vs Depth (Quaternary Alluvium)



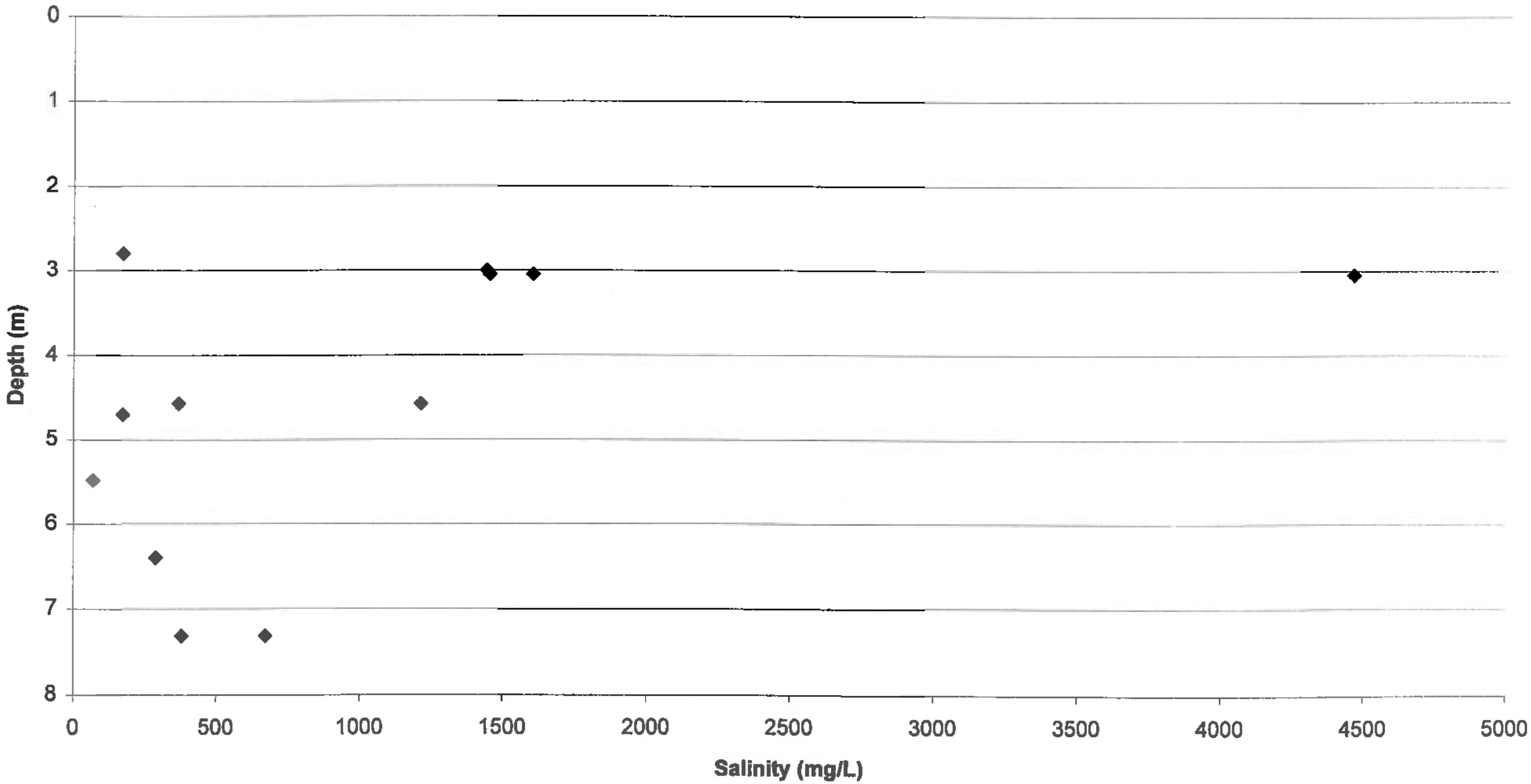

Hindmarsh River TDS vs Depth (Tertiary Limestone)
Depth (m)
0
50
100
150
200
250
300
0
500
1000
1500
2000
2500
TDS (mg/L)


Inman River Catchment - Salinity vs Depth
(Cape Jervis Beds)
Depth (m)
0
50
100
150
200
250
300
350
0
2000
4000
6000
8000
10000
12000
Salinity (mg/L)

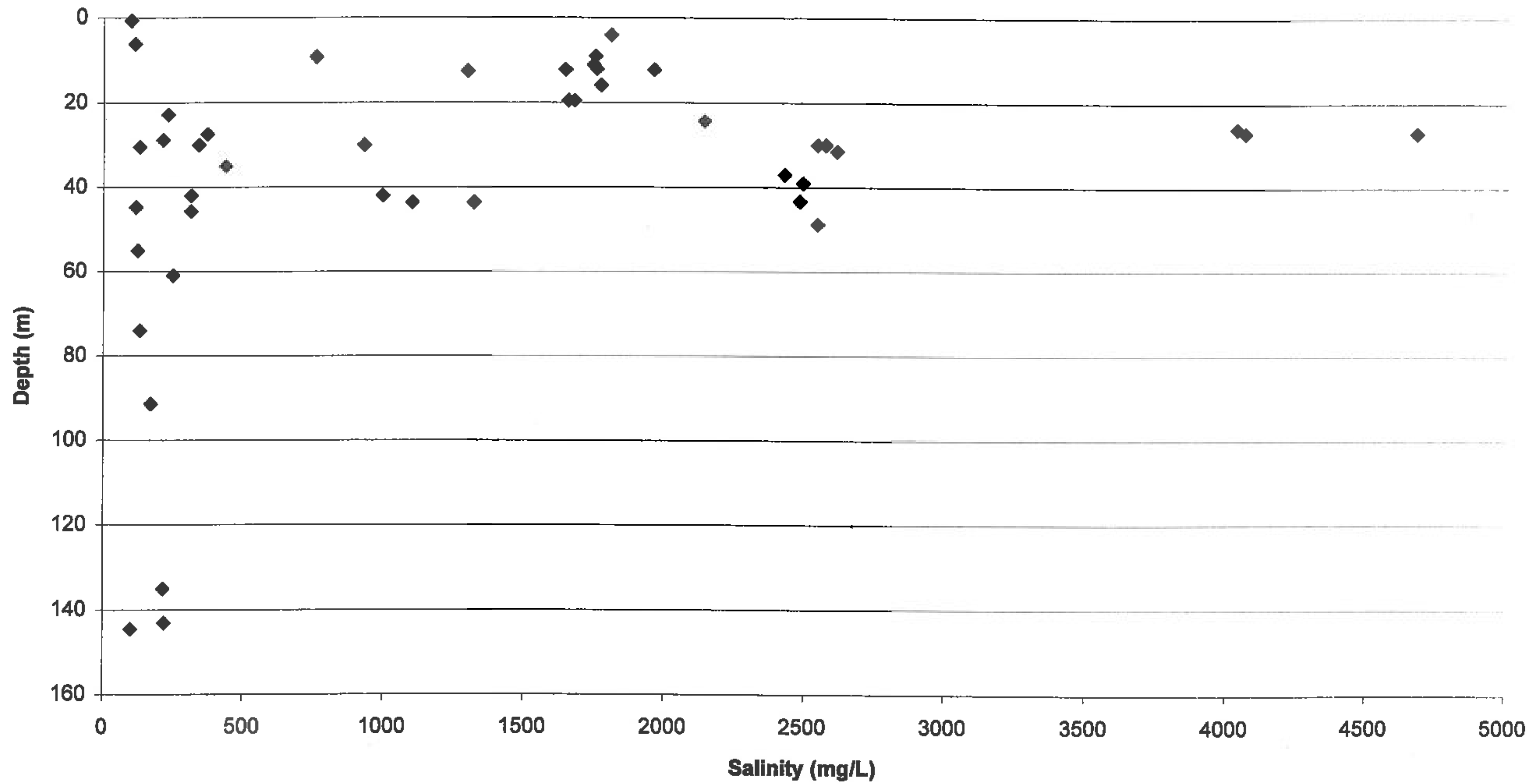
Inman River Catchment - Salinity vs Depth
(Kanmantoo Group)



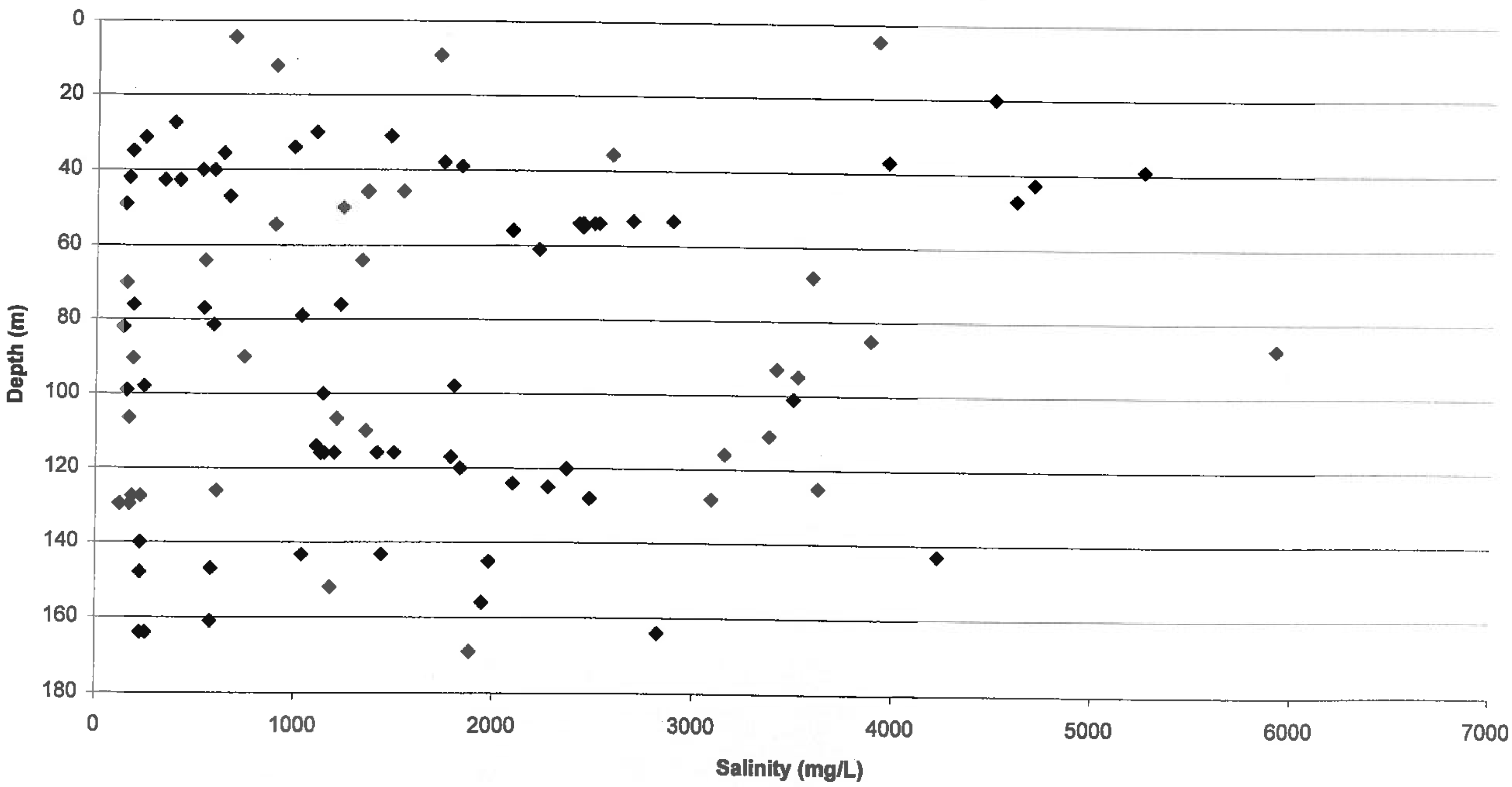
Inman River Catchment - Salinity vs Depth (Quaternary)



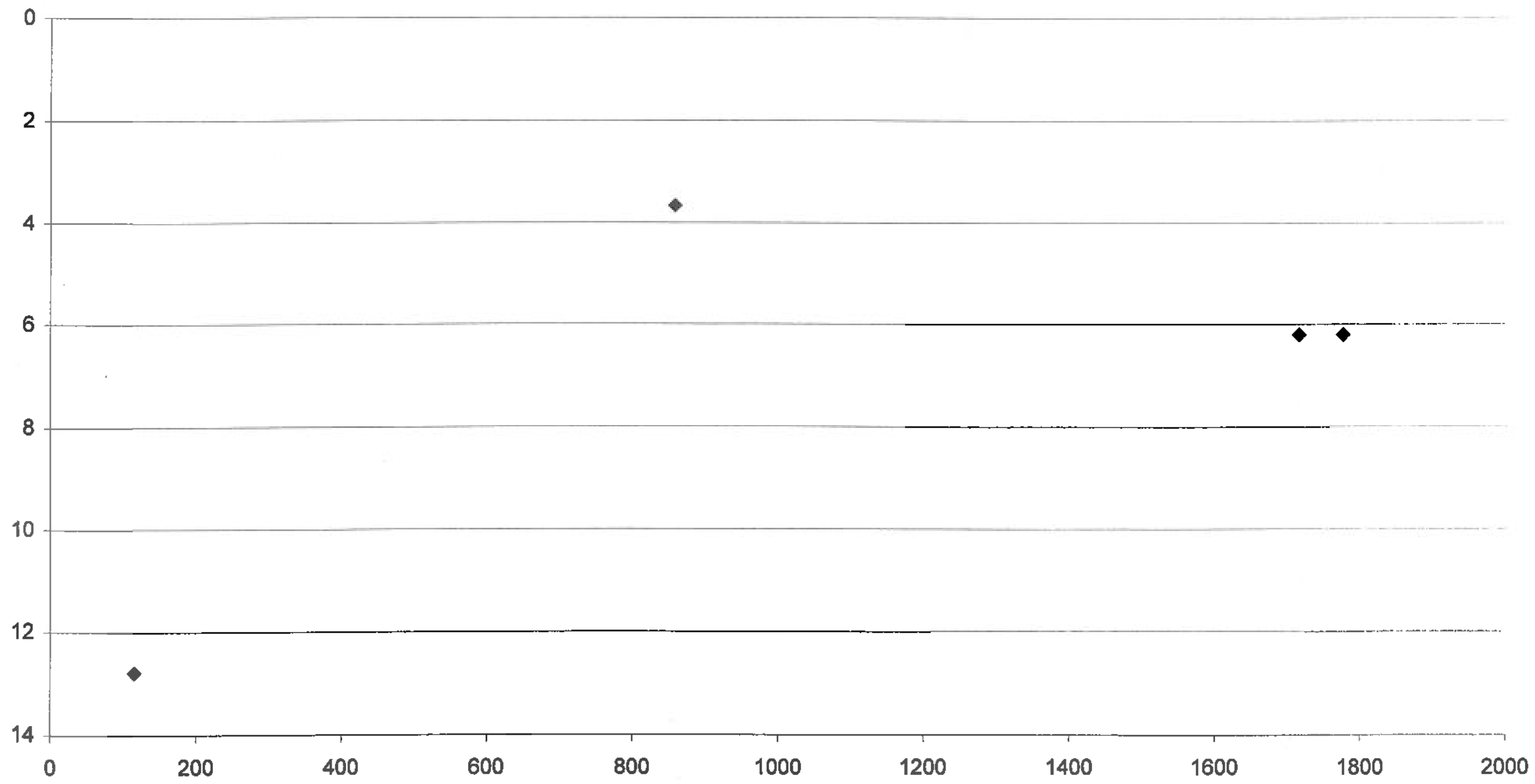
Currency Creek Catchment - Salinity vs Depth
(Cape Jervis Beds)



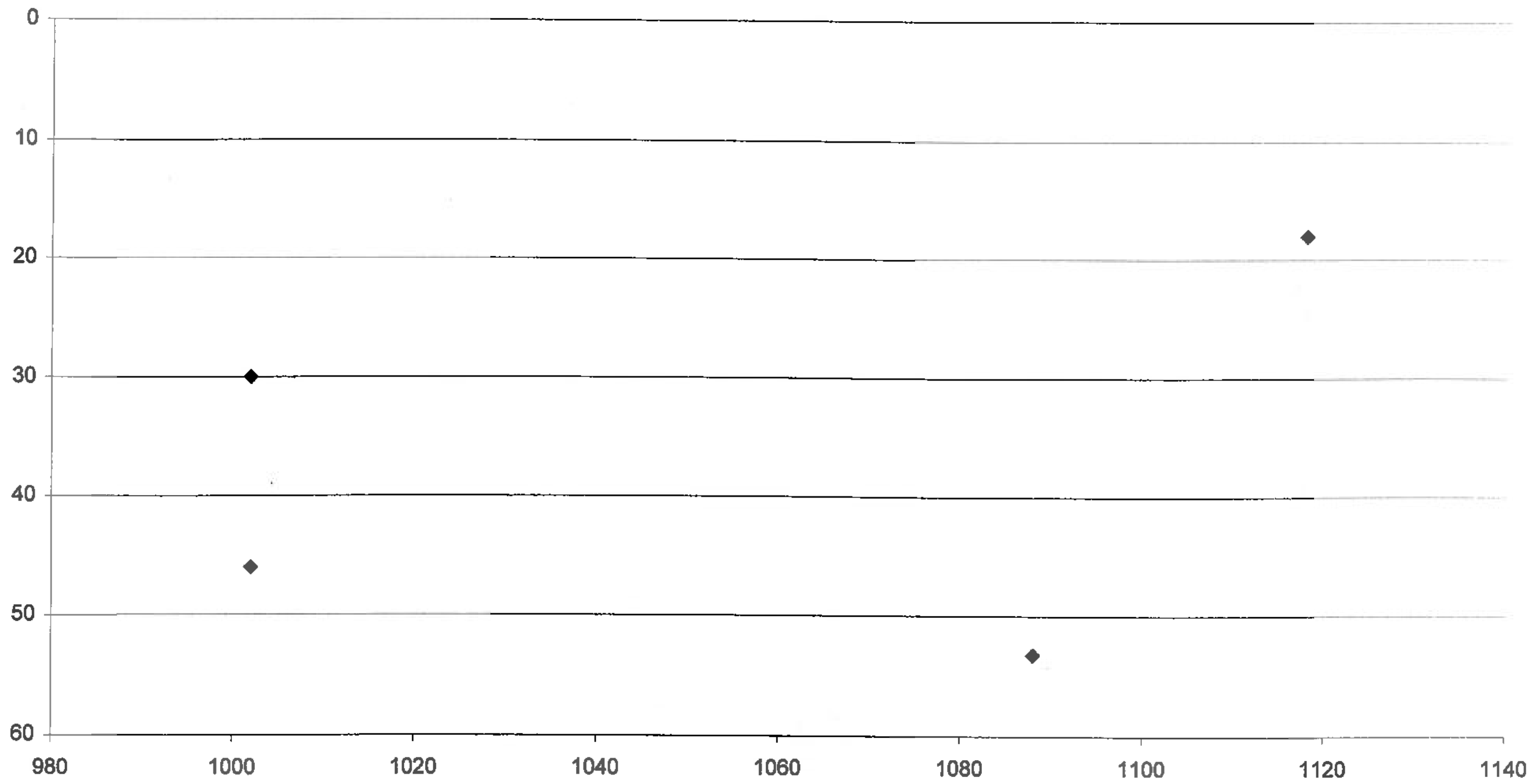
Currency Creek Catchment - Salinity vs Depth (Kanmantoo Group)



Currency Creek Catchment - Salinity vs Depth (Quaternary)



Currency Creek Catchment - Salinity vs Depth
(Tertiary Limestone)



Appendix 8

Total Dissolved Solids

(Salinity)

Total Dissolved Solids (Salinity)

The following information has been extracted from *the Australian Water Quality Guidelines for Fresh and Marine Water*, produced in November 1992 by the Australian and New Zealand Environment and Conservation Council.

" The salinity or total dissolved solids (TDS) concentration of irrigation water is an extremely important water quality consideration. AN increase in salinity causes an increase in the osmotic pressure of the soil solution, resulting in a reduced availability of water for plant consumption and possible retardation of plant growth. Table 5.6 contains the recommended guidelines for salinity in irrigation water. These guidelines are influenced by soil characteristics, crop tolerance, climate and irrigation practices."

Class	**Comment**	**Electrical Conductivity (μS/cm)**	**TDS (mg/L)**
1	Low-salinity water can be used with most crops on most soils and with all methods of water application with little likelihood that a salinity problem will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.	0-280	0-175
2	Medium-salinity water can be used if moderate leaching occurs. Plants with medium salt tolerance can be grown, usually without special measures for salinity control. Sprinkler irrigation with the more-saline waters in this group may cause leaf scorch on salt-sensitive crops, especially at high temperatures in the daytime and with low application rates.	280-800	175-500
3	High-salinity water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and the salt tolerance of the plants to be irrigated must be considered.	800-2300	500-1500
4	Ver high-salinity water is not suitable for irrigation water under ordinary conditions. For use, soil must be permeable, drainage adequate, water must be applied in excess to provide considerable leaching and salt-tolerant crops should be selected	2300-5500	1500-3500
5	Extremely high-salinity water may be used only on permeable, well-drained soils under good management, especially in relation to leaching and for salt-tolerant crops, or for occasional emergency use	>5500	>3500

Salinity Tolerances of Livestock (mg/L) (Solomon and Ashton, 1997)

Animal	Maximum concentration for growth or lactation	Maximum concentration to maintain condition	Maximum concentration tolerated
Sheep	6,000	13,000	*
Beef cattle	4,000	5,000	10,000
Dairy cattle	3,000	4,000	6,000
Horses	4,000	6,000	7,000
Pigs	2,000	3,000	4,000
Poultry	2,000	3,000	3,500

* Maximum levels depends on the type of feed

Appendix 9

Monthly Rainfall Statistics For Rain Gauge Stations In the Study Catchments

Table 1. Monthly Rainfall Statistics for the Hindmarsh River Catchment Rain Gauge Stations. All values are in mm.

Fernbrook Station 23823													
	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Average	31.8	29.8	31.7	72.1	102.2	114.8	135.7	112.5	87.3	67.9	43.4	36.9	864.2
Median	21.9	20.2	21.1	60.2	94.0	107.6	125.0	116.3	82.1	62.1	37.0	28.0	892.9
Minimum	1.0	0.0	0.4	3.0	29.2	23.8	38.4	21.1	26.4	11.0	2.4	5.6	482.9
Maximum	259.6	172.5	113.6	200.5	231.9	250.0	289.6	207.8	189.4	171.6	121.7	156.2	1344.0
Standard Deviation	39.6	32.5	30.2	46.6	52.0	55.8	58.7	46.1	38.8	38.2	26.8	26.6	180.7
Cv	1.2	1.1	1.0	0.6	0.5	0.5	0.4	0.4	0.4	0.6	0.6	0.7	0.2
Springmount Station 23824													
	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Average	27.1	26.5	37.4	76.5	101.6	127.0	138.5	125.1	93.9	71.2	43.3	39.6	905.9
Median	18.2	18.4	29.0	64.8	94.0	124.5	132.3	124.0	89.7	64.0	39.4	31.6	928.8
Minimum	1.3	0.0	0.0	0.0	15.7	33.0	40.6	36.8	17.8	15.5	1.0	6.1	529.9
Maximum	107.2	147.0	125.4	226.1	244.1	272.5	288.4	250.8	218.6	203.3	125.5	143.6	1370.1
Standard Deviation	23.9	30.5	31.0	52.4	53.7	57.6	60.6	51.7	41.8	40.8	25.6	29.5	195.1
Cv	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0
Hindmarsh Valley Station 23760													
	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Average	26.8	20.1	29.2	54.9	78.9	101.6	96.5	83.0	76.5	53.4	33.6	25.8	680.0
Median	19.3	10.9	18.6	42.7	74.8	92.7	91.6	83.3	73.0	49.8	27.2	19.0	674.3
Minimum	0.0	0.0	0.3	0.0	15.1	23.6	36.1	9.9	22.7	6.4	2.0	0.0	416.0
Maximum	291.6	96.2	170.6	171.5	215.9	238.3	198.7	158.1	156.3	119.4	95.3	69.6	939.2
Standard Deviation	40.4	22.4	30.3	36.9	41.8	51.0	37.1	33.2	34.2	26.4	22.4	18.8	125.1
Cv	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0

Table 2. Monthly Rainfall Statistics for the Inman River Catchment Rain Gauge Stations. All values are in mm.

Rivington Grange Station 23743													
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Average	24.6	27.7	27.0	54.3	79.2	95.3	106.2	90.1	76.0	56.4	36.6	31.5	704.1
Median	14.9	15.6	18.6	41.1	73.4	90.9	101.4	87.4	74.4	54.8	30.3	29.7	700.2
Minimum	0.0	0.0	0.2	0.3	14.5	16.6	32.5	11.2	21.4	8.2	2.8	1.5	394.3
Maximum	214.8	174.1	116.6	210.1	177.6	225.9	237.9	162.0	151.2	149.8	105.4	118.6	1066.6
Standard Deviation	31.9	32.2	23.2	40.2	39.0	46.2	40.4	36.8	32.9	29.5	23.2	20.6	133.9
Coefficient of Variation (C_v)	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0
Yankalilla Station 23723													
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Average	26.5	25.4	26.2	64.2	86.4	99.5	114.3	99.1	76.4	61.4	38.8	33.1	751.2
Median	16.1	16.0	17.5	53.7	80.4	95.6	104.5	102.6	74.3	57.1	31.1	25.1	749.7
Minimum	1.6	0.0	0.4	1.8	18.1	26.2	34.3	21.4	19.4	10.8	3.2	0.0	466.6
Maximum	205.6	185.4	101.2	231.8	209.7	197.2	287.6	184.4	171.9	157.8	121.2	118.2	1105.6
Standard Deviation	32.4	30.4	25.2	45.4	44.9	44.0	51.6	38.7	36.2	34.4	25.0	24.2	145.9
Coefficient of Variation (C_v)	1.2	1.2	1.0	0.7	0.5	0.4	0.5	0.4	0.5	0.6	0.6	0.7	0.2
Victor Harbour Station 23751													
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Average	21.1	19.4	23.0	43.0	60.9	71.3	74.9	67.1	56.3	44.9	28.1	24.2	535.7
Median	11.8	13.0	16.3	31.1	53.0	68.0	72.1	65.3	53.8	44.2	22.9	18.8	530.8
Minimum	0.0	0.0	0.0	0.0	10.1	8.7	20.6	12.8	7.8	4.5	0.0	0.0	271.3
Maximum	208.0	144.7	119.7	157.5	166.1	178.7	180.0	128.4	136.0	111.6	102.8	112.8	868.9
Standard Deviation	28.6	22.1	22.6	32.6	33.0	36.3	31.0	26.4	25.9	23.4	20.2	18.4	112.1
Coefficient of Variation (C_v)	1.4	1.1	1.0	0.8	0.5	0.5	0.4	0.4	0.5	0.5	0.7	0.8	0.2

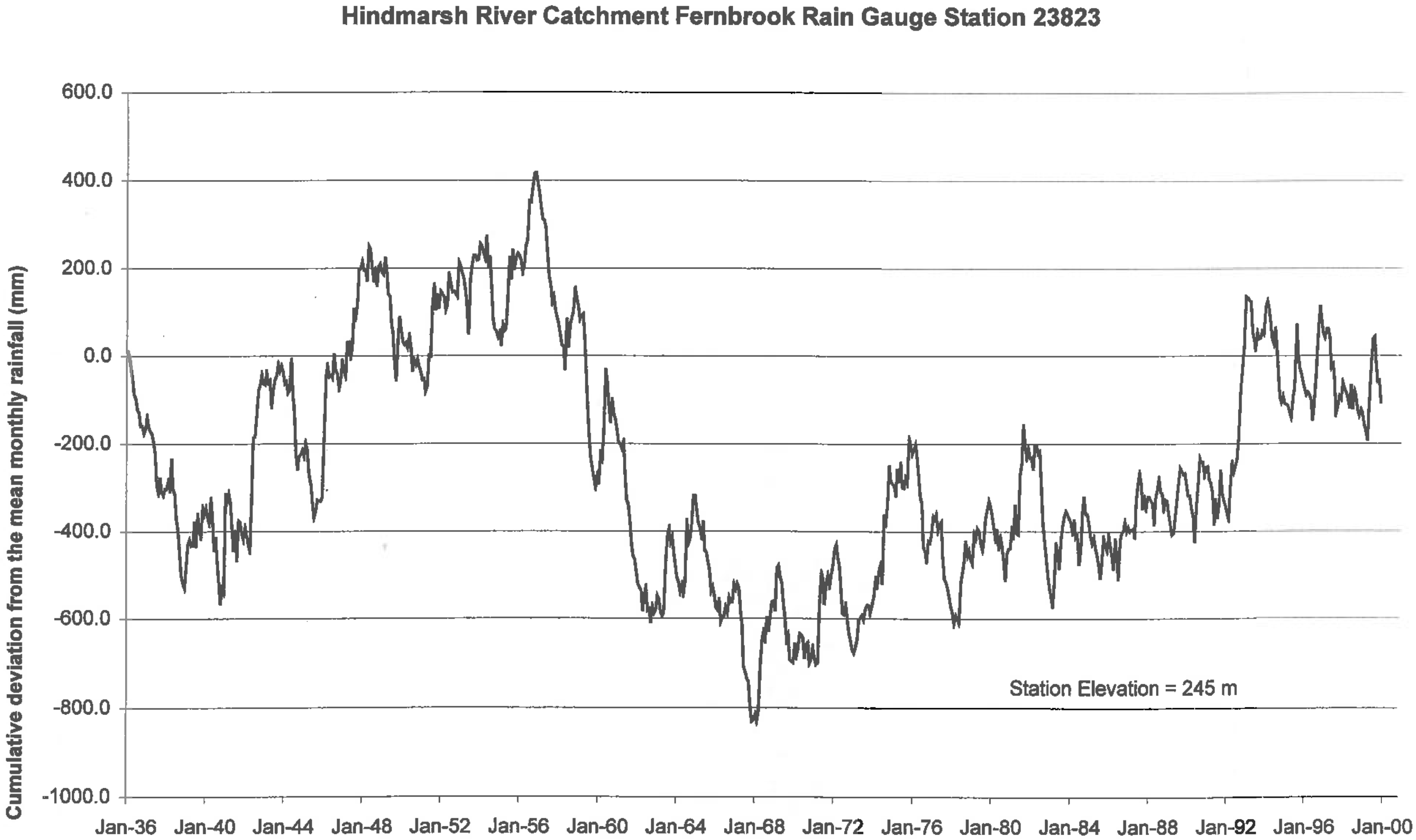
Willow Creek Station 23762													
	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Average	28.8	25.7	39.5	78.2	96.8	109.3	128.7	115.5	83.6	67.1	35.9	34.6	843.7
Median	18.1	16.7	32.5	67.3	91.0	99.6	127.3	116.7	79.5	65.8	31.4	29.1	854.1
Minimum	2.6	0.0	0.0	4.0	24.7	24.8	24.8	28.1	27.4	20.1	4.4	9.3	540.0
Maximum	90.9	115.6	100.0	209.0	204.1	226.8	307.1	200.6	161.4	158.8	122.7	106.2	1105.0
Standard Deviation	26.4	30.2	27.5	49.7	42.6	53.8	55.0	40.4	33.8	36.2	23.5	22.2	172.1
Coefficient of Variation (C_v)	0.9	1.2	0.7	0.6	0.4	0.5	0.4	0.3	0.4	0.5	0.7	0.6	0.2

Table 3. Monthly Rainfall Statistics for the Currency Creek Catchment Rain Gauge Stations. All values are in mm.

Mount Compass - Marshall Brae Station 23838													
	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Average	22.0	15.1	34.9	55.6	73.1	99.7	128.0	105.6	78.9	54.8	33.9	36.1	760.0
Median	21.2	13.8	22.4	49.9	64.2	100.2	136.2	111.4	71.8	48.0	35.0	22.8	752.4
Minimum	4.6	0.0	1.2	1.4	26.6	16.8	36.6	24.6	21.8	9.8	1.4	9.0	440.4
Maximum	71.4	70.2	152.2	117.0	126.2	210.6	224.2	176.4	181.6	110.6	76.8	148.8	1163.8
Standard Deviation	16.5	16.6	39.1	35.3	30.1	48.5	47.1	48.2	44.5	27.8	19.7	33.2	161.5
Coefficient of Variation (C_v)	0.7	1.1	1.1	0.6	0.4	0.5	0.4	0.5	0.6	0.5	0.6	0.9	0.2
Berrima Station 23834													
	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Average	19.9	13.6	39.1	56.6	74.6	107.4	118.4	100.3	85.1	50.7	38.6	33.0	703.6
Median	16.4	12.0	26.4	48.9	65.0	102.0	128.0	96.3	74.0	53.8	34.0	24.8	737.0
Minimum	0.0	0.0	0.0	0.0	29.0	43.5	41.0	32.0	23.8	11.2	0.0	0.0	71.1
Maximum	89.4	29.2	127.0	136.6	143.9	211.0	212.2	164.6	189.8	79.2	87.2	94.8	1064.3
Standard Deviation	19.8	9.0	36.7	40.0	32.9	40.3	46.1	43.9	43.3	20.9	27.2	29.0	211.8
Coefficient of Variation (C_v)	1.0	0.7	0.9	0.7	0.4	0.4	0.4	0.4	0.5	0.4	0.7	0.9	0.3
Mount Jagged Station 23777													
	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**
Average	19.9	34.6	56.6	69.1	103.5	154.1	139.4	107.1	117.3	74.8	51.4	37.8	962.0
Median	15.9	18.8	36.6	57.3	81.1	162.7	125.9	112.4	119.8	71.5	40.7	27.6	945.9
Minimum	0.9	2.5	12.4	13.6	29.2	36.2	75.7	18.6	33.4	8.9	9.9	0.0	578.5
Maximum	80.8	133.8	237.3	161.6	211.0	331.4	235.4	166.7	188.7	153.6	132.6	80.2	1306.2
Standard Deviation	19.0	39.5	57.0	44.0	59.5	73.8	49.6	43.7	52.2	35.6	36.0	25.4	224.7
Coefficient of Variation (C_v)	1.0	1.1	1.0	0.6	0.6	0.5	0.4	0.4	0.4	0.5	0.7	0.7	0.2

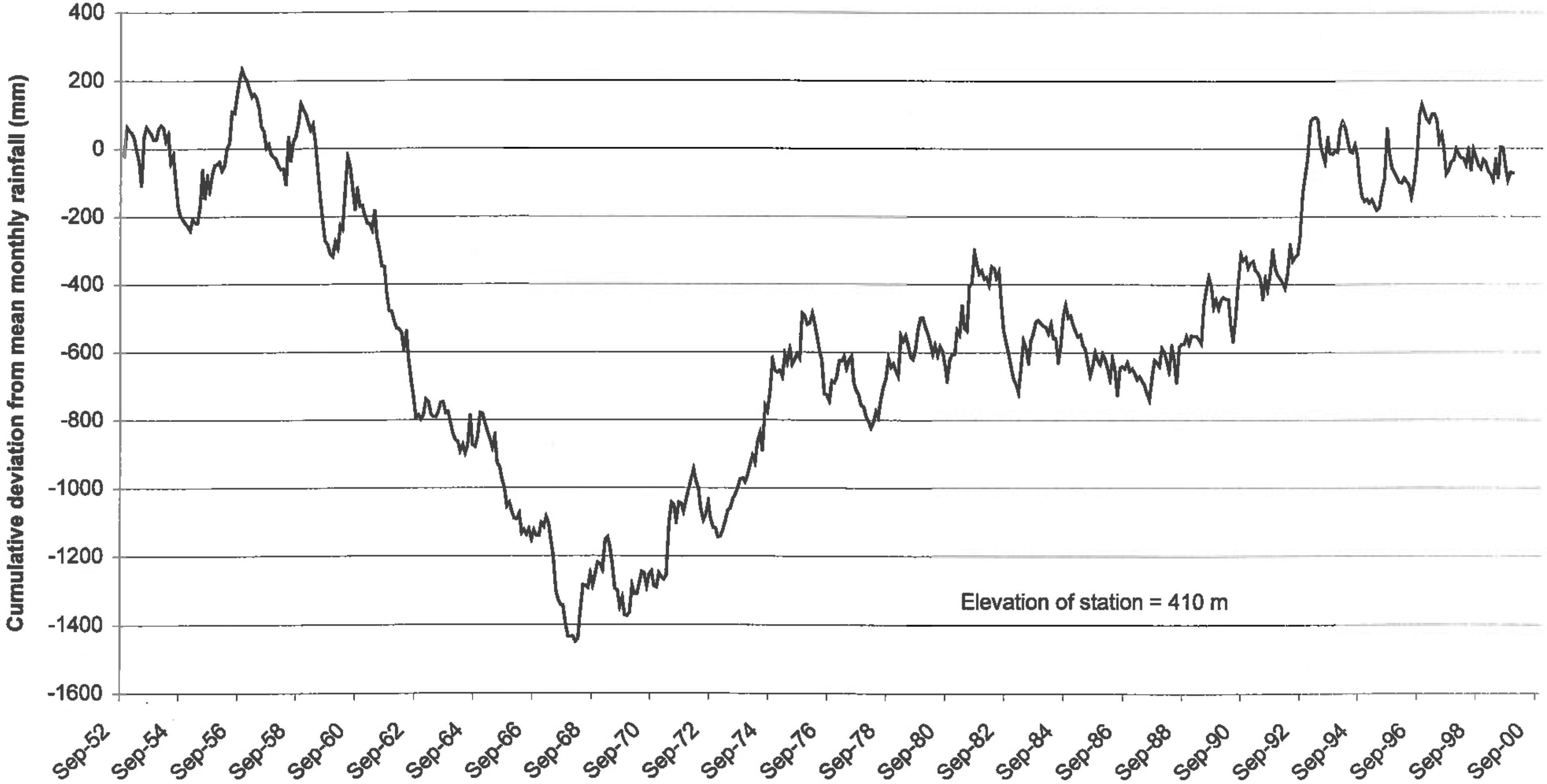
Appendix 10

Cumulative Deviations From Mean Monthly Rainfall For Rain Gauge Stations In the Study Catchments

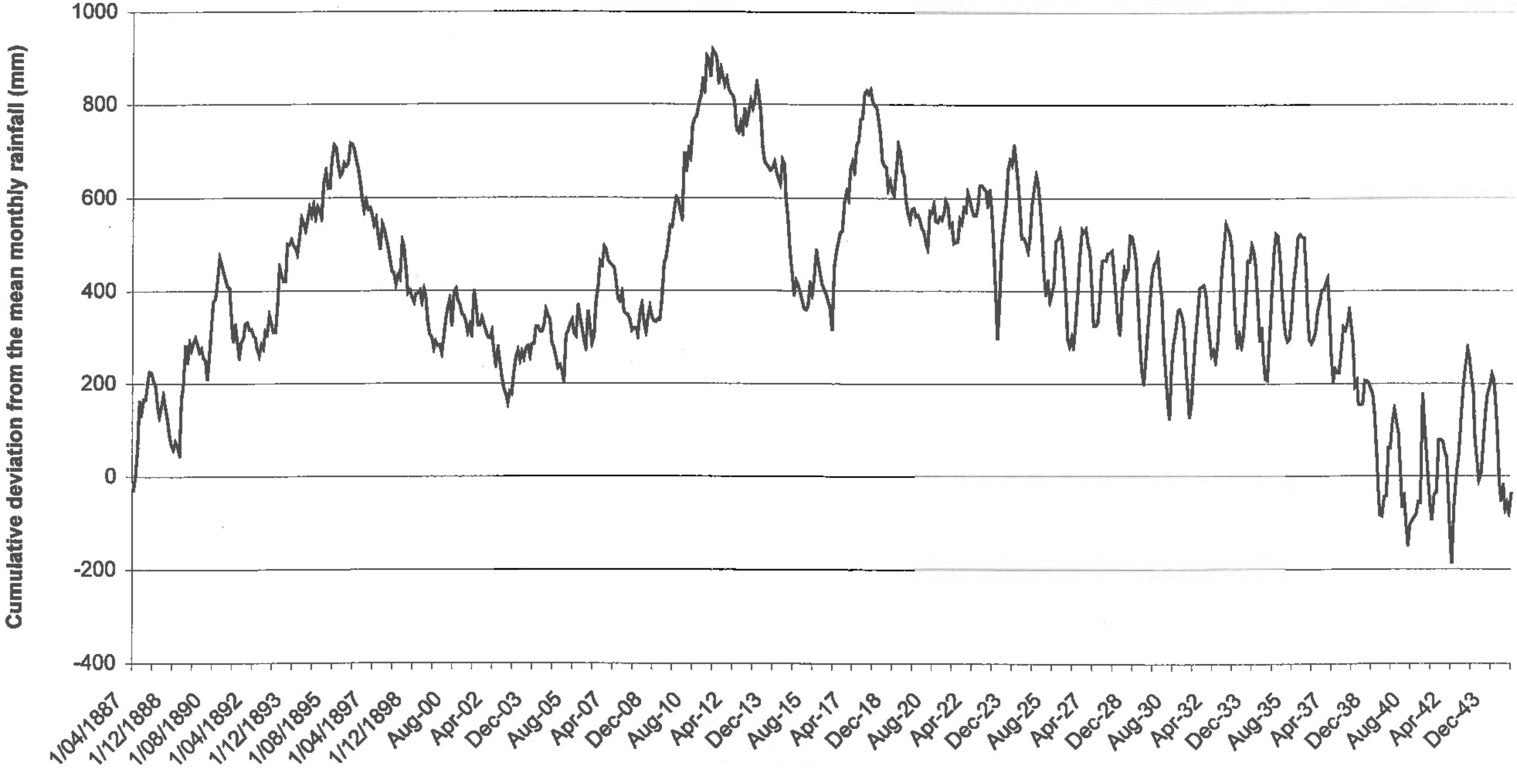


Hindmarsh River Catchment Fernbrook Rain Gauge Station 23823
Cumulative deviation from the mean monthly rainfall (mm)
600.0
400.0
200.0
0.0
-200.0
-400.0
-600.0
-800.0
-1000.0
Jan-36
Jan-40
Jan-44
Jan-48
Jan-52
Jan-56
Jan-60
Jan-64
Jan-68
Jan-72
Jan-76
Jan-80
Jan-84
Jan-88
Jan-92
Jan-96
Jan-00
Station Elevation = 245 m

Hindmarsh River Catchment
Springmount Rain Gauge Station 23824

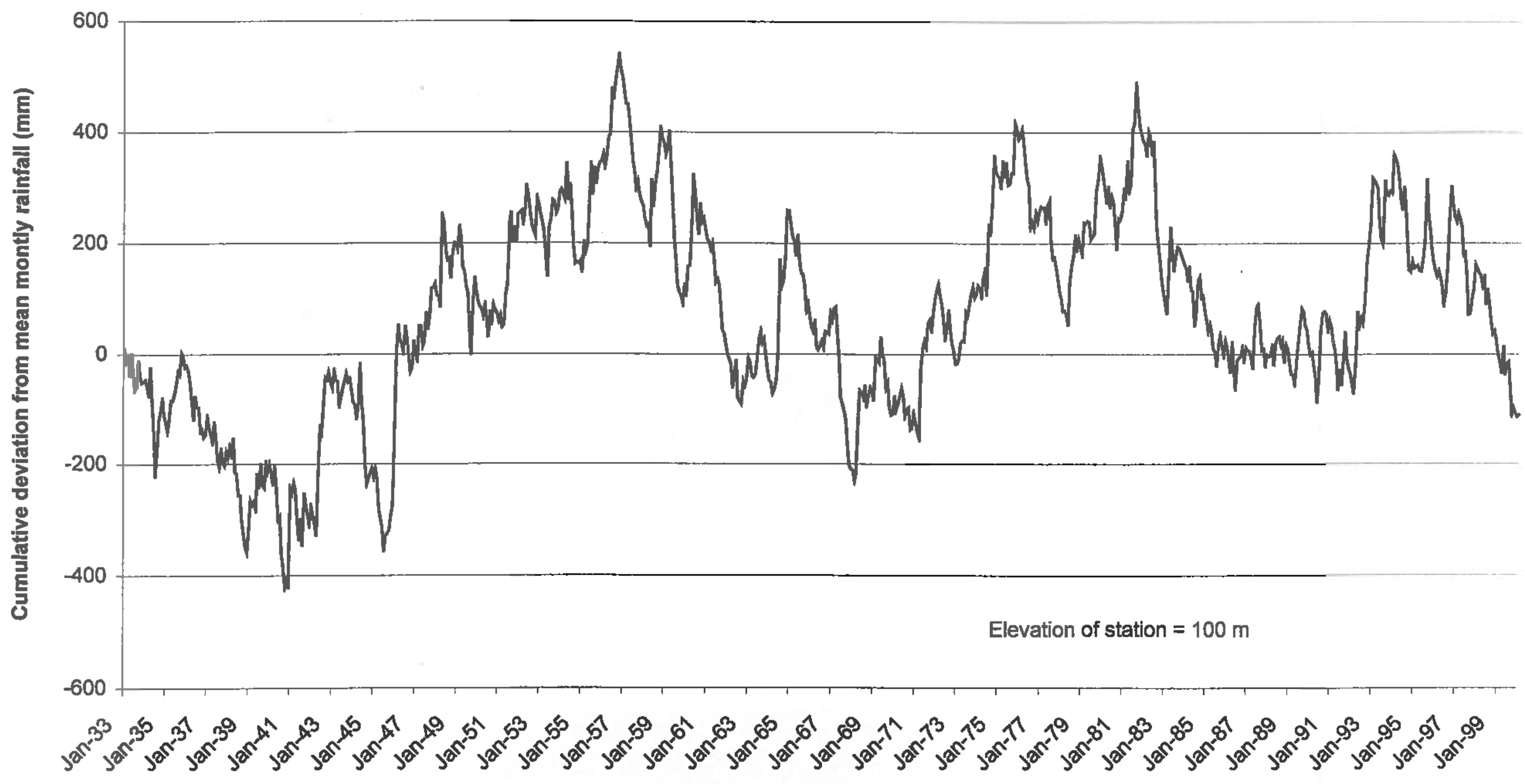


Hindmarsh River Catchment
Hindmarsh Valley Rain Gauge Station 23760

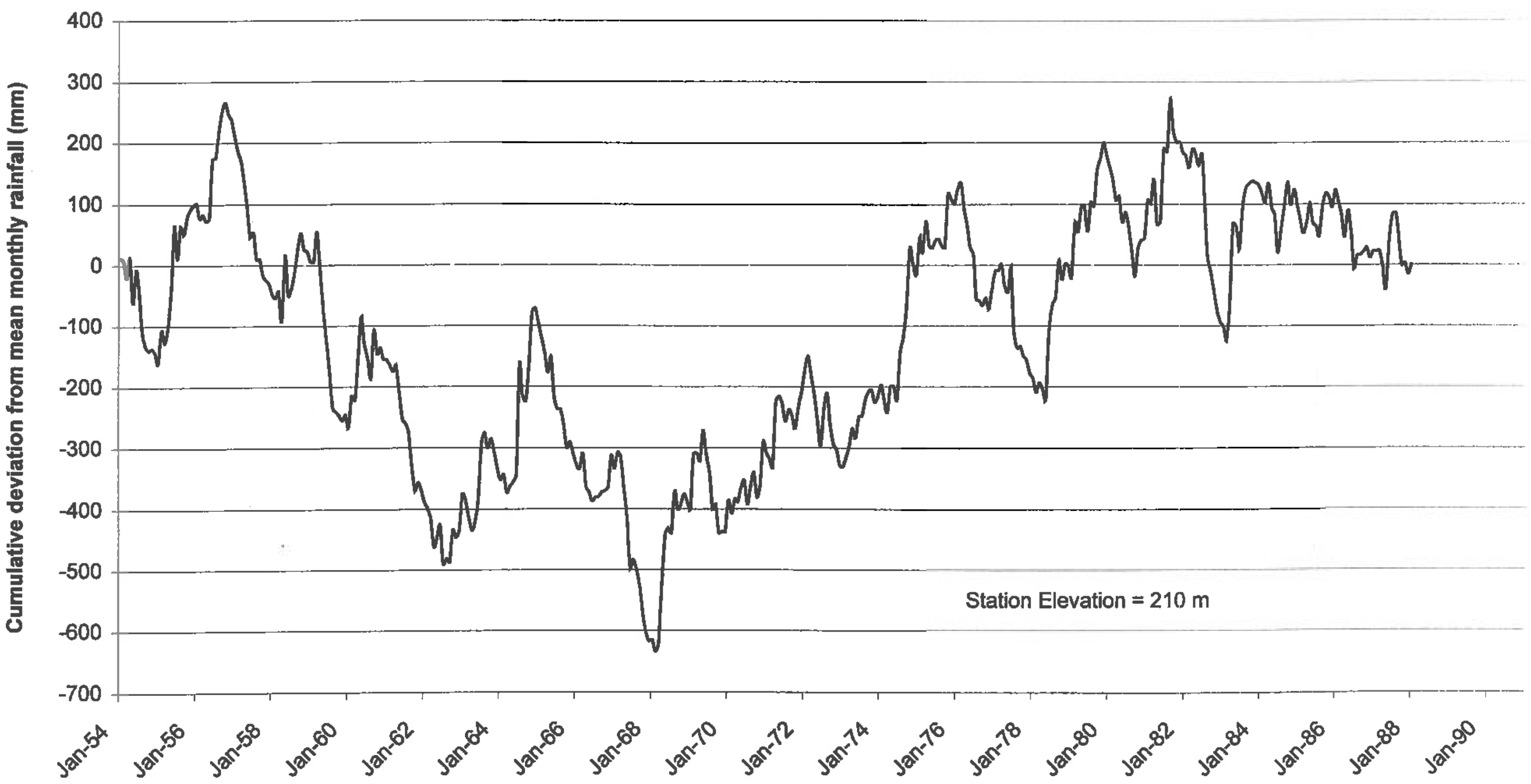


Inman River Catchment
Rivington Grange Rain Gauge Station 23743

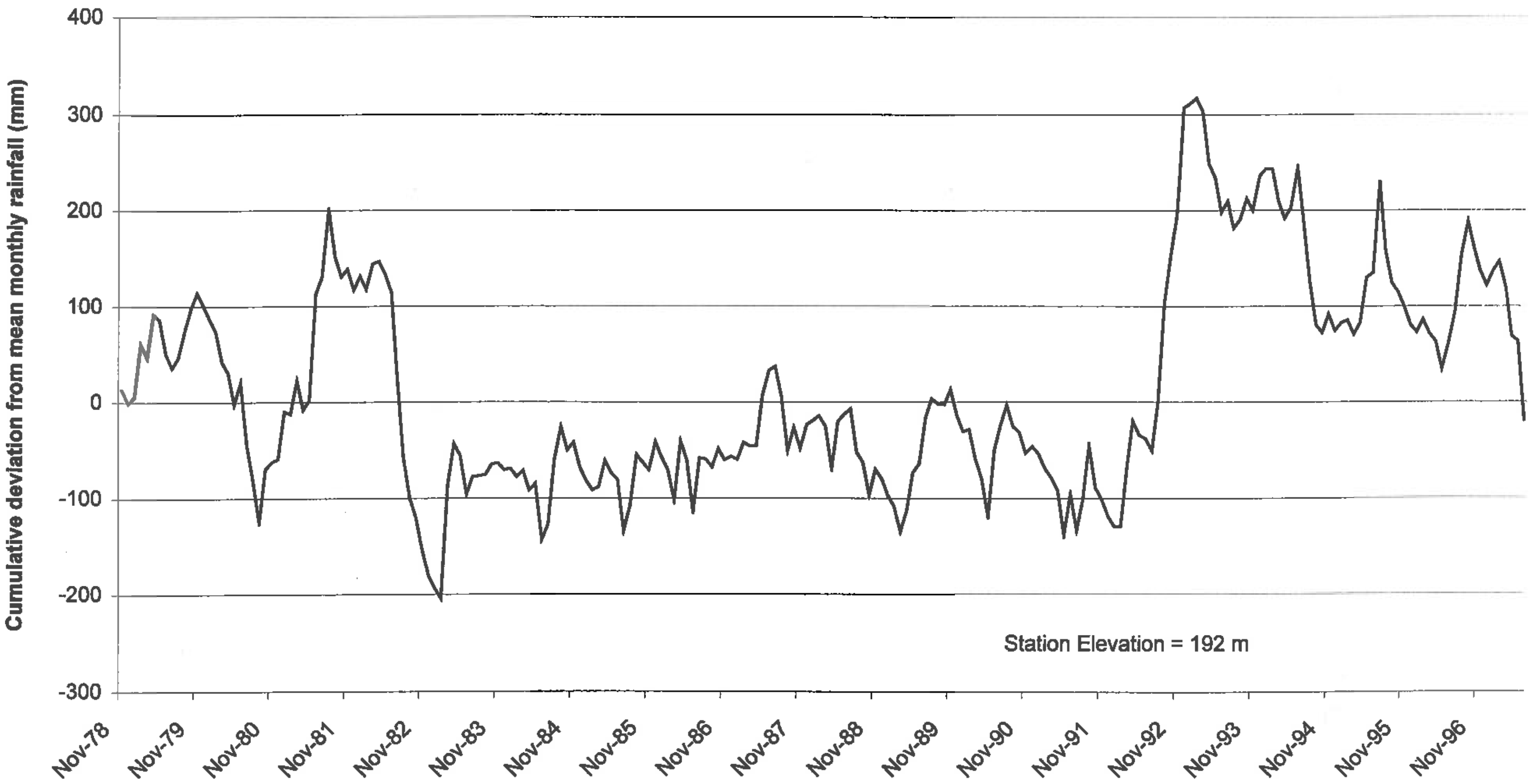
Inman River Catchment
Yankalilla Rain Gauge Station 23723

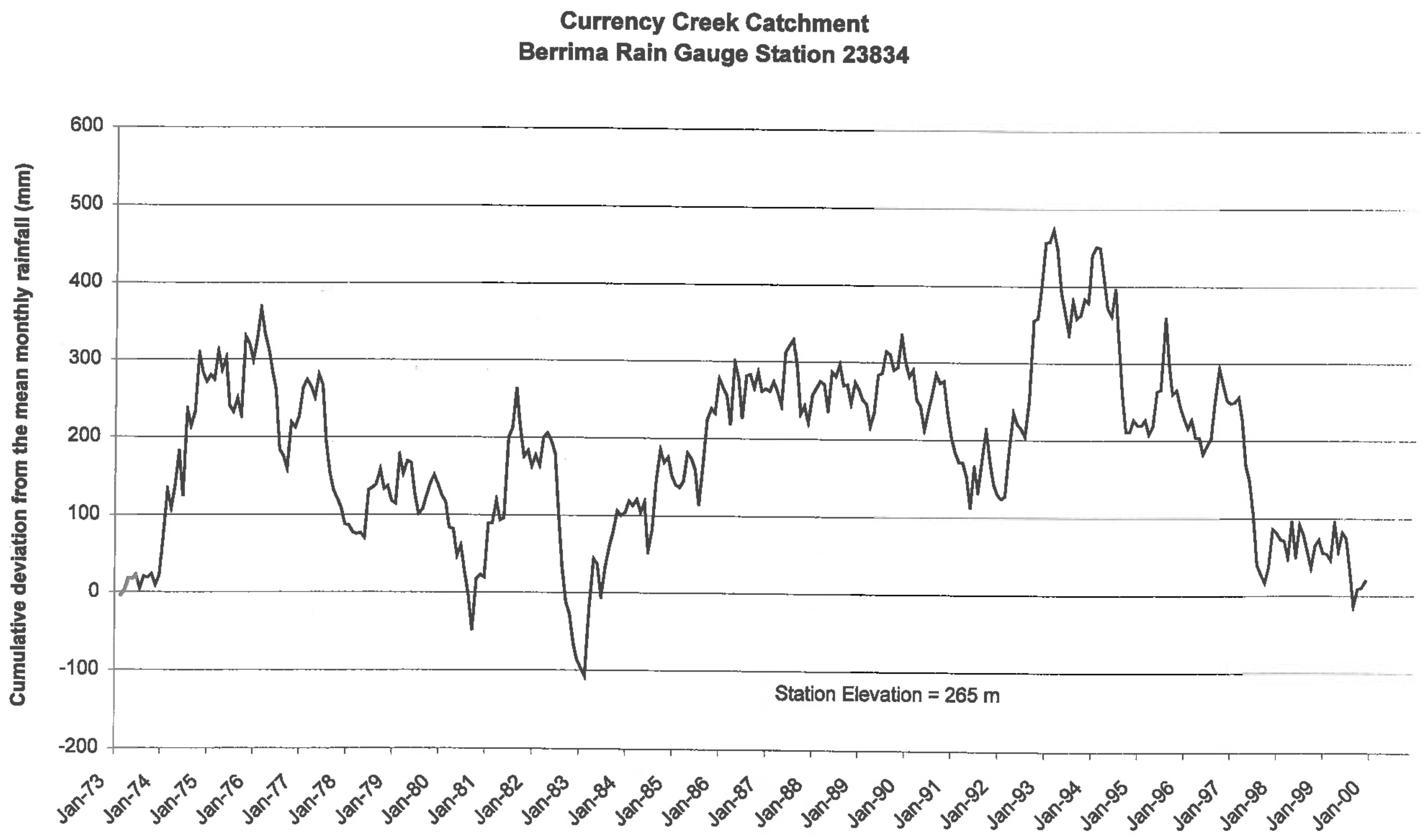


Inman River Catchment
Willow Creek Rain Gauge Station 23762

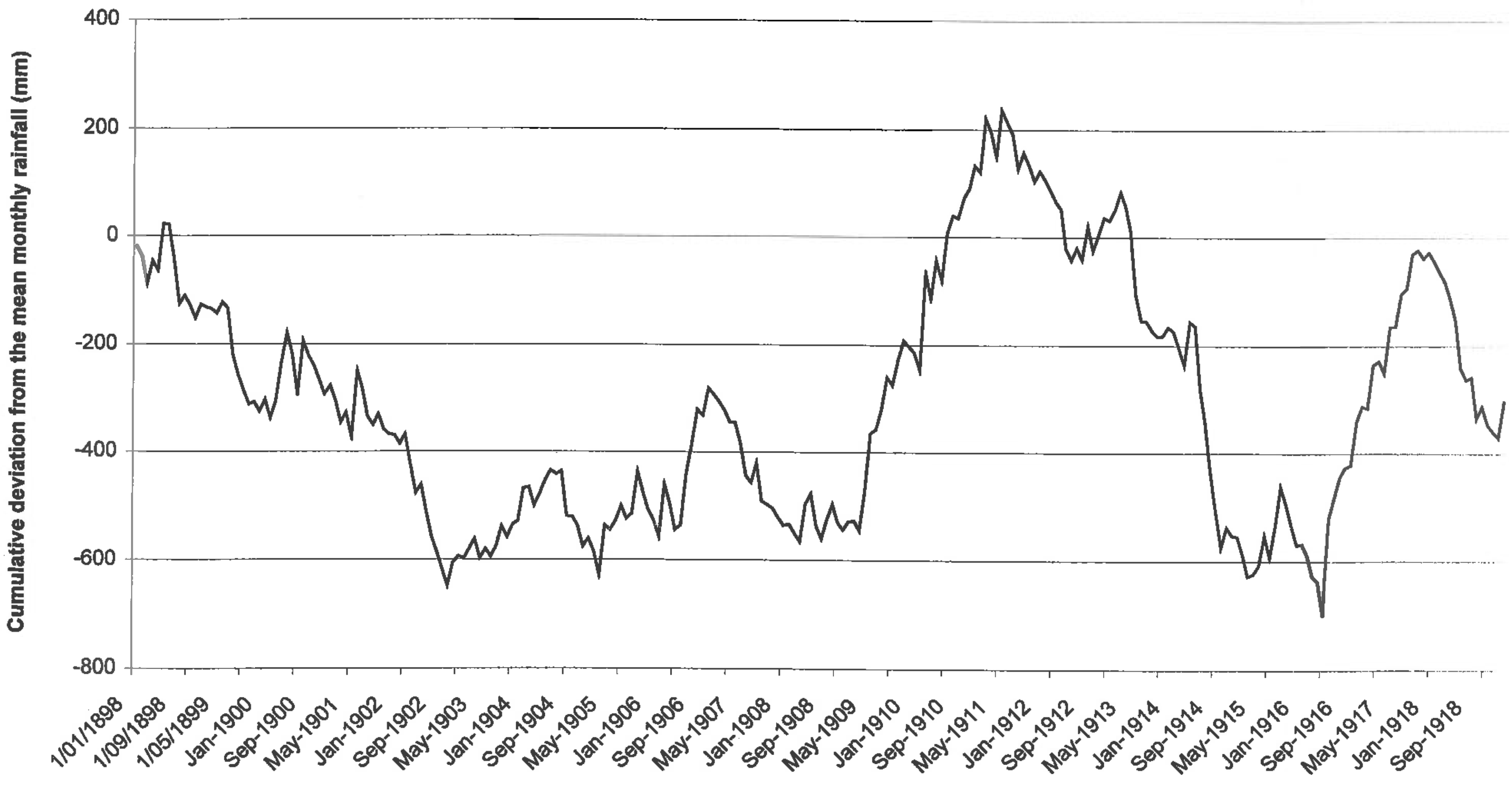


Currency Creek Catchment
Mount Compass - Marshall Brae Rain Gauge Station 23838




Currency Creek Catchment
Berrima Rain Gauge Station 23834
Cumulative deviation from the mean monthly rainfall (mm)
600
500
400
300
200
100
0
-100
-200
Station Elevation = 265 m
Jan-73
Jan-74
Jan-75
Jan-76
Jan-77
Jan-78
Jan-79
Jan-80
Jan-81
Jan-82
Jan-83
Jan-84
Jan-85
Jan-86
Jan-87
Jan-88
Jan-89
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
Jan-98
Jan-99
Jan-00

Currency Creek Catchment
Mount Jagged Rain Gauge Station 23777



Appendix 11

Summary statistics for Stream Gauge Stations In the Study Catchments

Table 1. Summary statistics for stream gauge station 501500 (Hindmarsh River Catchment). Data record used for this analysis was from June 1992 to November 1999. All results are in ML and no patching was done.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Average	74	33	46	64	238	707	2,107	1,746	1,371	782	248	394	6,741
Median	19	16	24	53	197	774	1,751	1,172	997	543	173	37	6,098
Maximum	286	125	186	123	526	983	6,068	5,440	4,773	2,836	838	2,264	11,428
Minimum	7	6	9	25	91	254	277	647	237	263	89	18	3,549
Standard deviation	105	42	68	38	163	265	1,891	1,713	1,575	895	264	831	3,362
Coefficicent of Variation (C_v)	1.42	1.29	1.40	0.54	0.76	0.39	0.84	0.90	1.11	1.05	1.01	2.11	0.50

Table 2. Summary statistics for stream gauge station 501503 (Inman River Catchment). Data record used for this analysis was from February 1995 to December 1999. All results are in ML and no patching was done.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Average	26	14	16	28	116	487	2,408	2,559	1,416	597	217	47	7,925
Median	23	12	16	24	113	374	1,181	1,494	1,127	352	132	36	4,412
Maximum	46	22	22	39	159	908	6,797	7,380	3,448	1,513	573	83	15,975
Minimum	11	10	12	13	78	203	237	489	556	278	92	20	3,456
Standard deviation	6	1	1	3	29	198	1,222	986	576	170	130	6	1,997
Coefficicent of Variation (C_v)	0.22	0.10	0.06	0.12	0.25	0.41	0.51	0.39	0.41	0.28	0.60	0.12	0.29

Table 3. Summary statistics for stream gauge station 426530 (Currency Creek Catchment). Data record used for this analysis was from January 1972 to January 1998 (patched dataset was used for this analysis). All results are in ML.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Average	30	20	32	75	180	505	1,558	1,626	1,101	530	119	131	5,908
Median	16	12	27	62	129	364	1,486	1,574	868	334	83	26	5,868
Maximum	182	129	116	231	452	1,915	4,220	3,650	4,197	2,266	476	2,346	14,425
Minimum	1	0*	3	23	56	91	179	161	88	53	9	5	1,003
Standard deviation	39	26	28	43	106	414	1,195	1,022	941	620	110	454	3,114
Coefficicent of Variation (C_v)	1.30	1.27	0.87	0.57	0.59	0.82	0.77	0.63	0.85	1.17	0.93	3.47	0.53

* patched value - lowest measured monthly streamflow in February was 5.0 ML

Appendix 12

Farm Dam Distributions And Volumes For the Study Catchments

Table 1. Distribution and volumes of farm dams in the Hindmarsh River Catchment.

Size Class	Number	Volume	Adjusted Volume
<0.5 ML	62	19	37
0.5-2 ML	52	48	72
2-5 ML	12	44	48
5-10ML	7	47	49
10-20ML	6	81	85
20-50ML	2	44	47
>50 ML	0		
Total	**142**	**283**	**338**

Table 2. Distribution and volumes of farm dams in the Inman River Catchment.

Size Class	Number	Volume	Adjusted Volume
<0.5 ML	88	28	55
0.5-2 ML	81	74	111
2-5 ML	20	56	62
5-10ML	7	44	46
10-20ML	12	166	174
20-50ML	5	163	171
>50 ML	3	264	277
Total	**216**	**794**	**896**

Table 3. Distribution and volumes of farm dams in the Currency Creek Catchment.

Size Class	Number	Volume	Adjusted Volume
<0.5 ML	56	18	36
0.5-2 ML	55	57	86
2-5 ML	25	74	81
5-10ML	8	65	68
10-20ML	6	86	90
20-50ML	2	71	75
>50 ML	2	209	220
Total	**154**	**580**	**656**

Appendix 13

Field Survey Results For the Study Catchments

Table 1. Field survey results for Hindmarsh River Catchment.

Irrigator	Property Section No.	Source of Irrigation Water	Geological Formation	Type of Crop Irrigated	# ha	Annual Irrigation Volume (ML)	Application Rate (ML/ha)
HR1	627	6627 8401	Kanmantoo Group	pasture	6.1	10.9	1.7
HR1	627	6627 7226	Kanmantoo Group	pasture		21.8	3.3
HR2		5 bores - unknown bore unit numbers	Tertiary Limestone	pasture	40.5	466.5	11.5
HR4	628	6627 223	Tertiary Limestone	pasture	25.0	98.3	3.7
HR5	134	6627 8040	Kanmantoo Group	pasture	5.0	24.5	4.6
HR6	38	6627 6813	Tertiary Limestone	pasture	17.5	196.0	10.5
HR6	42	6627 276	Cape Jervis Beds	pasture		98.0	5.2
HR7	57	6627 9387	Cape Jervis Beds	pasture	20.2	108.9	5.0
HR7	57	6627 9386	Cape Jervis Beds	pasture		43.5	2.0
HR9	706	6627 269	Tertiary Limestone	pasture	60.0	147.0	2.3
HR9	98	unknown bore unit number	Tertiary Limestone	pasture		293.9	4.0
HR9	98	unknown bore unit number	Tertiary Limestone	pasture	67.8	191.1	2.6
HR9	38	unknown bore unit number	Tertiary Limestone	pasture		293.9	4.9
HR9	38	unknown bore unit number	Tertiary Limestone	pasture	55.8	147.0	2.5
HR10	108	6627 9978	Cape Jervis Beds	pasture	12.0	176.4	14.7
HR10	108	6627 291	Cape Jervis Beds	pasture	8.0	78.4	9.8
HR11	41	6627 214	Tertiary Limestone	pasture	45.0	442.3	9.2

Irrigator	Property Section No.	Source of Irrigation Water	Geological Formation	Type of Crop Irrigated	# ha	Annual Irrigation Volume (ML)	Application Rate (ML/ha)
HR11	97	6627 8664	Tertiary Limestone	pasture	25.0	318.4	11.9
HR12	705	6627 8188	Tertiary Limestone	pasture		339.7	6.5
HR12	705	6627 9448	Tertiary Limestone	pasture	49.0	467.0	8.9
HR3	118	6626 255	Kanmantoo Group	pasture (lucern)	20.0	56.6	2.6
HR8	38	6627 194	unknown	pasture, potatoes, peas	16.0	156.8	9.1
HR13	132	dam		vines	4.0	3.9	1.0
HR14*	135	dam and bore 6627 8689	Cape Jervis Beds	vines	18.2	66.2*	3.6
HR15	?	dam and bore 6627 8689	unknown	golf course	75.0	607.5*	8.1
				Total	**570**	**4854**	

*speculated

Table 2. Field survey results for the Inman River Catchment.

Irrigator	Property Section No.	Source of Irrigation Water	Geological Formation	Type of Crop Irrigated	Number of ha irrigated	Annual Irrigation Volume (ML)	Application Rate (ML/ha)
IR1	250	6626 270 and 2 dams	Kanmantoo Group	orchard	8.9	59.7	6.7
IR2		dam		pasture	18.0	81.8	4.5
IR3	94	dams		pasture	8.0	14.0	1.8
				Total	**35**	**156**	

Table 3. Field survey results for the Currency Creek Catchment.

Irrigator	Property Section No.	Source of Irrigation Water	Geological Formation	Type of Crop Irrigated	# ha irrigated	Annual Irrigation Volume (ML)	Application Rate (ML/ha)
CC1	246	dam and 6627 9902	Kanmantoo Group	vines	20.3	50.1	0.7
CC1	246	dam and 6627 9902	Kanmantoo Group	olives	1.6		
CC2	2141	6627 9710	Kanmantoo Group	vines	7.5	5.6	0.7
CC2	2141	6627 7765	Kanmantoo Group	vines	7.5	5.6	0.7
CC2	172	6627 9994	Kanmantoo Group	vines	20.0	5.6	0.3
CC3	184	6627 7225	Tertiary Limestone	pasture	8.0	26.5	3.1
CC3	127 (lot 24)	6627 9607	Tertiary Limestone	pasture		53.1	6.2
CC4	239	6627 9661	Kanmantoo Group	pasture (white clover)	6.0	59.0	9.2
CC5	232	6627 9615 and 6627 9975	Cape Jervis Beds	vines	26.7	175.5	6.1
CC5	232	6627 9975 and 6627 9615	Cape Jervis Beds	olives	24.3	25.1	1.0
CC6	302	spring fed dam		pasture	14.2	127.5	9.0
CC7*	153?	dam		vines	5.0	16.0	3.2
CC8	155	6627 9246	Kanmantoo Group	vines	22.3	10.2	0.5
CC9	2073?	dam but new bore going in		vines	1.6	5.2	3.2
CC10	284	6627 9460	Cape Jervis Beds	pasture	4.0	9.3	2.3
CC10	229	6627 9406 and dam	Cape Jervis Beds	pasture	10.1	21.8	2.2
CC11	194/152	Currency Creek		pasture	8.1	5.5	0.7
CC12	239	spring fed dam		vines	30.0	311.0	10.4
				Total	**225**	**909**	

* unable to contact - estimated irrigation use

Appendix 14

Salinity Results from Field Survey

Table 1. Salinity Results from the Hindmarsh River Catchment Irrigation Bores

Bore Unit Number	Drilling Sampling Date	Salinity (mg/L)	Field Sampling Date	Salinity (mg/L)	Water Level (m)
6627 214	13-Apr-76	645	21-Nov-99	683	10.67
6627 8664	05-May-92	1055	21-Nov-99	1149	20
6627 6813	02-Mar-83	590	22-Nov-99	578	24.9
6627 276	09-Dec-75	719	22-Nov-99	699	22.86
6626 255	04-Apr-89	3001	24-Nov-99	1429	0
6627 9387	22-Mar-96	143	21-Nov-99	319	13.2
6627 8040	16-Mar-87	1049	23-Nov-99	3270	0
6627 8188	08-Feb-90	1154	24-Nov-99	882	15
6627 9448	24-Feb-97	938	24-Nov-99	827	18
6627 8401	11-Mar-91	699	22-Nov-99	611	0
6627 9978	17-Nov-98	127	19-Nov-99	165	1

Table 2. Salinity Results from the Currency Creek Catchment Irrigation Bores.

Bore Unit Number	Drilling Sampling Date	Salinity (mg/L)	Field Sampling Date	Salinity (mg/L)	Water Level (m)
6627 9710	2-Oct-97	1832	23-Nov-99	1945	12
6627 7765	4-Sep-87	2095	23-Nov-99	2273	18
6627 7225	10-Mar-88	1118	22-Nov-99	1088	2
6627 9607	11-Dec-96	1005	22-Nov-99	1016	3.5
6627 9661	30-Oct-97	226	22-Nov-99	253	25
6627 9975	30-Oct-98	220	20-Nov-99	99	14.5

Appendix 15

Glossary

Glossary of Terms

Aquifer: Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.

ANZLUC : Australia and New Zealand Land Use Codes

Baseflow: The part of the stream discharge from groundwater seeping into the stream.

Confined aquifers: Confined aquifers are bounded between upper and lower layers of impermeable clay or rock. They have a well defined recharge area where aquifer materials outcrop in the highlands. These aquifers are usually under pressure and discharge occurs as discrete springs (seepage eyes and mound springs).

DEHAA: Department of the Environment, Heritage and Aboriginal Affairs.

DCDB: Digital Cadastral Database

Discharge: Discharge is the process whereby groundwater escapes to the surface by evaporation, transpiration from vegetation, or from springs or seepage zones.

Drawdown: A lowering of the water table of an unconfined aquifer or the potentiometric surface of a confined aquifer caused by pumping of groundwater from the wells.

Evaporation: The process by which water passes from the liquid to the vapour state.

Evapotranspiration: The sum of evaporation plus transpiration.

GIS: Geographical Information Systems

GPS: Global Positioning System. A low-cost sensor/computer that obtains "fixes" from 3 or more satellites.

Groundwater: The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.

Hydrologic cycle: The circulation of water from the oceans through the atmosphere to the land and ultimately back to the ocean.

Infiltration: The flow of water downward from the land surface into and through the upper soil layers.

Interception: The process by which precipitation is captured on the surfaces of vegetation before it reaches the land surface.

Isohyet: A notational line of equal rainfall. Usually a line connecting points of equal mean rainfall.

Lithologic log: A record of the lithology of the rock and soil encountered in a borehole from the surface to the bottom. Also known as a well log.

Milligrams per litre (mg/L): The amount of dissolved solids in a solute in terms of milligrams of solute per litre of solution.

Observation well: A nonpumping well used to observe the elevation of the water table or the potentiometric surface.

Piezometer: A nonpumping well, generally of small diameter, that is used to measure the elevation of the water table or potentiometric surface. A piezometer generally has a short well screen through which water can enter.

PIRSA: Primary Industries and Resources of South Australia

Potentiometric Surface: A surface that represent the level to which water will rise in tightly cased wells. If the head varies significantly with depth in the aquifer, then there may be more than one potentiometric surface. The water table is a particular potentiometric surface for an unconfined aquifer.

Pumping test: A test made by pumping a well for a period of time and observing the change in hydraulic head in the aquifer. A pumping test may be used to determine the capacity of the well and the hydraulic characteristics of the aquifer.

Recharge: Recharge is the process whereby water is added to the groundwater system. Groundwater flows under gravity from recharge areas higher in the landscape to discharge areas lower down.

Recharge area: An area in which there are downward components of hydraulic head in the aquifer, Infiltration moves downward into the deeper parts of an aquifer in recharge areas.

Specific Yield: The ratio of the volume of a rock or soil will yield by gravity drainage to the volume of the rock or soil. Gravity drainage may take months to occur.

Storativity: The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is equal to the product of specific storage and aquifer thickness. In an unconfined aquifer, the storativity is equivalent to the specific yield.

Stream, gaining: A stream or reach of a stream, the flow of which is being increased by inflow of groundwater.

Stream, losing: A stream or reach of a stream that is losing water by seepage into the ground.

Surface water: Water found in ponds, lakes, inland seas, streams, creeks and rivers.

TDS: Total Dissolved Solids. TDS is one of the best measures of overall water salinity.

TIN: Triangulated Irregular Network data structures

Unconfined aquifers: Unconfined aquifers are like a bucket or sponge being filled with water where recharge occurs over broad areas of the landscape and discharge occurs when the watertable comes close to the land surface.

Water budget: An evaluation of all the sources of supply and corresponding discharges with respect to an aquifer or drainage basin.

Water table: The surface in an unconfined aquifer or confining bed at which the pore water pressure is atmospheric. It can be measured by installing shallow wells extending a few feet into the zone of saturation and then measuring the water level in those wells.

Weir: A device placed across a stream and used to measure the discharge by having the water flow over a specifically designed spillway.