GROUNDWATER AND SALINITY PROCESSES IN THE UPLANDS OF THE CAMPASPE RIVER CATCHMENT

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February 1992

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ABSTRACT

This paper details the hydrogeological input necessary for the development of a dryland salinity management plan for the Campaspe River Catchment. The catchment has been divided into Land Management Units and groundwater and salinity processes for each unit have been described. Understanding of processes has enabled a general assessment of the magnitude of recharge and salinity risk for each unit which was also a plan requirement.

BACKGROUND

The Campaspe dryland catchment has been identified by the Victorian government as a priority area for a salinity management plan (government of Victoria 1988). A community working group, made up of representatives from across the catchment, has been set up to develop such a plan. Their aim was to develop a policy and planning framework which will encourage implementation of salinity control strategies and assist in targeting limited resources to areas where they will have maximum effect. It is also envisaged that community development of the plan will ensure widespread adoption.

INTRODUCTION

The Campaspe Dryland Salinity Management Plan Area comprises some 454 000 ha. It extends from the Great Dividing Range in the south, to the Campaspe Irrigation district near Rochester in the north.

The plan area boundary mostly follows the true Campaspe River catchment divide, however deviation from the divide occurs towards the north for planning purposes. Even so, for the purpose of this paper the area will be referred to as the Campaspe dryland catchment.

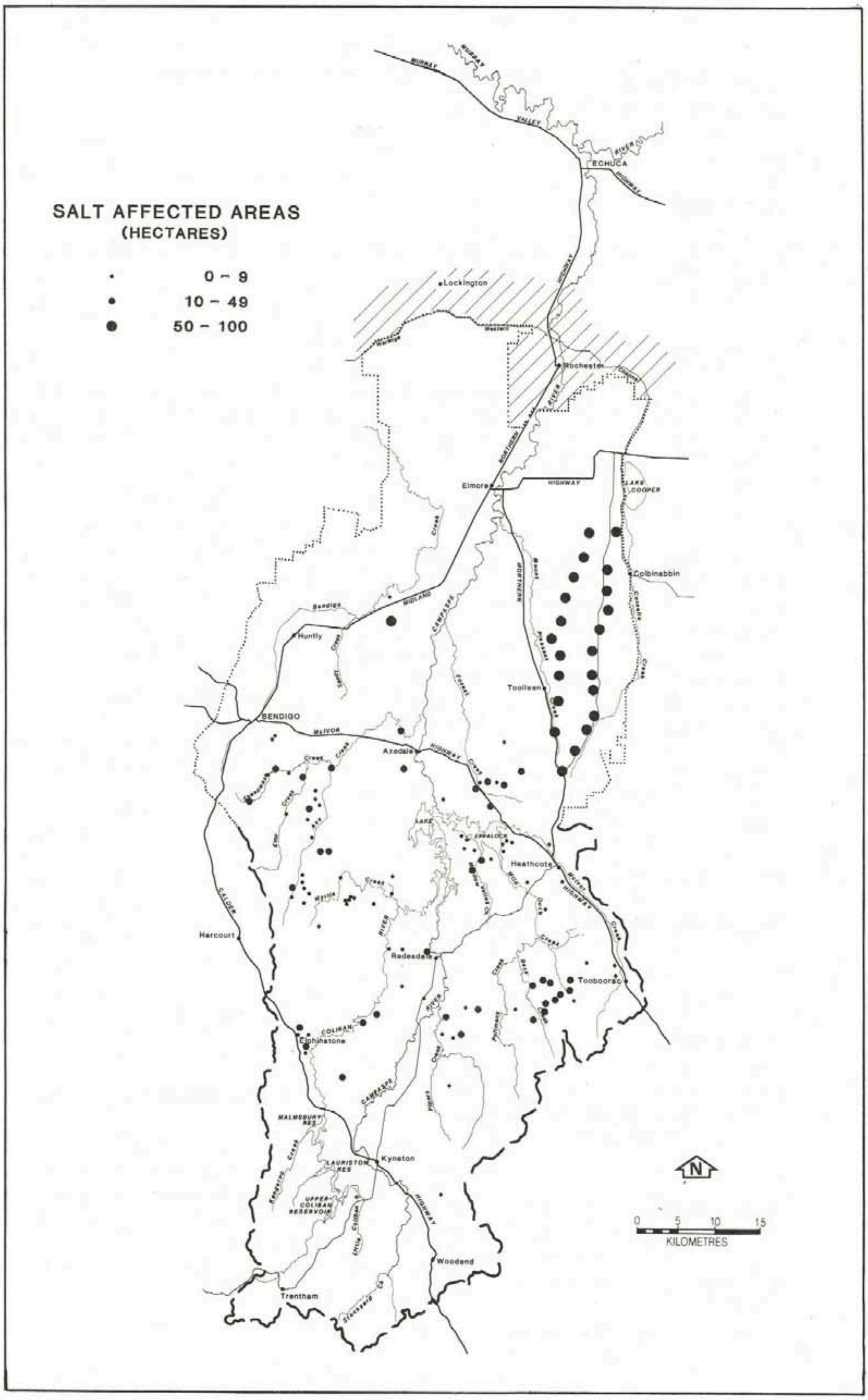
Within the catchment, 3 200 ha of salt affected land has been identified (figure 1) The majority of this salinity is associated with the Mt Camel Range to the east, and the sedimentary hill country across the centre of the catchment. This paper details the hydrogeological input necessary to the development of a salinity management plan. Collation and interpretation of both new and existing data was carried out so that general salinity processes across the catchment could be understood.

OBJECTIVES OF THE STUDY

The objectives of the study were as follows.

1. To investigate and document salinity processes in the uplands of the Campaspe dryland catchment.
2. Where appropriate, to identify high recharge areas which are likely to be priority areas for recharge control.
3. To assess the relative amounts of recharge occurring throughout different parts of the catchment.
4. To identify areas considered to be a future risk of salinity if current land management practices continue.

Figure 1 – Salt affected areas of Campaspe Dryland Catchment



GEOLOGY AND GEOMORPHOLOGY

Cambrian greenstones and shales, occurring in a northerly trending narrow belt, are the oldest rocks in the catchment. The Mt Camel Range, located on the northern end of the belt, forms a prominent ridgeline which is part of the true eastern divide. However, for planning purposes the entire range has been included in the plan area.

Ordovician sedimentary rock is common throughout the catchment, extending from dissected low hills in the south and centre of the catchment to gentle rises fringing the Riverine Plain in the north. The Harcourt, Cobaw and Crosbie granitic plutons of Devonian age have intruded into the sedimentary rock towards the centre of the catchment. The plutons are encircled by metamorphosed slates and sandstones, which formed prominent ridges. Mt Macedon, which is formed on Devonian ryodacite, forms the south-eastern catchment divide.

Permian tillites overlie Ordovician bedrock in a belt to the north and south of Lake Eppalock. Similarly basalt rocks overlie bedrock in the south of the catchment. The basalt flow has extended northwards infilling the old course of the Campaspe River. To the north of the catchment Quaternary alluvium overlies bedrock and Tertiary deep lead systems forming the flat to gently sloping Riverine Plain.

LAND MANAGEMENT UNITS

The Campaspe catchment has a wide range of hydrogeological, soil, land use and climatic environs, so that the cause, extent and severity of salinity varies from one area to another. To assist in planning and implementation , the catchment has been characterised with respect to general salinity processes. The basic unit for doing this is termed a "Land Management Unit". Such a unit groups together areas which have similar hydrogeology and hence, similar salinity processes. These areas also have common landform, soils and climatic conditions which in turn have a large bearing on land use practices. As a consequence, the same salinity control options are likely to apply throughout the one unit.

The Campaspe catchment has been divided into thirteen land management units (figure 2). The units occurring in the uplands are described in detail below and summarised in Table 1.

Volcanic Plains

Gently undulating volcanic plains comprise 34 073 ha. They extend from Woodend to Malmsbury and along the course of the Campaspe River to north of Axedale. Rock outcrop is common, particularly to the north, and flow boundaries are usually depicted by rocky scarps which drop away sharply to alluvial valleys. Several isolated rocky eruption points occur in the south, for example the Jim Jim near Woodend and Green Hill near Malmsbury.

Shallow well drained red brown gradational soils are associated with rocky eruption points, crests and scarps. Deeper gradational and duplex soils occur on gentle slopes and parts of the plain. Dark uniform clays occur in depressions and are often associated with scarps in the Redesdale area (Lorimer and Schoknecht 1987). Sheep grazing is the major land use. Minor cropping of cereals and legumes occurs in rock free areas.

Geology of the volcanic plains consists of Quaternary olivine basalt, with minor anorthoclase trachyte comprising Hanging Rock and the Camel's Hump to the south-east of the catchment. The volcanic rock, which varies in thickness, overlies Ordovician sediments and Tertiary Deep Leads (the location of which are not well defined).

Groundwater salinities in the fractured volcanic rock vary from 200 to 2500 µs/cm, but are usually less than 1000 µs/cm. As relief is predominantly flat to gently undulating and fracture permeability is usually high, groundwater flow is likely to occur over large distances across the plains. Localised groundwater mounds often develop under prominent crests due to preferential recharge in these areas. In these cases, fresh springs often occur at the break of slope. Minor salinity occurs in sedimentary areas on the edge of the volcanic plains. It is likely that recharge on the plains contributes to salinity in these areas. This salinity process has been observed in volcanic areas near Smeaton in the Loddon catchment. Drilling has confirmed that the volcanic Kangaroo Hills are recharging underlying sedimentary bedrock and increasing groundwater pressure so that saline discharge occurs where the sedimentary rock is exposed or close to the surface in the lower landscape (C.A. Day pers. comm. Salinity Research Officer, Centre for Land Protection Research). It is likely that similar processes are occurring on the volcanic plains north of Malmsbury. For example, recharge on the eruption point Green Hill is likely to contribute to the discharge that is occurring on the edge of the plains in adjacent sedimentary areas (figure 3).

Because of the potential for recharge on the volcanic plains to contribute to saline discharge, high recharge areas across the plains have been identified. These correspond to cleared stoney rises, crests and scarps where rock outcrop is common and shallow well drained soils predominate. These areas comprise some 1 330 ha. Moderate to low recharge occurs over the remaining landscape.

Volcanic Rises

Gently undulating volcanic rises and rolling low hills occur east of Kyneton and west of the Lauriston Reservoir, comprising 2925 ha altogether. Grazing is the main land use with minor cropping in rock free areas.

Rocky scarps and crest, which are associated with shallow well drained uniform and gradational soils, occur sporadically throughout the unit. Deeper gradational and duplex soils occur on slopes, with dark poorly drained gradational soils in depressions (Lorimer and Schoknecht 1987).

Geology comprises Quaternary olivine basalt overlying Ordovician bedrock, and Devonian granodiorite to the east of the catchment. Groundwater processes are likely to be similar to those operation on the volcanic plains. However, greater relief in this unit is likely to enhance the development of local groundwater systems. Groundwater salinities vary from 200 to 2500 µs/cm, but are usually less than 1000 µs/cm. Salinity is currently not a problem in this unit or in adjacent low lying sedimentary areas.

High recharge occurs on cleared rocky crests, scarps and cones comprising some 150 ha. Moderate to low recharge occurs in the remaining landscape.

Cropped Volcanic Rises

Gently undulating volcanic rises occurring in high rainfall areas to the south of the catchment near Trentham, comprises 7 333 ha. Deep well structured red gradational soils, which occur over much of the area, enable the cropping of potatoes, legumes and cereals. A small proportion of rocky crests and cones with associated shallow uniform or gradational soils, are restricted to grazing.

The geology of the area consists of Quaternary olivine basalt and minor anorthoclase trachyte, which overlie Ordovician sedimentary bedrock. Groundwater processes are likely to be similar to those operating in other volcanic areas in the catchment. However, greater relief in this area than on the plains is likely to enhance the development of local groundwater systems. Groundwater salinities vary from 200 to 2500 us/cm and groundwater is often utilized as a resource. Salinity is currently not a problem in the unit or in adjacent low lying sedimentary areas.

Compared to the other volcanic units, high recharge areas are less common, with rocky crests and cones occupying about 50 ha.

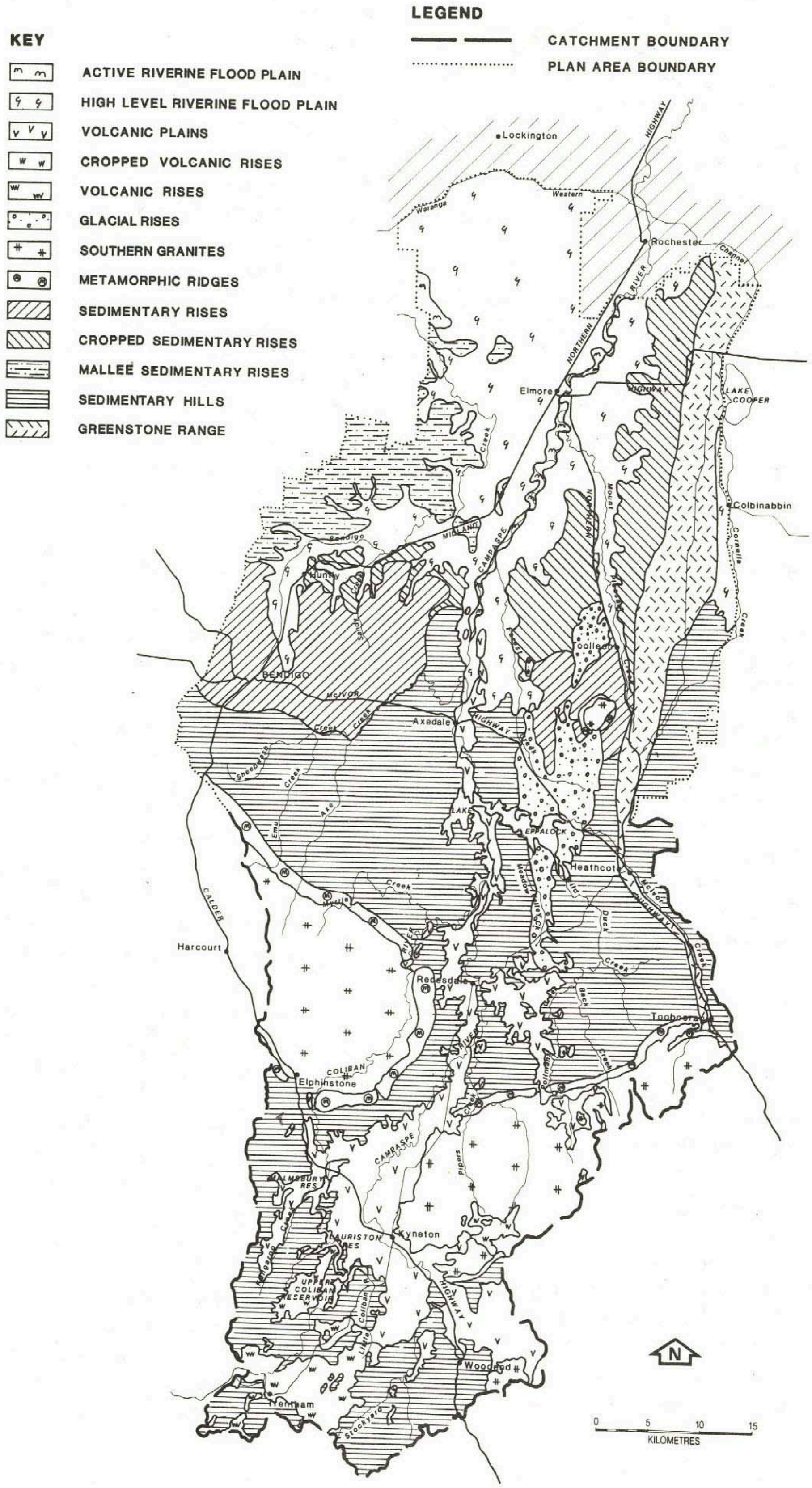
Glacial Rises

Gently undulating rises formed on Permian glacial deposits extend in a belt to the north and south of Lake Eppalock, comprising 9 538 ha. Yellow duplex soils occur both on rounded crests and gently slopes throughout the area. Cereal cropping and sheep grazing are the main land uses.

In areas experiencing salinity, the glacial deposits consist of dense, low permeability tillite which confines groundwater within sub-catchment divides, so that steep hydraulic gradients and local groundwater systems develop (Figure 4). Groundwaters are saline, ranging from 8000 to 16 000 us/cm. Reduced hydraulic gradients at the break of slope, result in groundwater discharge.

Seasonal groundwater fluctuation in observation wells in a salt affected sub-catchment at Knowsley show that rises in groundwater levels in response to wet winters are higher under crests than slopes (Figure 5). As aquifer properties appear uniform across the sub-catchment, these observations suggest that slightly higher recharge occurs in the upper landscape. Saturated hydraulic conductivities in clay sub-soils across the landscape are low (<10 mm/day, K Jackson pers. comm. Department Conservation & Environment, Bendigo Region). However, it is likely that the shallower duplex soils on crests have less water storage capacity so that they reach saturation more easily allowing greater deep percolation over wet winters.

Figure 2 – Land Management Units of the Campaspe Catchment



Southern Granites

The southern granites refers to rolling hills grading to more subdued undulating rises in the Harcourt, Cobaw and Crosbie granodiorites. The unit also includes Mt Macedon in the south-east corner of the catchment. Mt Macedon, which is developed on rhyodacite, is included because it has similar groundwater flow processes to that associated with granite rock. Altogether the unit comprises 49 263 ha.

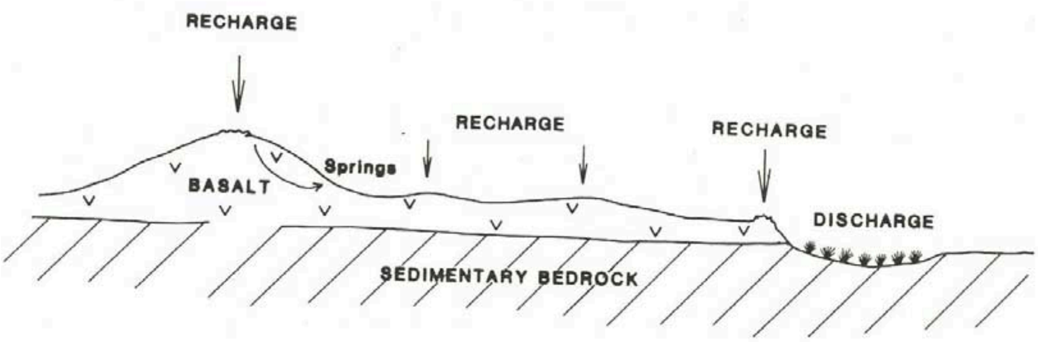


Figure 3 – Groundwater processes on the volcanic plains

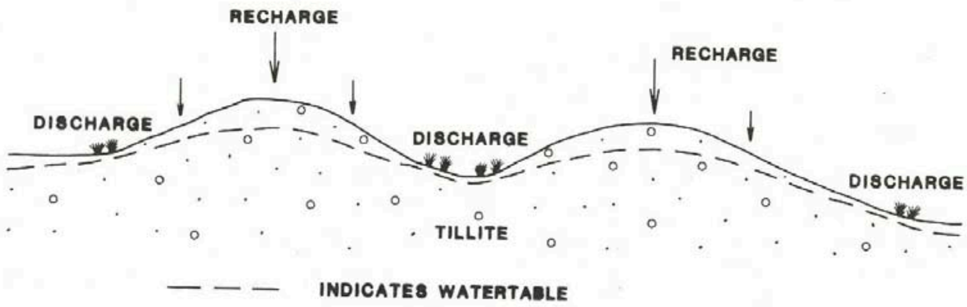


Figure 4 – Salinity processes in the glacial rises

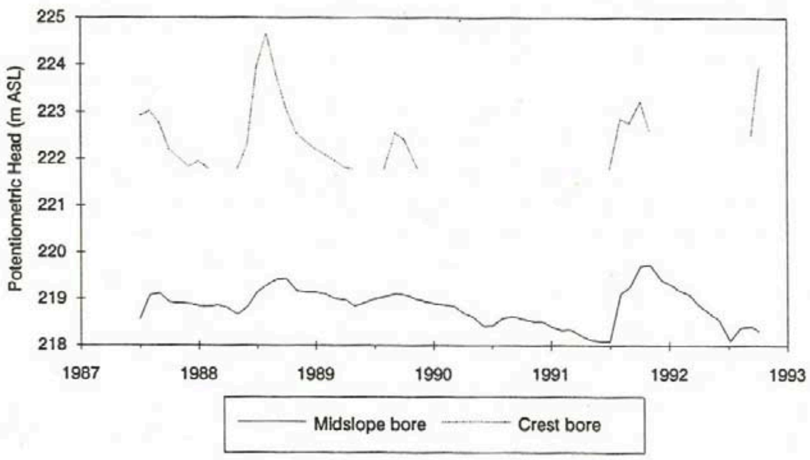


Figure 5 – Groundwater fluctuations under crest and slope at Knowsley

In granodiorite areas, shallow uniform sandy soils occur on rocky crests and yellow duplex soils are common throughout the remaining landscape. Many steep rocky areas remain under native forest and slopes have generally been cleared for grazing. The crest and upper slopes of Mt Macedon on the other hand, have shallow red gradational soils while deeper duplex and minor gradational soils occur on the mid to lower slopes (Lorimer and Schoknecht 1987). Native forest is retained over much of the upper landscape, while a large proportion of remaining areas have been cleared for grazing and low density housing.

Shallow local groundwater systems are a feature of this unit. As developed fracture systems are uncommon within rhyodacite and granodiorite rocks, most groundwater flow occurs along the weathered upper surface of the rock. Discharge, which occurs at the break of the slope due to reduced hydraulic gradients, is in the form of waterlogged depressions or springs. When the rate of discharge is greater than the rate of evaporation and the regolith has a low salt store, discharge is usually fresh (less than 30 µs/cm) and salinity is not a problem. This is the case for the springs eminating from the flanks of Mt Macedon and some of this water is used to supplement Woodend's water supply. However, salinity can occur in the granodiorites when salt stores are high and discharge rates are low so that salts become concentrated by evaporation (Figure 6). Recharge in the granodiorites is likely to be high in area of shallow uniform sandy soils which have high saturated hydraulic conductivities (>1000 mm/day). Moderate to low recharge is likely to occur through duplex soils throughout the remaining landscape.

Many other salt affected areas occur on the fringes of metamorphic aureoles which encircle granitic plutons. In this case saline discharge is likely to be a consequence of both recharge to the fractured sedimentary rock of the aureole as well as adjacent granitic areas.

Metamorphic Ridges

Prominent metamorphic ridges encircle the Harcourt, Cobaw and Crosbie granodiorites, comprising 9 058 ha. They consist of contact metamorphosed Ordovician slates and sandstones. Shallow stoney red gradational soils are common on rocky crests and steep upper slopes. Deeper reddish brown or brown gradational soils occur on mid to lower slopes (Lorimer and Schoknecht 1987). Forest cover has been retained on some rocky crests and the remainder has been cleared for grazing.

High recharge to fractured metamorphosed rock occurs on cleared crests and upper slopes where shallow soils have high saturated hydraulic conductivities (>1000 mm/day). High recharge areas comprise some 3 008 ha. Moderate to low recharge occurs through deeper soils on the mid to lower slopes.

Both local and intermediate groundwater systems are associated with metamorphic ridges, such that recharge on the ridges can be responsible for discharge in both adjacent sedimentary and granitic terrain (Figure 7). On the granitic side, local flow processes result in discharge at the break of the slope. Discharge is a consequence of reduced hydraulic gradients and differences in aquifer permeability at the contact between metamorphic and granodiorite rock. An example of this occurs at the foot of the Big Hill Range south of Bendigo, where recharge on the range is mainly responsible for discharge in adjacent granitic areas.

On the sedimentary side, intermediate groundwater systems can develop. Recharge on the metamorphic ridge can be responsible for local discharge at the break of slope, such as occurs at the top of the Axe and Emu Creek catchments. However, recharge in this part of the landscape is also considered partly responsible for discharge occurring in alluvial valleys further down catchment (Dyson MS). In this case, the fractured rock aquifer is fairly fresh and there is good groundwater connection between fractures so that groundwater can be transmitted for appreciable distances in intermediate flow regimes.

Sedimentary Rises

Gently undulating to undulating rises formed on weathered Ordovician bedrock comprising 27 130 ha, occur to the north-east of Bendigo. Erosion of weathered rock from crests has exposed the fractured rock aquifer in many areas. Lower in the landscape the weathering profile remains. Shallow, stony uniform and gradational soils are associated with the rocky crests, while red and yellow duplex soils occur throughout the remaining landscape (Lorimer and Schoknecht 1987). A large proportion of rocky crests are forested, while gentle lower slopes are often cleared for grazing.

Local groundwater systems occur within fractured rock aquifers (Figure 8). Low permeability weathered rock overlying fresher fractured rock confines groundwater within sub-catchment divides. The weathered rock layer has high salt storages which is responsible for high groundwater salinities in the lower landscape. Groundwater salinities vary from 400 to 21 000 µs/cm depending on position in the landscape and the degree of rock weathering. Saline groundwater discharge can occur in cleared areas at the break of slope due to reduced hydraulic gradients.

In cleared areas rocky crests, which have shallow stony soils with high saturated hydraulic conductivities (>1000 mm/day) are high recharge areas, which occupy approximately 500 ha.

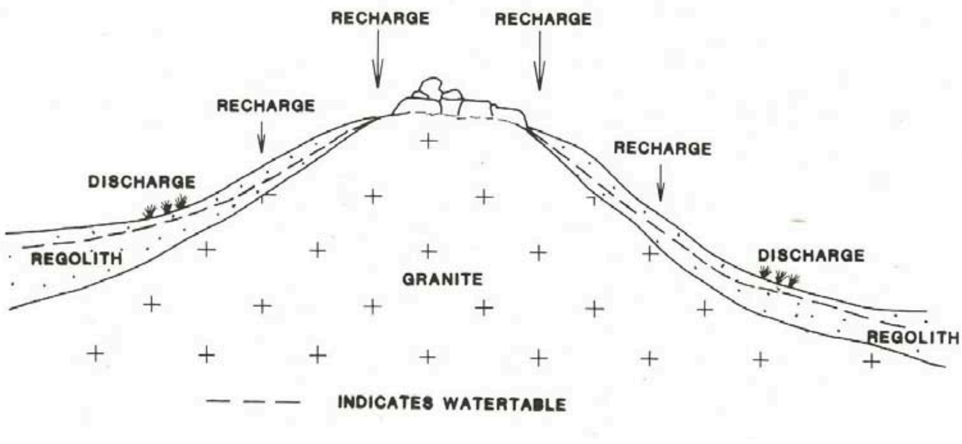


Figure 6 – Salinity processes in the southern granites

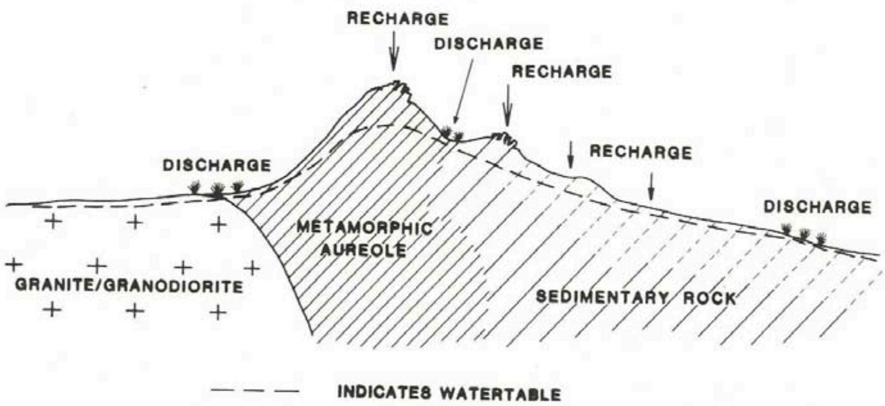


Figure 7 – Salinity processes associated with metamorphic ridges

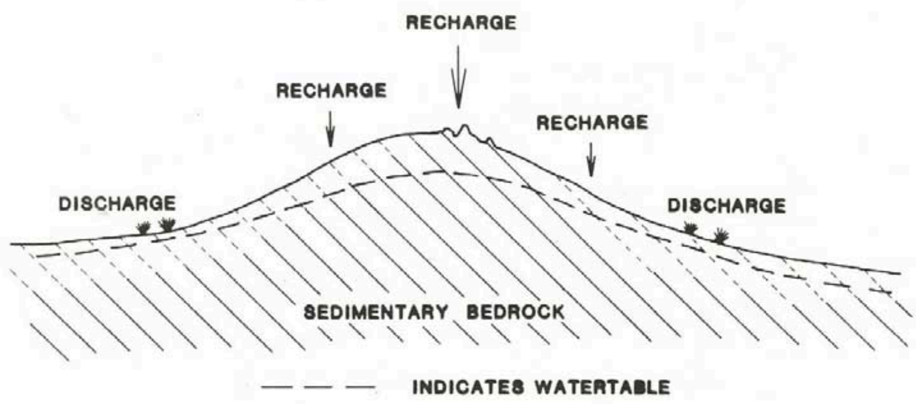


Figure 8 – Salinity processes in the sedimentary rises

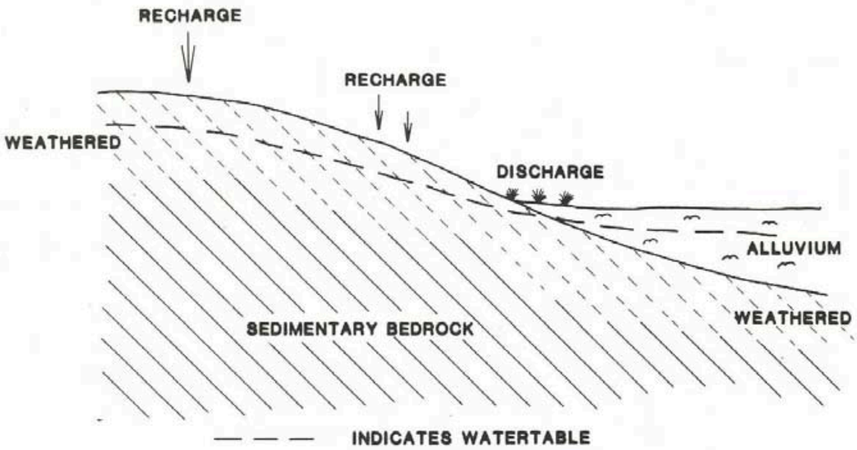


Figure 9 – Salinity processes in the cropped sedimentary rises

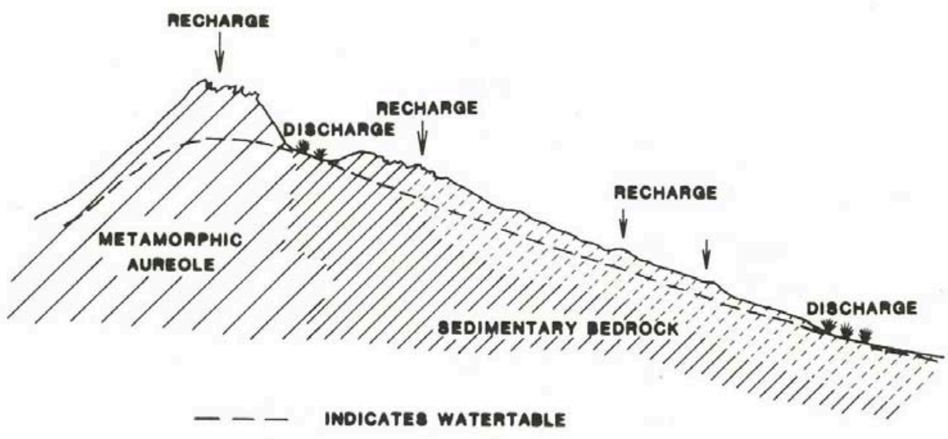


Figure 10 – Intermediate groundwater processes in the Axe Creek Catchment

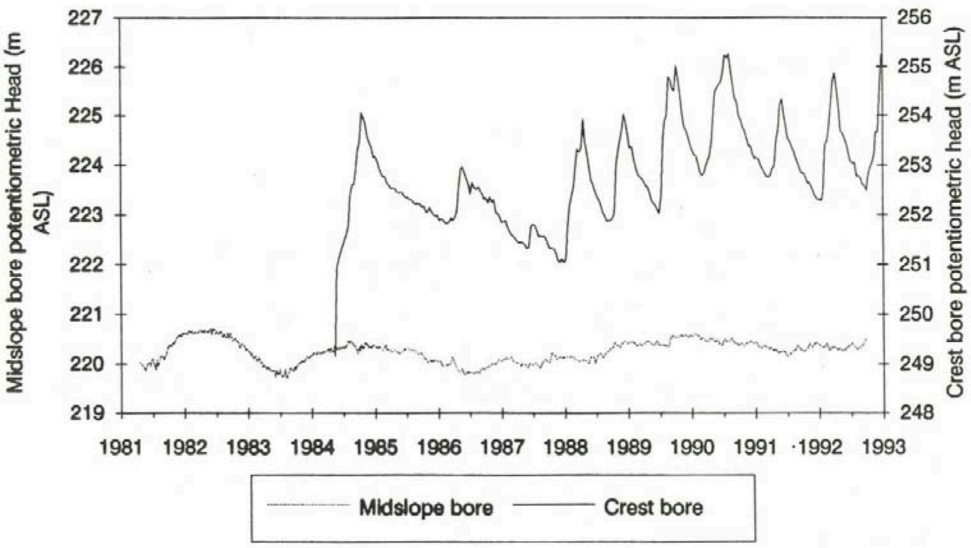


Figure 11 – Groundwater fluctuations under a rocky ridge and gentle slope in the Axe Creek Catchment

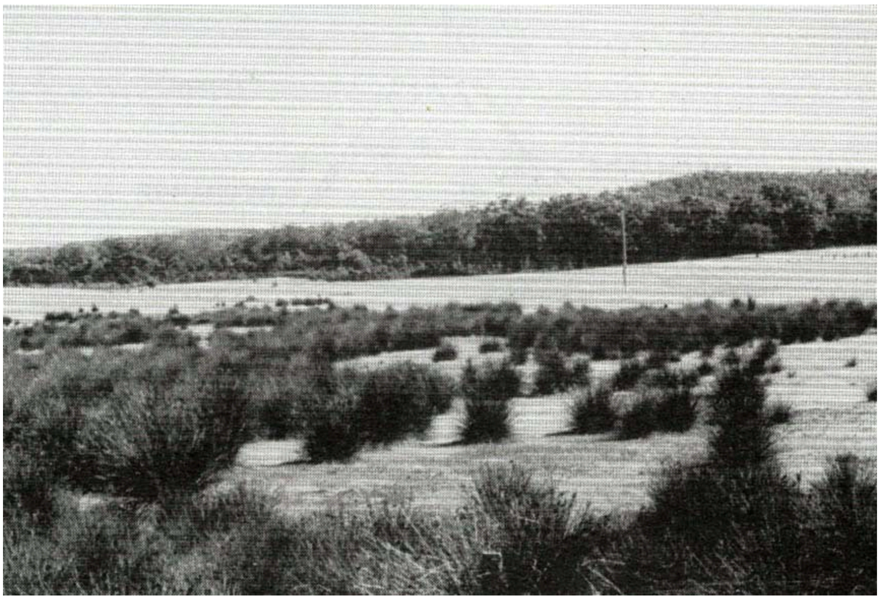


Figure 12 – Salt tolerant spiny rush is common in salt affected valleys of the Axe Creek Catchment

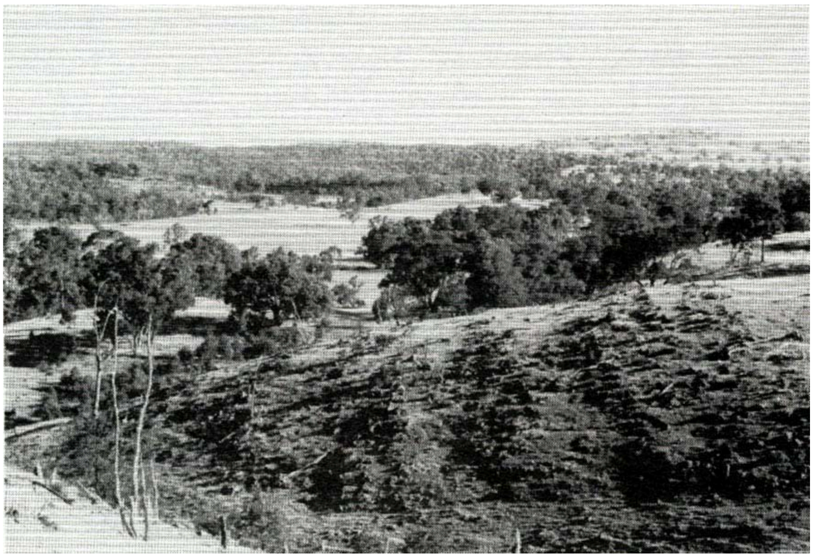


Figure 13 – High recharge areas in the Axe Creek Catchment

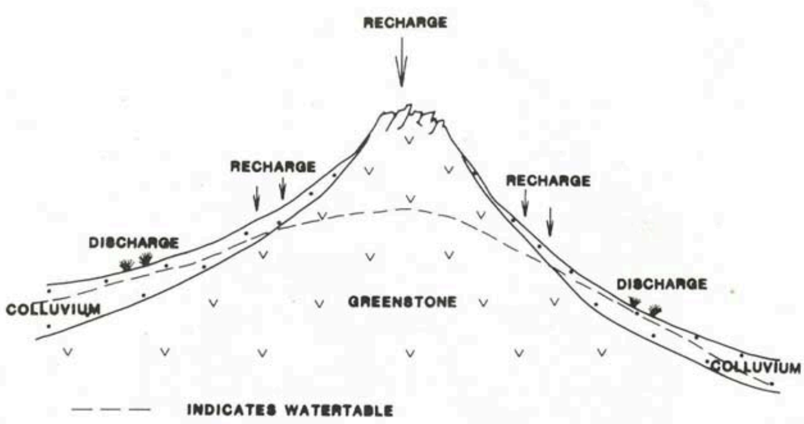


Figure 14 – Salinity processes at the Mt Camel Range

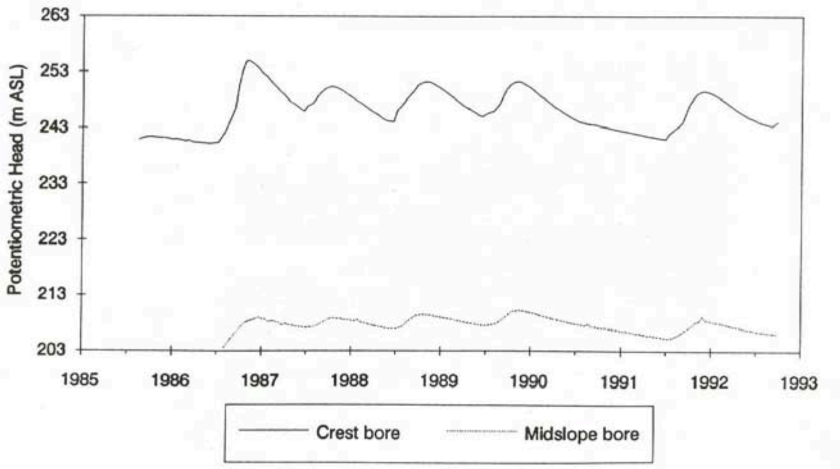


Figure 15 – Groundwater fluctuations under a rocky ridge and midslope at the Mt Camel Range

Figure 16 – Salt affected land at the Mt Camel Range

Figure 17 – Aerial view of salt affected valley at the Mt Camel Range

Cropped Sedimentary Rises
Gently undulating rises associated with weathered Ordovician bedrock from the northern extremities of the uplands, fringing the Riverine Plain. The unit comprises 29 855 ha and the main land use is cereal cropping.

Local groundwater systems occur within fractured rock aquifers (Figure 9). Low permeability weathered rock, which overlies fresher fractured rock, confines groundwater within sub-catchment divides. The weathered rock has a high salt store which is responsible for high groundwater salinities in the lower landscape. Groundwater salinities throughout the unit vary from 3 000 to 33 000 µs/cm depending on degree of rock weathering and position in the landscape.

Red duplex soils generally occur both on rounded crests and gentle slopes. However, soils on crests are often shallower and have a lower water holding capacity. As such, the crests are considered to have slightly higher recharge areas than slopes with deeper soil profiles (P.R. Dyson pers.comm. Senior Salinity Research Officer, Centre for Land Protection Research).
Discharge occurs at the break of slope, which coincides with the start of the Riverine Plain, due to reduced hydraulic gradients.

Mallee Sedimentary Rises

Gently undulating sedimentary rises with predominantly Mallee vegetation, occur in the north-west of the catchment, comprising some 17 187 ha.

Local groundwater systems are confined within sub-catchments by low permeability weathered rock. In cleared areas, minor salinity occurs at the break of slope due to reduced hydraulic gradients.

Sedimentary Hills

The unit comprises rolling hills grading to undulating rises which occur in the south and centre of the catchment, comprising some 168 815 ha. The sedimentary hills consist of Ordovician slates and sandstones, with the exception of the Mt Ida Range which is formed on Devonian sediments. Shallow, stony uniform and gradational soils occur on crests and steep upper slopes and yellow duplex soils are dominant throughout the remaining landscape (Lorimer and Schoknecht 1987). A large proportion of the crests and upper slopes are under native forest, and remaining areas have been cleared for grazing.

Both local and intermediate groundwater systems may occur in the fractured rock aquifers of sedimentary hills. Local groundwater systems are generally associated with more undulating landscapes to the north of the unit, where rock weathering is common and groundwater is confined within local topographic divides. By comparison, intermediate groundwater systems which are more common throughout the area, are associated with unweathered rock that enables groundwater transmission for appreciable distances (in the order of 10 km) in permeable open fracture systems. The Axe Creek catchment for example, has an intermediate groundwater system (Figure 10). The groundwater surface slopes gently from the metamorphic ridge in the south, with little variation in response to local topographic features. Discharge occurs where the ground surface intersects the groundwater surface in the lower catchment, coinciding with alluvial valleys and the base of streams. Dyson (MS) calculated that the Axe Creek transports 13 000 tonnes of salt from the catchment annually. High stream salinities such as this, are typical of intermediate groundwater systems in sedimentary areas.

Comparison of saturated soil hydraulic conductivities and groundwater fluctuations have enabled delineation of recharge areas in the Axe Creek catchment. High recharge areas correspond to rocky ridges and steep upper slopes where saturated soil hydraulic conductivities are high and large seasonal groundwater fluctuations (Figure 11) have been observed (Dyson 1983). Correspondingly, moderate to low recharge occurs in the remaining landscape where seasonal groundwater fluctuations and saturated hydraulic conductivities of sub-soils are moderate to low. Similar recharge patterns are likely to occur in other parts of the land management unit.

Greenstone Range

The unit comprises the narrow north-south treading belt of Cambrian rocks, which extends from Tooberac to just south of Rochester, encompassing 23 583 ha. The Cambrian rocks consist of greenstones, cherts and silicified shales. Rolling to low hills from the Mt Camel Range to the north of Heathcote and to the south, the belt consists of a series of undulating rises.

Shallow gradational and uniform soils occur on crests and upper slopes. Well structured red brown gradational soils occur on slopes associated with greenstones, while red and yellow duplex soils occur in areas of shales and cherts.

Localised groundwater flow is a feature of the fractured greenstones (Figure 14). Groundwater quality in the upper landscape is generally good (350-120 µs/cm), but becomes saline with progression downslope, so that saline groundwater is discharged at the break of slope due to reduced hydraulic gradients. In the order of 2000 ha of salt affected land is associated with the Mt Camel Range.

Large seasonal fluctuations in groundwater levels in observation wells (Figure 15) and accompanied high saturated soil hydraulic conductivities (350 – 2500 mm/day) in shallow soils on the rocky ridges indicates that high recharge occurs in these areas. Similarly, moderate fluctuations in groundwater levels in the same aquifer and moderate to low saturated hydraulic conductivities (0 – 350 mm/day) in the sub-soils of deeper gradational and duplex soils on the slopes, indicates that moderate to low recharge occurs on the mid to lower slopes.

Hydrogeological investigations at the Mt Camel Range also show that aquifer permeability and subsequent groundwater flow is greater in a north-south direction along the range. The implications for salinity control are the recharge reduction must be carried out along the entire length of the range to have an impact on discharge in low lying areas.

RECHARGE

Development of a salinity management plan has required an assessment of the magnitude of recharge occurring in different land management units throughout the Campaspe catchment. Areas of high recharge are a feature of many land management units. These are parts of the landscape which are capable of supplying a large proportion of recharge contributing to both current and potential salinity problems. Therefore as well as estimating total recharge it was necessary to determine the relative recharge contribution of these high recharge areas with respect to the remaining landscape. This has assisted in highlighting priority areas within certain land management units, for recharge control. It has also had an important bearing on the selection of appropriate recharge control options, which in turn has implications for plan economics.

High recharge areas have been identified in appropriate land management units throughout the uplands of the catchment. These generally correspond to areas of rock outcrop and associated shallow soils with high saturated hydraulic conductivities. For sedimentary bedrock country, these areas had previously been mapped on 1:100 000 scale by staff at the Centre of Land Protection Research. Mapping on the same scale was extended to volcanic units in the catchment. Detailed mapping of high recharge areas on the Mt Camel Range had already been carried out by Kevin and Dyson (MS) on 1:25 000 scale. Mapping for the Mt Camel range was also taken one step further to identify high recharge areas which are arable, non-arable and capable of being driven on by a bulldozer or bulldozer arable. Criteria for further division was based on slope and proportion of rock outcrop (Table 2). These categories have important implications for implementation of appropriate management practices for recharge control.

High recharge areas have been identified in the southern granites because in many cases these areas contribute to the generation of fresh springs, which do not constitute a salinity problem. Identification of recharge areas within the granites contributing to a salinity problem would require more detailed site specific investigations, which will be carried out during plan implementation. In the cropped sedimentary rises and glacial rises recharge occurs fairly evenly over the entire landscape and high recharge areas are not discernible. High recharge areas for appropriate land management units and sub-catchments have been summarised on Table 3.

Table 1 – Summary of Land Management Units

Land Management	Geology	Physiography	Soils	Land Use	Groundwater	Salinity
1. Volcanic plains	Quaternary olivine basalt with minor anorthoclase trachyte, overlying Ordovician bedrock and Tertiary deep leads.	Gently undulating plain with rocky scarps and eruption points. The basalt flow also follows the course of the Campaspe River to north of Axedale.	Red gradational and uniform soils, often shallow, with considerable roc outcrop on scarps, hillcrests and eruption points. Gradational and duplex soils on slopes and plain. Dark uniform clays often on slopes below scarps and in drainage depressions.	Mainly grazing on introduced pastures. Minor cropping of cereals and legumes in rock free areas.	Land and regional groundwater systems. Groundwater quality in the basalt is usually good, and varies from 200 – 2 500 µs/cm. Groundwater is often utilized.	Recharge contributes to minor salinity on the edge of the plains, in adjacent sedimentary areas.
2. Volcanic rises	Quaternary olivine basalt, overlying Ordovician bedrock and Devonian granodiorite.	Gently undulating rises to rolling low hills to the east of Kyneton and west of the Lauriston Reservoir.	Shallow, uniform and gradational soils on hillcrests, eruption points and scarps. Deep red gradational and duplex soil on slopes. Dark gradational soils in depressions.	Grazing on introduced pastures. Minor cropping.	Local and regional groundwater systems. Groundwater quality in the basalt is usually good, and varies from 200 – 2 500 µs/cm. Groundwater is often utilized.	Salinity is not a problem.
3. Cropped volcanic rises	Quaternary olivine basalt, and minor anorthoclase trachyte overlying Ordovician bedrock.	Gently undulating rises in higher rainfall areas near Trentham. Occasional rocky scarps and isolated eruption points.	Deep red gradational and minor duplex soils on slopes. Dark gradational soils in depressions. Minor shallow red uniform and gradational soils on scattered eruption points and rocky scarps.	Cropping of potatoes, legumes and cereals. Grazing in rocky areas.	Local and regional groundwater systems. Groundwater quality in the basalt is usually good, and varies in the area from 200 to 2 500 µs/cm. Groundwater is often used for irrigation of potato crops.	Salinity is not a problem.
4. Glacial rises	Permian glacial deposits consisting of tillites, conglomerates and sandstones.	Gently undulating rises extending in a belt to the north and south of Knowsley.	Mottled yellow duplex soils with bleached A_2 horizons. Buckshot and quartz are abundant in soils on both crests and slopes.	Grazing on introduced pastures and cereal cropping.	Local groundwater systems within low glacial deposits. Groundwater salinity varies from 8 000 to 16 000 µs/cm.	Salinity occurs at the break of slope, often coinciding with drainage depressions.
5. Southern granites	Devonian granodiorite. Also includes Mt Macedon rhyodacite.	Undulating rises to rolling hills of the Harcourt and Cobaw batholiths and Crosbie granodiorite. Mt Macedon in the south-east of the catchment.	In granitic areas: Course uniform sandy soils on rocky crests and predominantly yellow duplex soils on slopes. At Mt Macedon: Shallow red gradational soils on	Many rocky crests are forested. Grazing on native and introduced pasture is common in cleared areas.	Shallow, local groundwater systems, with most flow occurring on the top of hard rock. Groundwater salinities are often low, in the order of 200 µs/cm. However, in areas	Salinity resulting from recharge on adjacent metamorphic aureoles is common in granitic areas. Outbreaks associated with recharge within the granitic terrain also occur in some

Land Management	Geology	Physiography	Soils	Land Use	Groundwater	Salinity
			crests and upper slopes with duplex and gradational soils on slopes.		with salinity problems groundwater salinities can be as high as 15 000 µs/cm.	areas.
6. Metamorphic ridges	Contact metamorphosed Ordovician slates and sandstones.	Rolling hills forming prominent ridges encircling the Harcourt and Cobaw batholiths and Crosbie granodiorite.	Shallow, stony gradational and uniform soils on rocky crests. Reddish brown or brown gradational soils and occasional red duplex soils on slopes.	Predominantly sheep grazing on native pastures. A small proportion of forest cover has been retained on rocky crests.	Local and intermediate groundwater systems occurring in fractured rock aquifers. Groundwater salinities are in the order of 3 000 µs/cm, but can be higher in the lower landscape.	On the granitic side of the aureole local discharge occurs at the break of slope, coinciding with drainage depressions. On the sedimentary side, recharge on the aureole is responsible for discharge at the adjacent break of slope, as well as land and stream salination in the lower catchments.
7. Sedimentary rises	Ordovician slates and sandstones and associated Tertiary gravels.	Undulating rises north-east of Bendigo.	Shallow, stony gradational or uniform soils on rocky crests. Red or yellow duplex soils on slopes.	A large proportion of rocky crests are forested. Grazing is the main land use in cleared areas.	Local groundwater systems occurring in fractured rock aquifers. Groundwater salinities range from 400 µs/cm on crests to 21 000 µs/cm in the lower landscape.	Salinity occurs at the break of slope in cleared areas.
8. Cropped sedimentary rises	Ordovician slates and sandstones.	Gently undulating rises fringing the Riverine Plain.	Red duplex soils on rounded crests and slopes. Shallow, stony uniform or gradational soils on isolated crests.	Cereal cropping is the main land use.	Local groundwater systems occurring in fractured aquifers. Groundwater salinities vary fro 3 000 to 33 000 µs/cm, depending on position in the landscape and the degree of rock weathering.	Salinity occurs at the break of slope, on the edge of the Riverine Plain.
9. Mallee sedimentary rises	Ordovician slates and sandstones and associated Tertiary laterization.	Gently undulating rises in the north-west of the catchment.	Shallow red gradational and duplex soils on crests. Red and yellow duplex soils with bleached A_2 horizons and mottled clay sub-soils on slopes.	Mallee forest predominates and in many areas it is used for eucalyptus oil production.	Local groundwater systems occur in fractured rock aquifers. Groundwater salinities are high, varying from 16 000 – 21 000 µs/cm.	Minor salinity occurs in cleared areas
10 Sedimentary hills	Ordovician slates and sandstone. Devonian sandstone and siltstone.	Undulating to rolling low hills in the south and the centre of the catchment. Rolling hills forming the prominent Mt Ida and McIvor Range.	Shallow uniform and gradational soils on crests. Mottled yellow duplex soils on slopes.	A large proportion of rocky crests are forested. Grazing of native and improved pasture is the main land use in cleared areas.	Local and intermediate groundwater systems occur within fractured rock aquifers. Groundwater salinities vary from 5 000 – 13 000 µs/cm in the upper landscape, and are often greater than 20 000 µs/cm in low lying areas.	In cleared areas, discharge occurs in low lying areas and as base flow in streams and creeks.
11. Greenstone range	Cambrian greenstones and associated silicified shales; minor granodiorite intrusions.	Narrow, north-south trending belt comprising rolling to undulating low hills of the Mt Camel Range north of Heathcote, and a series of undulating rises to the south.	Shallow, stony uniform and gradational soils on rocky crests. Fertile red brown gradational soils predominate on slopes associated with greenstones, while red and yellow duplex soils occur on sedimentary slopes.	Cereal cropping is common, particularly on red brown gradational soils. Grazing on native and introduced pastures also occurs throughout the area.	Local groundwater systems, occurring in fractured rock aquifers. Groundwater salinities in the greenstones vary from 350 to 1 200 µs/cm on the crests to 900 to 5 000 µs/cm on the lower landscape. Groundwater salinities in the silicified shales are generally higher, ranging from 1 100 to 6 900 µs/cm.	Salinity occur s at the break of slope, often coinciding with drainage depressions.

It is difficult to obtain reliable quantitative estimates of groundwater recharge. The approach taken in this study was to incorporate where possible, recharge estimates obtained from detailed studies which have previously been conducted in the uplands of north-central Victoria. The land management unit approach to catchment characterisation of the Campaspe catchment enables extrapolation of research findings relevant to certain units across north-central Victoria with some degree of confidence.

The following section outlines quantitative estimates of recharge for each uplands land management unit and the methods used to obtain these estimates. The level of confidence in these estimates varies according to the availability of detailed information within each unit.

Cropped Sedimentary Rises

Total recharge at Kamarooka north-west of Bendigo in the Loddon Catchment, has been estimated in the order of 17 mm/year (Jenkin and Dyson 1983). As groundwater processes, geology, soils, landform and land use throughout the cropped sedimentary rises in the Campaspe catchment are similar to those at Kamarooka, this recharge estimate can be considered representative of the unit. Allowing for local rainfall variations, the total recharge range is likely to be in the order of 10 - 20 mm/year.

At Kamarooka, red duplex soils are the dominant soil type throughout the landscape. Duplex soils on many crests however are shallower (600 - 700 mm deep), and are likely to allow greater recharge due to lower available water storage (P.R. Dyson pers. Comm Salinity Research Officer, Centre for Land Protection Research, Bendigo). If slightly higher recharge of 30 mm/year is apportioned to the crests, recharge in the remaining areas is in the order of 5 mm/year. It should be noted that regardless of the exact figures, with respect to the establishment of argonomic options, recharge and soil conditions do not appear to vary dramatically across the area. As a result, recharge control options are likely to be similar throughout the entire unit. These conditions are likely to hold true for most of the cropped sedimentary rises.

Sedimentary Rises

Total recharge for Burkes Flat 100 km west of Bendigo in the Avoca catchment, was estimated to be in the order of 10 mm/year (Day 1985). As conditions at Burkes Flat area similar to those of the sedimentary rises in the Campaspe catchment, this recharge estimate can be considered representative of the land management unit. Allowing for local rainfall variations, the total recharge range is likely to be in the order of 10 - 20 mm/year. In salt affected sub-catchments within the unit, high recharge areas generally comprise approximately 10% of the total recharge areas. If recharge in the high recharge areas is in the order of 50 - 100 mm/year, recharge in the remaining landscape would be in the order of 5 - 10 mm/year. Given existing land use and soil conditions, these figures seem reasonable. If we accept these figures, the high recharge component is capable of supplying in the order of 50% of the recharge occurring throughout the sub-catchment.

Sedimentary Hills and Metamorphic Ridges

Total recharge for the Axe Creek catchment was estimated by a functional relationship,

$$Log_{10}\,(\text{Recharge}) = 2.77 \times \text{Log}_{10}\,(\text{Rainfall}) - 6.4, \text{ developed by Dyson (MS)}.$$

As groundwater and salinity processes in the Axe Creek area are considered typical of those occurring within Sedimentary Hills and Metamorphic Ridges throughout the Campaspe catchment, this relationship can be applied to other areas throughout the unit to obtain estimates of total recharge.

The high recharge component of any sub-catchment within the unit varies from 10 - 30%, but is usually in the order of 30% of the landscape. Dyson (MS) considers that high recharge in the Axe Creek catchment is in the order of 60 - 100 mm/year. It is likely that the magnitude of high recharge is similar in other areas of similar rainfall. If we accept these values, it appears that the high recharge component is capable of supplying in the order of 50 - 90% of the recharge occurring throughout the landscape within a 550 - 650 mm/year rainfall zone.

In higher rainfall zones within the Sedimentary Hills and Metamorphic Ridges, total recharge estimated using Dyson's functional relationship, is higher. It is likely that recharge in high recharge areas and remaining recharge areas is also higher. The recharge values given in Table 4 have been estimated by apportioning likely recharge to different parts of the landscape. With respect to local rainfall and soil conditions these recharge estimates seem reasonable.

Greenstone Range

Total recharge for the Mt Camel Range, which comprises most of the land management unit, was estimated to be in the order of 10 - 20 mm/year (Kevin and Dyson MS). High recharge is considered to be in the order of 50 - 100 mm/year, so that the high recharge component is capable of supplying 50 - 90% of the recharge occurring with the unit.

Volcanic Plains, Rises and Cropped Volcanic Rises
As recharge varies according to rainfall, total recharge has been approximated as a percentage of average annual rainfall and likely high recharge values have been apportioned to rocky areas (Table 4). These values are similar to estimates of recharge in the volcanics made by other authors, for example Shugg (1984).

Southern Granites
As recharge varies according to rainfall, total recharge, as a percentage of average annual rainfall is likely to be in the order of 15-25 mm/year. Recharge contributions from different parts of the landscape is often variable depending on local site conditions, so have not been estimated.

Glacial Rises
As recharge varies according to rainfall, total recharge, as a percentage of average annual rainfall is likely to be in the order of 10-25 mm/year. Duplex soils occur throughout the unit, however soils are shallower on hillcrests. Groundwater fluctuations under crests are higher than those in the lower landscape. As aquifer properties do not appear to vary throughout the landscape, these observations suggests that higher recharge occurs on crests. It is likely that shallower soils on the crests have a lower water holding capacity enabling more recharge in this part of the landscape. If slightly higher recharge, 30-40 mm/year, is apportioned to the crests, recharge in the remaining areas would be in the order of 5 mm/year. However, regardless of the exact recharge figures, recharge and broad soil conditions do not vary dramatically across the landscape, so recharge control options are likely to be similar throughout the entire unit.

Table 2 – Division of High Recharge Areas on the Mt Camel Range

High Recharge area 2775 ha		
Arable - slopes < 25% 1750 ha	Bulldozer arable - slopes between 25% and 33% 65 ha	Non arable - slopes > 33% - prominent rock outcrop 960 ha

SALINITY RISK

A requirement of the plan was to assess the future salinity status of the catchment under the ‘no intervention’ scenario. That is, to assess the likely future increase in land management regimes, without implementation of a salinity management plan.

Future Land Salinisation
Increased land salinisation is difficult to predict, however an assessment of future salinity risk in the uplands was made based on the following information:

1. Available bore data for interpretation of groundwater trends.

2. Observed past rates of increase in land salinisation within each land management unit, so that predictions could be made about future increases.

3. Knowledge of groundwater processes operating within each land management unit. The form and spread of salinity is closely related to the type of groundwater system that exists in different areas. For example, discharge associated with local groundwater systems usually occurs at the break of slope. The pattern of spread is predominantly upslope towards recharge areas. This understanding was used to estimate the spread of existing sites and to predict areas that may become salinised in the future.

4. Assessment of the equilibrium status of groundwater systems. When a groundwater system has reached equilibrium, recharge is equal to discharge and the amount of salinised land remains fairly static. Approximation of when groundwater systems will reach equilibrium has also been taken into account.

5. Morphology of discharge sites. Increases in land salinisation caused by rising groundwater levels is closely governed by the morphology of low lying areas. For example, rising groundwater levels are likely to cause large increases in land salinisation in broad flat valleys, whereas increases are expected to be minimal in narrow steep-sided valleys.

A salinity risk appraisal based on available information suggests that land salinisation associated with the uplands may increase to in the order of 10 000 ha in 50 years time under a ‘no intervention’ scenario. Areas considered to be a risk of future salinity are outlined in Table 5.

Table 3 – High recharge areas in the uplands of the Campaspe Catchment

Land Management Unit	Bendigo Creek		Campaspe		Mt Pleasant		Cornella		Axe Creek		Forest Creek		Myrtle Creek		Lower		Upper		Wild Duck		McIvor Creek		Pipers Creek		Upper Coliban		Mosquito		Total for Land	
	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested	cleared	forested
Volcanic Plains															161	0	651	68	136	0			168	0	210	0			1326	68
Volcanic Rises																							120	0	24	4			144	4
Cropped Volcanic																									44	24			44	24
Glacial Rises																														
Southern Granites																														
Metamorphic Ridges	0	116							536	400	16	0	392	52	840	220	416	224	456	72	112	0	240	80					3008	1164
Sedimentary Rises	32	2104			100	256	8	128	64	630	296	108																	500	3226
Cropped Sedimentary Rises																														
Mallee Sedimentary Rises	0	247																											0	247
Sedimentary Hills	28	1036					868	304	1022	2769	230	209	976	260	852	2608	2042	2484	6027	282	1120	1669	184	0	146	1668	552	1298	14047	14587
Greenstone Range			16	0	1585	16	1183	70			80	0									4	0							2876	86
Total for Catchment	60	3503	16	0	1685	272	2059	502	1622	3799	630	317	1368	312	1853	2828	3109	2776	6619	354	1236	1669	712	80	424	1696	552	1298	21945	19406

Table 4 – Estimates of Recharge for the uplands of the Campaspe Catchment

Land Management Unit	Rainfall Range (mm/year)	Total Recharge (mm/year)	Proportion of High Recharge Area	High Recharge (mm/year)	High Recharge Contribution	Moderate to low Recharge (mm/year)	Moderate to low Recharge Contribution
Volcanic Plains	400-550	10-15	3%	50-100	5-30%	1-10	70-95%
	550-650	15-25	3%	50-100	5-30%	1-15	70-95%
	650-775	25-40	3%	>100	5-30%	1-25	70-95%
	775-870	40-55	3%	>100	5-30%	1-40	70-95%
Volcanic Rises	650-775	25-40	3%	>100	5-30%	1-25	70-95%
	775-870	40-55	3%	>100	5-30%	1-40	70-95%
Cropped Volcanic Rises	775-870	40-55	<1%	>100	0-5%	1-40	95-100%
	870-1080	55-100	<1%	>100	0-5%	1-55	95-100%
	1080-1300	100-170	<1%	>300	0-5%	1-100	95-100%
Glacial Rises	500-600	10-25	-	-	-	1-40	100%
Southern Granitic Terrain	550-650	15-25	-	-	-	-	-
Metamorphic Ridges	550-650	15-25	10%	50-100	50%	1-10	50%
Sedimentary Rises	400-550	10-20	10%	50-100	50%	1-10	50%
Cropped Sedimentary	400-500	10-20	-	-	-	1-30	100%
Mallee Sedimentary Rises	400-550	10-20	10%	50-100	50%	1-10	50%
Sedimentary Hills	550-650	15-25	10-30%	50-100	50-90%	1-15	10-50%
	650-775	25-40	10-30%	>100	50-90%	1-25	10-50%
	775-870	40-55	10-30%	>100	50-90%	1-40	10-50%
Greenstone Range	45-550	10-20	10%	50-100	50-90%	1-10	10-50%

Table 5: Salinity risk in the Campaspe Uplands

Land Management Unit	Current Salinity (ha)	Area at risk of Salinity* in 50 years (ha)
Volcanic Plains	36	390
Volcanic Rises	-	20
Cropped Volcanic Rises	-	240
Glacial Rises	142	460
Southern Granites	90	120
Mallee Sedimentary Rises	-	30
Cropped Sedimentary Rises	65	1600
Sedimentary Rises	19	30
Sedimentary Hills	578	1000
Metamorphic Ridges	264	800
Greenstone Range	1992	2190

* It should be noted that in some cases recharge in one unit may contribute to salinity which occurs in an adjacent unit. Salinity risk areas in these cases is reported as being in the unit which is responsible for it.

Currently salinity at the Mt Camel Ridge accounts for approximately two thirds of the total catchment salinity. Long term groundwater data for analysis of trends is not available. However, observed marked increases in the size of salt affected areas suggest that groundwater pressures are continuing to rise and salinity may increase in the future. Assuming salinity will continue to spread at a similar rate, large increases in salinisation (in the order of an additional 2 190 ha in the next 50 years) can be expected. These would correspond to increases in existing salt affected sites as well as new outbreaks which are considered likely along the northern end of the range, under a 'no intervention' scenario.

Large increases in land salinisation associated with the cropped sedimentary rises (in the order of 1 600 ha in the next 50 years) are also considered likely under a 'no intervention' scenario. Most of these risk areas coincide with the junction of the rises and the Riverine Plain. Currently, groundwater pressures in most of these areas are well below groundwater surface (in the order of 20 m below ground). However, limited available groundwater data suggests that pressures are typically rising at a rate of 0.2 to 0.3 m per year (Figure 18). As the terrain is gently, if these trends continue large tracts of land may become salinised in the future.

Future increases in salinity (in the order of 1800 ha) are expected to be associated with the sedimentary hills and metamorphic ridges. Most of these areas correspond to small expansion of existing salt affected sites. Increases at individual sites are not expected to be large, because groundwater processes in many salt affected sub-catchments within the sedimentary hills are considered to be approaching equilibrium (Dyson MS). In addition to this, the morphology of many discharge sites is usually fairly steep, so that a large increase in land salinisation is unlikely.

Remaining risk areas in other land management units across the uplands, generally correspond to increases in existing sites and minor new outbreaks.

Future Stream Salt Loads

Reliable methods for quantitative analysis of likely future stream salt loads are not available. Therefore, a quantitative assessment of future stream loads for the fourteen sub-catchments within the Campaspe River catchment was carried out. The appraisal was based on knowledge of groundwater processes, the form, extent and likelihood of salinity spread, as well as landform, soil, vegetative and climatic factors throughout the catchment.

As a general rule, sub-catchments to the north of the Campaspe River catchment, which drain more gentle terrain, are likely to experience increased future salt loads. Future salinity risk is considered to be high in these areas so that increased stream salt loads are likely to result from saline runoff from future discharge sites. The sub-catchments concerned include Bendigo Creek, Campaspe Plains, Mt Pleasant Creek and Cornella Creek.

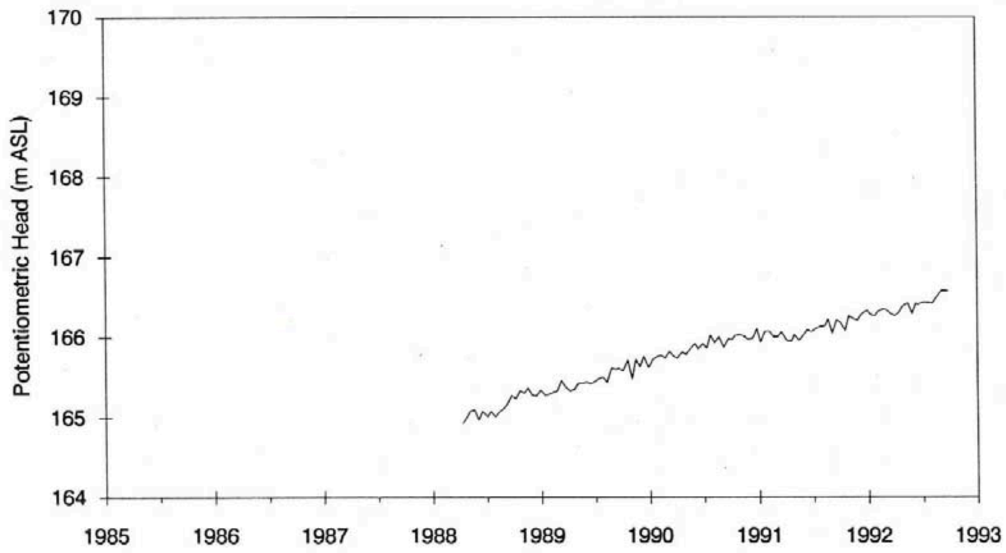
By comparison, high salt loads are currently generated from sub-catchments within the sedimentary hill country which are already salt-affected, such as the Wild Duck and Axe Creek catchments. As groundwater processes in these areas are considered to be approaching equilibrium, future increases in saline discharge are likely to be small and subsequent affects on future stream salt loads are considered to be minor.

FUTURE WORK

Investigations to date have provided a general understanding of groundwater and salinity processes necessary for the development of a Dryland Salinity Management Plan for the Campaspe catchment. Implementation of the plan will require more detailed investigations in some areas to ensure the most effective placement of salinity controls on the ground.

Groundwater levels under implemented salinity control options should be monitored so that their effectiveness can be assessed.

Groundwater monitoring networks should be increased to incorporate areas that are considered to be at risk of future salinity, so that salinity risk can be more accurately assessed.



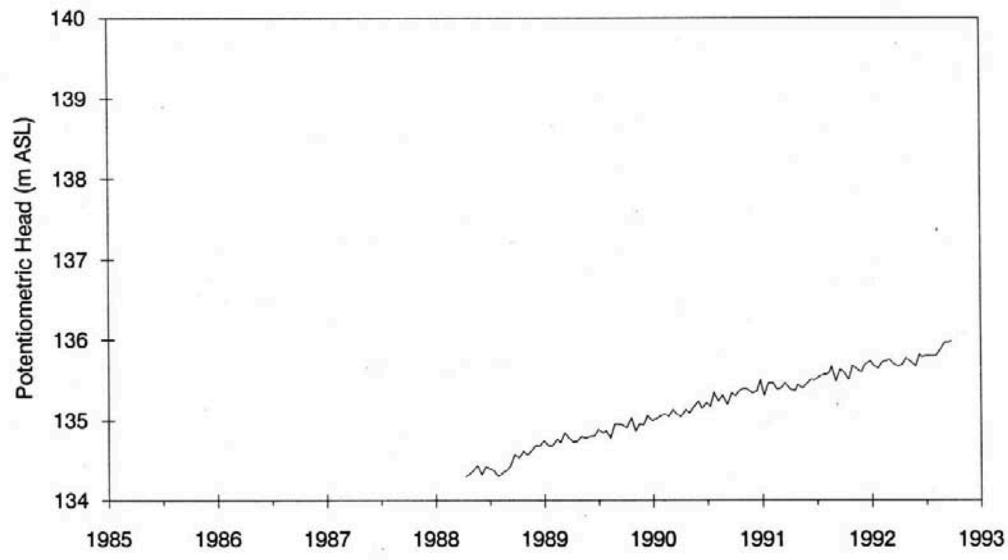


Figure 18 – Limited groundwater data suggests rising groundwater trends on the fringe of the Riverine Plain near Myola and Runneymede.

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