Tasmanian Geological Survey Record 2000/05

Hydrogeological Setting of Areas Subject to Soil Salinity in Tasmania

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Tasmania

AUSTRALIA

Natural Heritage Trust

Helping Communities Helping Australia

Tasmanian Geological Survey
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by Matthew Dell

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Executive Summary

The aim of this project was to determine the hydrogeological setting for areas in Tasmania that are subject to soil salinity so that remedial or other measures dealing with the problem are as effective as possible. The project involved the examination of hydrogeological conditions in five agricultural regions of Tasmania where soil salinity problems have been identified. Broad assessments of groundwater chemistry, groundwater levels, geological controls on groundwater flow, and groundwater flow directions were made.

Introduction

This project forms one of two concurrent National Heritage Trust (NHT)-funded salinity projects currently being undertaken in Tasmania. The project focussed on five small upper level catchments, each having distinct geomorphological and hydrogeological characteristics.

Local geological maps and geological cross sections were generated for each of the five catchments. Groundwater monitoring networks, comprising a total of 70 piezometers, were established, soil and groundwater salinity distribution maps were produced, and groundwater flow directions and groundwater flow rates were determined for each catchment.

Project Objectives

Three main objectives for the project were identified:

- To examine and determine the hydrogeological setting for areas identified as being affected by soil and water salinity problems;
- To aid in determining where salinisation problem areas within Tasmania fit within a classification system being developed nationally. Ultimately, this will be a significant aid in determining appropriate remedial action and whether land use changes are required;
- In combination with the Department of Primary Industries, Water and Environment (DPIWE), to develop methods of dealing with soil and water salinity and ensure methods are made known to property owners in affected areas.

Salt pans located in the Midlands region of Tasmania were described in early geological reports, and extensive use was made of the salt formed in them by the early settlers (Rodgers, 1993). Initial reports of saline soils were documented during soil mapping surveys in the 1950s and near-surface groundwater with a high salt content was noted in some of the drier parts of Tasmania in the late 1960s and early 1970s during hydrogeological surveys.

Initial salinity investigations were conducted statewide by the Department of Primary Industries, Water and Environment in the early 1990s (Grice, 1995). Further studies focussed on the major irrigation areas in the Midlands, Derwent Valley, South East, East Coast, North East and King and Flinders Island have shown all these areas to be affected. It is estimated that 12–14% of the irrigated land within the Cressy–Longford Irrigation Scheme, and Stage 1 and 2 of the South East Irrigation Scheme, are salt affected (Finnigan, 1995).

Salinisation is recognised as the most serious environmental problem currently facing Australia. It is estimated that salinisation causes damage totalling $270 million each year. Table 1 shows the number of hectares of Australian farmland affected by salt in 1996, and the number of hectares that could be affected if no solution is found (National Dryland Salinity Webpage 2000, http://www.ndsp.gov.au/).

Table 1

Area of salt affected land in Australian States

	Hectares salt affected (1996)	*Hectares at risk*
Western Australia	1 804 000	6 109 000
South Australia	402 000	600 000
Victoria	120 000	Unknown
New South Wales	120 000	5 000 000
Tasmania	20 000	Unknown
Queensland	10 000	74 000
Northern Territory	minor	unknown
Total	2 476 000	>11 783 000

The Salinity Process
(adapted from Coram, 1998)

Salt (NaCl) is present in some amount within all naturally occurring soils and water. Salinisation occurs where salt levels accumulate to a point where water or soils become degraded and plant growth is detrimentally affected (Table 2).

Primary salinisation results from natural processes and is commonly observed within natural salt pans and coastal marshlands and lagoons. Primary salinisation is very common within arid and semi-arid climates, and generally results from the concentration (through the process of evaporation) of salts received from rainfall.

The process of secondary salinisation results from an alteration in both volume and the way water naturally moves through the environment. This alteration of the hydrological balance has occurred since European settlement in Australia, and has mainly been a result of

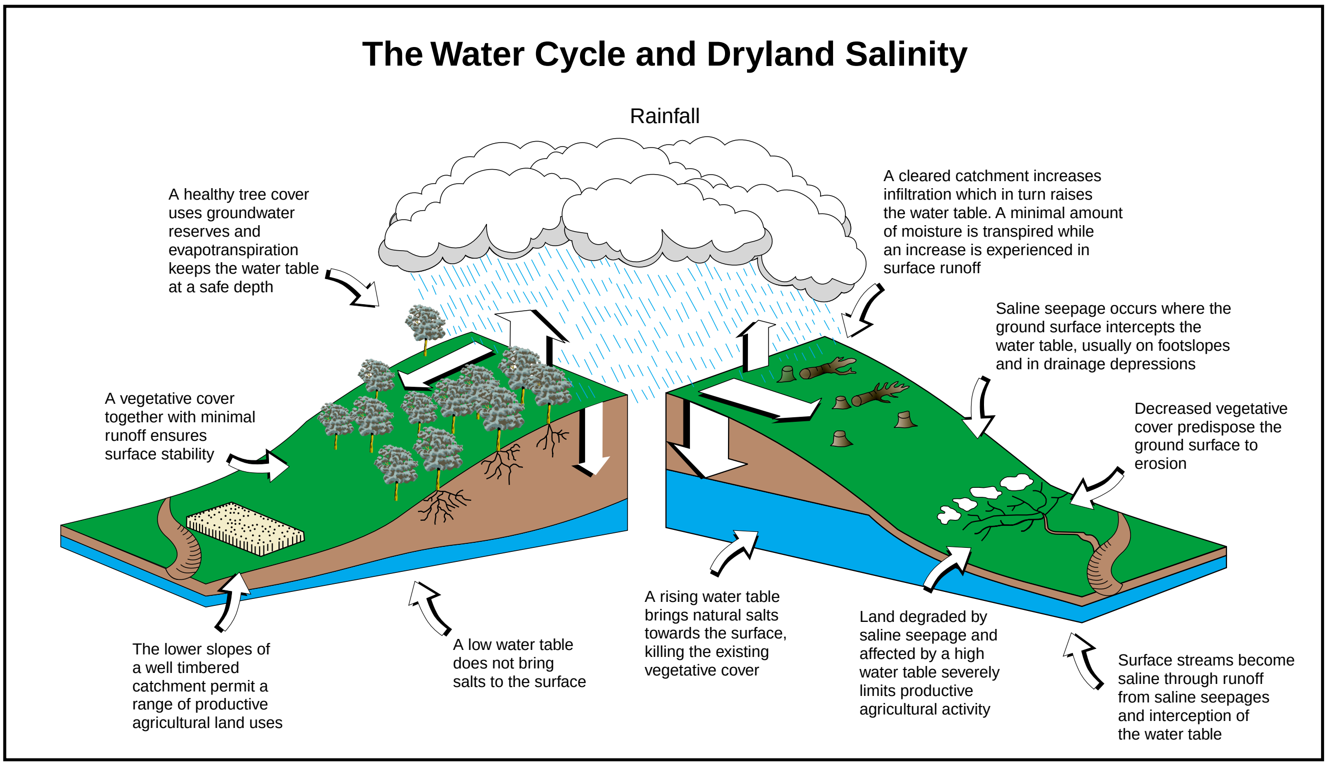

Figure 1

The water cycle (after Salt of the Earth, 1996)

Table 2

Salt levels in water

EC Units (µS/cm)	*Use or relative value*
0	distilled water
500	level at which humans can taste salt
800	desirable limit for human consumption (World Health Organisation)
800	reduced yield and growth possible from irrigation at this level
1000	1 dS/metre
2500	maximum limit for humans
3000	maximum for tomatoes
5500	limit for couch grass
6000	limit for poultry
6500	level at which water is considered saline
10000	limit for horses, ewes and lambs
16500	limit for beef cattle
23000	limit for adult sheep on dry feed
54000	seawater

extensive clearance and the replacement of native vegetation with shallow rooted, water-inefficient crops, through the damming or alteration of natural groundwater movement, and the introduction of irrigation practices. This is summarised diagrammatically in Figure 1.

A combination of hydrological disequilibrium and a source of salt are necessary for a landscape to suffer from salinisation. When considering the distribution of salinisation throughout Australia, it is not sufficient to understand the distribution of aquifer types alone; an understanding of the distribution of salt within a catchment, and how groundwater mobilises this salt store, is also required. Descriptions of the key factors that influence salinisation must therefore include those factors that control the distribution of salt, as well as those that control the flow of groundwater. Given that dryland salinity is an expression of a dynamic change in the groundwater system, factors such as climate and land use are also critical to understanding the distribution of salinisation.

The combinations of physiography and land attributes that are considered to have the highest risk for future dryland salinity to occur are:

- hydrogeology — particularly areas where groundwater flow is restricted by changes in subsurface geology;
- land use — particularly where grazing and cropping practices have greatly increased the volume of water infiltrating to the groundwater system;
- climate — particularly areas where annual evaporation greatly exceeds annual rainfall and with winter-dominant rainfall patterns;
- landform — particularly areas where there is a sudden reduction in steepness, such as occurs in foothill areas.

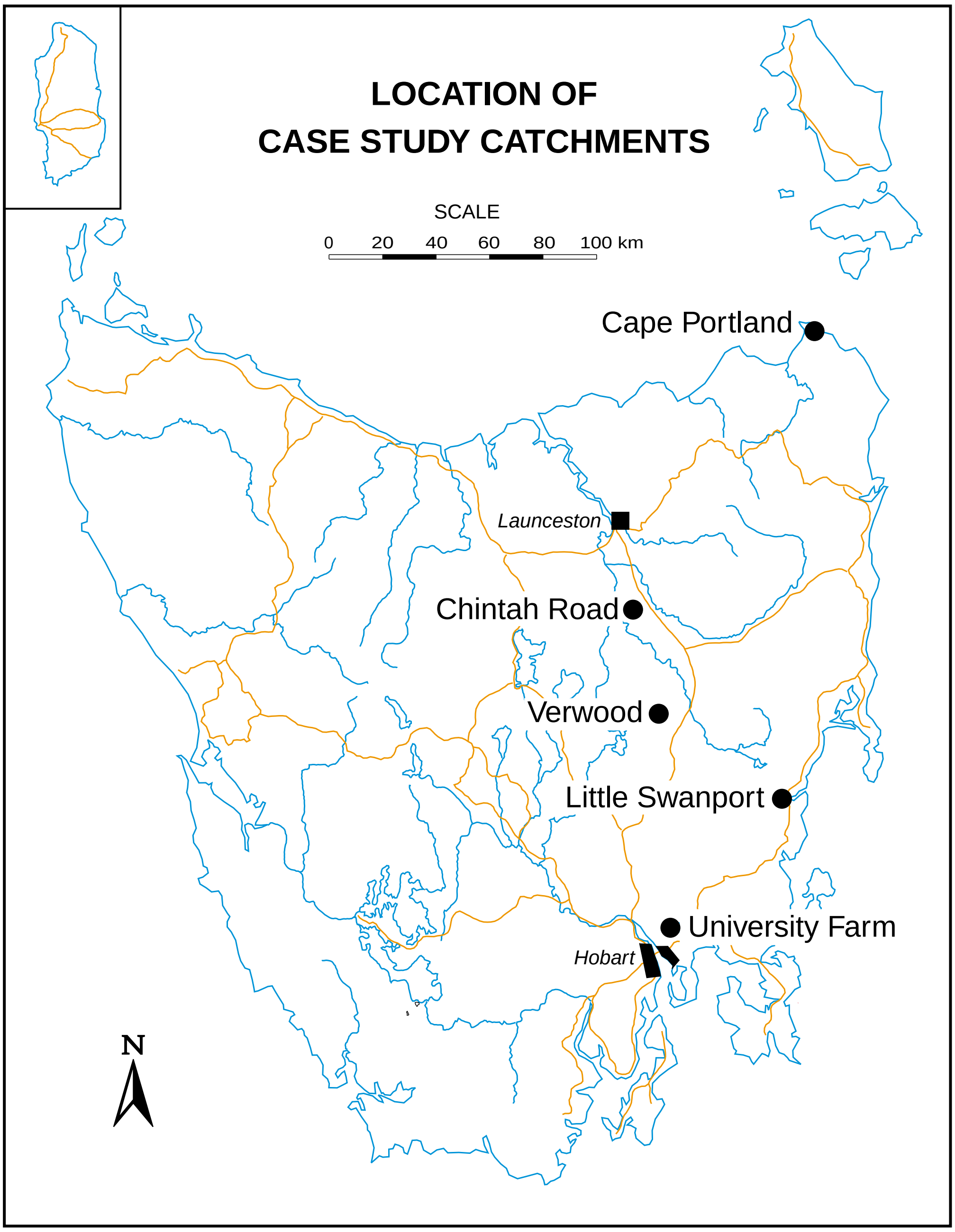

Figure 2

Methodology

Five case study catchments were selected in consultation with the Department of Primary Industries, Water and Environment, on the basis of previously recorded or observed salinity problems and their distinct hydrogeological setting. These areas (fig. 2) were located at:

- Cape Portland, about 20 km north of Gladstone in the far northeastern corner of Tasmania;
- Chintah Road, Powranna, about 30 km south of Launceston;
- Verwood, approximately 20 km west of Ross in the Central Midlands region;
- University Farm, approximately 18 km northeast of Hobart in southeast Tasmania;
- White Hut Creek, Little Swanport, approximately 20 km north of Triabunna on the east coast.

Geological maps of the five catchment study areas were produced at 1:10 000 scale. Subsurface geological information was acquired during the establishment of the groundwater monitoring networks. Over 100 holes were drilled with 70 piezometer sites being established. Drill cuttings were logged and the salt content of the spoil measured.

Groundwater was collected at each monitoring site and analysed for all major ions and anions.

Monthly measurements of groundwater depth and salinity levels were made for each of the 70 piezometers. Rainfall, temperature and evaporation data were collected throughout the course of the study, and the effects of these on the groundwater and salinity levels noted.

Groundwater salinity and soil salinity levels, hydraulic conductivity, groundwater depths and groundwater flow directions have been mathematically modelled using Golden Softwares *Surfer* program, a data gridding and modelling package. Spatial data displayed as contour maps has been modelled using the kriging algorithm. The data presented as contour maps and flow paths are only general guides to likely distribution and directions. A more comprehensive sample network needs to be established to properly constrain the hydrogeology and chemistry of the water and soil.

Determinations of hydraulic conductivity have been made using Hvorslev graphical determination.

Digital topographic information at 1:25 000 scale has been combined with differential Global Positioning System (GPS) readings at each piezometer to create the local Digital Elevation Models (DEM)/elevation wireframes.

Results

The characteristics of each of the five study areas are summarised in Table 3.

Each of the five case study areas showed elevated soil and near-surface groundwater salinity levels. Where water tables are present at, or within three metres of the ground surface, significant soil and groundwater salinity occurs. This is particularly so in areas where deep-rooted vegetation (trees) are absent. Any further rise in groundwater levels will result in significant crop yield reductions, tree mortality, and a degradation of soil, surface water and groundwater resources.

Average groundwater salinities observed within the five study catchments range from 10% to 25% of the concentration of seawater. As a result, near-surface groundwater present in the study catchments are unsuitable for irrigation.

Salt is present throughout the soil and geological profile. Generally the salt concentration of soil increases with depth. This suggests that large salt stores present within the landscape are not presently being expressed at surface. Current land practices and the expansion of irrigation cropping may bring these stored salts close to or at the ground surface, further degrading soil and water quality, and leading to a large expansion of saline affected land.

The processes governing salinisation are very complex and are poorly understood in the Tasmanian landscape. The main causes of salinisation on the Australian mainland are well documented. They include tree removal, excessive irrigation and irrigation with poor quality water, and the disruption

Table 3

Summary of salinity study data

	Cape Portland	*Longford*	*Tunbridge*	*University Farm*	*Little Swanport*
Area (square kilometres)	2.98	10.57	8.012	2.55	7.8
Number of piezometers	17	12	12	14	15
Annual rainfall (mm)	627	640	561	509	599
Annual pan evaporation (mm)	1022	1112	1138	1308	1025
Average groundwater salinity (µS/cm)	14477	10259	7567	8513	4756
Range	777–35309	2470–15000	613–16743	2306–13234	656–26800
Average depth to watertable (cm)	108	309	314	317	168
Range	58–227	110–1820	118–1191	+14–1301	1–544
Average profile soil salinity (µS/cm)	1835	644	434	417	425
Range	99–4600	237–945	103–1439	262–770	124–1588
Average surface soil salinity (µS/cm)	710	362	290	444	432
Range	105–2230	174–622	66–1171	204–707	49–2070
Hydraulic conductivity (metres/day)	0.125	0.07	0.1	0.08	0.08
Range	0.0026–0.39	0.0013–0.2	0.01–0.35	0.0003–0.35	0.0002–0.35
Groundwater type	Na, Cl HCO_3	Na, Cl, Mg, HCO_3	Na, Cl, HCO_3	Na, Mg, Cl, HCO_3	Na, Mg, Cl,
Vegetation cover (%)	1	10	35	10	20
Elevation range (m)	0–50	160–320	240–320	5–200	0–120
Salt in rainfall (mg/L)	101.1	32.0	73.0	41.6	57.6
mg salt received/ha/year	634 022 400	204 800 000	409 305 600	211 744 000	345 024 000
Tonnes salt received/hectare/year	0.63	0.20	0.41	0.21	0.35

of the hydrological cycle through the damming of surface and subsurface water.

Significant vegetation removal has occurred at each of the study sites. Vegetation clearance, particularly in recharge areas high in a catchment system, has resulted in increased groundwater recharge and a subsequent rise in the water table.

Average yearly evaporation rates exceed precipitation inputs in each of the study sites. The resulting evaporative concentration results in high salt levels in the near-surface groundwater, surface water and soil.

Salt present in rainfall contributes significantly to salt levels within surface water, groundwater and soil. Average annual salt inputs from rainfall ranged from 200 to 630 kilograms per hectare over the five study catchments. The highest salt inputs were observed in near-coastal environments.

Long term climatic records for the Midlands and East Coast indicate a trend towards a drier and hotter environment. This has significant implications for hydrological processes and agricultural sustainability.

Recommendations

Tasmania does have a salinity problem. Soil, water and groundwater salinity is present within prime and marginal agricultural areas around the State, as well as in some urban regions. It is critical that the public, and in particular farmers and local land managers, be made aware of this.

Vegetation removal is the primary cause of rising water tables, which in turn is the primary process responsible for the development of dryland and agricultural salinity. A moratorium on tree removal throughout catchments in the Midlands, Southern and Central East Coast, Derwent Valley, Coal River Valley and other salinised areas should be considered.

Within Tasmania, all areas where evaporation exceeds precipitation should be considered to be potentially salinised. Broad assessments of surface water, groundwater and soil salinity should be made in these areas, and appropriate, sustainable land use strategies implemented.

A comprehensive, Tasmania-wide, shallow groundwater monitoring network needs to be established. Particular areas of concern are the major irrigation and cropping districts within the State, broad acre agricultural regions, low lying near-coastal areas, and any areas with impermeable substrata producing impeded drainage.

Surface water quality monitoring needs to be undertaken on a regular basis across Tasmania. Spot conductivity measurements being collected by the growing network of Waterwatch groups is identifying new regions where surface water quality levels are above World Health Organisation acceptable levels.

It is recommended that where significant land use changes are contemplated, particularly in regard to land clearance and irrigation development, a basic study should be made to identify where salt is located within the environment. The likely impacts resulting from increased surface water and groundwater movement resulting from land use change should also be identified at this time.

The promotion of drainage for salinity management in Tasmania should proceed with caution until guidelines/policies are developed for the safe disposal/flushing of saline runoff and discharge from properties. This current unmanaged practice is to the detriment of Tasmania's water resources.

Comprehensive electromagnetic (EM31, Sirotem, Protem and Utem), radiometric and magnetic surveys should be carried out within all study areas, to help constrain geological, soil and saline groundwater distributions.

Further research into palaeo-salt stores needs to be undertaken. Suggested possible sources for salt include Permian and Triassic sedimentary rocks, Tertiary sediments, and palaeochannels present in Quaternary and Tertiary deposits (particularly basinal, floodplain and coastal marshland deposits).

Involvement of Tasmanian researchers and land managers in the Australia-wide National Dryland Salinity Program (NDSP) will assist in raising awareness nationally and locally of the Tasmanian salinity problem. The NDSP provides information more effectively to scientists, land users and community groups on the identification, management and rehabilitation of saline groundwaters and soils.

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[30 September 2000]

GLOSSARY

alluvial	deposited by a river
angular unconformity	lower, older beds dip at a different angle to younger, overlying beds
aquifer	water-bearing rock unit
Archaean	older than 2,500 million years
artesian	groundwater held under pressure in an aquifer
basalt	a fine-grained, volcanic rock
basement	unweathered igneous or metamorphic rock covered with unconsolidated sedimentary material
bed load	material carried by a stream near its base
bedrock	unweathered, consolidated rock beneath the regolith zone
biophysical	relating to biological and physical processes
break of slope	the point on a slope at which topographic gradient is reduced
capillary discharge	discharge occurring as the result of the suction between water and solids in the unsaturated zone
catchment	the area from which surface water is received as defined by the topographic drainage divide
colluvial	loose deposits of rock fragments transported by gravity
confined flow	groundwater flow that is restricted by overlying rocks and is consequently under pressure
crystalline rock	igneous or metamorphic rock
dendritic	a drainage pattern developed in unconsolidated or poorly consolidated material
discharge	flow of groundwater from the saturated zone to the surface
dolerite	a medium-grained igneous rock
downgradient	further down along a gradient
dryland	cleared or naturally treeless, non-irrigation, non-urban land
dS/m	Decisiemen/metre, equal to 1000 µS/cm
dyke	a linear body of igneous rock that cuts across other rock structures
electrical conductivity	(EC) estimates the amount of total dissolved salts (TDS) or the total amount of dissolved ions in the water. µS/cm (microseimens per centimetre) are the units of measurement for electrical conductivity
EC1:5	A ratio measurement used to determine the electrical conductivity of soils or rocks. 1 part of soil or rock that has been dried and crushed is diluted in 5 parts distilled or de-ionised water. EC1:5 is the conductivity measured from this solution.
endorheic	drainage basin without outlet
Fault	a rock fracture along which observable displacement has occurred
geomorphology	the study of land forms
granitic rocks	coarse-grained igneous rocks
hydraulic conductivity	the rate at which water is transmitted
hydraulic gradient	the change in groundwater level elevation over the distance at which the change occurs
hydrochemical	relating to the chemistry of water
hydrogeological	relating to groundwater
hydrological	relating to surface water
igneous	rocks that formed through the crystallisation of magma
impermeable	relatively impervious to the passage of water
infiltration	the unsaturated movement of water through the soil and regolith
irrigation salinity	salinity caused by the raising of the water table or addition of salty waters
Jurassic	190–136 million years ago
lacustrine	sediments derived from a lake
laterite	hard material made of iron oxides
lunette	a source-bordering dune
mafic	consisting predominantly of iron and magnesium-rich minerals
metasediments	metamorphosed sediments
numerical model	computer model based on mathematics
orogen	a period of geological deformation
palaeodrainage	drainage lines that existed in the geological past

Palaeozoic	545–230 million years ago
piezometer	a tube or pipe used for the measurement of the groundwater or potentiometric surface
perched aquifer	a hydraulically conductive rock with saturated groundwater flow that is underlain by an unsaturated zone
perennial pastures	pastures that grow all the year round
permeable	able to transport water
potentiometric surface	An inferred surface defined by the static head of groundwater as measured in a well/bore/ piezometer. The water table is an example of a potentiometric surface
primary salinity	saline groundwater discharge that existed prior to European land use changes
Proterozoic	2500–545 million years ago
Quaternary	2 million years ago to the present
recharge	infiltration of water from the surface to the saturated zone
regolith	weathered rock
residence time	the time that water remains in a groundwater system
rising head slug test	measures hydraulic conductivity by removing a 'slug' of water from the bore and watching the rate at which the bore recovers
salt mobilisation	transport of salt stored in the unsaturated zone by rising groundwater
salinisation	the process by which saline groundwater is discharged into streams and at the surface
saprolite	weathered material with the same volume as the original rock material
secondary salinity	discharge of saline groundwater that has occurred as the result of European land use changes
sediments	derived from erosion of pre-existing rocks
seeps	areas where there is continuous discharge of groundwater
semi-confined	transient between confined (under pressure) and unconfined (under atmospheric pressure only)
skeletal soil	thin, poorly developed soil
slug test	see rising head slug test
stratigraphy	stratified rocks, particularly sedimentary and volcanic rocks
surface scalds	areas where continuous discharge of saline groundwater has resulted in denudation of the soil
Tertiary	65 million years ago to 2 million years ago
topographic gradient	steepness of the ground surface
topography	the general configuration of a land surface or any part of the Earth's surface, including its relief and the position of its natural or man-made features
transmissivity	ability to transmit water, reflecting both the hydraulic conductivity and the area of the rock
Triassic	225–190 million years ago
unconfined flow	groundwater flow that is not restricted by overlying rocks and which is consequently at atmospheric pressure
unconformity	a plane that separates older rocks below from younger rocks above, and represents a break in deposition
unconsolidated	loosely compacted; uncemented
unsaturated zone	the zone above the water table that is not saturated in water
µS/cm	microsiemens/centimetre, a unit of measurement of apparent salinity. These are the measurement units for electrical conductivity (EC). The EC value is determined by a sensor that consists of two metal electrodes that are exactly 10 mm apart and protrude into the water. A constant voltage is applied across the electrodes. An electrical current flows through the water due to this voltage and is proportional to the concentration of dissolved ions in the water — the more ions, the more conductive the water resulting in a higher electrical current which is measured electronically. Distilled or de-ionized water has very few dissolved ions and so there is almost no current flow across the gap (low EC)
water table	the upper surface of the saturated zone
weathering	the process by which rocks are decomposed

CASE STUDY 1

CAPE PORTLAND

Surface salt precipitation in drainage depression, Cape Portland Study Area

Salt scald developed in open sandy soil with minor clay and common polymict, well rounded gravel. Sea Barley Grass is present on the edges of the drainage line. Cape Portland Study Area

Overview

Farming began in the Cape Portland area before 1850, with the majority of the property cleared by the early 1940s. Before clearing the vegetation consisted of silver tussock, open *Allocasuarina* forest, lily sags, woodlands, peatlands and coastal scrub (Hugh Mills, pers. comm., 2000). The study area now supports less than one percent native vegetation cover, being used exclusively for sheep grazing.

Location

Cape Portland is located in the far northeast of Tasmania, approximately 20 kilometres north of Gladstone (fig. 3). The study area (584 500 mE, 5 487 500 mN) covers 2.98 square kilometres and is entirely within the Cape Portland property, which is presently managed by Hugh and Jane Mills.

Geomorphology

The study area is situated within low undulating terrain between 5 and 40 metres above mean sea level. The catchment drains to the west through a shallow drainage network into the Tregaron Lagoons. Throughout the duration of the study (18 months) ending in April 2000, the drainage lines were observed to be flowing on one occasion only.

Bedrock is exposed in low undulating hills and within some drainage trenches. There is a localised overburden of sand and gravel on hillslopes and depressions. The catchment is a maximum of two kilometres from the sea at any one point. Salt deposition from sea spray frequently occurs across the site during periods of onshore weather.

The surface and near-surface drainage of the catchment is primarily controlled by the undulating bedrock and its weathered derivatives. Bedrock, which crops out to the south of piezometer Cape 20 and to the northwest of piezometer Cape 6, controls and constricts the local drainage.

Vegetation

Approximately 20 native *Allocasuarina* sp. are remnants of the original vegetation of the study area. The property has been grazed for over 50 years during which the native vegetation has been replaced by perennial pastures. Many salt indicator species are

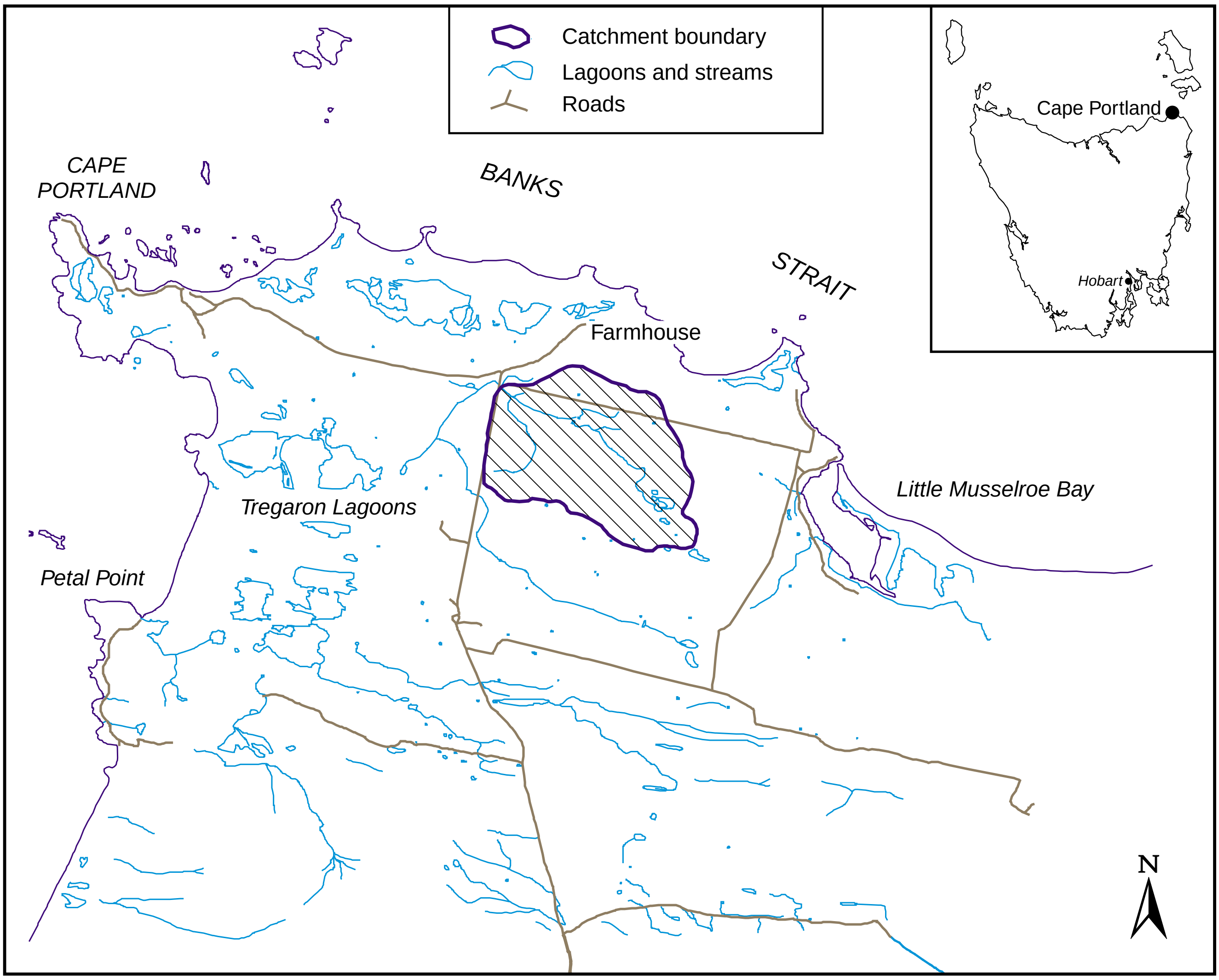


Figure 3

Location of Cape Portland study area catchment

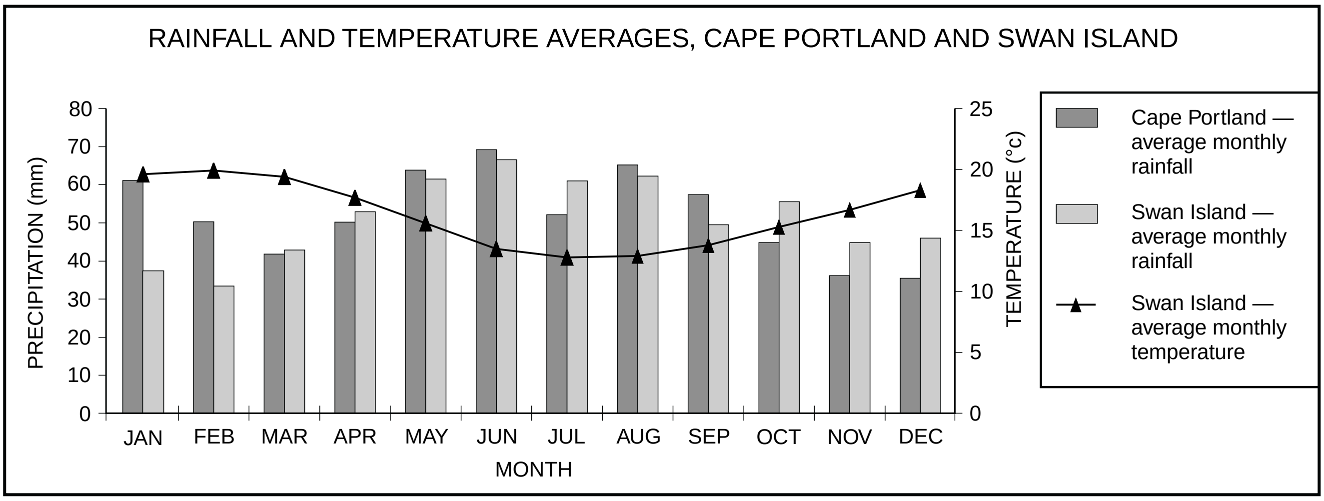


Figure 4

Climate data for Cape Portland and Swan Island

present, the principal species being Bucks Horn Plantain (*Plantago coronopus*) and Sea Barley Grass (*Hordeum marinum*).

Climate

Data from the Swan Island weather station, located one kilometre northeast of the study catchment, indicates that the area has a mean maximum daily average temperature of 16.3°C, with a maximum of 19.9°C in February and a minimum of 8.0°C in August. Swan Island receives an annual average of 613 millimetres of rainfall over an average 133 days (fig. 4). Rainfall records from the property at Cape Portland show an average of 627 millimetres per year. An analysis of long term rainfall figures for the East Coast region indicates a trend towards lower annual rainfall.

Average yearly pan evaporation at Scottsdale is 1022 mm per year. The exposed nature of the Cape Portland area would suggest a higher value than that for Scottsdale. Even so this value is over 1.5 times the precipitation rate.

Geology

The geology of the area has been described by Jennings and Sutherland (1969). An overview of the geology (fig. 5, adapted from Jennings and Sutherland, 1969) indicates that the bedrock comprises dolerite and basaltic rocks. A veneer of windblown sand overlies the bedrock. Localised quartz-rich pebble horizons and shingle beds are also present.

Quaternary deposits

Brown and grey sand is common at and near the surface throughout the study area, occurring at depths from 0.1 to 3 metres. The sand is windblown in origin, being derived from numerous high longitudinal dune systems and blowouts to the west and north. The sand deposits abut the bedrock highs and occur as low stabilised dune features, sandy plains, or sandbanks. The sand is incorporated into the soil profile to produce a rich loam (Jennings and Sutherland, 1969).

Thick impermeable clay layers, interpreted to be saprolite or transported clay, are present above the doleritic and basaltic bedrock. These clays and their derivatives may be up to two metres thick.

Tertiary basalt

Two types of basalts have been identified within the study area (Jennings and Sutherland, 1969), a blue to grey-blue, fine-grained vesicular tholeiitic rock and amygdaloidal alkali rocks. These occur as low rubbly outcrops, minor elevated plateaux and large well-rounded boulders. Numerous basaltic fragments were noted in auger cuttings from piezometers 1, 3, 4 and 5 in the western part of the study area, indicating the possible eastern extent of the basalts. The observed north-trending distribution of the basalts appears to be controlled by topographic highs of dolerite, to the east and west of the study area.

Jurassic dolerite

From its exposed extent, it is assumed that the dolerite forms the bedrock throughout the study area, east to Swan Island and south to Rushy Lagoon. The dolerite is generally medium grained and exhibits well developed, near-vertical jointing, trending NNW–SSE and E–W (Jennings and Sutherland, 1969).

Study parameters

Seventeen water monitoring bores or piezometers were established within the study area (see fig. 6) and monitored for the 18-month duration of the project. Water levels and salinity were monitored on a monthly basis. Piezometers were sited to intersect the water table and all piezometers terminated in bedrock, to a maximum depth of 6.3 metres (Cape 20). The bores were distributed along the length of the drainage system within the study area.

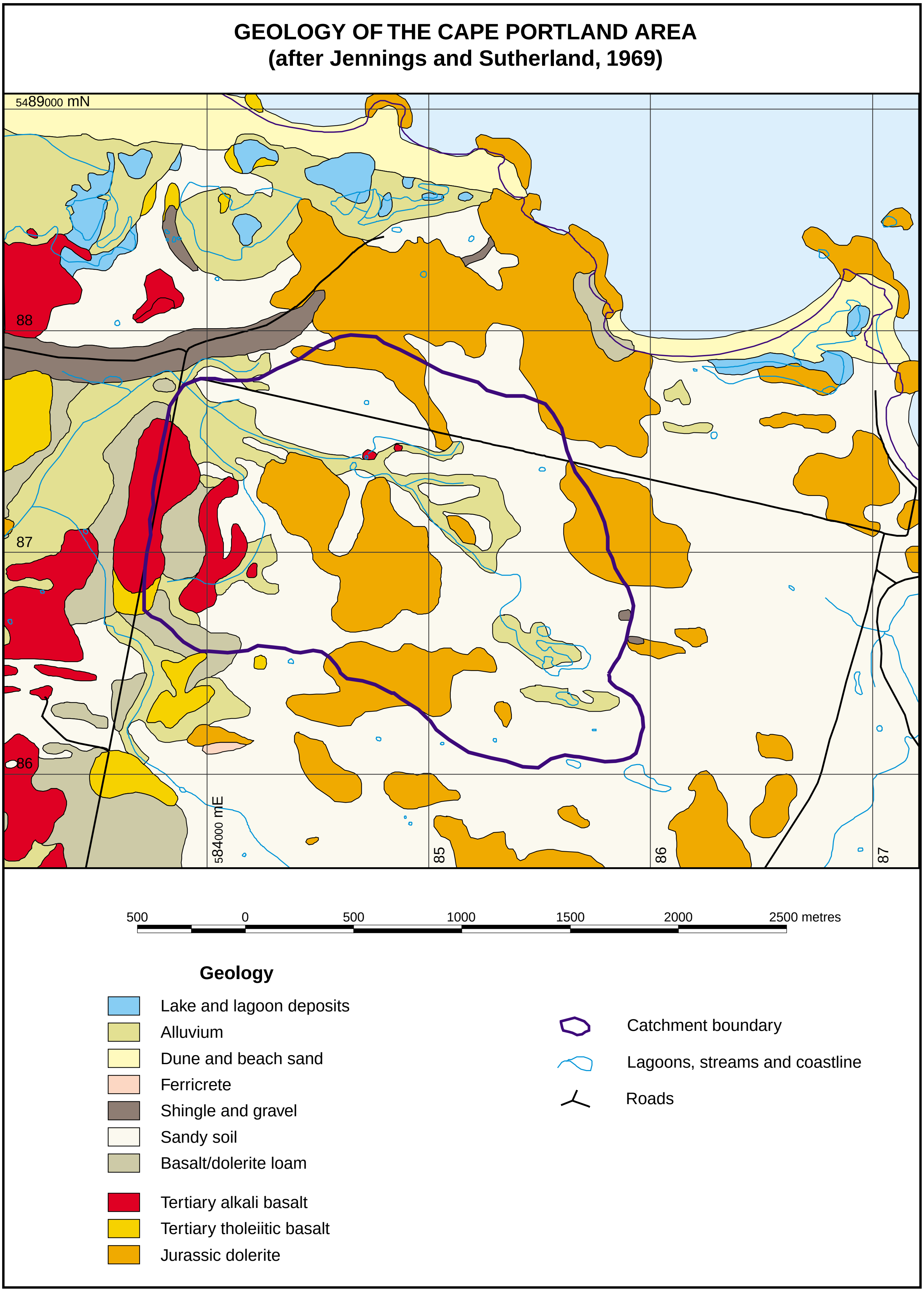

GEOLOGY OF THE CAPE PORTLAND AREA
(after Jennings and Sutherland, 1969)
5489000 mN
88
87
86
584000 mE
85
86
87
500
0
500
1000
1500
2000
2500 metres
Geology
Lake and lagoon deposits
Alluvium
Dune and beach sand
Ferricrete
Shingle and gravel
Sandy soil
Basalt/dolerite loam
Tertiary alkali basalt
Tertiary tholeiitic basalt
Jurassic dolerite
Catchment boundary
Lagoons, streams and coastline
Roads

Figure 5

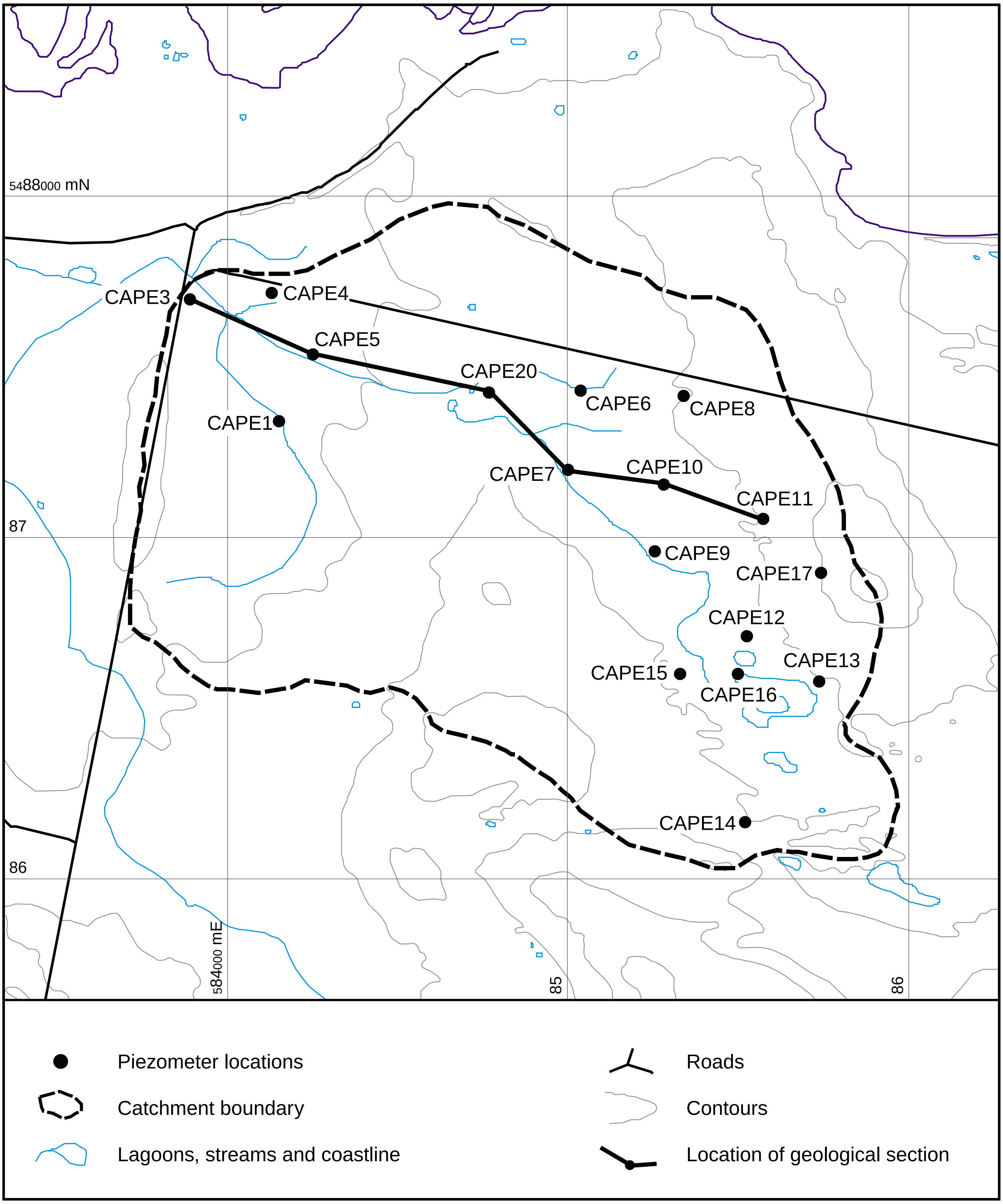


Figure 6

Piezometer locations, Cape Portland Study Area

Cape Portland — Geological Section

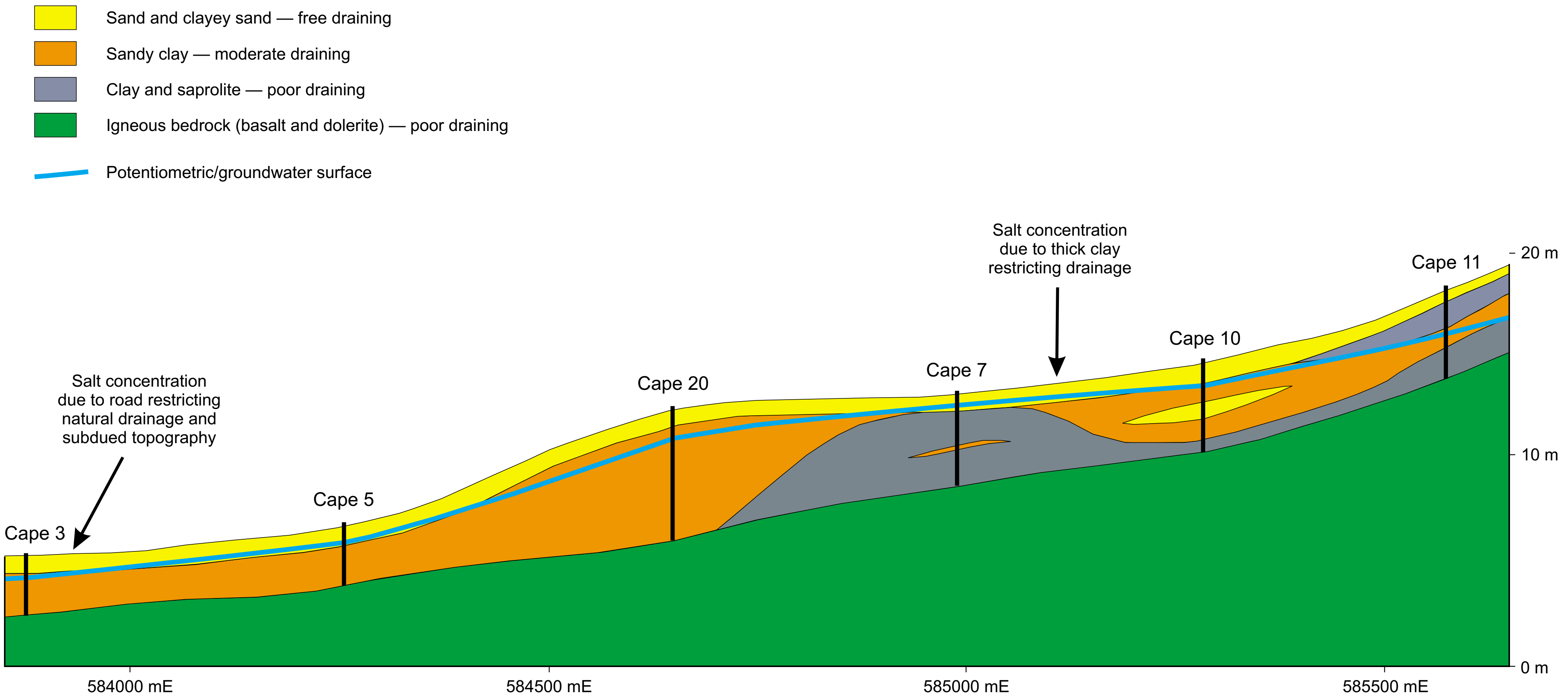


Figure 7

Comprehensive logs of the cuttings from each piezometer have been prepared. A representative geological section for the catchment is shown in Figure 7. This section shows a thin (0.5 to 1 m) layer of poorly consolidated free-draining sand overlying up to five metres of sandy clay and clay saprolite. Dolerite and basalt form the basement to the study area.

Results and discussion

Groundwater levels and salinity trends

Water level and salinity measurements from all piezometers were collected at monthly intervals over a period of 18 months. The average groundwater salinity (conductivity) for all piezometers in this period was 14 477 µS/cm, ranging from 777 µS/cm (Cape 14) to 35 309 µS/cm (Cape 7). The mean water table was 1.08 m below the surface, with a range from –580 mm (Cape 7) to -2270 mm (Cape 8).

Highly saline groundwater was present in two distinct areas (fig. 8). Salinities between 30 000 and 40 000 µS/cm are centered around piezometers Cape 7 and 9, while salinities between 17 000 and 35 000 µS/cm occur around piezometers Cape 1, 3 and 5. Both areas correspond to areas where groundwater occurs within one metre of the ground surface (fig. 9). Distinct areas of low salinity occur around piezometers 13, 14 and 17.

All piezometers in the Cape Portland area responded to groundwater fluctuations in a very similar way. In most piezometers, a major rainfall event produced a rising groundwater level, with a corresponding decrease in salinity, reflecting a dilution of the groundwater by the rainfall. Two piezometers within the study area did not conform to this general pattern. Cape 14 and Cape 17 showed increased salinities immediately after the rainfall event, presumably due to rain-dissolved surficial salt transported into the groundwater surrounding the bores. This effect was most noticeable at these two sites because of the relatively low groundwater salinity levels, averaging below 1000 µS/cm. This behavior is typical of catchments with a relatively uniform geological profile and little deep-rooted vegetation to intercept and use the water.

The catchment response to major rainfall events is typified by the period between 1 December 1999 and 7 January 2000 (fig. 10). A rapid rise in water table (from -1327.1 mm to -460.59 mm below ground level) was associated with a temporary fall in observed salinity (from 15 343 µS/cm to 9361 µS/cm). Both the water table and salinity levels had returned to pre-event levels within three months.

Groundwater flow directions.

Groundwater flow directions in the Cape Portland study area are controlled primarily by outcropping bedrock, which forms low hills up to 50 m high or is present at shallow depth. The contours of the groundwater surface plotted on Figure 11 indicate steep hydraulic gradients around the low bedrock hills, with an essentially flat-lying water table through the middle of the catchment, from piezometers 6 to10. The hydraulic gradient then dips steeply northwest to another area, in the vicinity of piezometers 1-5, where it is again flat lying. These areas of low hydraulic gradient correspond very closely with the areas of high groundwater salinity (fig. 8).

Hydraulic conductivities

Hydraulic conductivity was evaluated at each piezometer using rising head slug tests. This procedure involves removing a 'slug' or quantity of water from the bore and recording the rate at which the water table recovers. The hydraulic conductivity of the 17 piezometers within the Cape Portland study area varied between 0.0026 metres per day (m/day) and 0.39 m/day. This is consistent with a range of representative values determined (after Morris and Johnson, 1967) for clay (0.002 m/day), basalt (0.01 m/day) and fine sand (2.5 m/day).

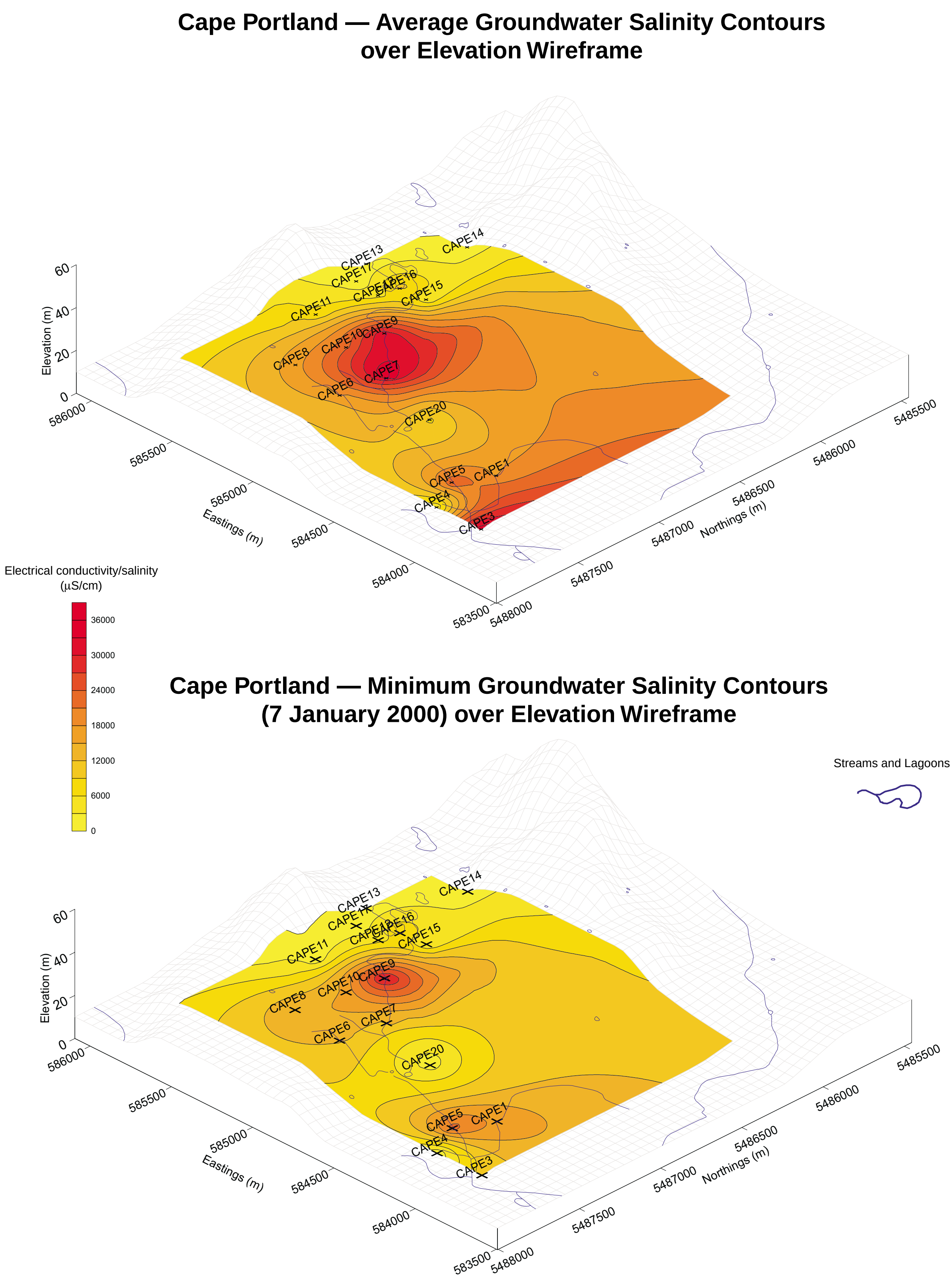
The diagram generated from the slug test data (fig. 12) shows a number of areas of high hydraulic conductivity. These are centered about piezometers Cape 9 and Cape 16, with lesser highs around piezometers Cape 8, 5, 1 and 3. All these sites (with the exception of Cape 8) were very close to drainage lines on flat or very shallowly sloping ground.

Areas of low hydraulic conductivity were also identified (particularly at piezometers Cape 6, 7 and 20), effectively providing a western barrier boundary to groundwater movement in the catchment system. The rate of groundwater movement is likely to be further diminished by constriction of the drainage channel, caused by topographic highs in the vicinity of piezometers Cape 6 and 7. This reduction in groundwater movement and corresponding increase in residence time tends to lead to increased groundwater and soil salinity, resulting from evaporation of near-surface pore waters and absorption of salts from bedrock of sediments.

Water chemistry

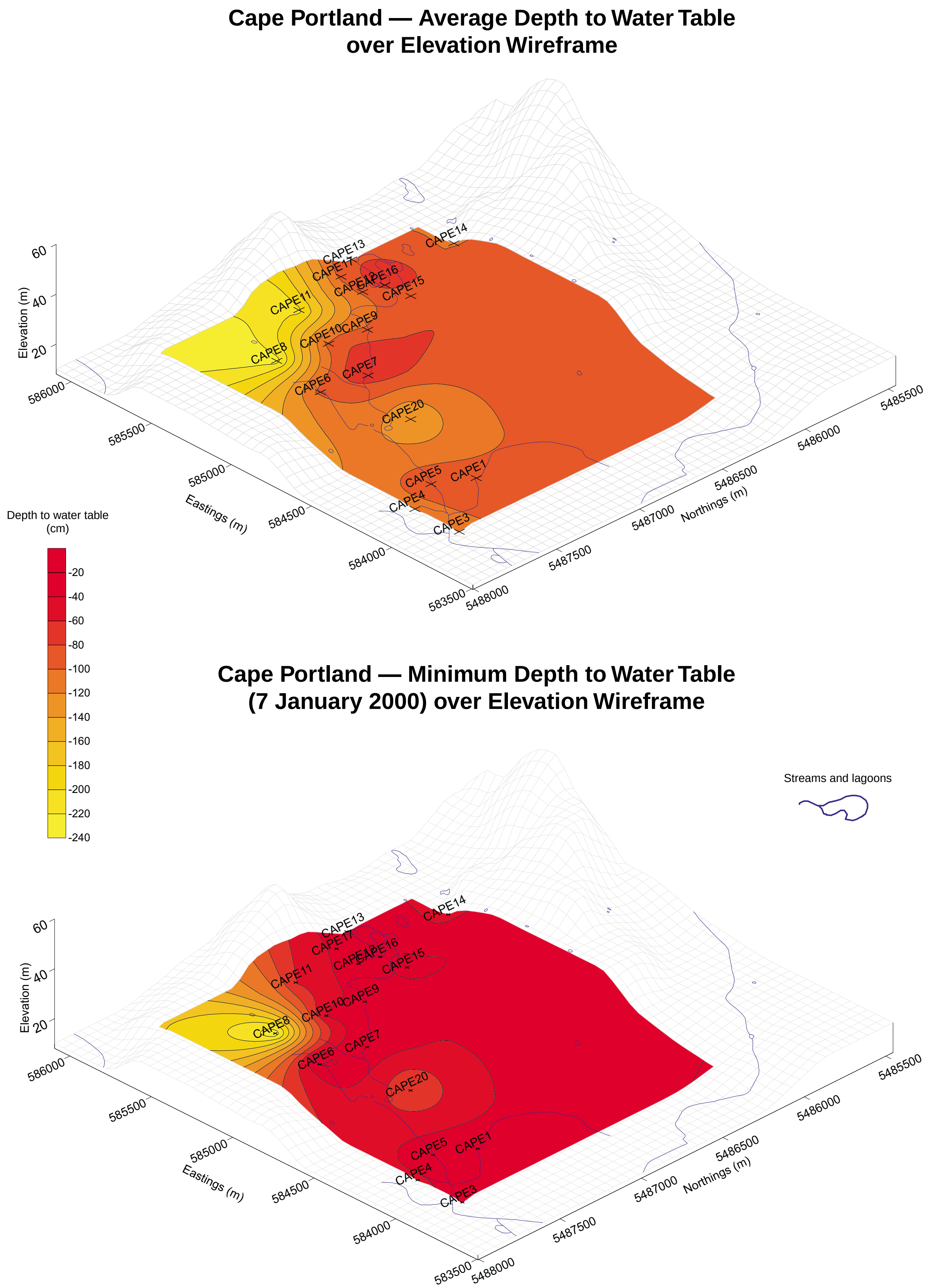
Groundwater chemistry information for water samples extracted from all piezometers was determined by the MRT Laboratory. Analyses (Table 4, Appendix 5) showed that all waters had the same trace element components, with sodium (Na) and chloride (Cl) being the dominant ions. This is consistent with near-coastal rainfall being the principal source of recharge to the catchment.

Based on the general criteria for irrigation water salinity of Hart (1974), the Total Dissolved Solids (TDS) values for the Cape Portland groundwaters show that water from all holes is medium to extremely highly saline, which are generally considered unsuitable for irrigation. Only the groundwater from piezometers Cape 13 and 14 fall below the accepted maximum



Extensive areas of moderate to severe saline groundwater (4000–40 000 µS/cm) are centred around piezometers 7, 9 and 10. This area of salinisation appears to be experiencing impeded drainage to the west, caused by a shallow ridge of doleritic bedrock. This observation is supported when compared to the free draining sites on steeper topography such as around piezometers 13, 14 and 17 which have low apparent salinities. Hydraulic conductivity values presented in Figure 11 also show low hydraulic conductivities around piezometers 6, 7 and 20, supporting the idea of impeded drainage. The lower diagram shows less severely saline groundwater after a large rainfall event during December 1999. Note the expansion of low salinity groundwater around piezometers 11, 13, 14, 17 and 18.

Figure 8



These two figures illustrate the shallow depth at which the groundwater sits below the ground surface. The piezometers indicate that the average depth to the water table is 1.1 metres. The lower diagram shows the effect of a high rainfall event on the catchment during January 2000 when the catchment water table rose to an average depth of just below 500 mm from the ground surface.

Figure 9

Table 4

Groundwater chemistry results

Piezometer Number	Ca^{++} (mg/l)	Mg^{++} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	HCO_3^{--} (mg/l)	CO_3^{--} (mg/l)	SO_4^{--} (mg/l)	Cl^{-} (mg/l)	TDS (mg/l)
CAPE1	498.9	637.1	4150	35.0	248.3	0	1171.5	7823.1	16668
CAPE3	913.2	1549.7	8100	55.6	332.1	0	2232.5	16005.5	33064
CAPE4	132.6	195.1	1018	22.5	169.1	0	307.4	1917.5	4097
CAPE5	599.7	667.6	4150	44.6	164.5	0	1342.4	8036.5	16511
CAPE6	519.3	605.5	3520	38.8	257.6	0	857.9	7076	14556
CAPE7	1269	1701.3	8530	71.9	270.0	0	2079.9	17855.5	38951
CAPE8	424.4	448.6	3260	42.1	197.1	0	860.6	6328.9	12968
CAPE9	929.6	797.9	5830	59.7	474.9	0	1365.1	11380.7	23694
CAPE10	865.8	934.3	4440	67.5	299.5	0	1296.0	9993.2	21254
CAPE11	96.1	91.8	1780.7	11.2	151.3	0	718.8	2838.9	6057
CAPE12	120.6	59.7	654.0	28.4	168.4	0	313.7	1195.3	2842
CAPE13	18.85	15.5	186.7	8.1	12.4	0	20.9	362.8	762
CAPE14	8.84	13.4	87.8	9.6	10.8	0	37.5	179.6	423
CAPE15	143.3	103.6	1543.7	36.4	183.1	0	505.4	2582.8	5241
CAPE16	198.4	82.1	1064.7	22.8	383.3	0	326.0	2134.5	4644
CAPE17	36.02	20.6	293.8	9.1	146.5	0	95.5	367.9	1052
CAPE20	31.33	36.2	689.4	7.3	141.8	0	194.1	863.2	1911

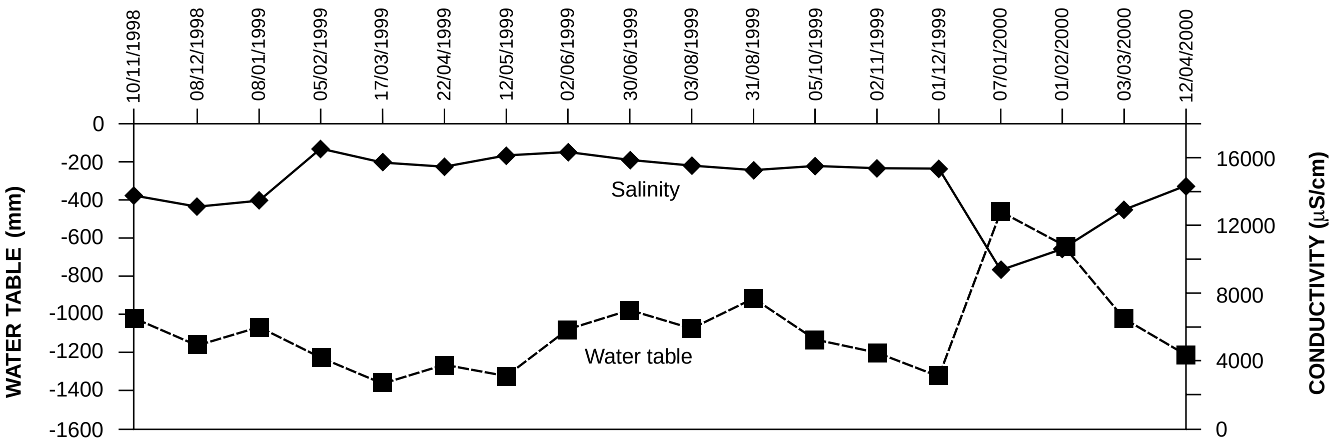


Figure 10

Average catchment water table and salinity levels

value for human consumption of 800 mg/l TDS. Table 5 shows the five irrigation classes that Hart defined.

Soil salinity

Drill cuttings recovered at 900 mm depth intervals during the installation of each piezometer were dried, crushed and placed in a mixture of five parts water to one part soil sample, mixed and then analysed for salt content. The average EC1:5 salinity values for the cuttings of each piezometer have been plotted on a contour map in Figure 13. The highest salt concentration (4693 µS/cm) is centered around piezometer Cape 7, located in an area which forms the damming feature of the upper catchment. Water at this site sits, on average, just over 500 mm from the ground surface, where considerable evaporation and concentration of salts would occur.

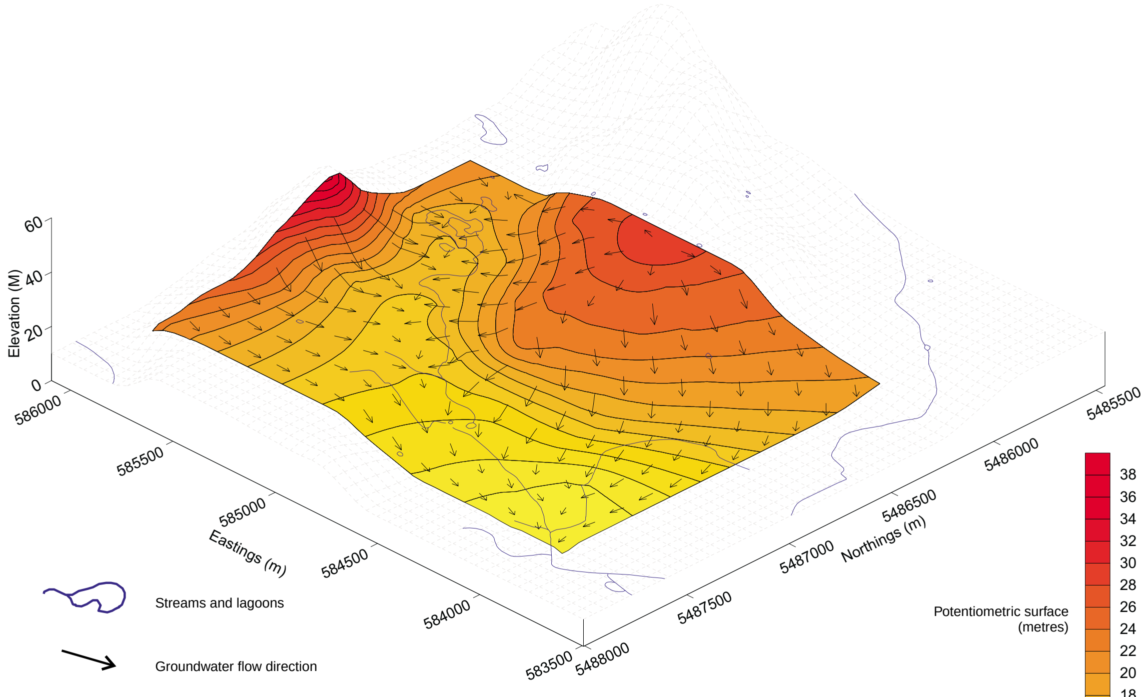
Surface soil salinity levels taken from the top 900 mm of the profile (fig. 13) are considerably lower than theaveraged total soil salinity values for each piezometer. This is attributed to the leaching of salts from the upper, more sandy soils to lower in the profile. This is significant as signs or absence of signs of surface salting may not reflect salt levels at depth.

Hydrological observations

The main current source of salt within the Cape Portland area is from aeolian salts within wind, rain and salt spray. Measurements of rainwater from the site and heavy salt mists during windy weather support these observations. The low-lying and near-coastal nature of much of the study area suggests it may once have been subject to marine incursion, providing a further source of salt.

Drainage through the middle of the catchment, notably around piezometers Cape 6 and 7, is poor due to bedrock highs and impermeable clay. These

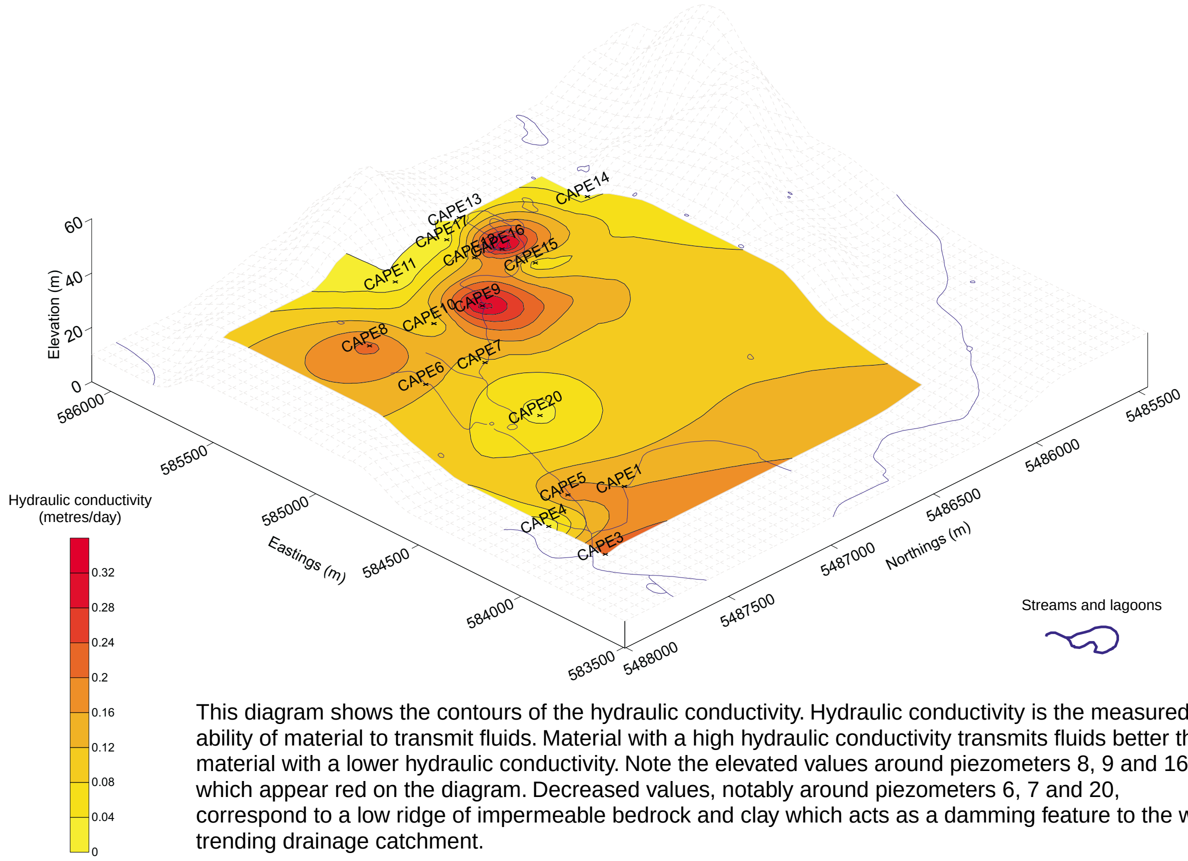
Cape Portland — Potentiometric Surface and Groundwater Flow Directions over Elevation Wireframe



This diagram shows the groundwater flow directions as black arrows. These arrows overlie a contour map of the potentiometric surface generated from the measured groundwater levels. The groundwater flow direction in this case mimics the surface water flow, as only a shallow veneer of sand overlies the bedrock which controls the topography and the groundwater level. The piezometric surface contours show two essentially flat-lying areas of water within the catchment. These areas are the result of damming or ponding of groundwater behind bedrock highs, and are coincident with the location of the highly saline groundwater.

Figure 11

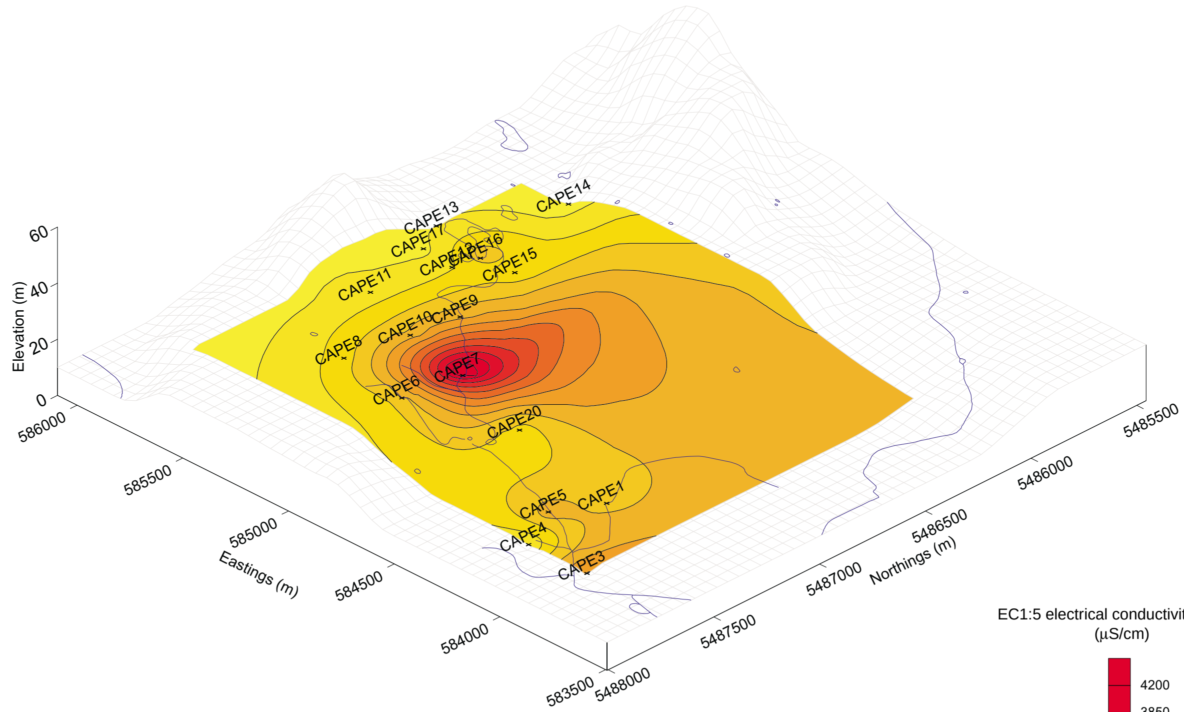
Cape Portland — Hydraulic Conductivity Contours over Elevation Wireframe



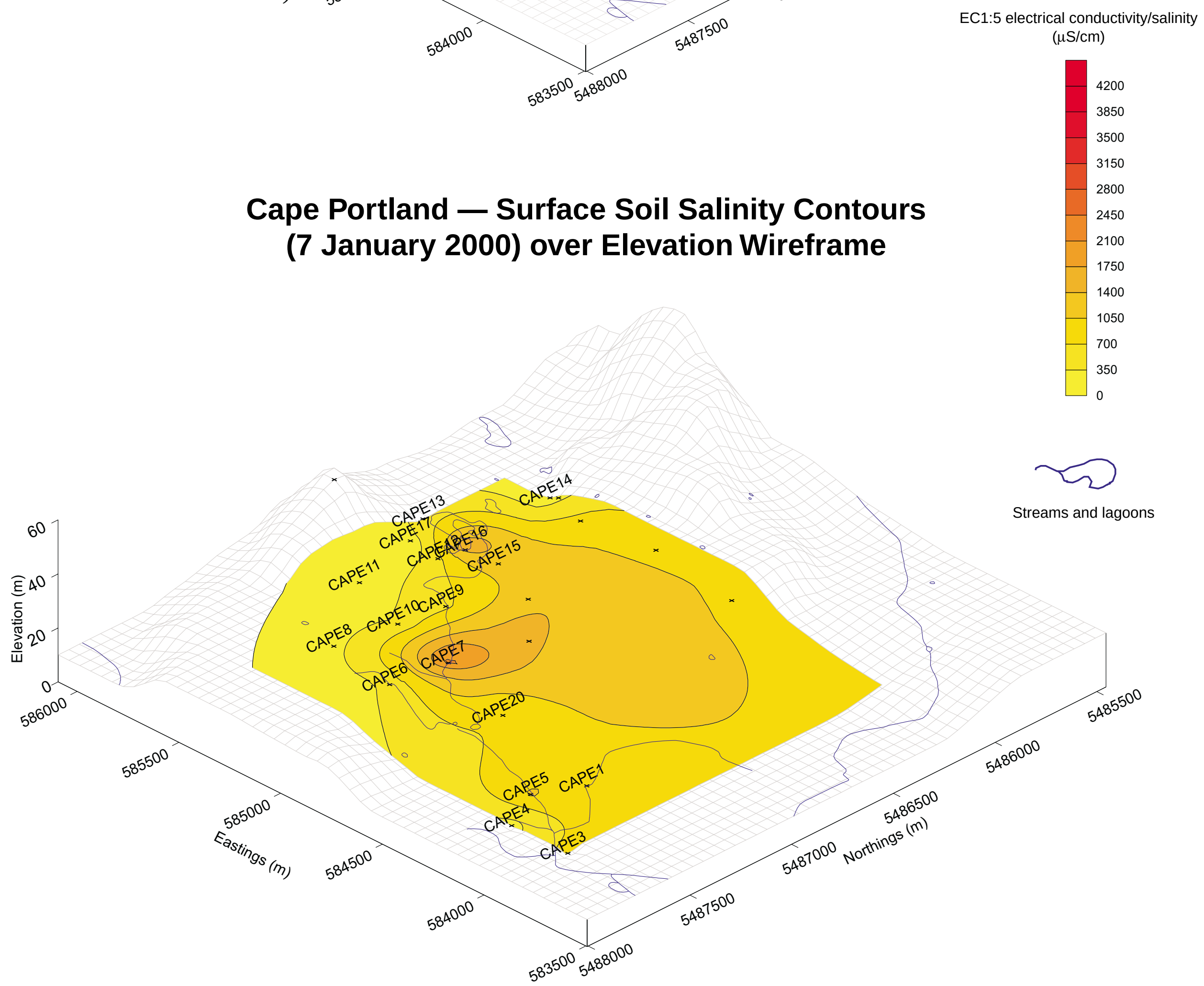
This diagram shows the contours of the hydraulic conductivity. Hydraulic conductivity is the measured ability of material to transmit fluids. Material with a high hydraulic conductivity transmits fluids better than material with a lower hydraulic conductivity. Note the elevated values around piezometers 8, 9 and 16 which appear red on the diagram. Decreased values, notably around piezometers 6, 7 and 20, correspond to a low ridge of impermeable bedrock and clay which acts as a damming feature to the west-trending drainage catchment.

Figure 12

Cape Portland — Average Soil Profile Salinity Contours over Elevation Wireframe



Cape Portland — Surface Soil Salinity Contours (7 January 2000) over Elevation Wireframe



The important features to note on these diagrams are the extensive areas of moderately to severely saline soils centred around piezometer Cape 7 and to a lesser extent Cape 16. This surface area of salinisation correlates directly with the high levels of groundwater salinity observed in Figure 8. The surface soil salinity levels are lower than the average soil profile values which can be attributed to leaching of salts from the upper, more porous sandy soil profile.

Figure 13

Table 5

General criteria for irrigation water salinity (from Hart, 1974)

Class	Total dissolved solids (mg/l)	Electrical conductivity (µS/cm)
Class 1 (C1): Low salinity water, generally safe; little chance of salinity problems, some leaching needed on clayey low-permeability soils.	0–175	0–280
Class 2 (C2): Medium salinity water; may be used if moderate leaching occurs; Plants with medium salt tolerance may be grown. Sprinkler irrigation may cause leaf-burn in sensitive crops.	175–505	280–805
Class 3 (C3): High Salinity water; cannot be used on soils with restricted drainage. Soils must be permeable; salt-tolerant crops need to be considered.	500–1500	800–2300
Class 4 (C4): Very high salinity water: not generally suitable for irrigation: Soils must be permeable, drainage adequate, water applied in excess to promote leaching; salt tolerant crops selected.	1500–3500	2300–5500
Class 5 (C5): Extreme salinity water: Not Suitable for irrigation.	> 3500	> 5500

impermeable barriers effectively dam the groundwater, raising it close to the surface, and allowing salt to concentrate by evaporation.

Water budget calculations, of 627 mm of rain falling over the 2.98 km^2 catchment area each year, give an average water input of 1868.46 cubic metres per year. Based on an average rainfall salinity of 158 µS/cm or 101 mg/L, the annual salt input into the catchment is 630 kilograms/hectare. Much of this water received as rainfall currently moves through the soil to the groundwater due to the lack of deep-rooted vegetation to intercept or use the water.

National catchment classification

This case study area fits within the *Local Model (i) – Discharge over lower hydraulic conductivity structures* as outlined in Coram (1998). Examples of this type of model are documented in Western Australia at the 'Upper 52' creek catchment in Konjonup, in South Australia at the Seddon Plateaux on Kangaroo Island, and in NSW at Box Hill at Inverell.

Recommended action

The Cape Portland study area has very saline groundwater, which occurs at shallow depth. A reduction of groundwater salinity, groundwater levels and a minimisation of soil and land degradation could be achieved by the following strategies:

- Maintain a good cover of vegetation and do not overgraze. Grow deep-rooted pasture crops.
- Revegetate areas with higher recharge with *Allocasuarina* sp. Planting trees most suited to local conditions will ensure healthy growth, therefore helping to utilise water, preventing excess groundwater recharge and salt mobilisation to lower slopes. Revegetation can be also incorporated into shelter belts, therefore helping to lower evaporation rates exacerbated by prevailing winds.
- Fence off all bare and scalded areas from stock access and plant with salt tolerant pasture species and saltbush. Species selection should be done in accordance with surface and near-surface salinity levels. Appropriate establishment techniques should be followed, and species allowed at least 18 months to fully establish prior to grazing.
- Investigate the chemistry of the soil and rocks to determine other possible salt sources, such as sediments from old lagoons or palaeochannels.
- Continue monitoring of groundwater conditions in order to establish long-term trends under varying climatic/rainfall patterns and possible future changes in land use.

Summary

Salt within the Cape Portland study area is presently derived from aeolian salt inputs. The close proximity to the coast results in the study area being subject to near continuous salt input from sea spray during easterly, northerly or westerly weather. Salt may also have been sourced from saline marine or dune deposits or introduced during a marine incursion.

Salt within the groundwater is concentrated through a process of evaporation, especially around piezometer Cape 7 where the groundwater depth averages less than 0.5 metres below ground level.

The highest salinity levels are observed in areas of low hydraulic gradient, high hydraulic conductivity and upslope of damming features.

Case Study 2

CHINTAH ROAD — LONGFORD BASIN STUDY CATCHMENT

Surface salt precipitation in drainage depression, Longford study area

Salt scald with Yellow Water Buttons and Buck's Horn Plantain in drainage line, Longford study area

Overview

The earliest records of farming within the study area date to 1912, when Isacc Smith established 'Smithfield' as part of a Closer Settlement Scheme. The land around this farm was cleared between 1912 and 1940. The original vegetation of the area comprised native grasses, open Black Peppermint (*Eucalyptus amygdalina*), and *Acacia dealbata* forest. The area covered by the study is presently used for sheep, cattle and deer grazing, and grain and fodder crops.

Location

This study area encompassed 10.57 square kilometres of land in the Longford Tertiary Basin (Matthews, 1983) in northern Tasmania. The area (fig. 14) was contained within eight separate farm holdings in area situated generally northeast of the intersection of Chintah and Powranna roads (518 000 mE, 5 384 000 mN), about 30 kilometres SSE of Launceston.

Geomorphology

The study area was located on the eastern margin of the Longford Basin. The catchment is located within low undulating terrain between 160 and 320 metres above sea level (ASL). The catchment is bounded to the south by the the Hummocky Hills and to the east and north by a series of low gravelly rises rising up to 190 m ASL.

The dendritic drainage pattern within the catchment dissects the upper level coarse quartz gravel and sand deposits and lies mainly within the orange and brown Tertiary clay, silty clay and sandy clay. A deflation zone of bare scalded ground is clearly visible from the road adjacent to piezometers Long1 and Long2, and another is developing around piezometer Long7. The catchment drains through a perennial stream system into the Macquarie River before it reaches Cressy.

Vegetation

Exotic pastures dominate the lower catchment where up to 95% of the remnant vegetation has been cleared. Remnant Black Peppermint (*Eucalyptus amygdalina*) and *Acacia dealbata* forests are preserved within the upper catchment, particularly within the quartz-rich gravel rises. Many salt indicator species are present, particularly within drainage lines and areas of

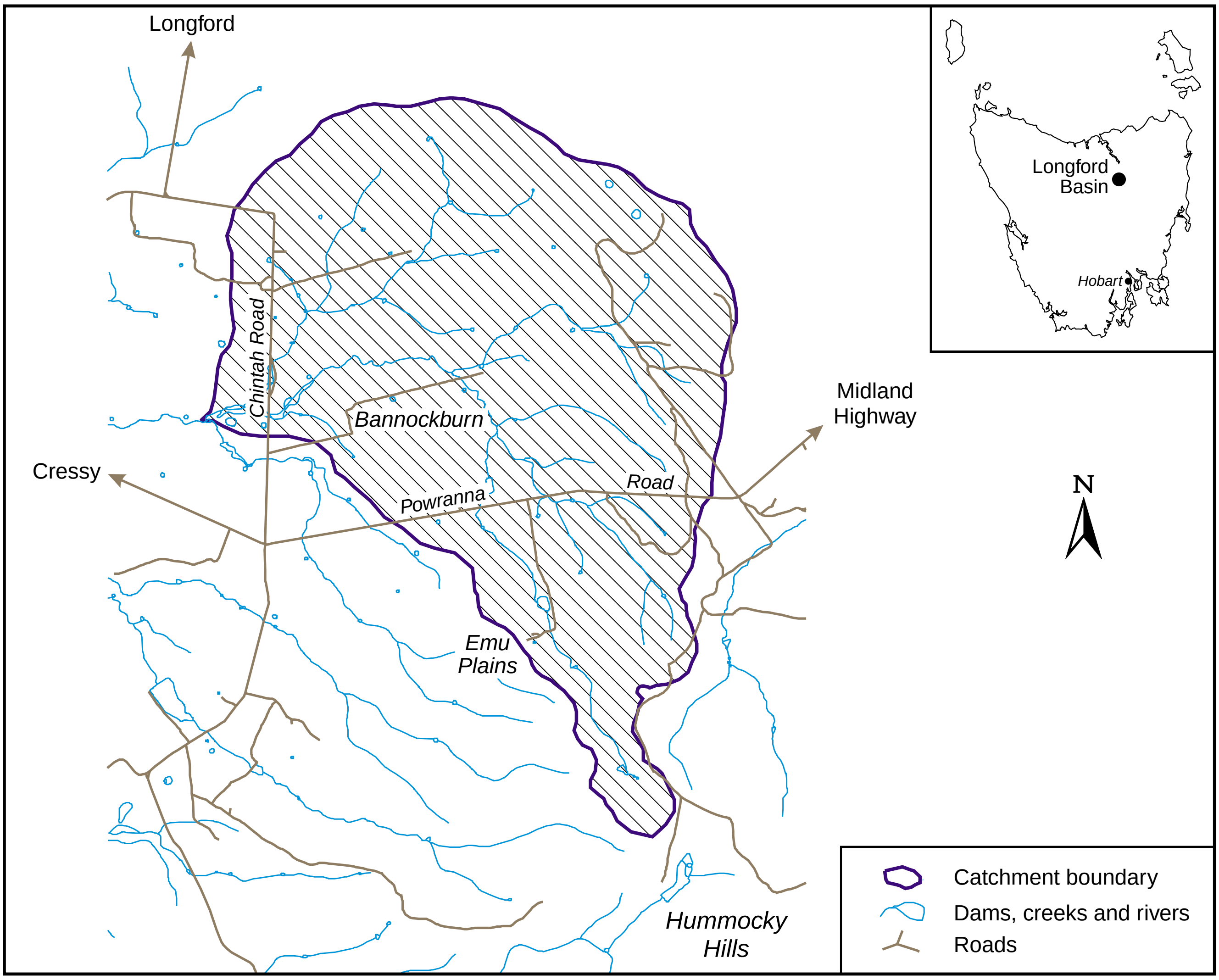


Figure 14

Location of Longford Basin study area catchment

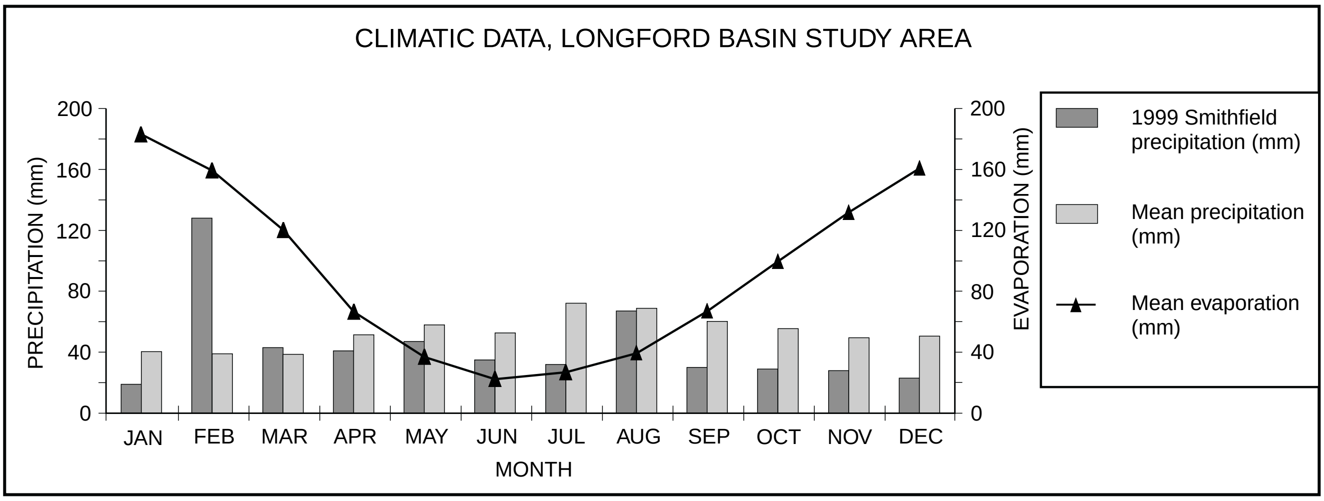


Figure 15

subdued relief. The principal species occuring are Bucks Horn Plantain (*Plantago coronopus*) and Yellow Water Buttons (*Cotula coronopifolia*).

Climate

The Cressy Research Station, located ten kilometres west of the study area, has recorded a mean maximum daily average temperature of 16.3°C, with a daily average maximum of 23.6°C in January and February and a daily average minimum of 0.9°C in July (fig. 15). Cressy receives an average of 640 millimetres of rainfall per year, with precipitation occuring on average 123 days. Average yearly pan evaporation at Cressy is 1112.1 mm per year. Bureau of Meteorology records indicate that evaporation exceeds precipitation for eight months of the year.

Climatic conditions during the course of the study were unusual, with above average temperatures and significantly reduced average rainfall. This is clearly shown in the Figure 15, with only February and March receiving above average rainfall. Long-term rainfall figures from Cressy, and much of the northern and eastern parts of Tasmania, indicate a trend towards a drier climate.

Geology

Jurassic dolerite, which crops out on Hummocky Hills, forms the basement to a westward-thickening wedge of Tertiary sediments which occur over much of the study area. Tertiary sediments overlying the dolerite basement attain a depth of up to 148 m within the catchment (Matthews, 1983). The geology map (fig. 16) has been adapted from Matthews (1983).

Quaternary sediments

A thin veneer (0.5–2 m) of fine wind-blown sand is banked against the foot slopes of the Hummocky Hills.

Reworked Tertiary quartz and ironstone gravels are present as a surficial lag over the Tertiary sediments and within drainage lines. Deposits of sand, silt and clay with common ironstone gravel and quartz granules are exposed low in the catchment in saline scald deflation zones, particularly around piezometers Long1 and 2.

Tertiary sediments

The Tertiary sediments of the Longford Basin were most likely to have been derived from the erosion of Triassic rocks and deposited in a non-marine, lacustrine depositional environment (Direen, 1995; Direen and Roach, 1997).

Two distinct Tertiary lithofacies are present within the study area:

- white quartz gravel and sand deposits up to 2 to 3 metres thick, which form part of the Brickendon Surface (Nicolls, 1958). This material, which forms low rises on the eastern and northern boundaries of the catchment, has been interpreted to be part of a deflated lateritic weathering surface (Matthews, 1983);
- orange to brown and grey clay and sandy to silty clay which form the Brumby Surface (Nicolls, 1958). These sediments contain minor surficial ironstone gravel and concretions, quartz and lithic fragments. In profile the clay and silty to sandy clay show strong horizontal platy mottle and dark grey stiff clay band development near surface and at depth close to the current water table.

Jurassic dolerite

Regional geological mapping (Matthews, 1983) and geophysical modelling (Direen, 1995) suggest that fine to medium-grained Jurassic dolerite forms the basement over much of the study area.

Triassic shale

A strongly indurated, metamorphosed shale with quartz and lithic sandstone horizons has been intruded by Jurassic dolerite on the flanks of Hummocky Hills. The shale is part of a freshwater

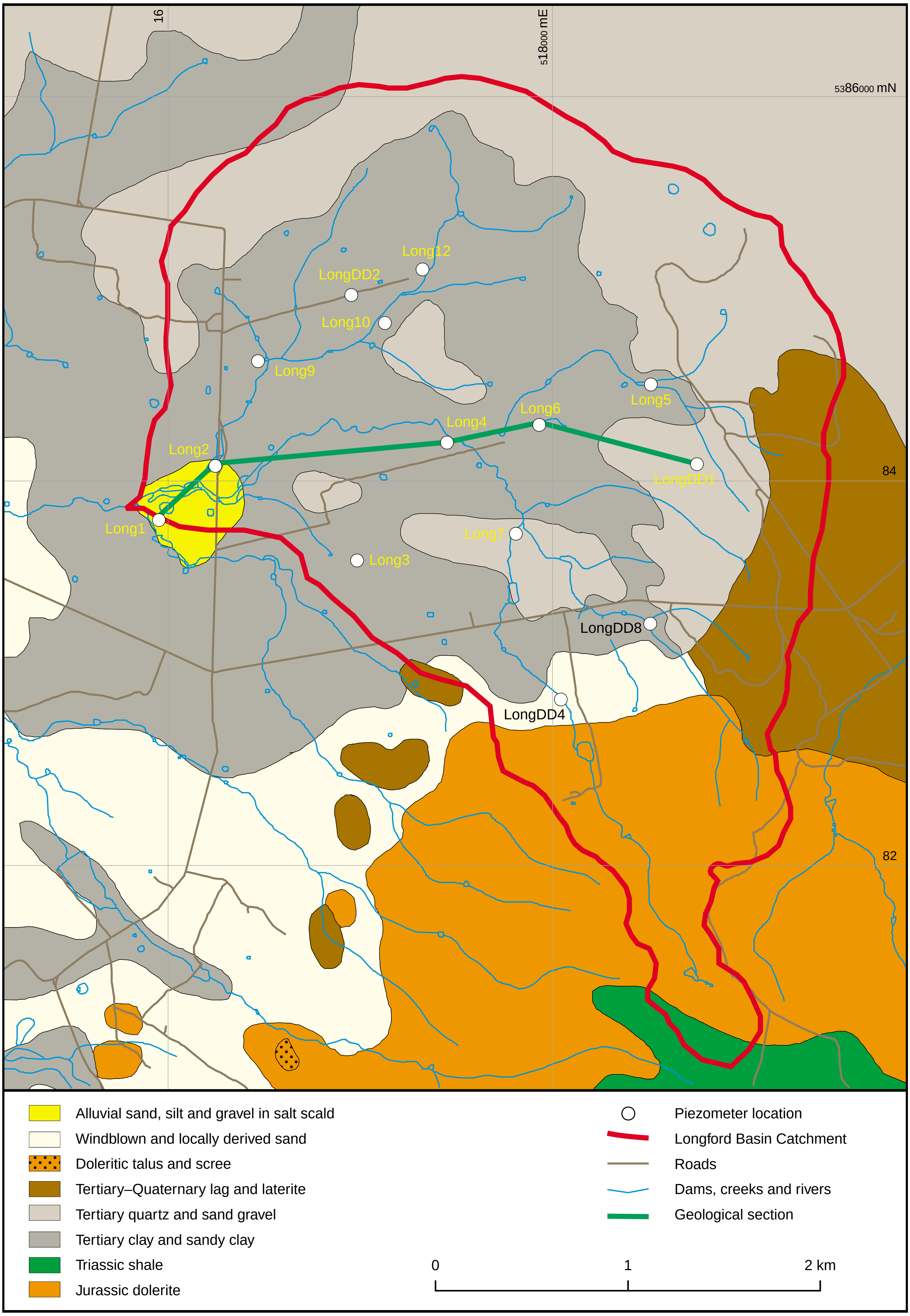


Figure 16

Geology and bore locations, Longford Basin Study Area

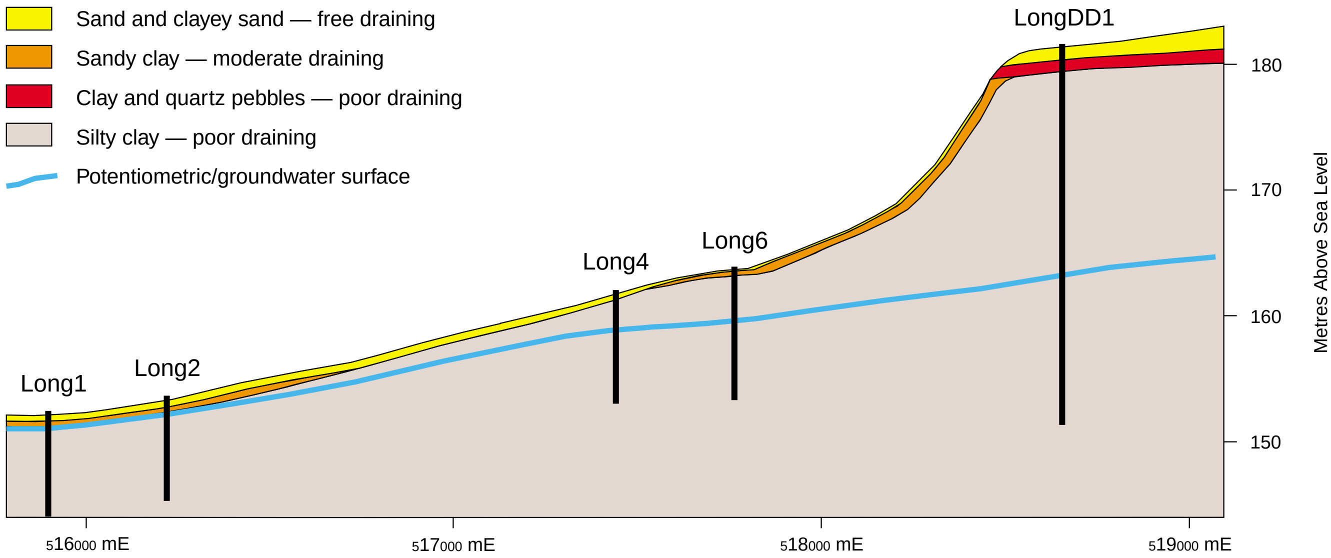


Figure 17

Geological section (see Figure 16 for location of section line)

sequence and forms the uppermost bedrock of the water catchment. The Late Triassic rocks have been suggested as a possible salt source (Direen, 1995).

Study parameters

Twelve water monitoring bores or piezometers were established within the study area (fig. 16). Water levels and salinity were monitored on a monthly basis for the 18 month duration of the project.

Piezometers were sited to intersect the subsurface standing water table and all holes were drilled until water was encountered or until the maximum depth of drilling was reached at 10.4 metres. The deepest piezometer (LongDD1) was drilled to 30 metres depth. The piezometers are evenly spread along the length of the major drainage system within the study area.

Comprehensive logs of the cuttings from piezometer installation were collected. A representative geological type section for the catchment has been produced from these logs (fig. 17). This section shows a thin veneer of gravel, sand and sandy clay up to one metre thick overlying a thick sequence of silty to sandy clay. Dolerite forms the deep basement of the study area.

Results and Discussion

Groundwater properties and salinity trends.

Groundwater and salinity measurements of the twelve piezometers were collected at monthly intervals for 18 months. The average groundwater salinity/conductivity for all holes over this period was 10 259 µS/cm. The average water table depth, excluding deep piezometers, was 3090 mm below ground level. Average salinity ranged from 15 007 µS/cm in Long3 to 2470 µS/cm in LongDD4. Water table depth ranged from –1100 mm in Long1 to –18 200 mm in LongDD1.

All piezometers responded to rainfall events with a corresponding rise in observed water table and a decrease in groundwater salinity (fig. 18). The catchment response was typified by the effect of 67 mm

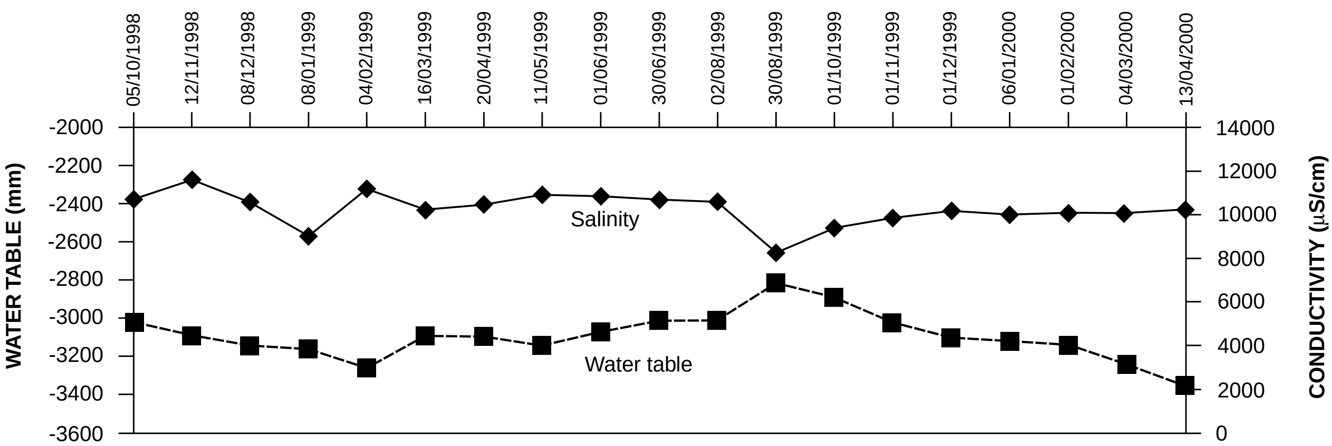


Figure 18

Average catchment water table and salinity levels of rain during August 1999. After this rainfall event the average catchment water table rose 200 mm and the average catchment salinity decreased by 2000 µS/cm.

Average catchment salinity levels showed a steady increase and average groundwater levels a steady decrease after the August 1999 rainfall event. This trend corresponds with a period of below average rainfall and above average temperatures.

Groundwater salinity data show a gradual increase in salinity towards the base of the catchment (fig. 19). Holes LongDD4 and Long8, which intercept groundwater flowing from Hummocky Hills, produced the best quality water, with salt concentration gradually increasing with distance from this location, reaching a maximum in the flat lower reaches of the catchment about piezometers Long3 and Long1. This gradual increase in salt concentration may result from either the long residence time of the groundwater, allowing maximum possible salt dissolution from the Tertiary sediments, or evaporation of near-surface waters, causing increased salt in the groundwater.

Groundwater levels were within two to four metres of the ground surface through much of the lower catchment (fig. 20). The result of this was visible as considerable areas of bare, scalded ground, particularly about piezometers Long 1, 2, 9 and 7. These areas of near-surface groundwater correspond closely to areas of high soil salinities.

Groundwater flow directions

Groundwater flow directions in the Longford Basin study area are controlled primarily by topography, with the groundwater mimicking surface water flow. The contours of the potentiometric surface indicate a moderate hydraulic gradient in the southeast of the catchment draining off Hummocky Hills, with an essentially flat-lying water table through the lower, gently undulating plains of the east and northeast of the catchment (fig. 21). These areas of low hydraulic gradient correspond very closely with the areas of high water salinity (fig. 19).

Hydraulic conductivity

The local hydraulic conductivity was evaluated at each piezometer by using a rising head slug test. This procedure involves removing a 'slug' or quantity of water from the piezometer and recording the rate at which the water table recovers. Within this study area, the hydraulic conductivity of the seventeen piezometers varied between 0.0013 metres per day (m/d) and 0.2 m/d. This is consistent with a range of representative values determined (after Morris and Johnson, 1967) for clay (0.0002 m/d), silt (0.08 m/d) and fine sand (2.5 m/d).

The diagram generated from the slug test data (fig. 22) shows a broad area of high hydraulic conductivity (highlighted in red) co-incident with the major northwest to west-trending drainage line.

Water chemistry

Groundwater chemistry information for water samples extracted from all piezometers was determined by the MRT Laboratory. Analyses (Table 6, Appendix 5) showed that all waters had the same trace element components, with sodium (Na), chloride (Cl), magnesium (Mg) and bicarbonate (HCO_3) being the dominant ions. The Na and Cl is consistent with rainfall being the principal present source of salt to the catchment. The Mg and HCO_3 components are most likely derived from dissolution of minerals in weathered dolerite.

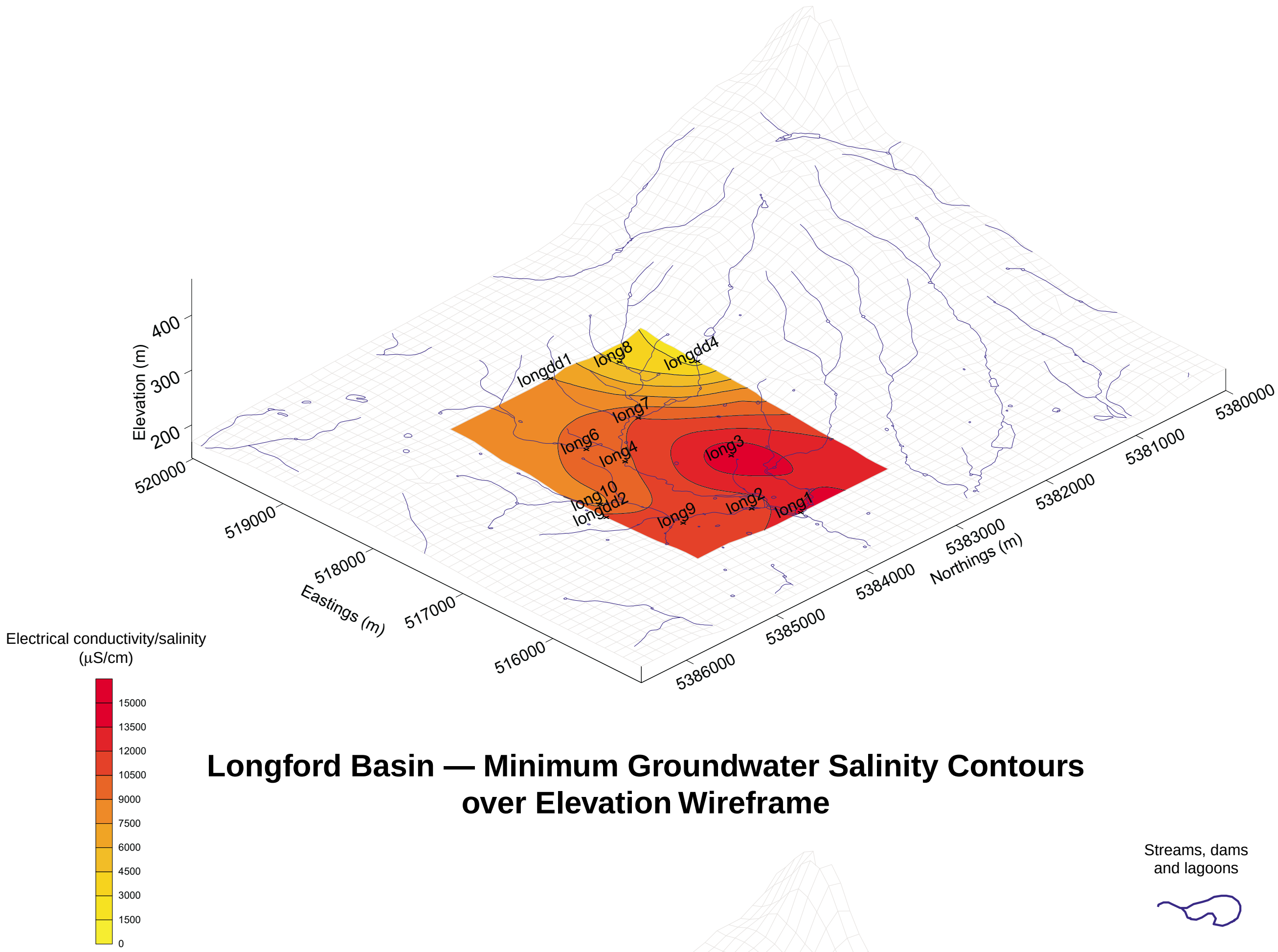
Based on the general criteria for irrigation water salinity of Hart (1974), the total dissolved solids (TDS) values for the Longford groundwaters show that water from all holes is very highly to extremely highly saline and is generally considered unsuitable for irrigation. None of the groundwater sampled had salinities below the accepted maximum of 800 mg/*l* TDS, regarded as fit for human consumption. Table 5 shows the five irrigation classes that Hart defined.

Table 6

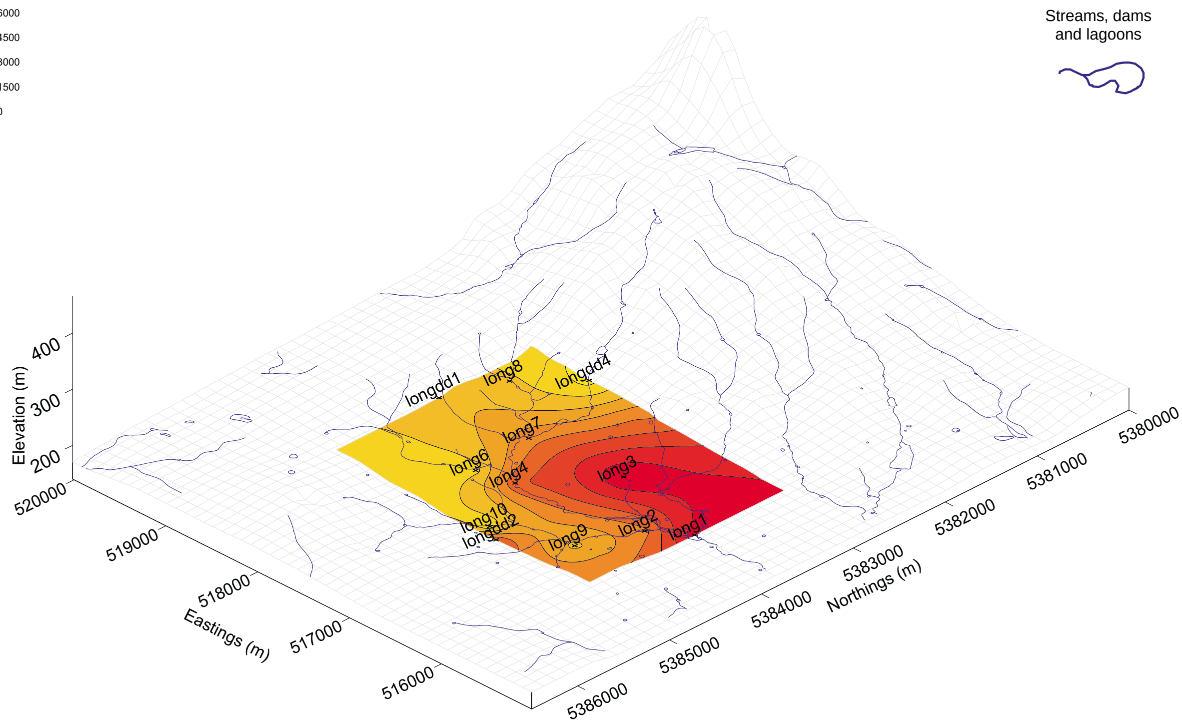
Groundwater chemistry results

Piezometer Number	Ca^{++} (mg/l)	Mg^{++} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	HCO_3^{--} (mg/l)	CO_3^{--} (mg/l)	SO_4^{-} (mg/l)	Cl^{-} (mg/l)	TDS (mg/l)
LONG1	118.3	325.44	2557.8	1.68	9.31	0	330.34	5058.8	9839
LONG2	168	271.29	2234.3	8.3	48.11	0	335.78	4411.4	8874
LONG3	154	426.95	2863.4	18.4	113.31	0	465.87	5759.7	11063
LONG4	137.26	274.85	2013.15	12.23	560.35	0	241.75	3504.1	6719
LONG6	159.78	325.27	2283.45	20.67	293.36	0	387.65	4198.6	8038
LONG7	236.75	432.85	1918.96	13.59	779.21	0	170.44	3950.6	7792
LONG8	108.96	195.97	837.034	6.37	807.15	0	59.120	1580.2	3416
LONG9	132.88	324.62	2170.83	8.03	87.70	0	240.76	4053.3	7513
LONG10	116.63	308.37	2107.21	11.4	43.46	0	180.48	3947.0	7306
LONGDD1	345.82	522.28	645.8	18.26	344.59	0	78.387	2898.3	5860
LONGDD2	252.2	372.48	1915.43	23.59	307.17	0	301.36	4039.2	7820
LONGDD4	110.05	109.98	299.46	7.27	623.69	0	17.126	602.33	1630

Longford Basin — Average Groundwater Salinity Contours over Elevation Wireframe



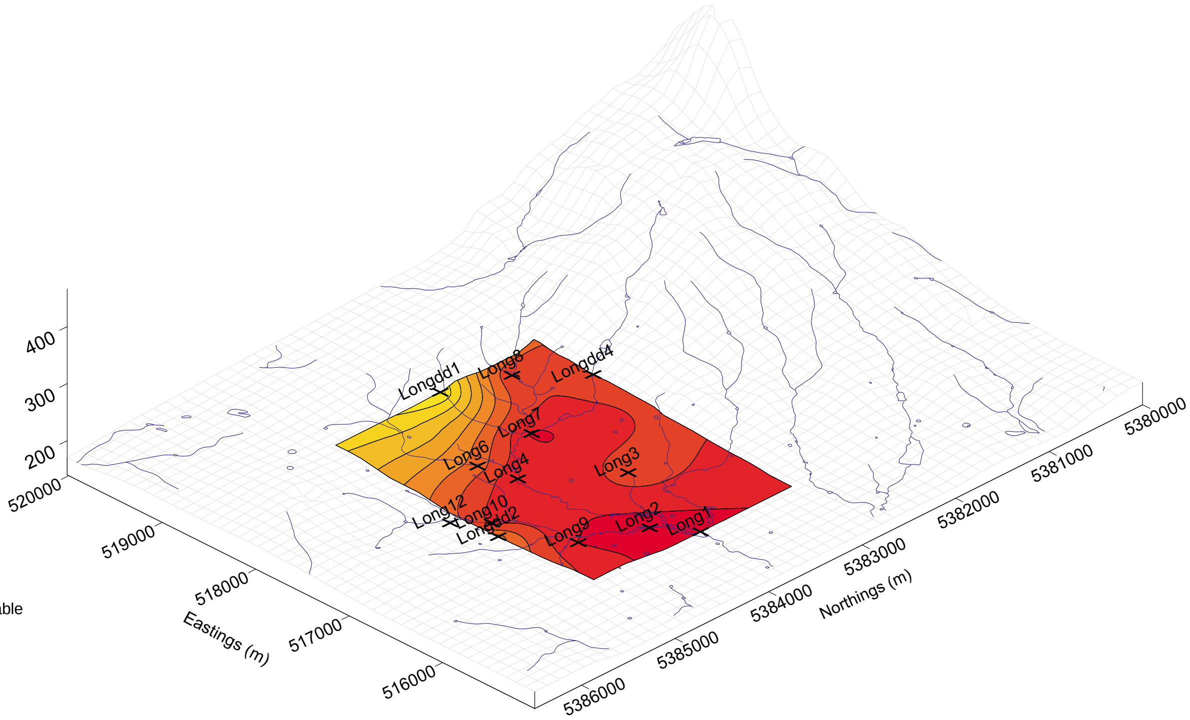
Longford Basin — Minimum Groundwater Salinity Contours over Elevation Wireframe

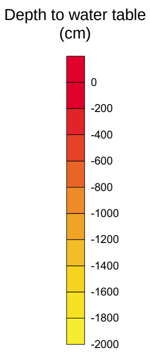


These diagrams show high average groundwater salinity levels about holes Long1 and Long3. This area corresponds to an area of subdued topography, and in the case of Long1 a large salt scald. The lower diagram shows the effect of a high rainfall event with a considerable influx of fresh groundwater into the northern and eastern part of the catchment.

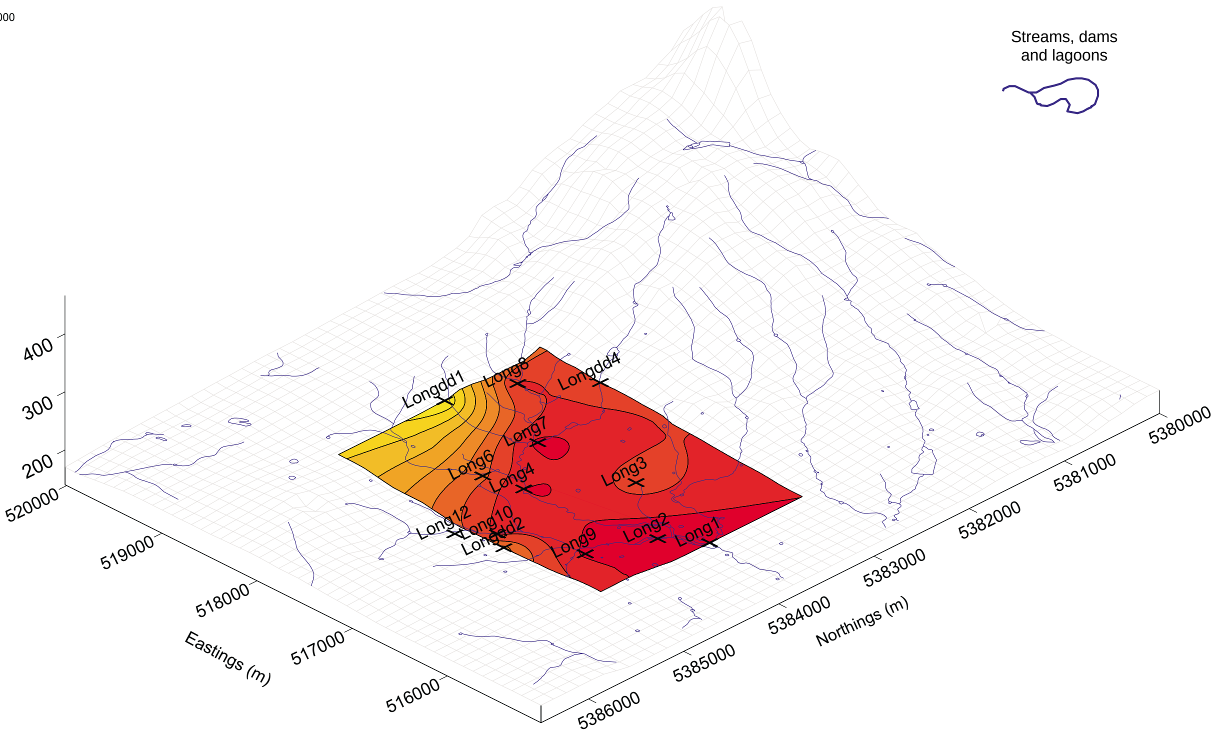
Figure 19

Longford Basin — Average Depth to Water Table over Elevation Wireframe





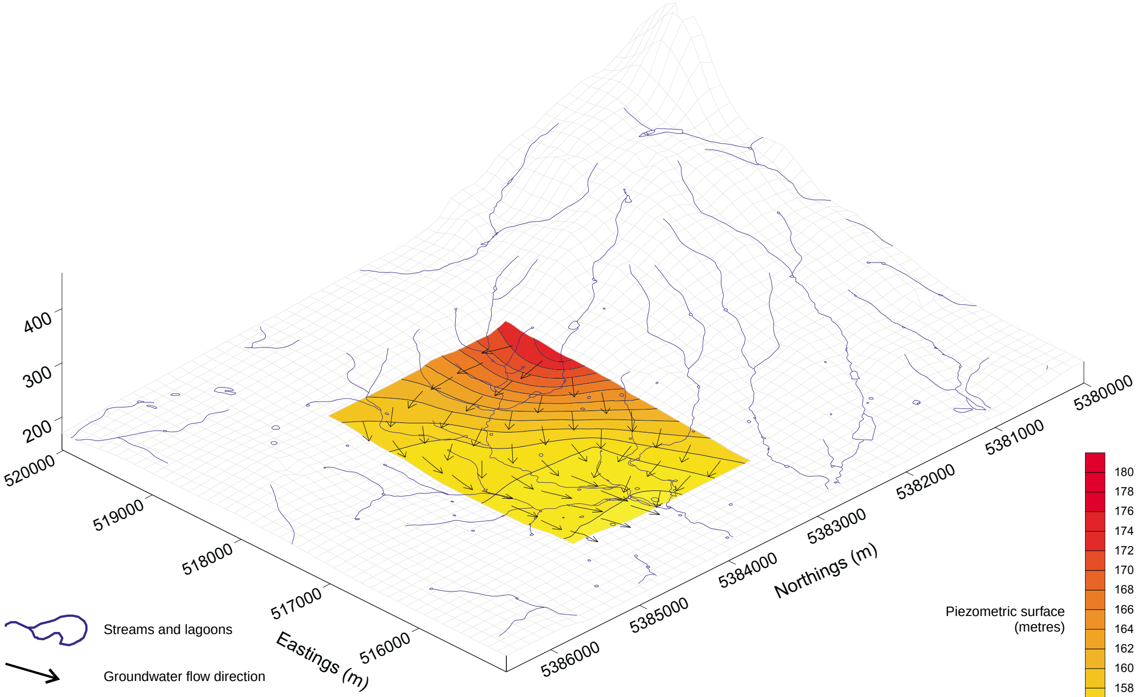
Longford Basin — Minimum Depth to Water Table over Elevation Wireframe



These two figures illustrate the shallow depth at which the groundwater sits below the ground surface. The piezometers indicate that the average depth to the water table is 3.09 metres. The lower diagram shows the effect of a high rainfall event on the catchment when the water table rose to an average depth of 2.80 metres.

Figure 20

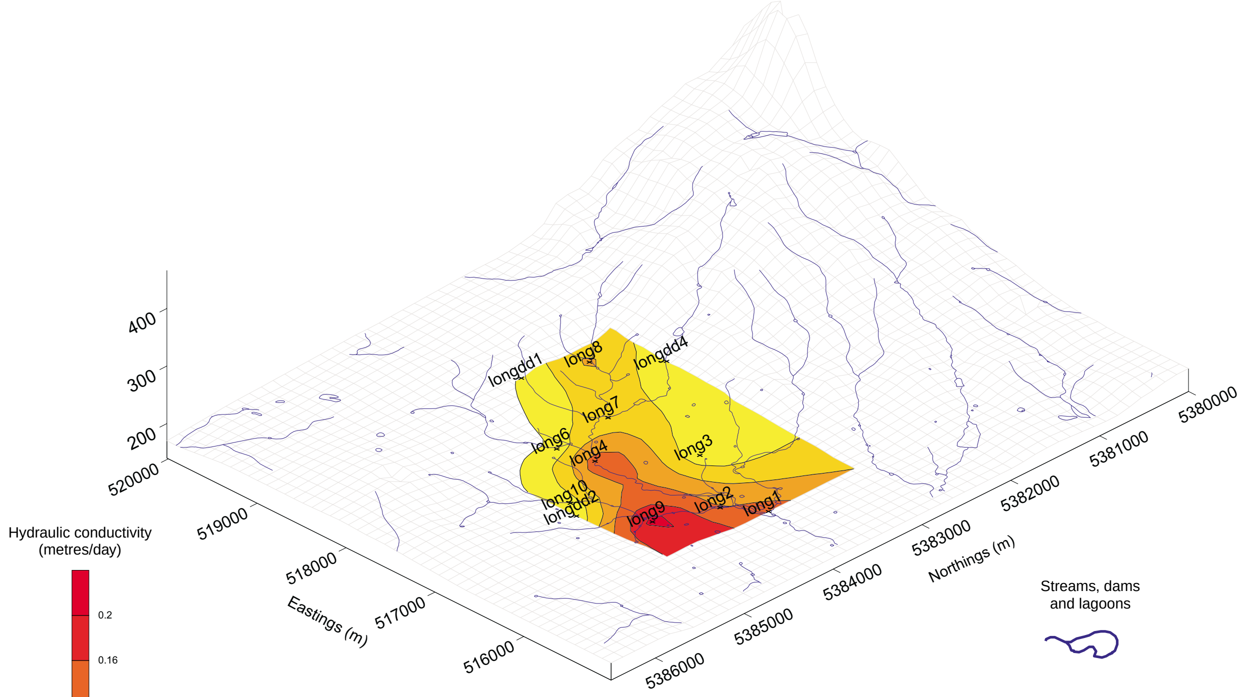
Longford Basin — Potentiometric Surface and Groundwater Flow Directions over Elevation Wireframe



This diagram shows the groundwater flow directions as black arrows. These arrows overlie a contour map of the potentiometric surface generated from the measured groundwater levels. The groundwater flow directions in the Longford Basin area are controlled initially by shallow skeletal soils over the dolerite and then by impermeable layers in the Tertiary clay through the lower areas of the catchment. Information about piezometers Long4 and LongDD2 has been removed because of irregularities in groundwater level records, possibly caused by blocked casing or surface runoff.

Figure 21

Longford Basin — Hydraulic Conductivity Contours over Elevation Wireframe



This diagram shows the contours of the hydraulic conductivity. Hydraulic conductivity is the measured ability of material to transmit fluids. Material with a high hydraulic conductivity transmits fluids better than material with a lower hydraulic conductivity. Hydraulic conductivities range from 20 mm to 200 mm per day. The most obvious feature is the area of higher conductivity present along the drainage line through the centre of the catchment. The areas of low to very low hydraulic conductivity ranging from 20 to 80 mm per day are due to thick Tertiary clay sequences.

Figure 22

Soil salinity

Drill cuttings recovered at 900 mm intervals during piezometer installation were dried, crushed and placed in a mixture of five parts water to one part sample, mixed and then analysed for salt content. The average EC1:5 salinity values for the cuttings of each piezometer have been plotted on a contour map in Figure 23. The highest salt concentration of 945 µS/cm was centered around piezometer Long3. Soil salinity values are also high surrounding piezometers Long 1 and 2. The water table at these sites was encountered at an average depth of approximately 900 mm below ground level, indicating the potential for considerable evaporation and concentration of salt.

Surface soil salinity levels (fig. 23) are considerably lower than the average hole values. This is attributed to the leaching of salts from the upper, more sandy soils to units lower down the profile.

Hydrological observations

Direen (1995) has suggested three possible sources for the high salt loads observed within the Tertiary sediments of the Longford Basin:

1. Salty sediments derived from the erosion of Triassic sediments;
2. Relict meteoric salt sourced from the Tamar estuary; and
3. Ions released from the lateritisation of basalts.

A well-developed incised surface drainage network is present through the middle and upper catchment. This watercourse is dammed twice in the lower catchment on the Bannockburn property. The largest of these dams retains water with a salinity of 1800 µS/cm, while water in the reservoir held by a secondary dam lower in the catchment had a salinity of 6200 µS/cm. Irrigation from either of these dams would severely effect yield of most crops and pastures and would add significant amounts of salt into the groundwater system.

Extensive low-lying areas of the catchment, particularly around Long3, are poorly drained and very boggy after moderate to heavy rainfall events. The presence of clay aquitards within the sediments of the Longford Basin inhibits groundwater movement to a significant degree and reduces the opportunity for dilution. Groundwater flow rates in the catchment are generally low because of the impermeable clay. Where groundwater is close to the surface, salt concentration is increased through evaporation.

Water budget calculations, based on 640 mm of measured rainfall falling over the 10.57 km^2 catchment each year, indicate an average water input of 6764.8 cubic metres per year. Using a recorded rainfall salinity of 50 µS/cm or 32 mg/L gives an approximate annual salt input into the catchment of 200 kilograms per hectare. Most of the rainwater can be assumed to infiltrate as groundwater because of the lack of deep rooted vegetation to intercept or use the water.

National catchment classification

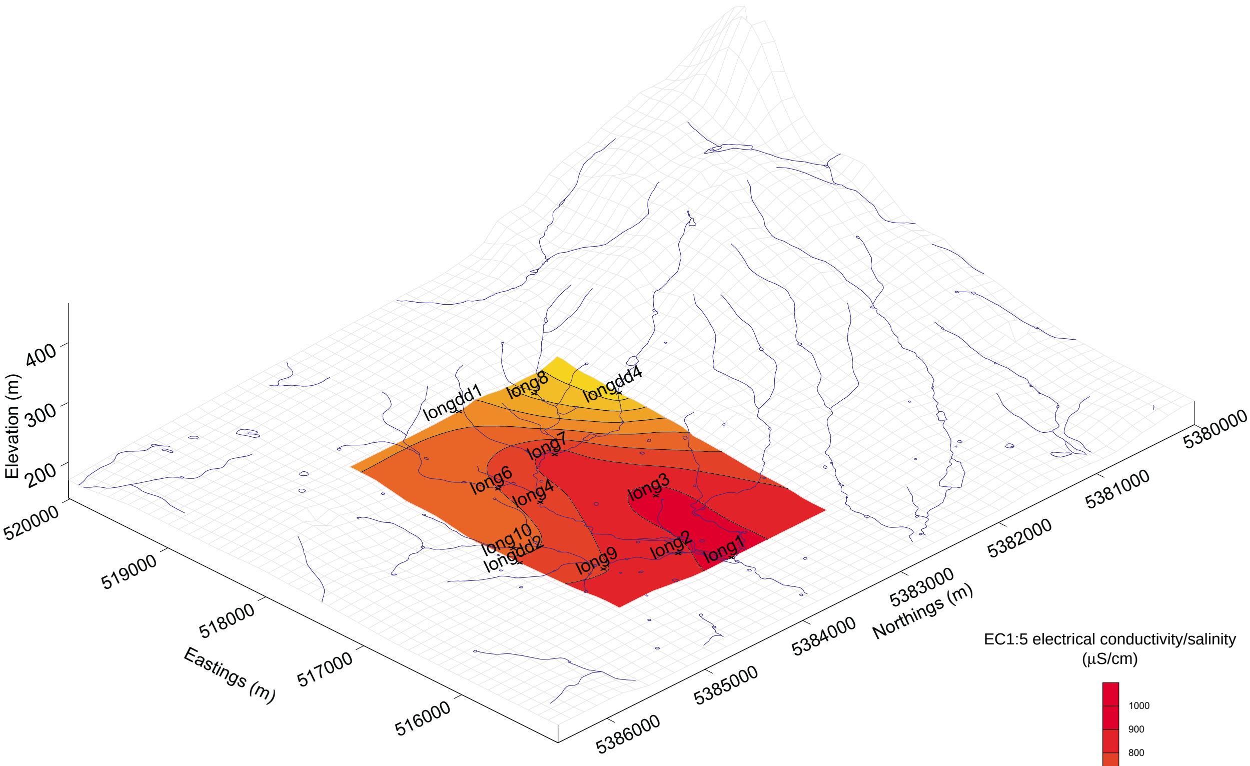
This case study area fits within the *Local Model (viii) — Discharge from low hydraulic conductivity aquifers*, as identified in Coram (1998). Examples of this type of model are documented in Western Australia at the Mills Lake Catchment on the south coast, and in Victoria at Barwon Downs.

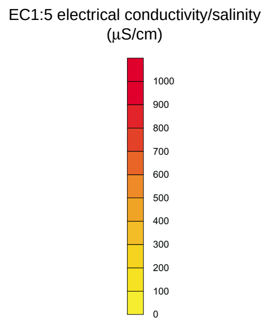
Recommended action

The Longford Basin study area has very saline groundwater, which occurs at variable depths. A reduction of groundwater salinity, groundwater levels and a minimisation of soil and land degradation could be achieved by the following strategies:

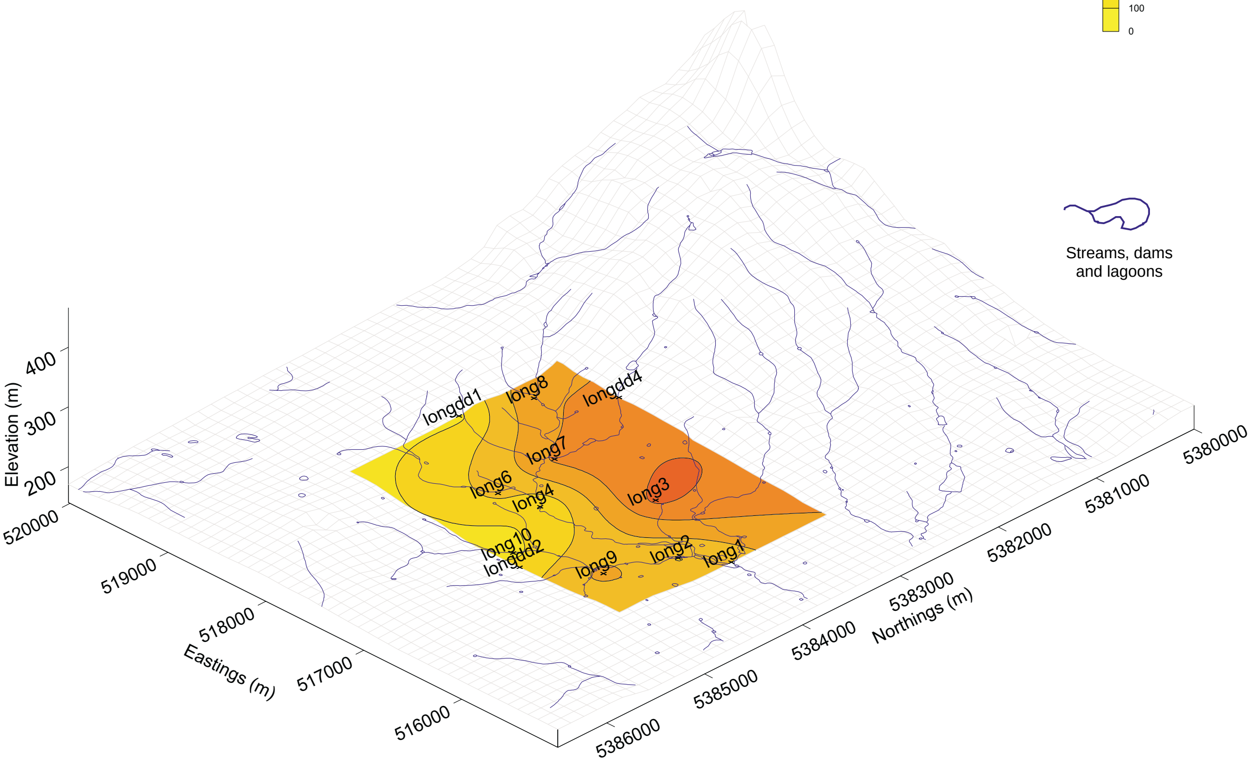
- Maintain a good cover of vegetation and do not overgraze.
- Revegetate identified areas of higher recharge, particularly the lower slopes of Hummocky Hills and on the quartz gravel country of the Brickendon Surface, with local well adapted species. This will help to utilise water, preventing excess groundwater recharge and salt mobilisation into the lower catchment. This strategy can be also incorporated into shelter belts, therefore helping to lower evaporation rates exacerbated by prevailing winds.
- Fence off all bare-scalded areas from stock and plant with salt-tolerant pasture species and saltbush. Species selection should be done in accordance with surface and near-surface salinity levels.
- Re-plant deep-rooted eucalypt species upslope and around the areas of elevated saline groundwater to increase water use and decrease groundwater levels.
- Investigate the chemistry of soil and rocks to determine other possible salt sources such as sediments from old lagoons or palaeochannels.
- Continue monitoring of groundwater conditions in order to establish long-term trends under varying climatic/rainfall patterns and possible future changes in land use. The introduction of cropping and irrigation in the region should be done with extreme caution, and will most likely exacerbate rates of salinisation. Surface drainage and subsurface drainage would be an essential management tool under these land use changes, but would have devastating consequences on the surface water and groundwater resources in the region.

Longford Basin — Average Soil Profile Salinity Contours over Elevation Wireframe





Longford Basin — Surface Soil Salinity Contours over Elevation Wireframe



The important features to note on these diagrams are the very highly saline geological profiles centred around piezometers Long1, 2, 3 and 7 adjacent to the main drainage line. The top diagram shows a very similar distribution to the average groundwater salinities (fig. 19). The distribution of salts within surficial soils shows elevated values within poor draining clay around the footslopes of Hummocky Hills. The surface soil salinity levels are generally much lower than the average soil profile values, which can be attributed to the sandy and free draining nature of the upper soil profile.

Figure 23

Summary

Salt within the Tertiary sediments in the Longford Basin study catchment may be derived from one or more of five main sources:

- salt derived from the erosion of Triassic sediments;
- relict meteoric salt sourced from the adjacent Tamar estaury;
- salt released from the laterisation of basalt;
- salt received in rainfall; and
- salt from saline irrigation water (mainly on farm storages).

Saline groundwaters are expressed surficially as scalding and reduced yields in crops where water approaches to within two metres of the ground surface.

Deep drilling indicates considerable salt storage beneath the root zone of crops.

Highly saline groundwaters are located in the lower catchment and are generally in areas of low hydraulic gradient and low hydraulic conductivity.

Case Study 3

VERWOOD

Looking north over West Bar Lagoon.
Tree decline is evident around much of the lagoon

Looking north over East Bar Lagoon, Verwood study area

Overview

Farming began in the Verwood area before 1850, with the majority of the current Verwood property being cleared by about 1950. Before clearing, the vegetation consisted of silver tussock, open *Eucalyptus* sp. and *Acacia* sp. forest (Andrew Dowling. pers. comm.). The study area currently supports around 15% native vegetation cover and is used for cropping and cattle and sheep grazing.

Location

The Verwood study area (527 000 mE, 5 343 500 mN) covers 8.012 square kilometres of land wholly within the Verwood property, which is presently managed by Andrew and Charles Dowling. Verwood is located in the eastern Central Midlands of Tasmania, approximately 20 kilometres west of the township of Ross (fig. 24).

Geomorphology

The study area is situated on the footslopes and within the rain shadow of the Great Western Tiers. The terrain varies between 240 and 320 metres above mean sea level. The catchment drains from around 320 m on the slopes of the Great Western Tiers, and from low laterite rises, into Bar Lagoon. Considerable doleritic alluvium and colluvium has been deposited as high level alluvial terraces where the Tiers meet the flat plains.

The study area forms part of an old elevated and planar Tertiary weathering surface. This low undulating surface contains two major and a series of smaller ephemeral salt pans. Both Bells Lagoon and Bar Lagoon salt lake systems are endorheic closed drainage networks, with no surface water outflow from either lagoon. The elevated surface forms a broad drainage divide, channeling adjacent surface waters north into the Isis River and south into the Blackman River.

Vegetation

The lowland vegetation present on laterite rises and within the open plains is dominated by open *Eucalyptus amygdalina* forest with a scrub understorey and open native and improved grasslands.

The property has been grazed for over 50 years, during which time much of the native vegetation has been replaced by perennial pastures. Many salt indicator species are present in the area surrounding Bar Lagoon, the principal species being Bucks Horn Plantain (*Plantago coronopus*).

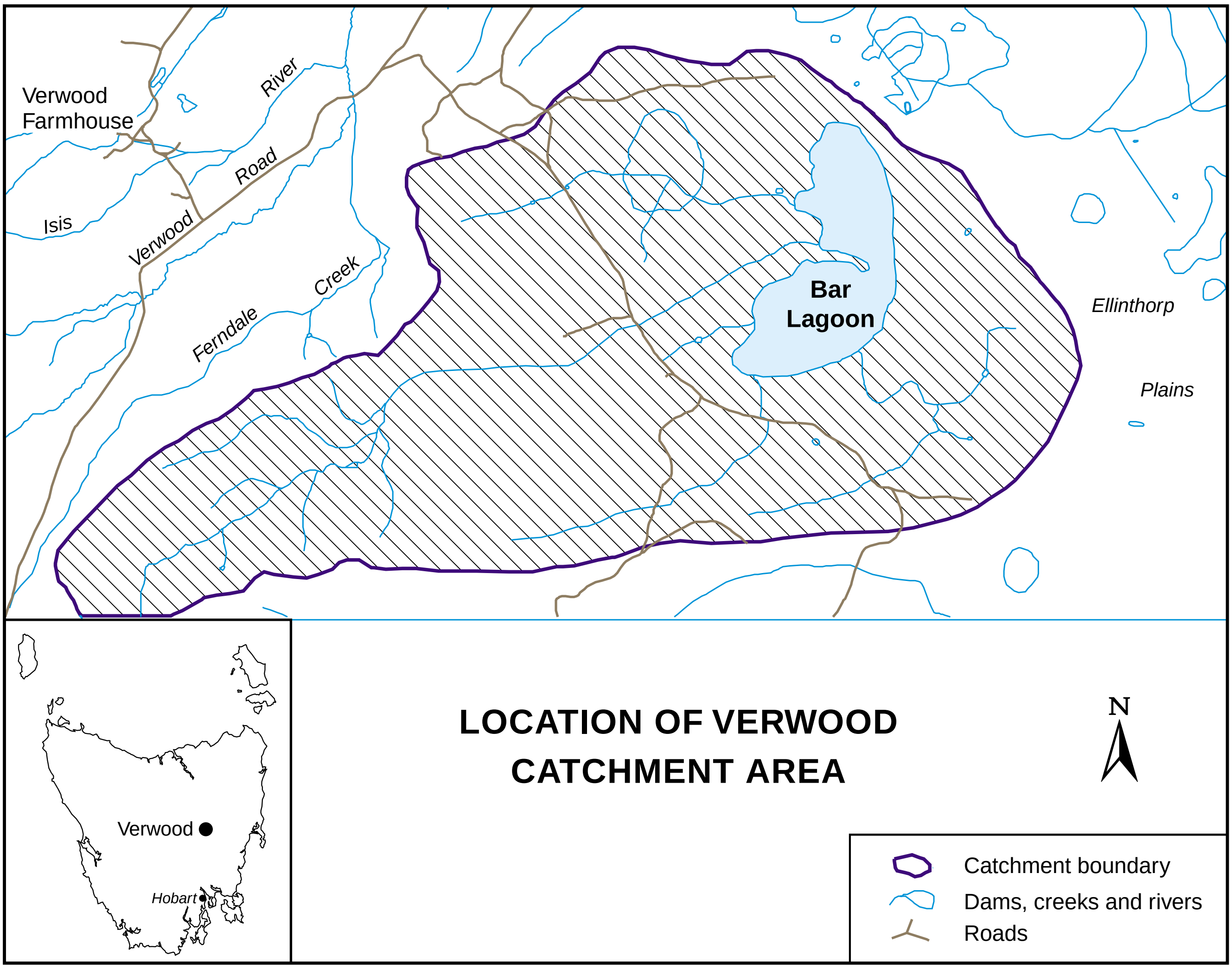


Figure 24

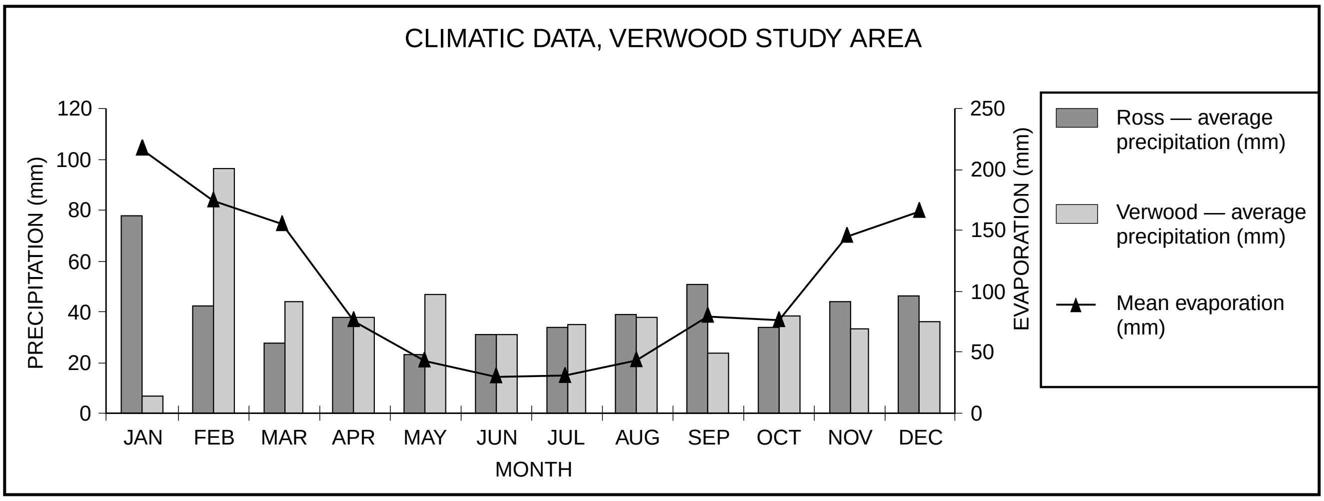


Figure 25

Climate

Data from the Campbell Town weather station, located 30 kilometres northeast of the study area, indicates that the area has a mean maximum daily average temperature of 16.8°C, with a maximum of 24°C in January and a minimum of 0.3°C in July. Campbell Town receives an average annual rainfall of 561 millimetres falling over 133 days. Rainfall figures from the Verwood property (fig. 25) show that the area received 466 millimetres during 1999. An analysis of long-term rainfall figures for the Midlands region indicates a trend towards lower annual rainfall. Average yearly pan evaporation at Campbell Town is 1138 mm per year.

Climatic conditions through the course of the study were unusual, with above average temperatures and significantly decreased average rainfall.

Geology

An overview of geology (fig. 26) indicates that the study area is bounded to the west by the doleritic rocks of the Great Western Tiers, and to the east by doleritic and Triassic rocks which form Steeles Bluff and Kitchener Ridge. A sequence of lateritised Tertiary silt, sand and clay is present through the middle of the study area and forms the valley floor. These sediments are host to a series of shallow seasonal lagoons, salt pans and associated dune fields. The geology Figure 26 and some geological descriptions have been adapted from Forsyth (1986).

Alluvium

Alluvial deposits within the floodplains and braided channels comprised a basal cobble unit between 0.1 and 2 metres thick, containing clasts of dolerite and weathered lithic fragments with very common ferruginous pisoliths. This coarse basal unit is generally absent where alluvium is present over the saprolitic Tertiary clay. Where present, the coarse basal unit is overlain by between 0.05 and 2 metres of sand, silt and clay, which may also contain pisoliths. An organic layer between 0.05 and 2 metres thick overlies the finer grained sediments.

Quaternary dune and sheet deposits

Windblown deposits of sand, silt and clay form lunette, dune and sheet deposits on the east and southeast sides of Bar Lagoon. Primary and secondary dunes up to three metres in height occur. Calcareous nodules (2 to 10 mm) and occasional lateritic gravel, pisoliths and lithic fragments are present within the deposits.

Lagoonal sediments

The sediments exposed in Bar Lagoon consist of brown, grey and black organic coarse silt, sand and clay. The sediments contain very high levels of salt and a salt crust was observable on the lagoon floor during extended dry periods.

High level alluvial terraces

Doleritic boulders, pebbles, sand, silt and clay have been deposited as high level alluvial terraces at the base of the Great Western Tiers. The material was dropped as bed load where the rivers draining the higher steep dolerite country reached the flatter valley floors.

Laterite duricrust, pisoliths and gravel

Nodular and pisolitic duricrust and gravel are present along low ridges dissected by the drainage lines flowing into Bar Lagoon. The duricrust appears as a red, brown, purple, orange and yellow, variably cemented, iron-rich, round pisolitic gravel and massive nodular crusts. These duricrusts represent an old water table level and are produced through the dissolution and precipitation of iron.

Saprolitic Tertiary sediments

A leached pallid zone of grey to blue-grey clay and sandy clay underlies the duricrust and gravel. The clay contains sand and quartz gravel bands, which are exposed within stream cuttings in the valley floors

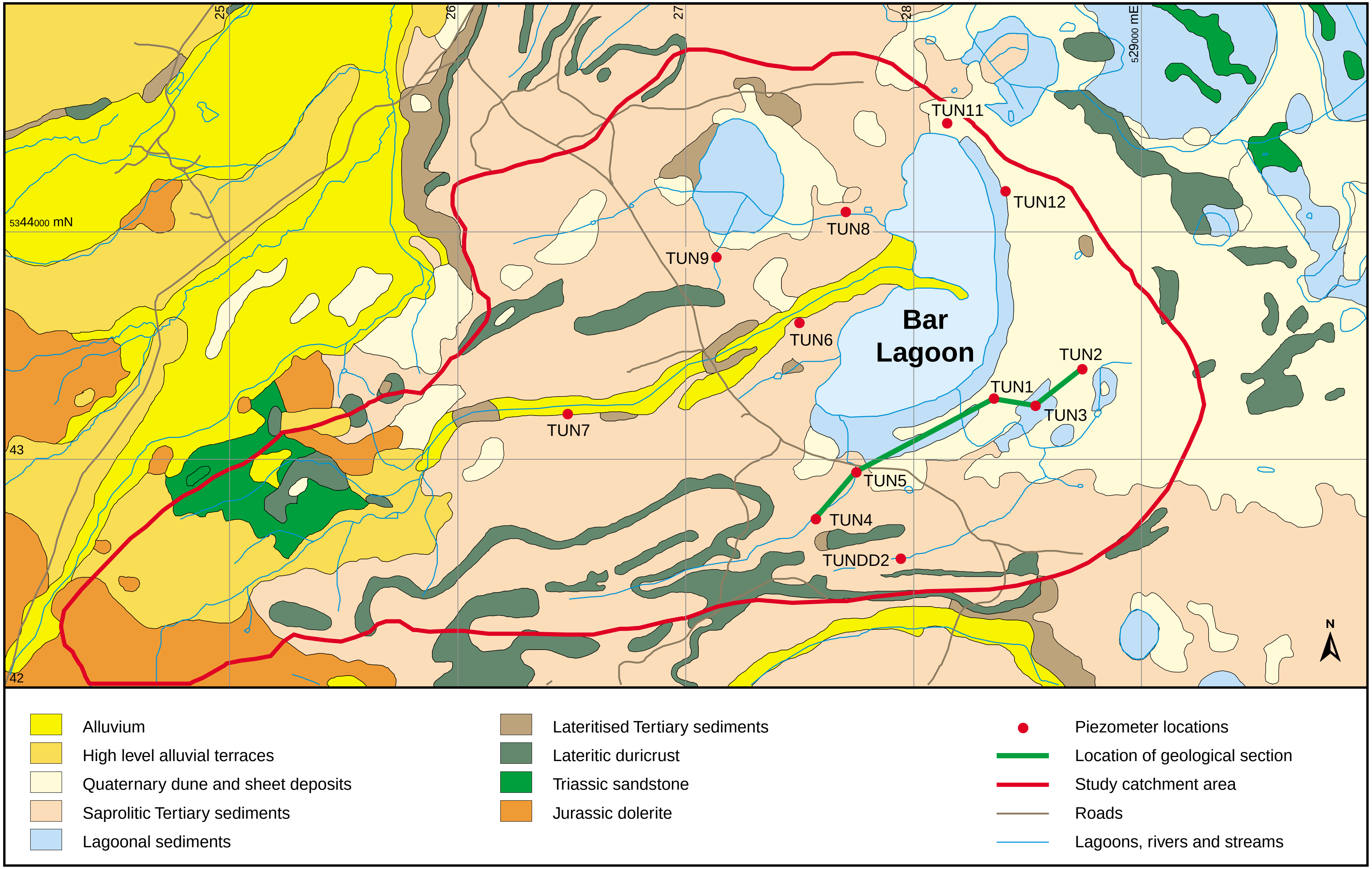


Figure 26. *Geology and piezometer locations, Verwood Study Area (geology adapted from Forsyth, 1986)*

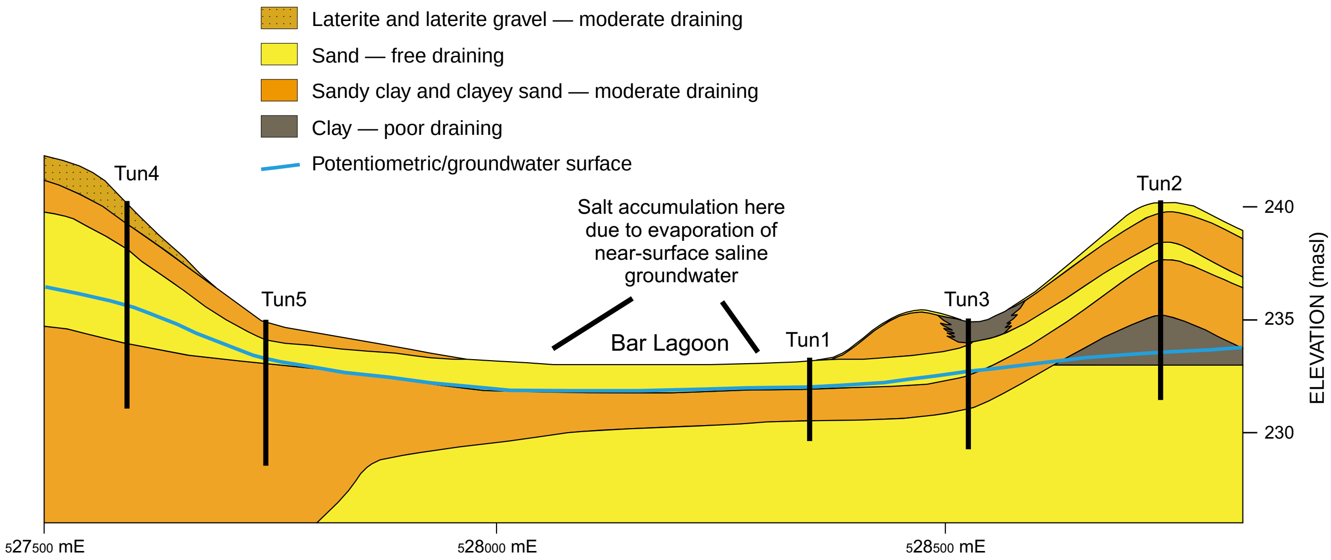


Figure 27

Geological section, Verwood area. See Figure 26 for location of section line

between laterite ridges. Where not present in outcrop, the saprolite is overlain by a thin veneer of sand and a surficial lag of ironstone nodules, pisoliths and lithic fragments.

Triassic sandstone

Small outcrops of fine to medium-grained lithic sandstone occur adjacent to the high level terrace deposits at the foot of Gavins Sugarloaf.

Dolerite

Fine to medium-grained Jurassic dolerite forms the western boundary to the study area. This dolerite reaches over 610 metres in height at Gavins Sugarloaf.

Study parameters

Twelve water monitoring bores or piezometers were established within the study area. Water levels and salinity were monitored on a monthly basis for the 18 month duration of the project. Piezometers were sited to intersect the water table and all were terminated upon intersecting the water table. The bores were distributed along the length of the drainage systems and surrounding the lagoon (fig. 26). Comprehensive logs of the cuttings from each piezometer installation were prepared. A representative geological section for the catchment is shown in Figure 27.

Results and discussion

Groundwater properties and salinity trends

Water level and salinity measurements from all bores were collected at monthly intervals over a period of 18 months. The average groundwater salinity (conductivity) value for all piezometers in this period was 7567 µS/cm, with a range from 613 µS/cm (Tun7) to 16 743 µS/cm (Tun12). The mean water table was 3.14 m below the surface, with a depth range from 1.18 m (Tun7) to 11.91 m (TunDD2) below ground level.

Highly saline groundwater was present in and about Bar Lagoon (fig. 28). Salinity values ranging between 10 000 and 16 000 µS/cm were centered around piezometers Tun1, 2, 3 and 12. An area of low salinity (1000 µS/cm) occurring around piezometers Tun6 and 7 was associated with fresh groundwater draining off the Great Western Tiers.

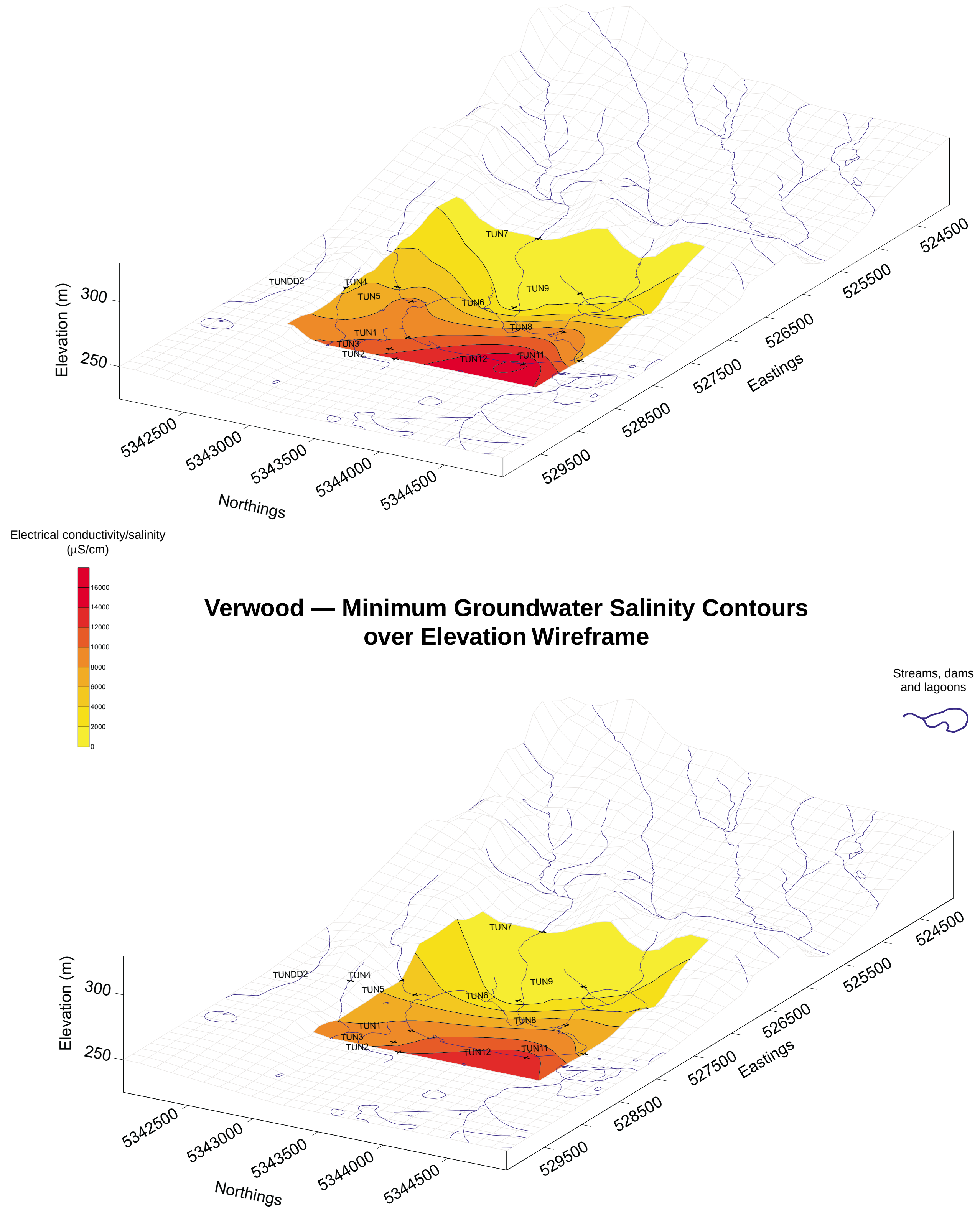
The catchment response to major rainfall events is typified by the period between 4 February 1999 and 16 March 1999 (fig. 28–30). A rapid rise in the water table (from -3150 mm to -3050 mm below ground level) was associated with a temporary fall in observed salinity (from 7527 µS/cm to 7137 µS/cm). Within one month subsequent to this event, both water table and salinity levels had returned to pre-event levels.

The average catchment water table depth showed a slow steady decrease throughout the course of the study. This decline is attributed to the unusually dry and hot seasonal conditions. The steady decrease in groundwater level was matched by a steady increase in average groundwater salinity by evaporative concentration from around 6500 µS/cm in October 1998 to near 8000 µS/cm in March 2000.

Groundwater flow directions

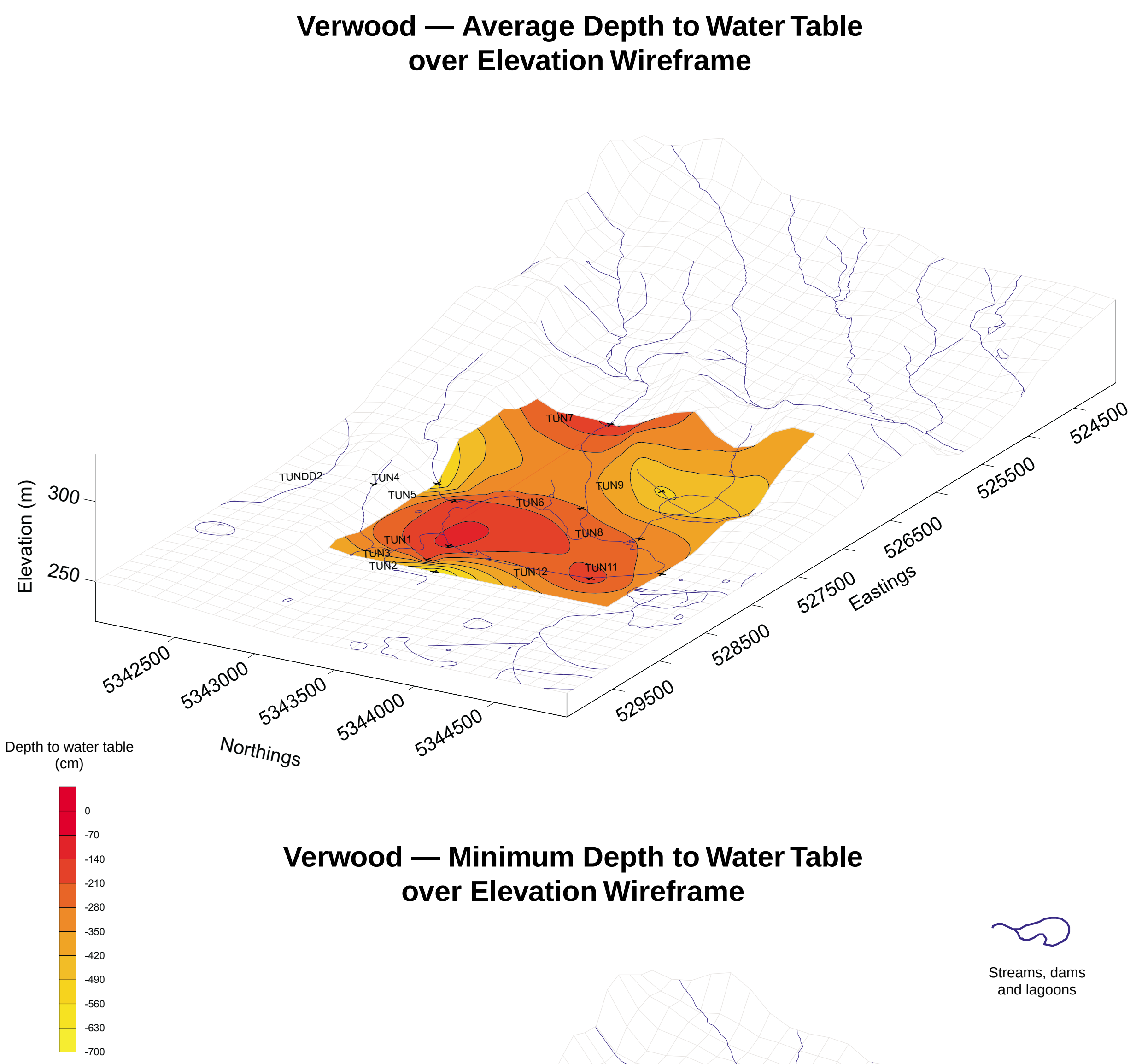
Groundwater flow directions in the Verwood study area are controlled primarily by thick impermeable saprolitic clay and low lateritic gravel ridges. The contours of the potentiometric surface (fig. 31) indicate steeper hydraulic gradients around the ridges and valleys feeding the Bar Lagoon system, with an essentially flat-lying water table through the Bar Lagoon. Groundwater flow directions all trend towards the centre of the lagoon, indicating a closed drainage network. The area of flat-lying hydraulic

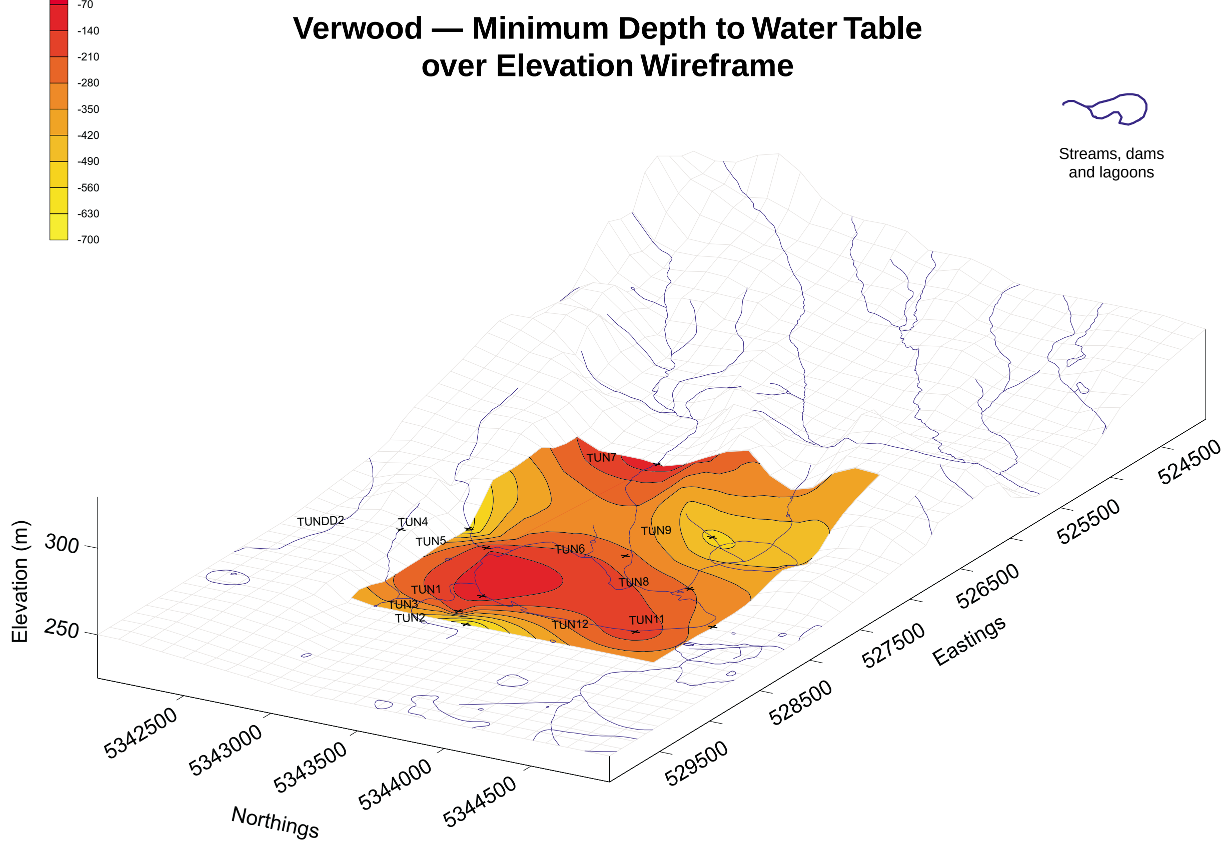
Verwood — Average Groundwater Salinity Contours over Elevation Wireframe



The important features to note on these diagrams are the areas of moderate to sever saline groundwater (4000–16 000 µS/cm) centred around Bar Lagoon at piezometers 1, 2, 3 and 12. Low salinity ground and surface water flow into the lagoon system from the west as measured by piezometers 6, 7 and 9. The lower diagram shows less severe saline groundwater, particularly within piezometers adjacent to Bar Lagoon, after a large rainfall event during November 1998.

Figure 28





These two figures illustrate the shallow depth at which the groundwater sits below the ground surface. The piezometers indicate that the average depth to the water table is 3.4 metres. The lower diagram shows the effect of a high rainfall event on the catchment (109 mm) during November 1998 when the watertable rose to an average depth of about 3 metres. The most obvious feature is the large area of shallow groundwater and surface water around Bar Lagoon.

Figure 29

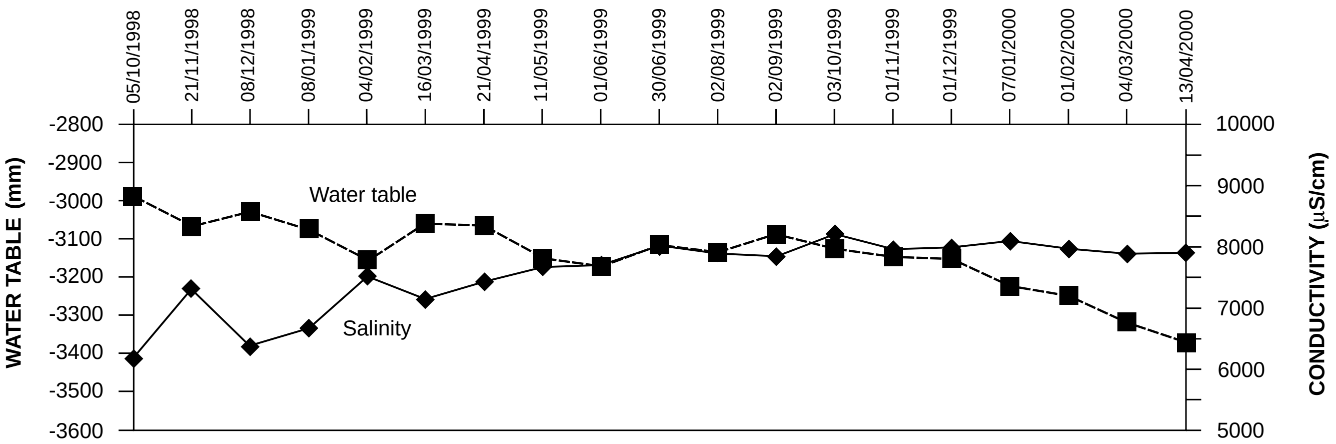


Figure 30

Graphical representation of average catchment water table and salinity levels

gradient corresponds closely with the areas of high groundwater salinity (fig. 28).

Hydraulic conductivity

The hydraulic conductivity was evaluated at each piezometer by using a rising head slug test. This procedure involves removing a 'slug' or quantity of water from the bore and recording the rate at which the water table recovers. The hydraulic conductivity of the twelve piezometers within the Verwood study area varied between 0.01 metres per day (m/d) and 0.23 m/d. This is consistent with a range of representative values determined (after Morris and Johnson, 1967) for clay (0.002 m/d) and fine sand (2.5 m/d).

The diagram generated from the slug test data (fig. 32) shows several areas of high hydraulic conductivity (highlighted in red) centered about piezometers Tun1 and Tun12. These sites correspond closely to elevated and poorly consolidated sandy and silty lunette deposits very close to the edge of the Bar Lagoon.

Areas of low hydraulic conductivity were also identified (particularly at piezometers Tun4, 5, 7 and TunDD2); these areas correspond to geological profiles containing thick units of low permeability kaolinitic clay. This reduction in groundwater flow rate and corresponding increase in residence time tends to lead to increased groundwater and soil salinity, resulting from a combination of the evaporation of slow moving near-surface pore water and from the absorbtion of salt from the weathered sediments.

Water chemistry

Groundwater chemistry information for water samples extracted from all piezometers was determined by the MRT Laboratory. Analyses (Table 7, Appendix 5) showed that all waters had the same trace element components, with sodium (Na) and chloride (Cl) being the dominant ions. Water from two piezometers adjacent to a freshwater stream draining off the Great Western Tiers were bicarbonate (HCO_3) enriched, most likely derived from dissolution of minerals in weathered dolerite.

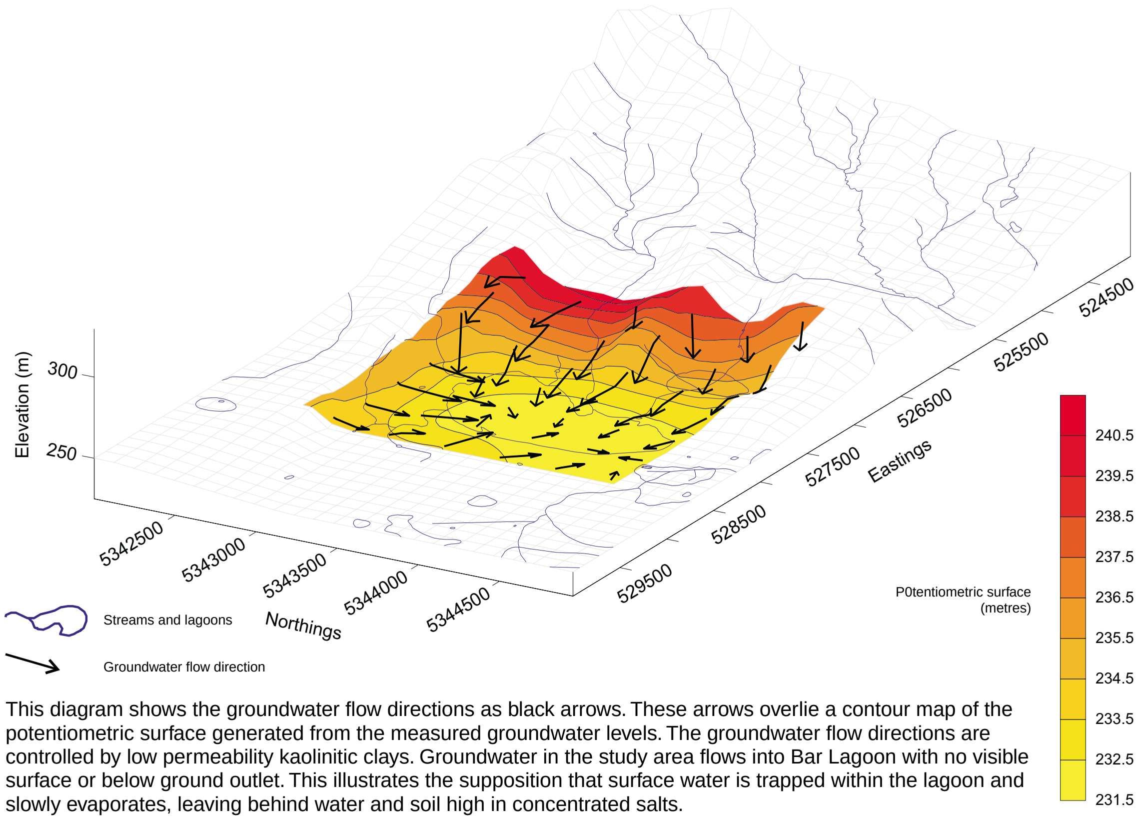
Based on the general criteria for irrigation water salinity of Hart (1974), total dissolved solids (TDS) values for the Verwood groundwaters show all holes

Table 7

Groundwater chemistry results

Piezometer Number	Ca^{++} (mg/l)	Mg^{++} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	HCO_3^{--} (mg/l)	CO_3^{--} (mg/l)	SO_4^{-} (mg/l)	Cl^{-} (mg/l)	TDS (mg/l)
TUN1	212.9	247.62	1697.1	15.27	498.26	0	386.00	3571.81	7762
TUN2	358.8	446.43	2199.3	25.31	831.98	0	304.16	4834.76	9598
TUN3	261.7	314.04	1838.2	19.78	436.17	0	333.14	3966.71	8241
TUN4	27.05	74.57	1321.5	0.83	45.01	0	289.83	2091.86	4036
TUN5	100.3	64.66	1439.3	2.08	152.11	0	285.88	2315.98	4722
TUN6	20.21	17.93	157.38	0.704	321.30	0	29.64	131.63	543
TUN7	15.44	18.61	92.9	1.3	224.29	0	11.19	106.72	377
TUN8	104	120.35	1888.5	4.65	572.76	0	286.21	3166.25	6120
TUN9	25.34	16.78	178.14	3.951	88.47	0	54.83	224.12	740
TUN11	121.6	100.27	1108	8.58	248.35	0	130.59	2244.83	4479
TUN12	448.9	679.18	2989.3	17.3	388.05	0	619.52	6560.19	13107
TUNDD2	69.58	100.32	994.47	3.89	148.12	0	231.04	1838.90	3590

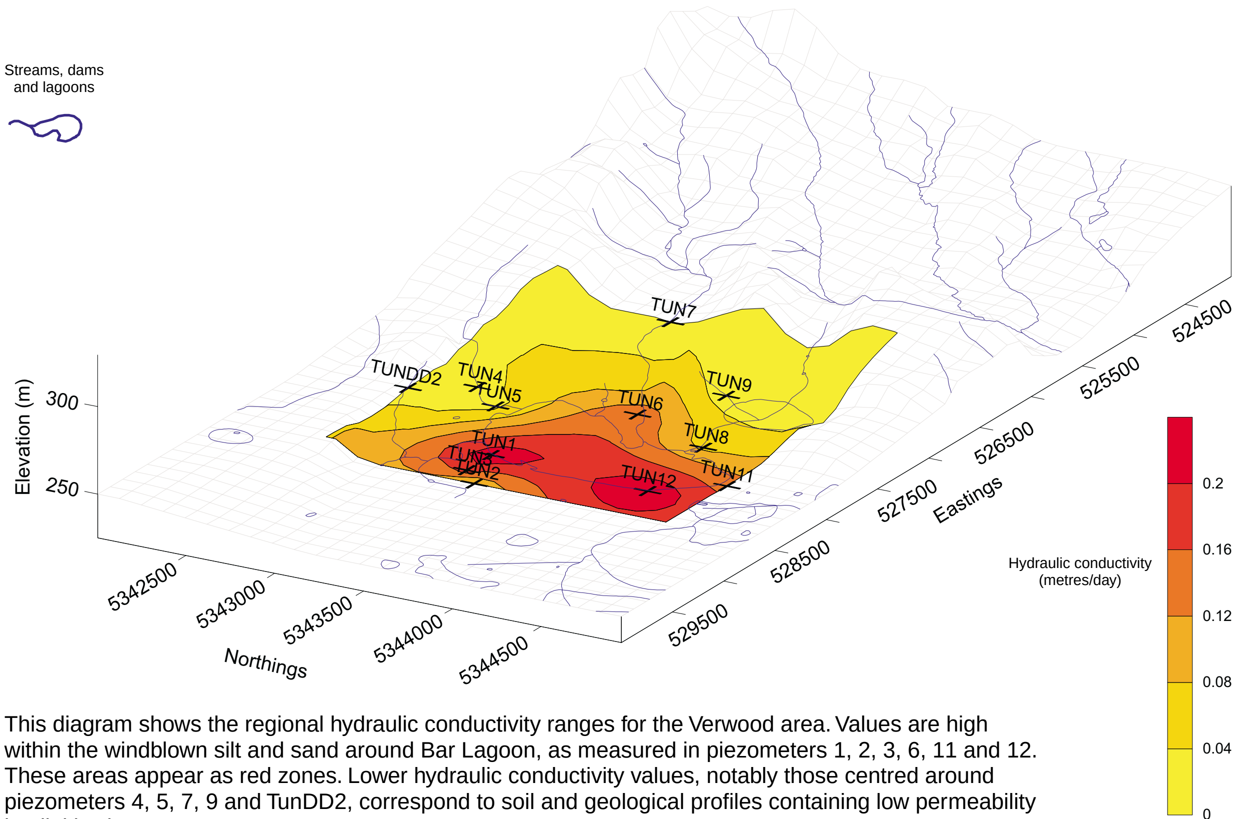
Verwood — Potentiometric Surface and Groundwater Flow Directions over Elevation Wireframe



This diagram shows the groundwater flow directions as black arrows. These arrows overlie a contour map of the potentiometric surface generated from the measured groundwater levels. The groundwater flow directions are controlled by low permeability kaolinitic clays. Groundwater in the study area flows into Bar Lagoon with no visible surface or below ground outlet. This illustrates the supposition that surface water is trapped within the lagoon and slowly evaporates, leaving behind water and soil high in concentrated salts.

Figure 31

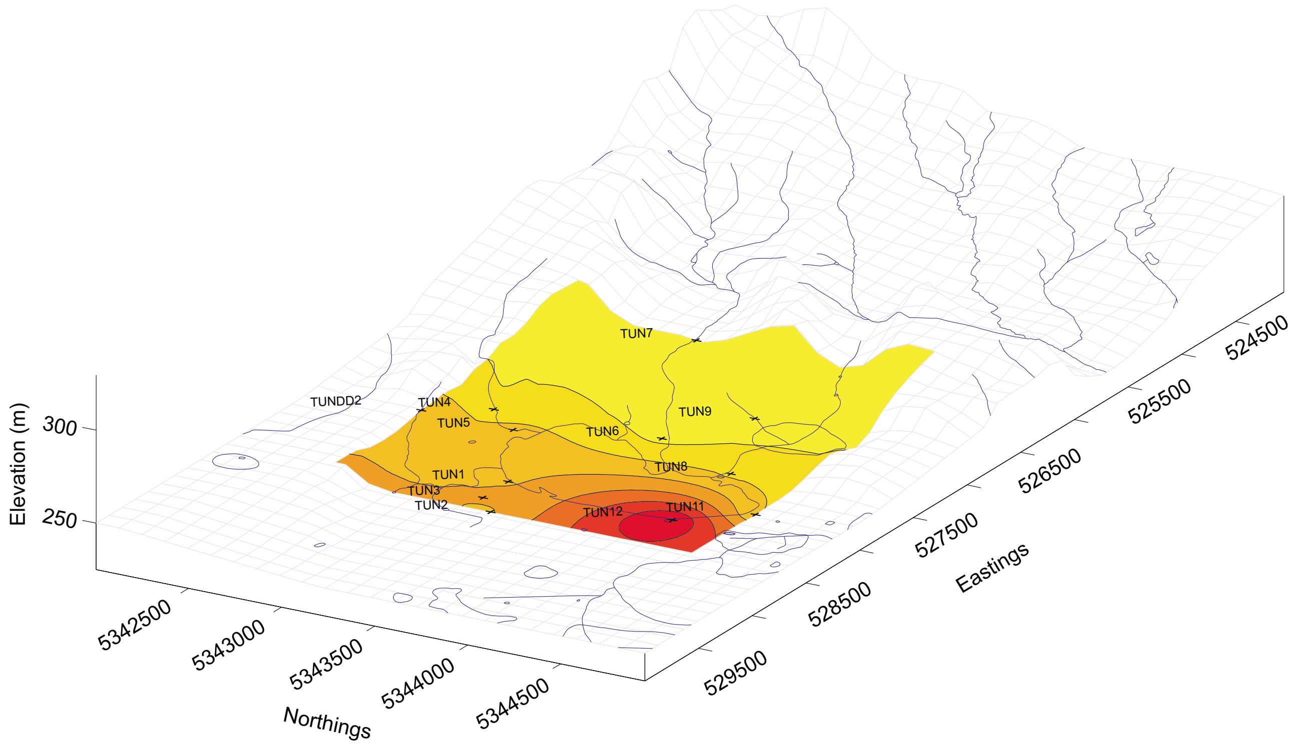
Verwood — Hydraulic Conductivity Contours over Elevation Wireframe



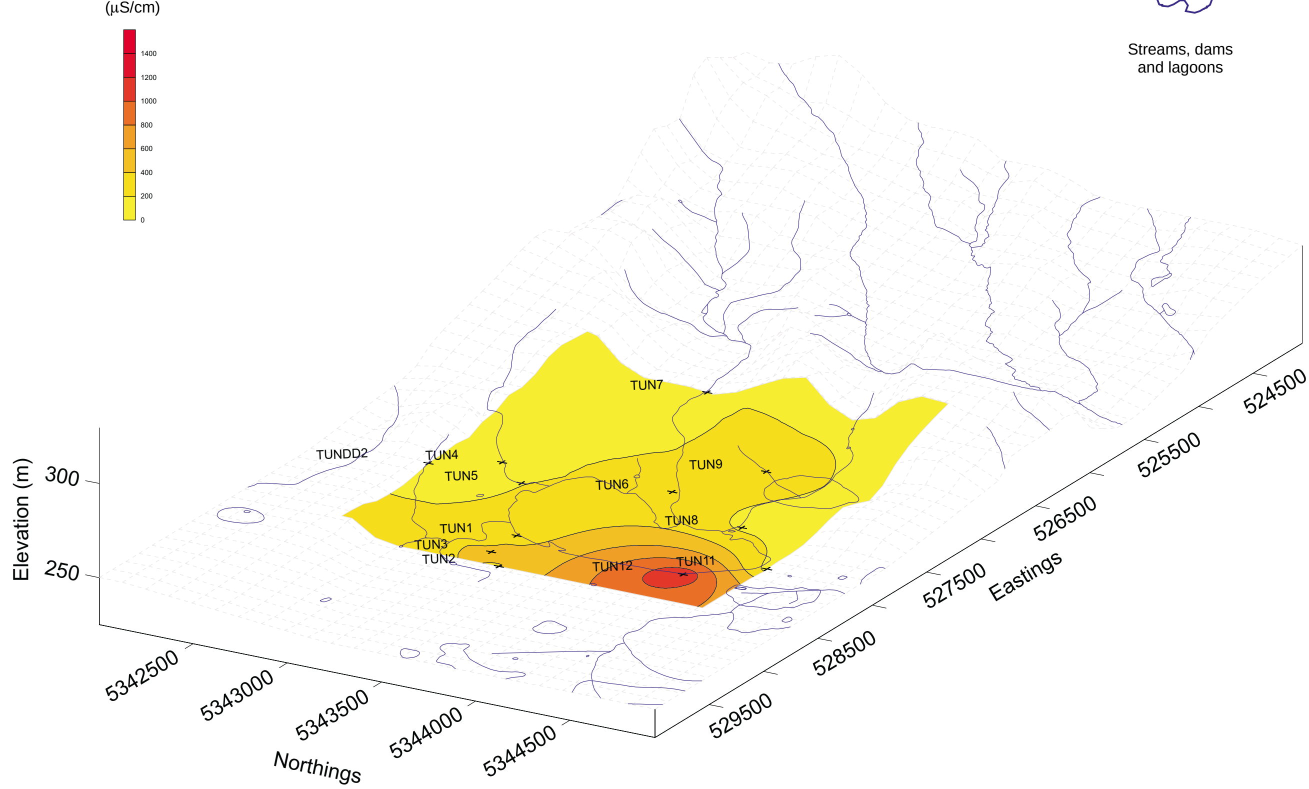
This diagram shows the regional hydraulic conductivity ranges for the Verwood area. Values are high within the windblown silt and sand around Bar Lagoon, as measured in piezometers 1, 2, 3, 6, 11 and 12. These areas appear as red zones. Lower hydraulic conductivity values, notably those centred around piezometers 4, 5, 7, 9 and TunDD2, correspond to soil and geological profiles containing low permeability kaolinitic clay.

Figure 32

Verwood — Average Soil Profile Salinity Contours over Elevation Wireframe



Verwood — Surface Soil Salinity Contours over Elevation Wireframe



These diagrams clearly illustrate the high soil salinity levels present around Bar Lagoon, with the highest value centred around piezometer Tun12. Surface soil salinity levels are generally higher than average soil profile salinities, particularly close to Bar Lagoon. This is likely to be due to either near-surface evaporation concentrating salt within the upper two metres, or wind deposited salt contributing to observed high surface soil salinity levels.

Figure 33

to contain medium to extremely highly saline waters, which are generally considered unsuitable for irrigation. Only the groundwater from piezometers Tun 6, 7 and 9 fall below the accepted maximum of 800 mg/L TDS regarded as the upper limit fit for human consumption.

Soil salinity

Drill cuttings, recovered at 900 mm intervals during piezometer installation, were dried, crushed and placed in a mixture of five parts water to one part soil sample, mixed and then analysed for salt content. The average EC1:5 salinity values for the cuttings of each piezometer have been plotted on a contour map in Figure 33. The highest salt concentration of 1400 µS/cm was centered about piezometer Tun12. This piezometer, and piezometers Tun1, 2, 3 and 11 which have the highest surface and average profile soil salinity values, all lie on the lunette and dune systems adjacent to Bar Lagoon. These dune systems have been formed by wind deposited silt and sand, together with salt and clay, which are exposed on the lagoon floor during dry conditions. The depth of the water table at piezometers Tun1, 3 and 12 averaged approximately one metre below ground level, providing the potential for considerable evaporation and concentration of salts within the upper part of the soil profile.

Salinity profiles from most of the deeper piezometers (Tun2, 5, 8, 10, 11 and TunDD1 and 2) show a steady increase in salt levels with depth. The occurrence and distribution of these salts should be considered before intensive irrigation is undertaken.

Hydrological observations

The main source of salt into the Verwood area is from aeolian salts within rain and wind. Salt is also stored throughout much of the lower parts of the catchment within lateritised Tertiary sediments, aeolian sand deposits, lacustrine sediments and the lunette systems present on the leeward sides of the current salt lakes.

The study area is an example of a primary salinisation process (formation of a salt lake) being exacerbated by land clearance and modern farming practices. Bar Lagoon is a closed basin, acting as an evaporation pond for rainwater and low salinity groundwater. Over a long time period (of the order of hundreds to thousands of years), salts have been concentrated by evaporative processes in and around the lagoon system. During dry periods salt, silt, sand and clay are blown from the lake floor by prevailing northwesterly winds, and deposited as poorly consolidated dune sequences on the leeward side of the lagoon. The salt contained in these dune systems is then recycled back into the lagoon by percolating groundwaters during and after rainfall events. Through this closed system process salinity levels remain high and will continue to increase through time under present climatic conditions.

Water budget calculations of 466 mm of rain falling over the 8 km^2 catchment area each year give an average water input of 3728 cubic metres per year. Based on an average rainfall salinity of 114 µS/cm or 73 mg/L, the annual salt input into the catchment is 410 kilograms per hectare. Because of the closed nature of the Bar Lagoon system and lack of deep-rooted vegetation to intercept or use the water, most of this water infiltrates into the soil as groundwater.

National catchment classification

This case study area fits within the *Local Model (viii) – Discharge over low hydraulic conductivity aquifers* as outlined in Coram (1998). Examples of this type of model are documented in Western Australia at the Morilla swamp, in the northern wheatbelt, and in Victoria at Barwon Downs.

Recommended action

The Verwood study area has very saline groundwaters, particularly close to Bar Lagoon. A reduction of groundwater salinity, groundwater levels and a minimisation of soil and land degradation could be achieved by the following strategies:

- Maintain a good cover of vegetation and do not overgraze.
- Revegetate identified areas of higher recharge, particularly on the southern, southeastern and eastern sides of Bar Lagoon with *Allocasuarina* sp., or local drought resistant and deep rooted species. By careful selection of tree species, healthy growth and survival rates will help utilise water, preventing excess groundwater recharge and salt mobilisation back into the Bar Lagoon system. This strategy can be also incorporated into shelter belts, therefore helping to lower evaporation rates exacerbated by prevailing winds.
- Fence off all bare-scalded areas from stock and plant with salt-tolerant pasture species and saltbush where appropriate. Species selection should be done in accordance with surface and near-surface salinity levels. This will reduce salt cycling by stabilising salty sediments mobilised through rain and wind, and prevent further degradation of the highly saline soils.
- Replant deep-rooted, salt-tolerant eucalypt species (*E. crenulata*, *E. ovata*) or currently surviving species in the area around the lagoon system to help reduce the encroachment of saline groundwater away from the lagoon. This should be incorporated with a good understorey network.
- Investigate the chemistry of the soils and rocks to determine other possible salt sources, such as sediments from old lagoons or palaeochannels.
- Continue the monitoring of groundwater conditions in order to establish long-term trends

under varying climatic/rainfall patterns and possible future changes in land use. The introduction of cropping and irrigation in the region should be done with extreme caution, and will most likely exacerbate rates of salinisation. Surface drainage and subsurface drainage would be an essential management tool under these land-use changes, but would have devastating consequences on the surface and groundwater water resources in the region.

Summary

Salt within the Verwood study area is currently derived either from aeolian salt inputs or from the remobilisation of older salts present within Bar Lagoon and other local salt lake systems.

Salt present within the groundwater is concentrated through a process of evaporation, especially around and within Bar Lagoon. The lagoon is commonly full during the winter months and at other times the average water table adjacent to the lagoon is less than 1.2 metres below the ground surface.

The highest groundwater salinity levels are observed in areas of low hydraulic gradient, high hydraulic conductivity and in areas surrounding Bar Lagoon.

Considerable salt is present within the soil and sediments at depth through much of the study area.

Case Study 4

UNIVERSITY FARM

Looking southeast over the University Farm, circa 1930. Notice the good cover of bushland behind the cleared paddocks in the foreground.

Looking southeast over the University Farm, 1999. Note the extent of cleared land compared to the 1930 photo. For a visual reference a large old eucalypt tree is present to the right of centre in both photos.

Overview

Richard Hanslow established 'Summerhill' as a private farm in 1851 at the site of Lou Hanslow's present 'Summerhill' property. Most of the original vegetation present on and around the study area was cleared by the early 1940s. The study area now supports less than 1% remnant native vegetation cover, being used for sheep grazing, viticulture, fruit orchards, cropping and high intensity irrigation cropping. Several tree belts have been established close to the current drainage lines in an effort to lower saline groundwater levels.

Salt was commercially harvested from the shoreline of Pitt Water at the base of the study catchment as early as 1839 (Rodgers, 1993). Evidence for salting is present throughout much of the lower catchment and these areas have shown a marked increase in surficial extent since the advent of irrigation in the district (Lou Hanslow, pers. comm.).

Location

The University Farm study area is located approximately 18 km northeast of Hobart in the Cambridge area of southeast Tasmania (fig. 34). The study area (535 000 mE, 5 262 000 mN) covers 2.55 square kilometres, and is contained within four properties. The government- owned University Farm property and 'Summerhill' occupy the lower catchment below Colebrook Road, while two private landholdings comprise the upper catchment on the east-facing slopes of Clemens Hill.

Geomorphology

The study area is situated within low undulating terrain between 5 and 200 m above mean sea level. The catchment drains to the east through an incised drainage network into Pitt Water. The drainage lines were observed to be flowing on only one occasion throughout the eighteen month duration of the study which ended in April 2000.

Jurassic dolerite is exposed on the crest and upper slopes of Clemens Hill, with doleritic alluvium and colluvium occurring in some past and present drainage lines. A localised overburden composed of sand, silt, gravel, ironstone fragments and polymict lithic fragments is present on the lower slopes and foothills. Relict alluvial and colluvial fan deposits are

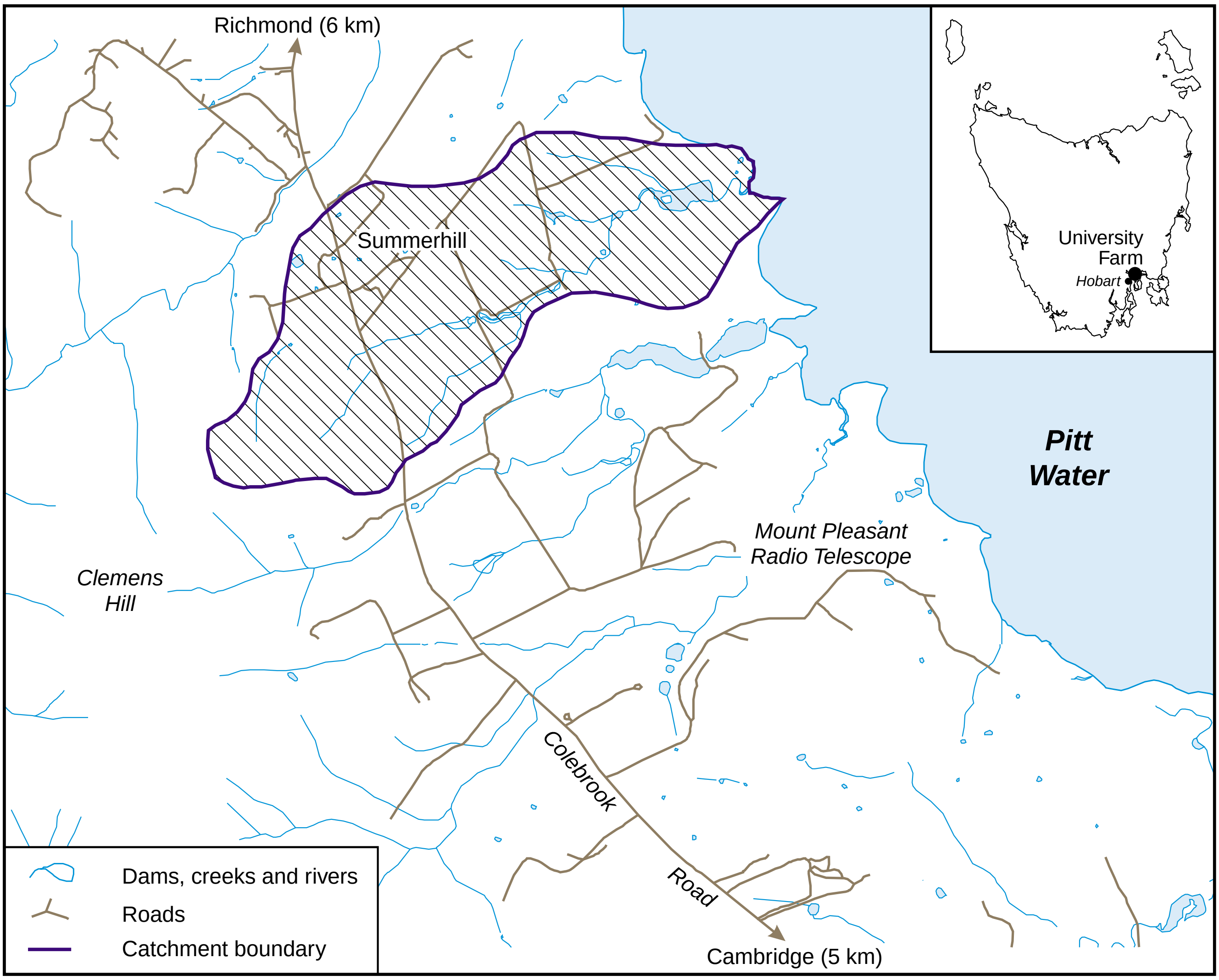


Figure 34

Location of University Farm study area catchment

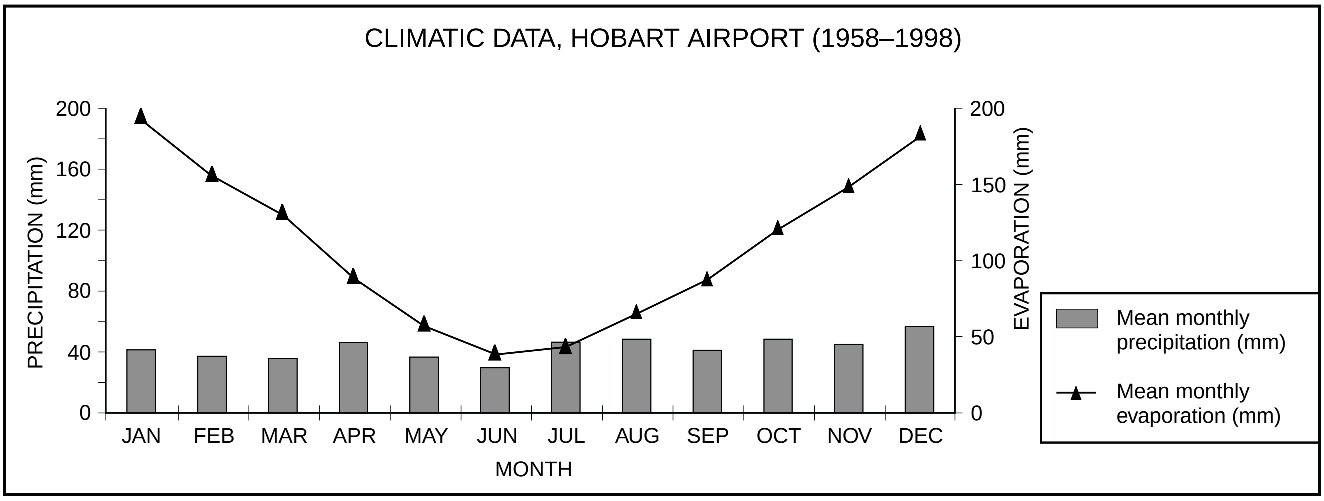


Figure 35

extant below where Belbin and Pigeon Hole rivulets emerge into the Coal River valley, and these materials underlie the bulk of the lower catchment.

The catchment is a maximum of two kilometres from the sea at any one point. Salt deposition, as marine derived wind-borne aerosol, was observed at the site during periods of onshore weather, particularly during summer with the onset of strong southeasterly sea breezes.

The surface and near-surface drainage of the upper catchment is primarily controlled by the undulating bedrock and its weathered derivatives. East of Colebrook Road, strongly weathered Tertiary clay and Quaternary fan sequences are incised and a complex surface drainage pattern channels surface water into the main creek lines. The creeklines flow out to sea via a network of coastal saline lagoons and marshes.

Vegetation

Before clearing the vegetation probably consisted of grasslands with open *Eucalyptus* sp., and Acacia woodland with *Allocasuarina* and *Bursaria* forest common along the coastal margin. Remnants of the open eucalypt and Acacia woodland are present on the western, upper slopes of the catchment. The catchment has been grazed for over 50 years, during which most of the native vegetation has been replaced by perennial pasture. Many salt indicator species are present, the principal species being Bucks Horn Plantain (*Plantago coronopus*) and Sea Barley Grass (*Hordeum marinum*).

Climate

Data from the Hobart Airport weather station, eight kilometres southeast of the study area, indicate that the area has a current mean maximum daily average temperature of 17.3°C, with a maximum of 22.3°C in January and a mean daily minimum of 4.0°C in July (fig. 35). The mean average annual rainfall for Hobart Airport is 509 mm, with rain fallaing on 142 days.

An analysis of long-term rainfall figures for the South East region indicates a trend towards lower annual rainfall. Average yearly pan evaporation at Hobart Airport is 1308 mm per year, with evaporation exceeding precipitation for ten months of the year. Climatic conditions throughout the course of the study were unusual, with above average temperatures and significantly reduced average rainfall.

Geology

An overview of geology (fig. 36) indicates that the bedrock in the upper catchment comprises dolerite and some Triassic sedimentary rocks. The lower catchment is primarily underlain by Tertiary sediments and overlying alluvial and colluvial units. The geology map has been adapted from new mapping by Mineral Resources Tasmania (Forsyth, in prep.).

Alluvium and colluvium

Alluvium occurs as clay, sand, silt and gravel deposits, both within and adjacent to current and past drainage lines throughout the study catchment. Localised colluvial deposits, consisting of clayey gravel derived from weathered dolerite, and sandy alluvium, sourced from Triassic and Permian bedrock, occur along the base of Clemens Hill in the west of the study area.

Pleistocene alluvial fan deposits

Large alluvial fan deposits, over one square kilometre in area, occur downslope of where Belbin and Pigeon Hole rivulets emerge into the Coal River valley. The alluvium is highly variable, consisting of lenses of clay, silt, sand, gravel and boulder beds, and contains clasts of dolerite and Triassic and Permian sedimentary rocks. Ironstone granules and concretionary ironstone fragments are common at surface and within the profile. The alluvial fan units have been divided into older and younger units on the basis of dominant clast components and weathering rinds of dolerite clasts. Fans containing mostly Permian clasts with occasional

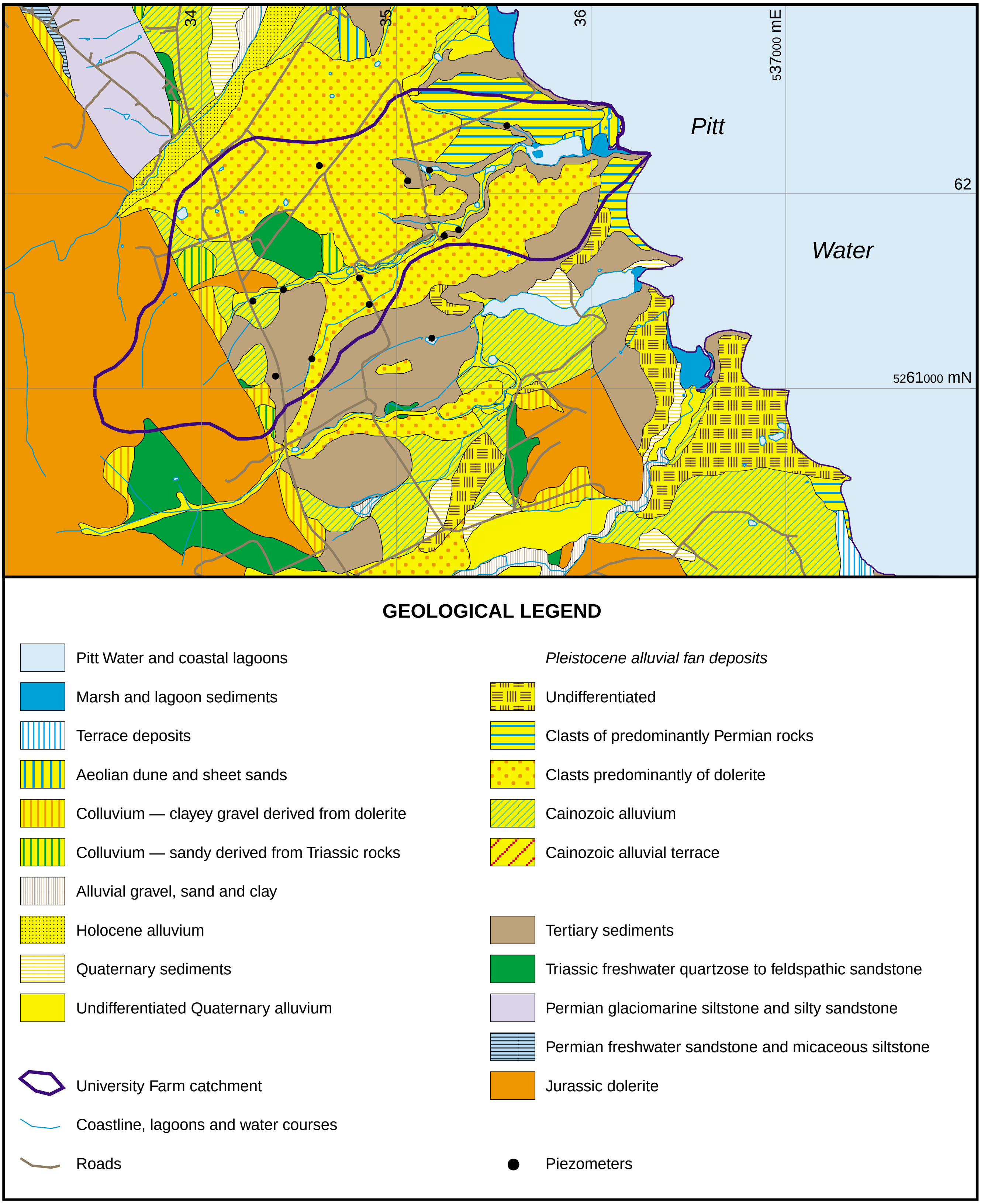


Figure 36

Geology of the University farm area (from Forsyth, in prep.)

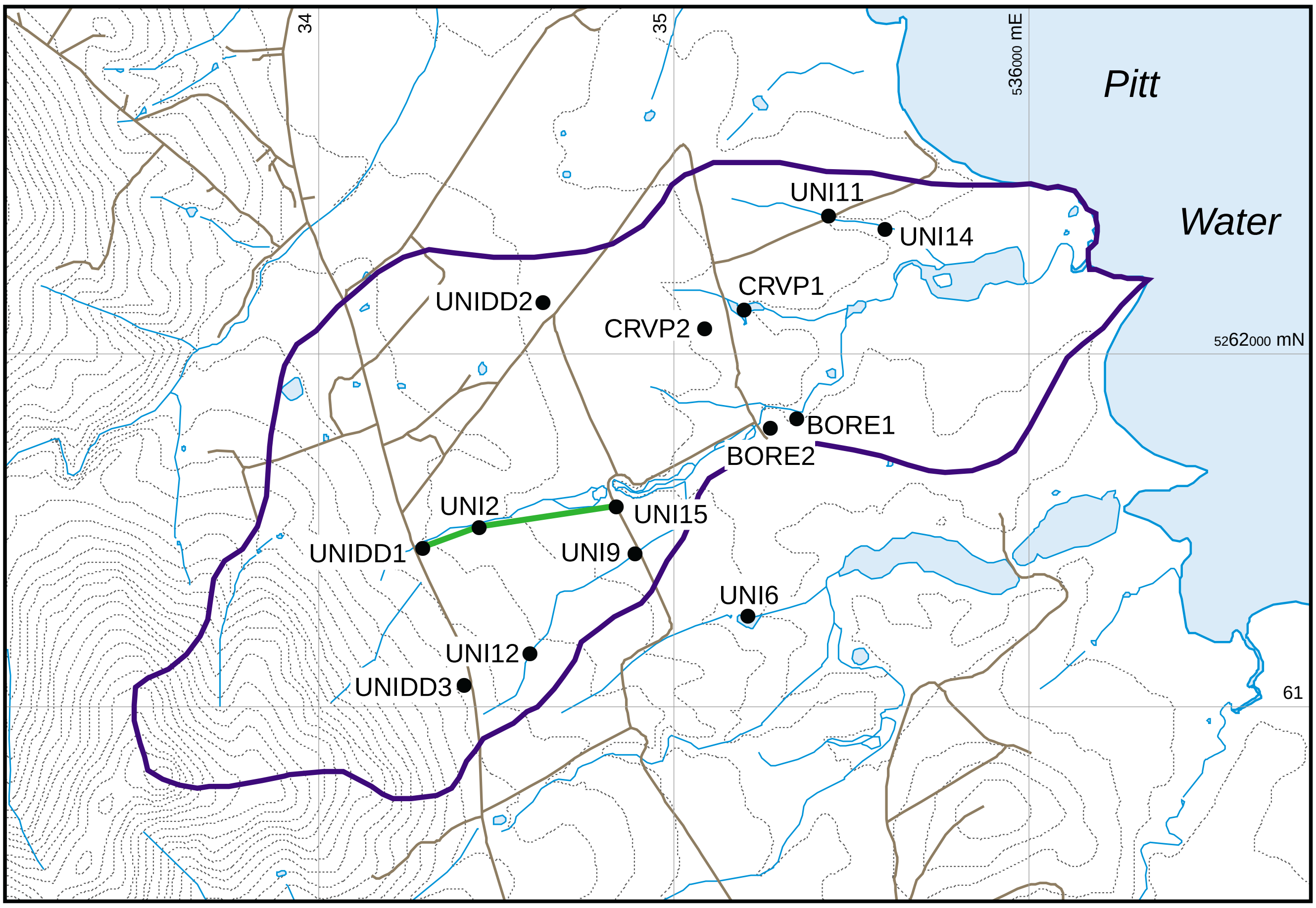


Figure 37

Locations of piezometers and geological section, University Farm study area

strongly weathered dolerite clasts are considered to be the older deposits.

Tertiary sediments

Flat-lying to shallowly west-dipping brown, grey, green and orange-brown, poorly consolidated, mudstone, siltstone and sandstone units occur as a basement to more recent alluvial material throughout much of the lower catchment. Fragmental ironstone concretions are present at surface and as hard, indurated bands in profile. The Tertiary sediments are commonly exposed in incised drainage depressions within the alluvial fan deposits. Thin lenticular deposits of coal and plant-rich sediments were intercepted during piezometer installation. Analysis of pollens from these deposits showed the presence of eucalypt, fern and *Allocasurina* spores which are most likely Early or Late Tertiary species (S. M. Forsyth, pers. comm., 2000).

Triassic sediments

Grey and light brown freshwater cross-bedded quartzose to feldspathic sandstone crops out on the southwest boundary of the catchment and is closely subcropping in the vicinity of 'Summerhill'.

Jurassic dolerite

Geophysical investigations show that dolerite forms the bedrock throughout the western upper catchment area (Leaman, 1971). The dolerite is variably medium to fine-grained and exhibits well developed near-vertical jointing, trending NNW, NNE and southeast.

Study parameters

Fourteen water monitoring bores or piezometers were established within the study area (fig. 37), with water levels and salinity being monitored on a monthly basis for the 18-month duration of the project. Piezometers were sited to intersect the water table and all piezometers were terminated apon reaching water, with a maximum depth of twelve metres (UniDD2). The bores were distributed along the length of the drainage system within the study area.

Comprehensive logs of the cuttings from each piezometer have been prepared. A representative geological section for the catchment is shown in Figure 38.

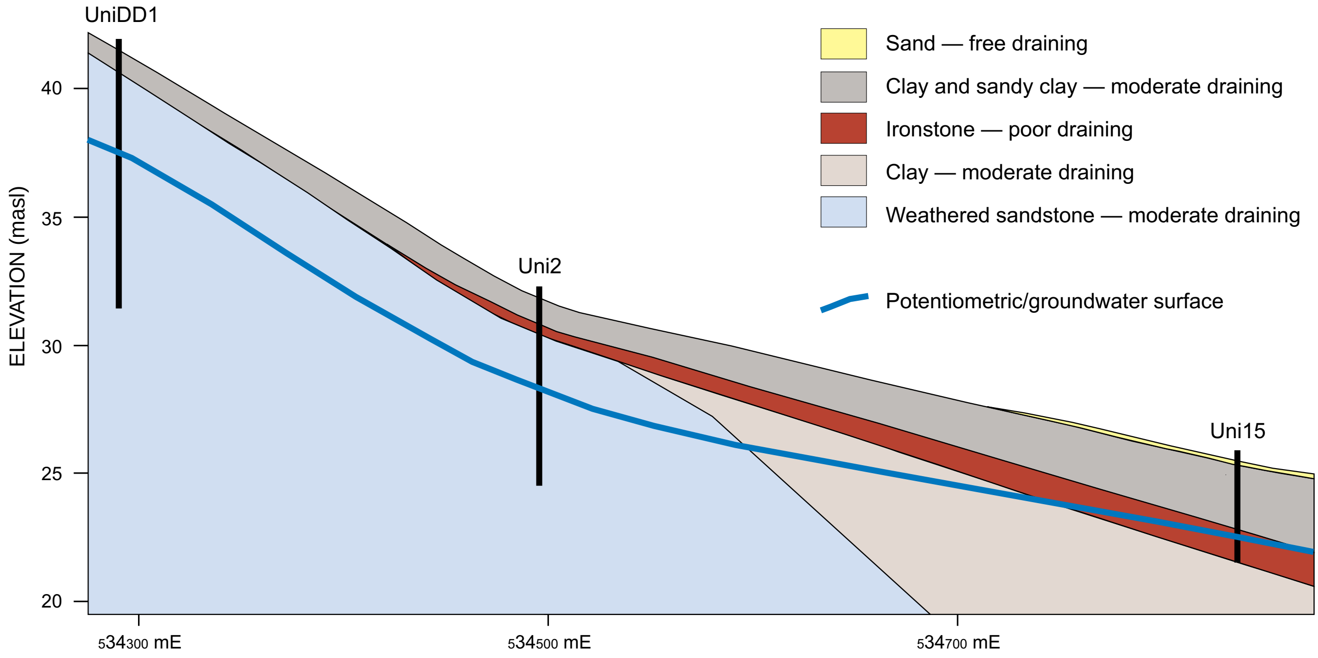


Figure 38

Geological section, University Farm study area

Results and discussion

Groundwater levels and salinity trends

Water level and salinity measurements from all piezometers were collected at monthly intervals over a period of 18 months. The average groundwater salinity (conductivity) for all piezometers over this period was 8513 µS/cm, ranging from 2306 µS/cm (UniDD3) to 13 234 µS/cm (Uni9). The mean water table was 3.17 m below the surface, with a range from 0.14 m above ground surface (artesian) at piezometer CRVP1 to 13.01 m below the surface at UniDD3.

Highly saline groundwater occurred in two distinct areas (fig. 39). Salinities between 14 000 and 18 000 µS/cm were centered around piezometers Bore 1 and Uni14, which were situated in the lowest areas of the catchment, being less than ten metres above sea level. Salinities ranging between 10 000 and 14 000 µS/cm occurred around piezometer Uni9. Both these areas, and most areas with salinities above 10 000 µS/cm, are located in areas of low subdued relief within the Tertiary sediments and Pleistocene alluvial fan deposits. A distinct area of lower groundwater salinity occurs in the upper catchment around piezometers Uni2, 12 and UniDD1 and 3.

Groundwater was present at very shallow depths throughout much of the lower catchment; in the case of piezometer CRVP1 the water table was commonly 100 to 200 mm above ground level (artesian). The shallow groundwater in the lower catchment is to some degree a product of piezometer location, with the majority of sites close to or within incised drainage lines.

The catchment response to major rainfall events is typified by the period between 3 December 1999 and 10 January 2000 (fig. 40, 41). A rapid rise in water table (from 3.26 m to 2.97 m below ground level) was associated with a temporary fall in observed salinity (from 8993 µS/cm to 8190 µS/cm).

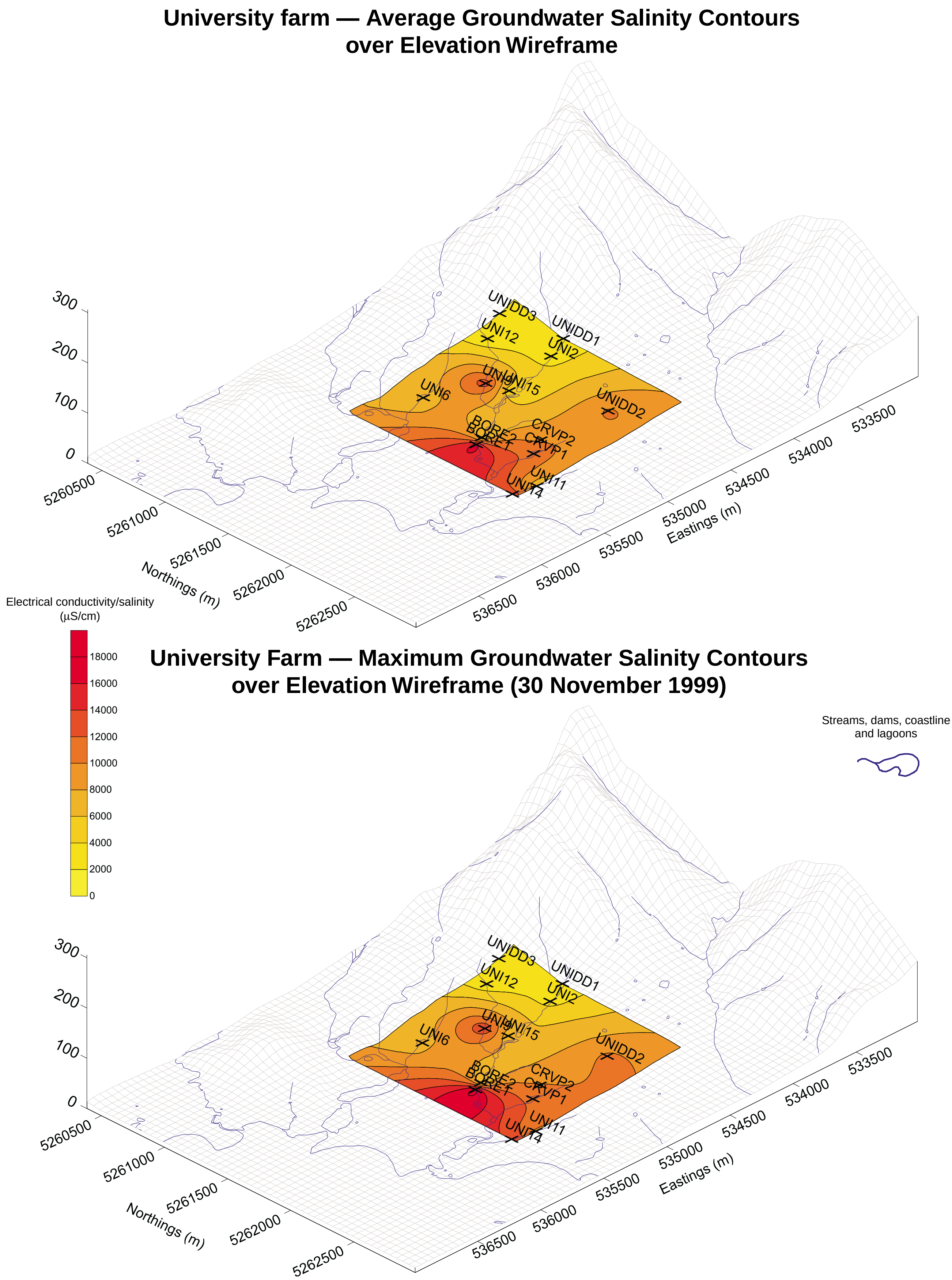
Groundwater flow directions

Groundwater flow directions in the University Farm study area mimic the ground surface topography which slopes gently to the east (fig. 42). The groundwater flow directions of the upper catchment are controlled primarily by outcropping and subcropping doleritic bedrock. Impermeable clay layers and layers of coarser gravel and sand within the Tertiary sediments appear to control groundwater flows in the lower catchment. Evidence of old water table levels, indicated by the presence of ironstone bands, were intersected during the drilling program.

Hydraulic conductivity

The hydraulic conductivity was been evaluated at each piezometer, using rising head slug tests. This procedure involves removing a 'slug' or quantity of water from the bore and recording the rate at which the water table recovers. Within the University Farm study area, the hydraulic conductivity of the fourteen piezometers varied between 0.0003 metres per day (m/d) and 0.35 m/d (fig. 43). This is consistent with a range of representative values determined (after Morris and Johnson, 1967) for clay (0.002 m/d), silt (0.08 m/d) and fine sand (2.5 m/d).

The diagram generated from the slug test data (fig. 43) shows a distinct area of high hydraulic conductivity, highlighted in red, centered about piezometers CRVP1 and 2. These sites are within drainage lines, which dissect perched aquifers on flat or very shallowly sloping ground. Of these two holes, CRVP1 is the site of a large salt scald where water levels have a positive



Extensive areas of moderate to severely saline groundwater (14000–18000 µS/cm) are centred around piezometer Bore 1, with lesser levels of salinity around piezometers Uni9, 14 and CRVP1. These areas of high groundwater salinity are located at break of slopes and within areas of subdued topography. The lower diagram shows groundwater salinity levels as at 30 November 1999, after a prolonged period of below average rainfall. The diagram shows an expansion of the area underlain by moderate to highly saline groundwater, particularly around piezometers UniDD2 and Uni11.

Figure 39

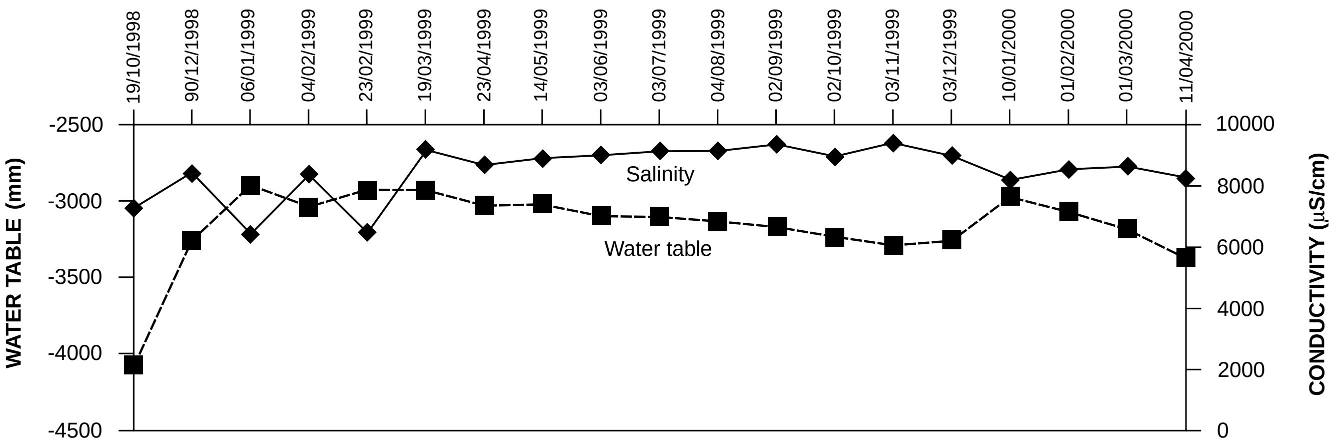


Figure 40

Graphical representation of average catchment water table and salinity levels

artesian level, which averaged 140 mm above the ground surface.

Large areas of low hydraulic conductivity were also identified (particularly at piezometers Uni 2, 9, 15 and UniDD 1, 2 and 3). These large areas of low to very low flow rates (from 3 mm to 60 mm per day) correspond to thick Tertiary clay horizons. The reduction in groundwater flow rates and corresponding increase in residence time tends to result in increased groundwater and soil salinity from evaporation of near-surface pore waters

Water chemistry

Groundwater chemistry information for water samples extracted from all piezometers was determined by the MRT Laboratory. Analyses (Table 8, Appendix 5) showed that all waters had the same trace element components, with sodium (Na), magnesium (Mg), chloride (Cl) and bicarbonate (HCO_3) being the dominant ions. The significant level of Na and Cl components is consistent with near coastal rainfall being a principal source of recharge to the catchment. Mg and HCO_3 are most probably derived from dissolution of silicate minerals in dolerite or its weathered derivatives.

Based on the general criteria for irrigation water salinity of Hart (1974) (Table 5), total dissolved solids (TDS) values for the University Farm groundwaters show all holes to be very high to extremely highly saline, and are therefore generally considered unsuitable for irrigation. None of the groundwater falls below the accepted maximum of 800 mg/L TDS, regarded as the maximum level fit for human consumption.

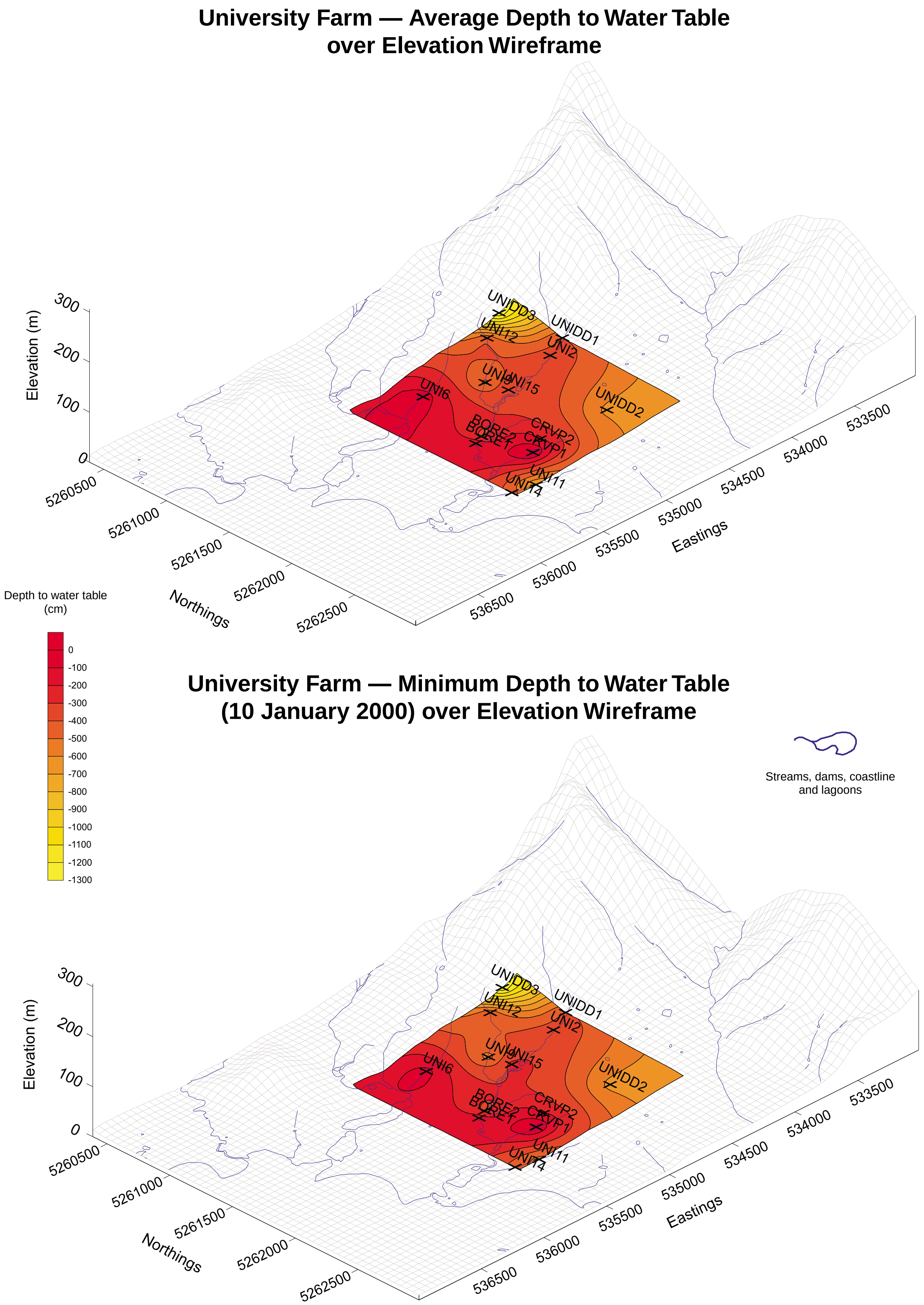
Soil salinity

Drill cuttings recovered at 900 mm intervals during piezometer installation were dried, crushed and placed in a mixture of five parts water to one part soil sample, mixed and then analysed for salt content. The average EC1:5 salinity values for the cuttings of each piezometer have been plotted on a contour map (fig. 44). The highest average salt concentration, at 770 µS/cm, is centered around piezometer CRVP1, located

Table 8

Groundwater chemistry results

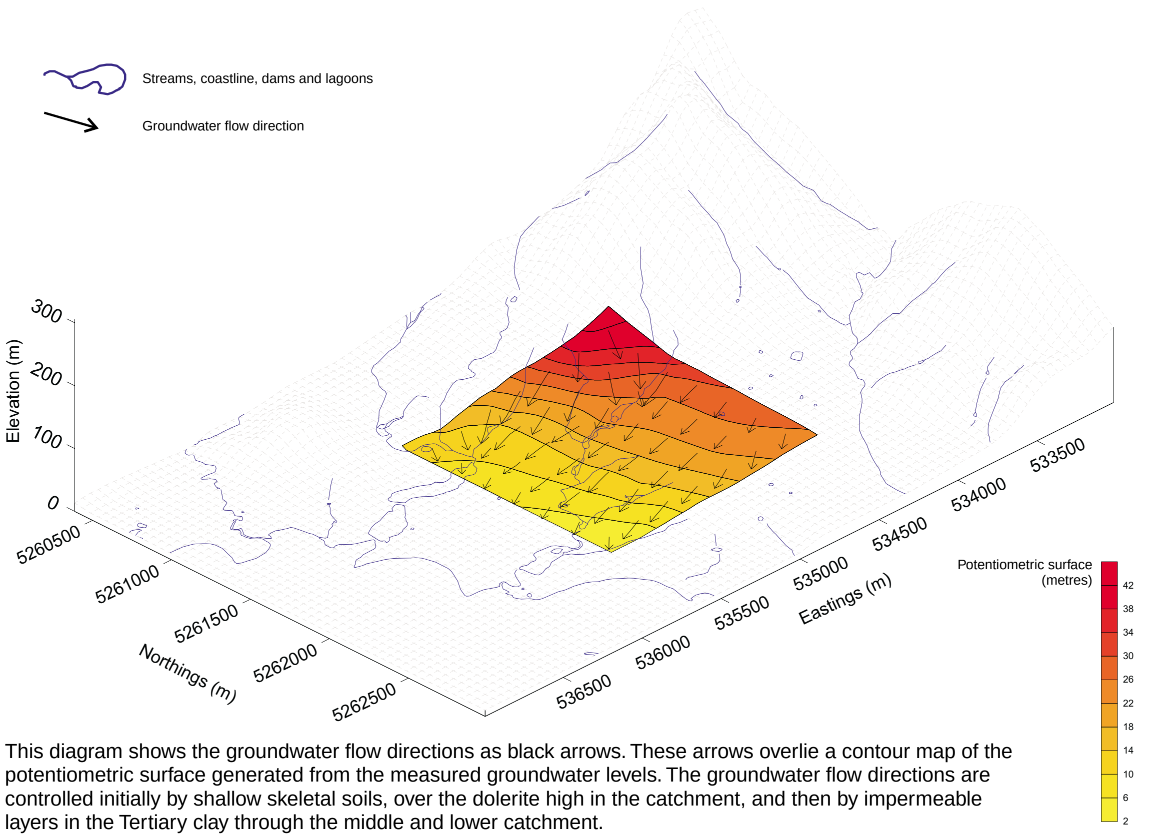
Piezometer Number	Ca^{++} (mg/l)	Mg^{++} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	HCO_3^{--} (mg/l)	CO_3^{--} (mg/l)	SO_4^{-} (mg/l)	Cl^{-} (mg/l)	TDS (mg/l)
BORE1	457.80	706.53	2980.00	10.24	610.02	0	654.11	6328.95	13782.00
BORE2	120.30	243.20	1208.00	9.99	1161.06	0	176.87	1775.24	4011.00
UNI2	65.90	208.29	517.00	15.55	720.23	0	97.16	900.07	2424.00
UNI6	126.50	303.69	1284.00	17.91	988.76	0	242.41	2148.78	4861.00
UNI9	371.80	696.97	2240.00	38.61	1153.30	0	714.05	4763.61	11261.00
UNI11	151.70	303.18	1330.00	37.27	593.72	0	291.98	2522.33	5412.00
UNI12	56.00	143.47	380.00	8.24	600.71	0	51.05	619.02	1688.00
UNI14	214.10	496.00	2530.00	36.98	523.10	0	458.80	4870.34	11504.00
UNI15	34.60	174.56	1086.00	24.92	953.06	0	198.27	1341.21	3259.00
CRVP1	209.20	568.08	1920.00	22.37	932.88	0	416.64	4052.09	9081.00
CRVP2	127.40	459.14	1936.00	31.68	1005.84	0	346.32	3447.30	7480.00
UNIDD1	89.59	137.71	423.92	17.58	765.59	0	85.14	742.92	2039.00
UNIDD2	161.80	438.25	1809.12	43.68	1275.46	0	297.58	3290.09	7421.00
UNIDD3	103.77	120.73	246.77	4.88	686.07	0	51.22	502.36	1675.00



These two figures illustrate the depth at which the groundwater sits below the ground surface. The diagrams show deeper depths to groundwater higher in the catchment system around piezometers Uni12 and Uni9 and piezometers UniDD1, 2 and 3. Groundwater comes close to the ground surface close to the main drainage lines within the catchment, particularly around piezometers CRVP1, Bore1 and 2, and Uni6.

Figure 41

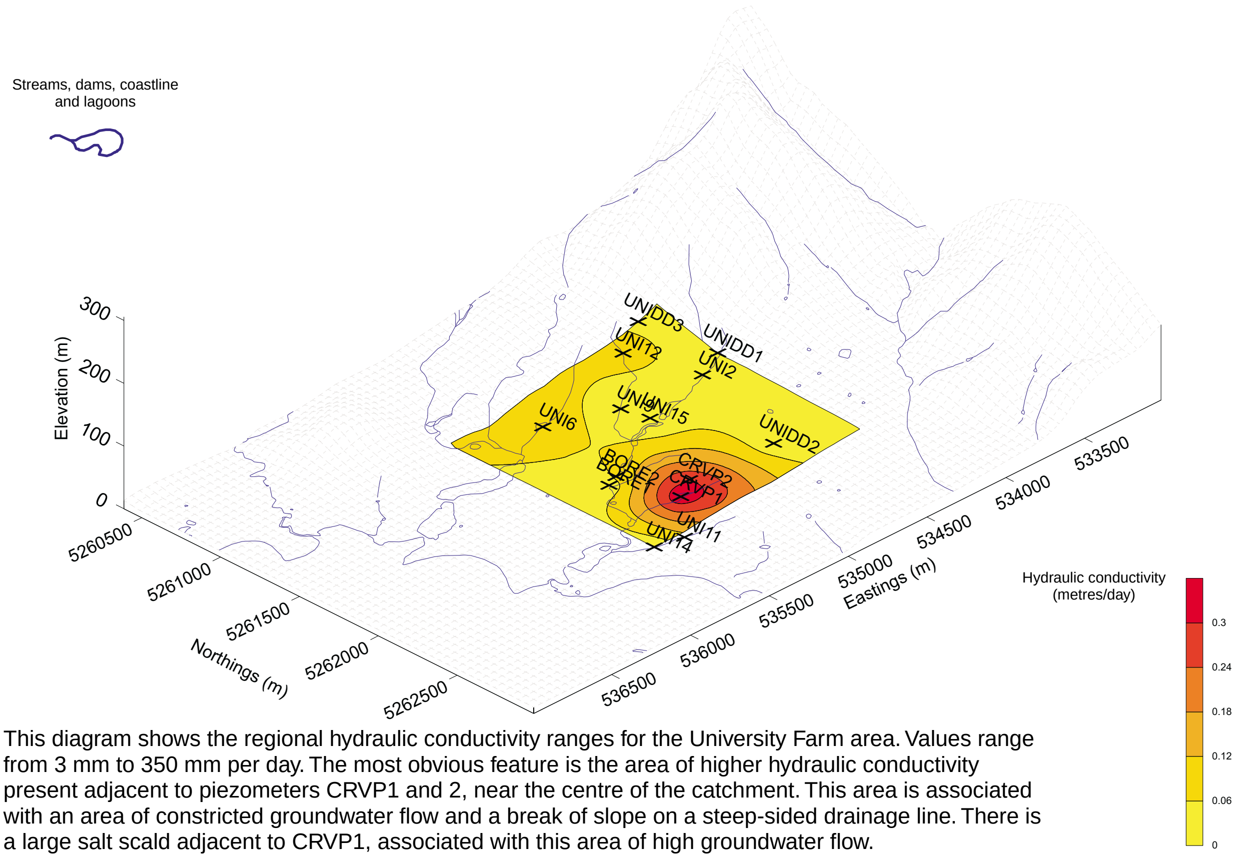
University Farm — Potentiometric Surface and Groundwater Flow Directions over Elevation Wireframe



This diagram shows the groundwater flow directions as black arrows. These arrows overlie a contour map of the potentiometric surface generated from the measured groundwater levels. The groundwater flow directions are controlled initially by shallow skeletal soils, over the dolerite high in the catchment, and then by impermeable layers in the Tertiary clay through the middle and lower catchment.

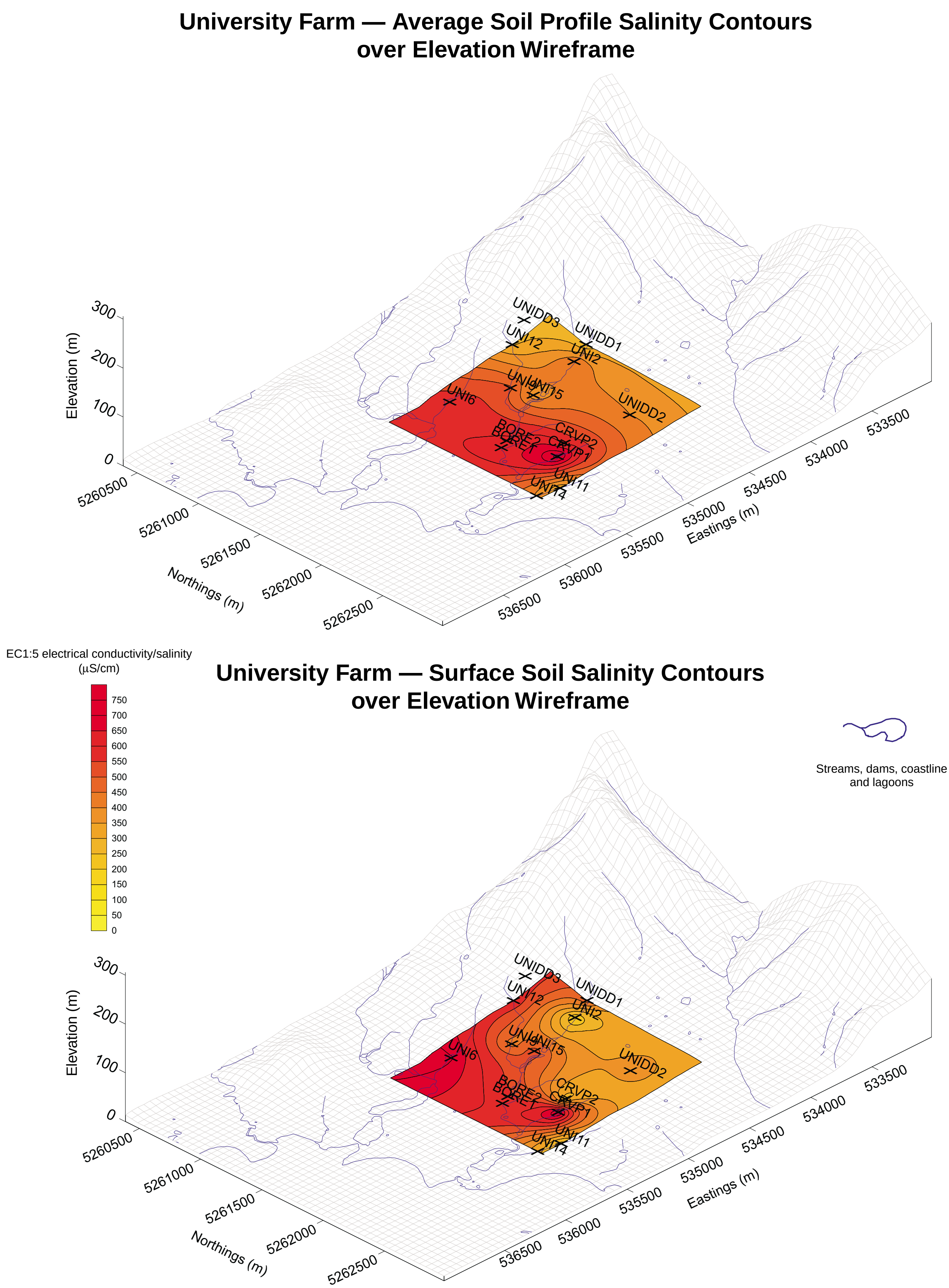
Figure 42

University Farm — Hydraulic Conductivity Contours over Elevation Wireframe



This diagram shows the regional hydraulic conductivity ranges for the University Farm area. Values range from 3 mm to 350 mm per day. The most obvious feature is the area of higher hydraulic conductivity present adjacent to piezometers CRVP1 and 2, near the centre of the catchment. This area is associated with an area of constricted groundwater flow and a break of slope on a steep-sided drainage line. There is a large salt scald adjacent to CRVP1, associated with this area of high groundwater flow.

Figure 43



These diagrams illustrate the concentration of salt within the geological profile. The highest average salt concentration of 770 µS/cm is centred around piezometer CRVP1, which is located within a saline discharge site. Average profile salt concentration generally increases downslope towards Pitt Water. Surface soil salinity levels are generally lower than average profile levels. This is attributed to the leaching of salts from the upper, more sandy soils to lower in the profile. The areas of high soil salinity correspond to areas where groundwater occurs at, or within one metre of the ground surface (CRVP1), or where thick clay soils are present at surface (Uni6).

Figure 44

within a saline discharge site where the water table averages 140 mm above ground level, and where considerable evaporation and concentration of salts would be likely to occur.

Surface soil salinity levels (fig. 44) are generally considerably lower than the averaged total soil salinity values for each piezometer. This is attributed to both the leaching of salts from the upper, more sandy soils to lower down in the profile, and the flushing and dilution effects of groundwater flow within the drainage depressions. This is significant as signs or absence of signs of surface salting may not reflect salt levels at depth.

Hydrological observations

The main source of salt into the University Farm study area is from dissolved salts within irrigation waters from the South East Irrigation Scheme (SEIS). Water from the SEIS has an average TDS concentration of 325 mg/L, which may rise to 900 mg/L during summer months (Finnigan, 1995). Secondary sources of salt are aeolian salts within wind, rain and salt spray. The low-lying and near-coastal nature of much of the study area suggests it may once have been subject to marine incursion, providing a further source of salt.

Groundwater drainage throughout the catchment is poor, due to the impermeable nature of the Tertiary clay and associated sediments. The impermeable clay increases the residence time of the groundwater. This increases the dissolution rate of salts contained within the sediments, with further concentration resulting from evaporation when groundwater approaches within 2 or 3 metres of the ground surface.

Water budget calculations, of 509 mm of rain falling over the 2.55 km^2 catchment area each year, indicate an average water input of 1297.95 cubic metres per year. Based on an average rainfall salinity of 65 µS/cm or 41 mg/L, the annual salt input from rainfall into the catchment is 210 kilograms per hectare. The lack of deep rooted vegetation to intercept or use the water results in most of this water infiltrating as groundwater.

National catchment classification

This case study area contains examples from a number of models as outlined in Coram (1998). *Local Model (vi) – Discharge controlled by perched aquifers* was observed in a dissected alluvial fan deposit above the site of piezometer CRVP1 (fig. 45). Here, saline groundwaters form active salt scalds as they emerge at surface from gravel layers overlaying fine clay, contained within the fan deposits, and from the contact between the fan deposits and underlying Tertiary clay. Examples of this type of model are documented in Western Australia at the East Belka catchment, Bruce Rock, eastern wheatbelt, in South Australia at the Agery–Weetulta and Minlaton catchments on the Yorke Penninsula, and in Victoria on the Mallee dunes.

Figure 45

Active salt scald where saline groundwater emerges at the surface

Examples of *Local Model (viii) – Discharge from low hydraulic conductivity aquifers* were also observed around piezometer CRVP1 and within other incised drainage lines near piezometers Bore 1 and 2 and Uni11 and 14. Examples of this type of model are documented in Western Australia at the Morilla swamp, in the northern wheatbelt, and in Victoria at Barwon Downs.

Recommended action

The University Farm study area has very saline groundwater, particularly lower in the catchment. A reduction of groundwater salinity, groundwater levels and a minimisation of soil and land degradation could be achieved by the following strategies:

- Maintain a good cover of vegetation and do not overgraze areas under pasture.
- Revegetate areas of higher recharge with high water using crops and deep-rooted native vegetation. This process of revegetation will help to utilise water, preventing excess groundwater recharge and salt mobilisation to lower slopes. This can be also incorporated into shelter belts, therefore helping to lower evaporation rates exacerbated by prevailing winds.

- Regulate the input of saline irrigation water to the groundwater system to maintain soil health and productivity.

- Increase and improve the current surface drainage systems, particularly within the lower catchment, to avoid saline water accumulating in the closed lagoon systems. Flushing of this area, enabled by improved drainage, will not detrimentally affect surface water or biodiversity, as it enters directly into Pitt Water.

- Fence off all bare scalded areas from stock access and plant with salt-tolerant pasture species and saltbush. Species selection should be done in accordance with surface and near-surface salinity levels.

- Investigate the chemistry of the soil and rocks to determine other possible salt sources, such as sediments from old lagoons or palaeochannels.

- Continue monitoring groundwater conditions in order to establish long-term trends under varying climatic/rainfall patterns and possible future changes in land use.

- Minimise the length of time that land is left fallow in order to reduce any increase in groundwater recharge.

- Crop selection should be done in accordance with soil and irrigation water salinity levels, in order to ensure maximum growth and groundcover and achieve the highest water use to reduce runoff and recharge.

Summary

The majority of salt within the University Farm study area is currently derived from irrigation water, with lesser inputs from aeolian sources. The close proximity to the coast results in the study area being subject to salt input from sea mists during southeasterly and southerly weather. Salt may also have been introduced into the lower catchment system during a marine incursion. Analysis of drill spoil indicated salt is also contained within Triassic, Tertiary and Quaternary sediments present throughout much of the mid and lower catchment.

Salt occurring in the groundwater is concentrated during the long residence time in the Tertiary sediments and through a process of evaporation in near-surface waters, especially around piezometer CRVP1, where artesian conditions exist.

The highest salinity levels are observed in areas of low hydraulic gradient, within Tertiary sediments and particularly within the lower catchment where groundwater is less than ten metres from mean sea level.

Case Study 5

WHITE HUT CREEK — LITTLE SWANPORT STUDY AREA

Surface salt scalding in midslope discharge site (SwanDD4), Little Swanport Study Area

Salt scald at base of White Hut Rivulet. The Tasman Highway is downslope in the right of the image

Overview

Farming in the Little Swanport area began before 1850. Before clearing, the vegetation consisted of dry sclerophyll forest (Tom Tenniswood, pers. comm.). The study area now supports around 30 to 40% native vegetation cover, the cleared land being used for sheep grazing, agistment, cropping, irrigation cropping and as a recreation area around the 'Gumleaves' property.

Location

White Hut Creek is located at Little Swanport on the central East Coast of Tasmania, approximately 20 kilometres north of Triabunna (fig. 46). The study covered an area of 7.8 km² (575 000 mE, 5 310 000 mN), wholly within four properties.

Geomorphology

The study area is situated within low undulating terrain between one and 150 metres above mean sea level. The catchment drains to the east through a shallow drainage network into the Little Swanport. The drainage lines were observed to be flowing on only two occasions throughout the 18-month duration of the study, which ended in April 2000.

Dolerite is exposed on the western hillslopes and sandstone crops out and subcrops in the lower and southern parts of the catchment. There is a localised overburden of sand, gravel and dolerite boulders on the western hills and footslopes. Sandy to clayey colluvium and soil are present below the contact between the dolerite and sandstone. Thin, gently sloping colluvial deposits and flat-lying floodplain sediments within present and past anastamosing stream systems dominate the lower catchment. The catchment is a maximum of two kilometres from the sea at any one point.

The surface and near-surface drainage of the catchment is primarily controlled by the undulating bedrock and its weathered derivatives in the upper catchment, and poorly consolidated floodplain and colluvial sediments in the lower catchment.

Vegetation

Approximately 60% of the catchment area has been cleared, with the steep dolerite country, which forms the bulk of the western and northern parts of the catchment, and the rubbley sandstone outcrops being covered by remnant dry schlerophyl forest. The forest

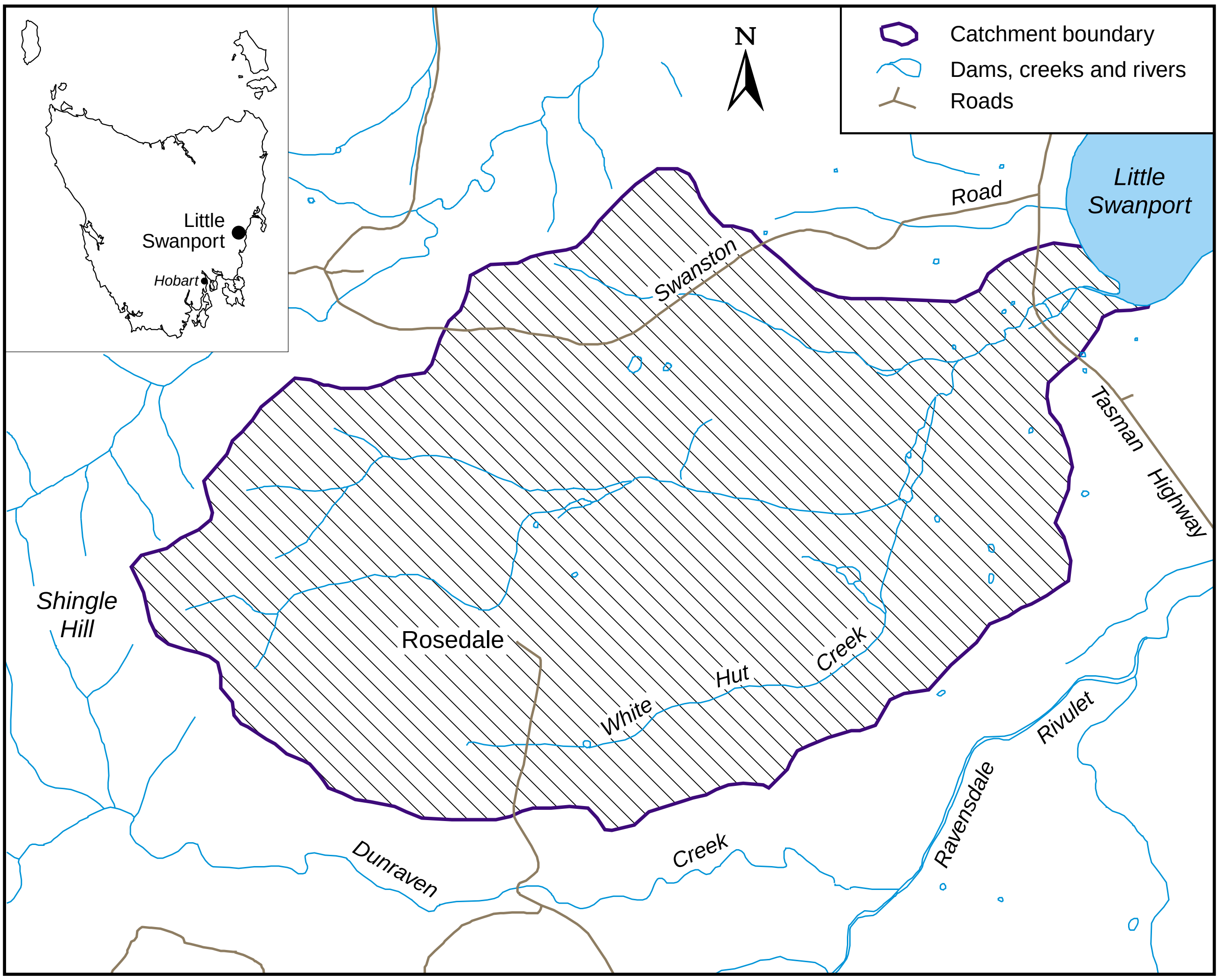


Figure 46

Location of Little Swanport Study Area catchment

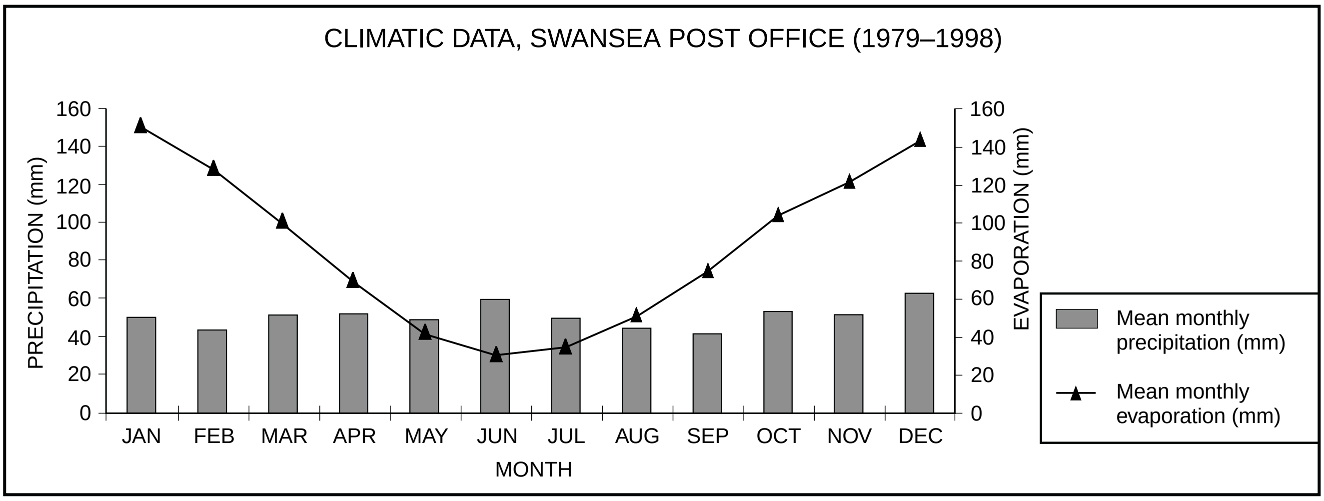


Figure 47

was primarily *Eucalyptus globulus* and *E. viminalis*, with lesser stands of *Acacia dealbata* (Silver Wattle) and *Callitris rhomboidea* (Oyster Bay Pine). Many salt indicator species are present, particularly in the lower catchment, with the principal species being Bucks Horn Plantain (*Plantago coronopus*) and Sea Barley Grass (*Hordeum marinum*).

Climate

Data from the Swansea weather station, about 27 km north of the study area, indicates that the area has a mean maximum daily average temperature of 17.7°C, with a maximum of 22.1°C in January and a minimum of 3.5°C in July. Swansea receives an average annual rainfall of 599 mm, falling on 118 days (fig. 47). An analysis of long-term rainfall figures for the East Coast region indicates a trend towards lower annual rainfall. Average yearly pan evaporation at Swansea is 1025 mm per year. Evaporation exceeds precipitation for nine months of the year.

Analysis of rainwater collected in the study area revealed that high concentrations of salt are present. Conductivity readings averaged 90 µS/cm.

Geology

The bedrock to the study area comprises Jurassic dolerite and Triassic sandstone (fig. 48). These rocks are overlain on the lower slopes by variably sandy, clayey, silty, gravelly and rocky colluvium. Quaternary alluvium, overbank and floodplain sediments occur in the lower catchment.

Quaternary alluvium and colluvium

Sand, silt, clay and gravel occur as stream and overbank deposits close to existing watercourses. Fine to medium-grained sand and minor clay, with uncommon dolerite and sandstone pebbles and boulders, occur as colluvium on the slopes below outcropping or closely sub-cropping Triassic sandstone units.

Floodplain sediments

A downward-grading sequence of sand, sandy clay and basal sandy clay containing dolerite cobbles occurs within the floodplain sediments deposited adjacent to the Ravensdale and White Hut Rivulet systems. These sequences of overbank and floodplain sediments form an expansive floodplain throughout much of the lower catchment.

Jurassic dolerite

Grey to blue-grey, medium to fine-grained dolerite forms the low western hills of the study catchment. The dolerite unconformably intrudes and overlies the Triassic sedimentary rocks. A more silicic and fine-grained dolerite occurs along the chilled margin between the dolerite and Triassic rocks.

Triassic sandstone

Fine to medium-grained, mostly flat-lying, variably feldspathic, micaceous and siliceous sandstone crops out in creek cuttings and as low rises in the lower parts of the catchment. Chalcedonic quartz and chert fragments occur as float close to the contact between the sandstone and dolerite. Ironstone concretions, granules and iron staining are common in outcrops in the lower catchment. Calcareous concretions commonly occur along bedding planes and fractures within the sandstone where it is exposed in the creek bed to the north of the Rosedale homestead.

Study parameters

Fifteen water monitoring bores or piezometers were established within the study area (fig. 48). Water levels and salinity were monitored on a monthly basis for the 18-month duration of the project. Piezometers were sited to intersect the water table and all piezometers were terminated on reaching water, with a maximum depth of sixteen metres (SwanDD2). The bores were distributed along the length of the drainage system within the study area. Comprehensive logs of the drill

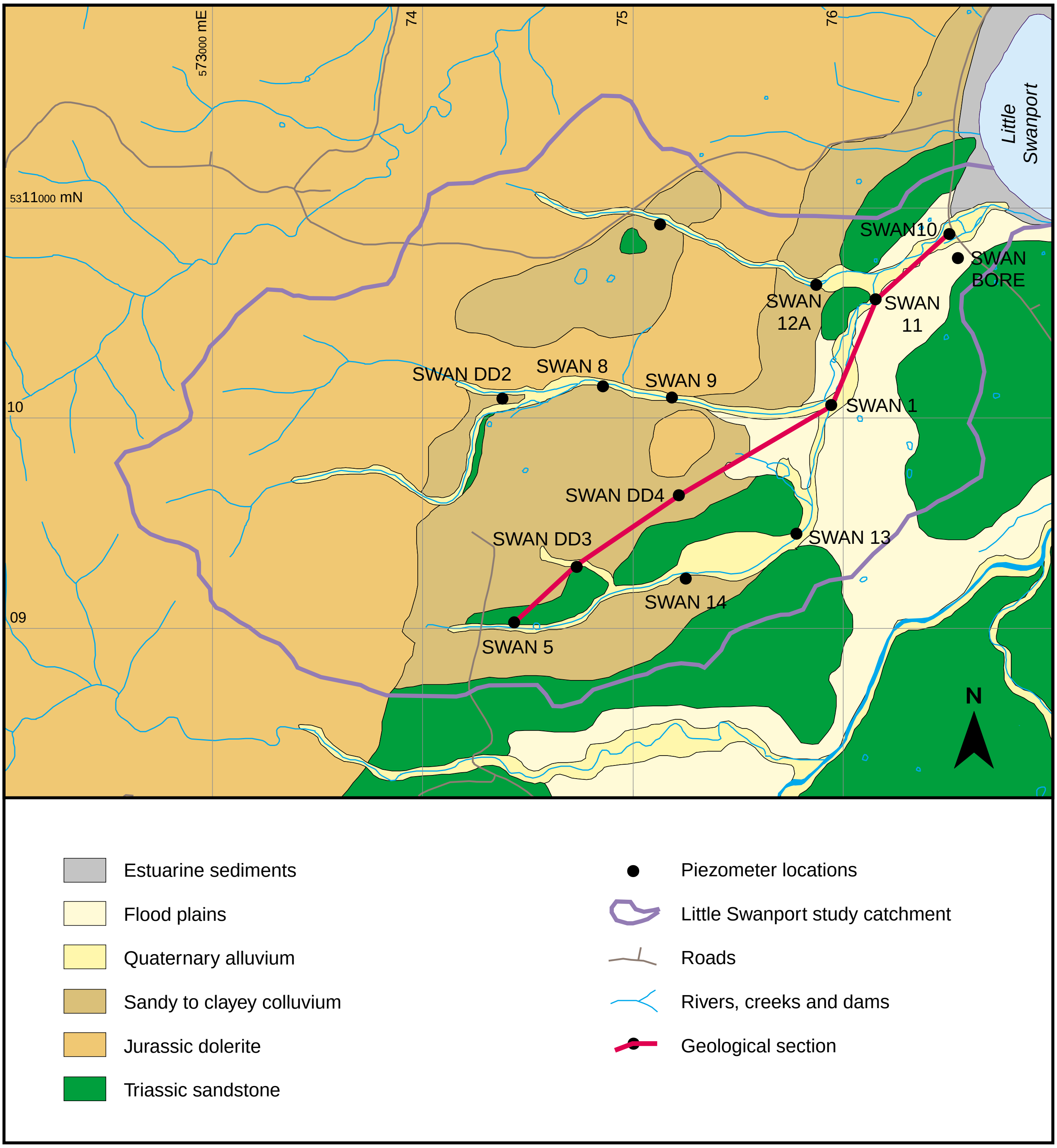


Figure 48

Geology of Little Swanport Study Area

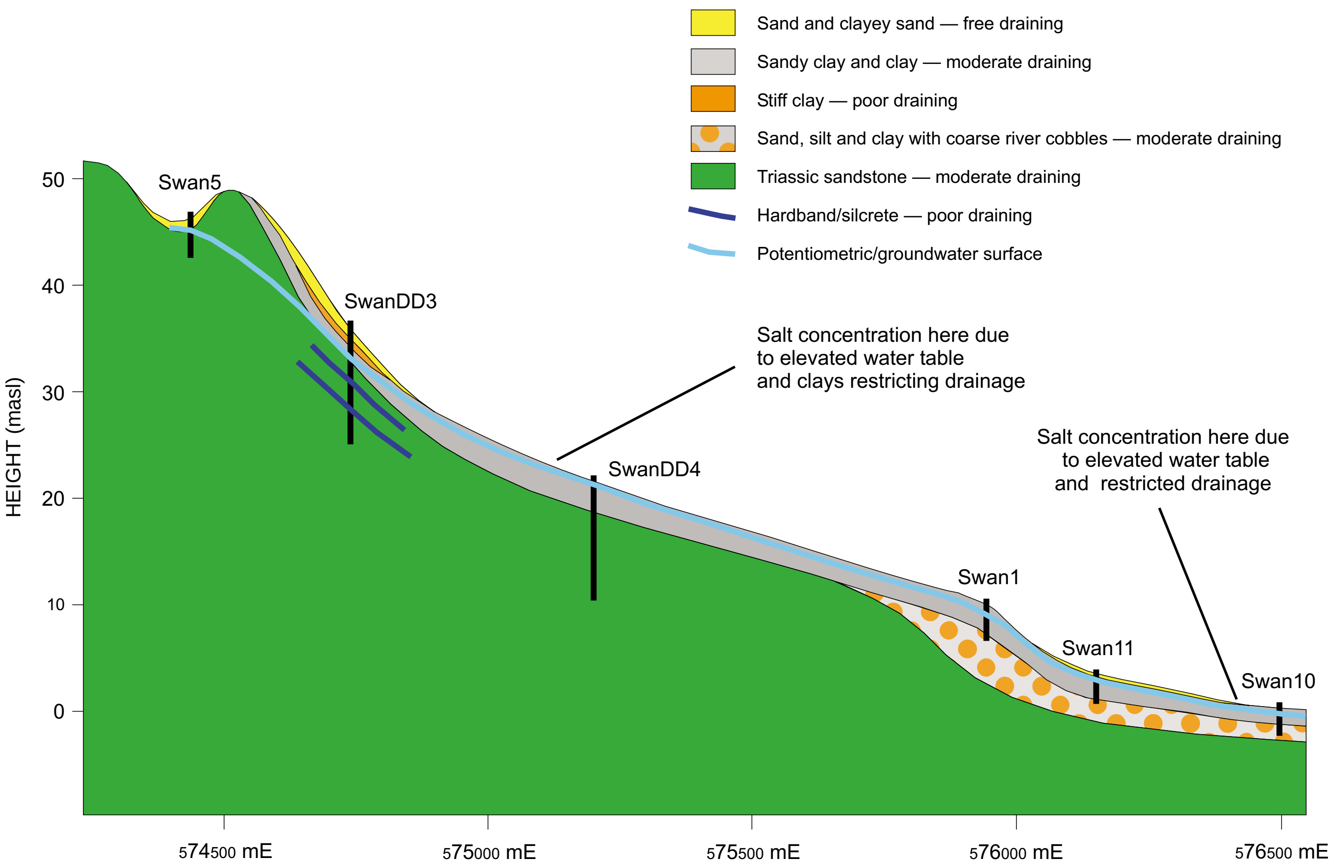


Figure 49

Geological section, Little Swanport area (see Figure 48 for location of section line)

cuttings from each piezometer have been prepared. A representative geological section is shown in Figure 49.

Results and discussion

Groundwater levels and salinity trends

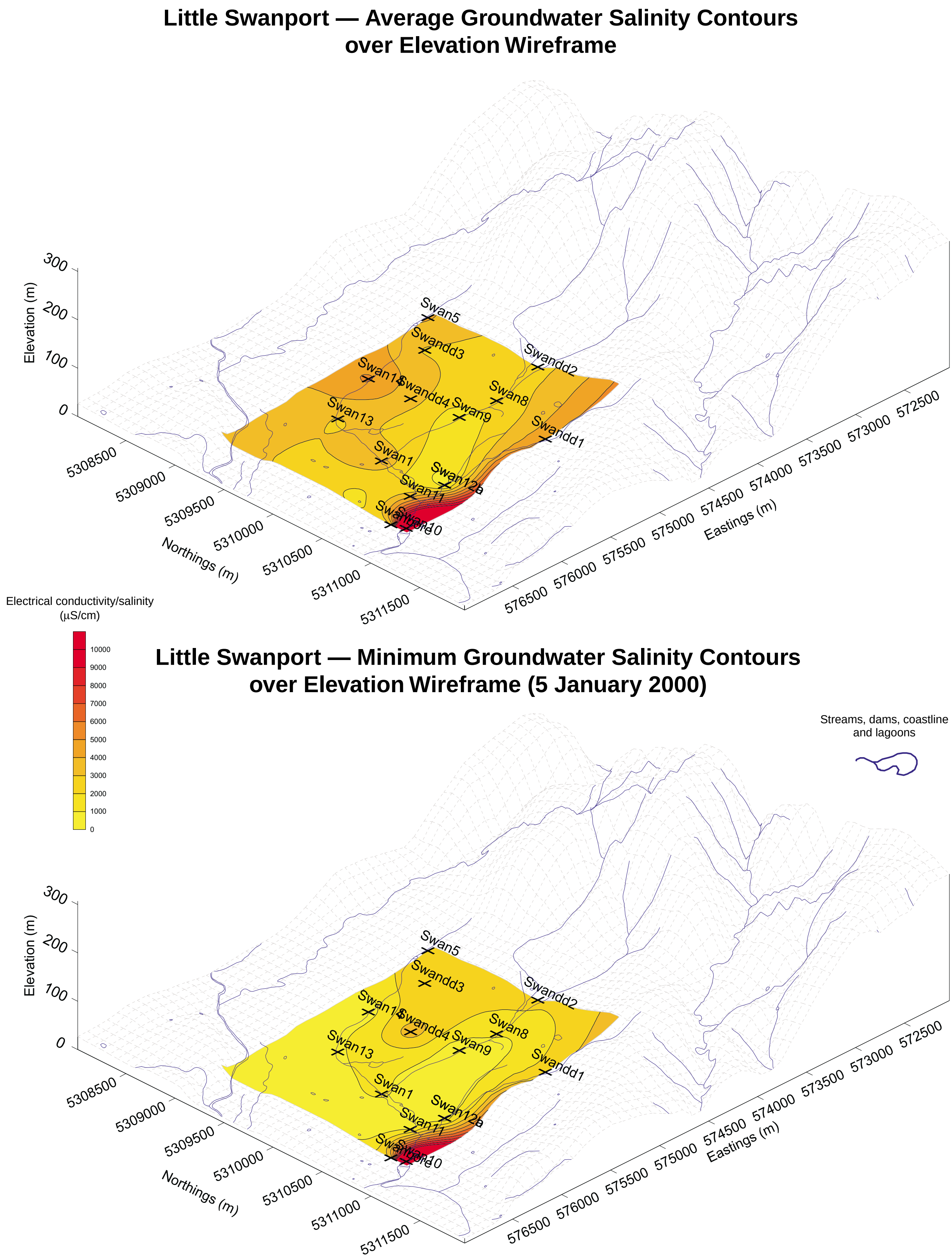
Water level and salinity measurements from all piezometers were collected at monthly intervals over a period of fifteen months. The average groundwater salinity (conductivity) for all piezometers over this period was 4756 µS/cm, with a range between 656 µS/cm (Swan12B) to 26 800 µS/cm (Swan10). The mean water table depth was 1.68 m below the surface, with a range from 0.01 m at piezometer SwanDD4 to 5.44 m below the surface at SwanDD2.

Extremely saline groundwater (10 000–30 000 µS/cm) was centered around piezometers Swan10 and Swan Bore (fig. 50). These piezometers were the lowest in the catchment, with Swan10 being only 0.9 m above mean sea level. Swan10 was located within five metres of White Hut Creek, which fills with saline water during extremely high tides. The high salt concentration about these piezometers is in part explained by the saline incursions during these high tide events and by the damming effect of the Tasman Highway, which interrupts groundwater flow out into the Little Swanport lagoon system.

Salinities ranging between 4000 and 6000 µS/cm occur around piezometer SwanDD1, which was located in a dolerite fracture system which feeds the lower catchment. Moderately saline groundwater (3000–5000 µS/cm) occurred within piezometers Swan1, 5, 14 and SwanDD3 and 4; all these bores were located within Triassic sandstone or floodplain sediments. A distinct area of lower groundwater salinity (700–1400 µS/cm) occurred in the middle and lower catchment around piezometers Swan9 and 12. Both these areas are located within well-vegetated and well-drained marshy areas where surface water and near-surface groundwater is present.

The flushing of saline groundwater from the catchment by rainfall after six months of very much below average rainfall is well illustrated in Figures 50 and 51. Average catchment groundwater salinity levels dropped sharply from 5412 µS/cm (1 December 1999) to 3304 µS/cm (5 January 2000) after good rains during November and December 1999. Groundwater salinity levels remained high in piezometers SwanDD3 and SwanDD4, which is explained by their isolation from major drainage lines.

Groundwater occurred at very shallow depths throughout much of the lower catchment (fig. 52). The water table at piezometer Swan10 averaged only 0.45 m below ground level for the duration of the study. SwanDD4, which like Swan10 is the site of a large salt scald, had an average groundwater level of 15 mm below ground surface.The shallow groundwater in the lower catchment is to some degree



The important feature to note on these diagrams is the area of severely saline groundwater around piezometer Swan10. This area appears to experience impeded drainage to the east by the Tasman Highway. The area is also subject to minor tidal influx through the White Hut Rivulet system. Salinities up to 35 000 µS/cm are common in and around piezometer Swan10. Less severely saline groundwater was present after a large rainfall event in January 2000. Groundwater salinity dropped, particularly close to the two main creeklines. Areas isolated from drainage lines and not subject to groundwater flushing (such as piezometers SwanDD3 and SwanDD4) still show elevated groundwater salinities.

Figure 50

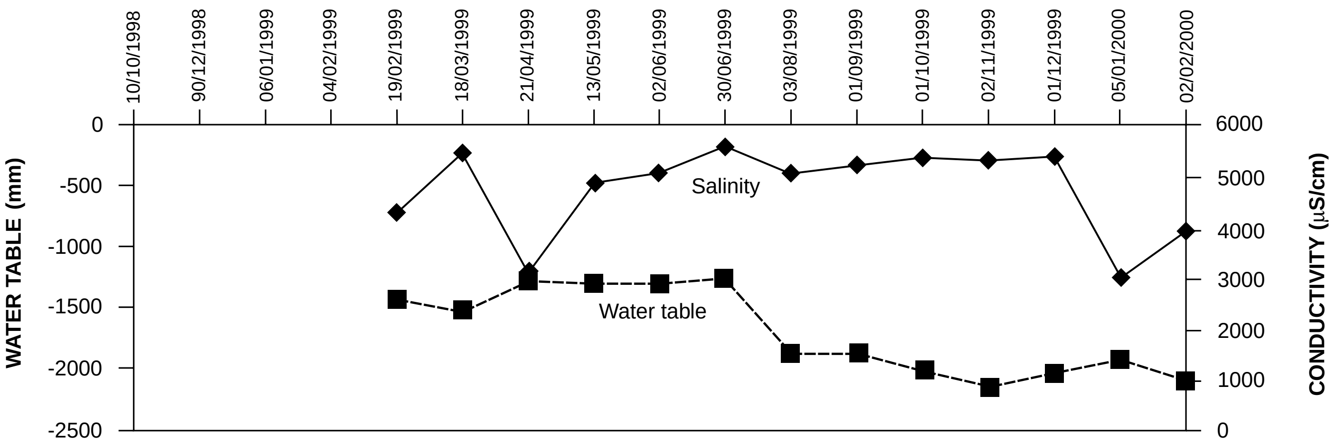


Figure 51

Graphical representation of average catchment water table and salinity levels

a product of piezometer location, but also reflects the very subdued topography within the floodplain sediments.

The catchment response to major rainfall events is typified by the period between 1 December 1999 and 5 January 2000. A rapid rise in the water table level (from 2.02 m to 1.90 m below ground level) was associated with a temporary fall in observed salinity (from 5412 to 3304 µS/cm) (fig. 51, 52).

Groundwater flow directions

Groundwater flow directions in the Little Swanport study area mimic the ground surface topography which slopes gently to the east (fig. 53). The groundwater flow directions of the upper catchment are controlled primarily by outcropping and subcropping dolerite bedrock. Groundwater flow directions in the lower catchment appear to be controlled by the poorly consolidated floodplain sediments that overlie the gently undulating sandstone bedrock.

Hydraulic conductivity

The hydraulic conductivity was evaluated at each piezometer using rising head slug tests. This procedure involves removing a 'slug' or quantity of water from the bore and recording the rate at which the water table recovers. The hydraulic conductivity of the fifteen piezometers within the Little Swanport study area varied between 0.0002 metres per day (m/d) and 0.35 m/d (fig. 54). This is consistent with a range of representative values determined (after Morris and Johnson, 1967) for clay (0.002 m/d), silt (0.08) and fine sand (2.5 m/d).

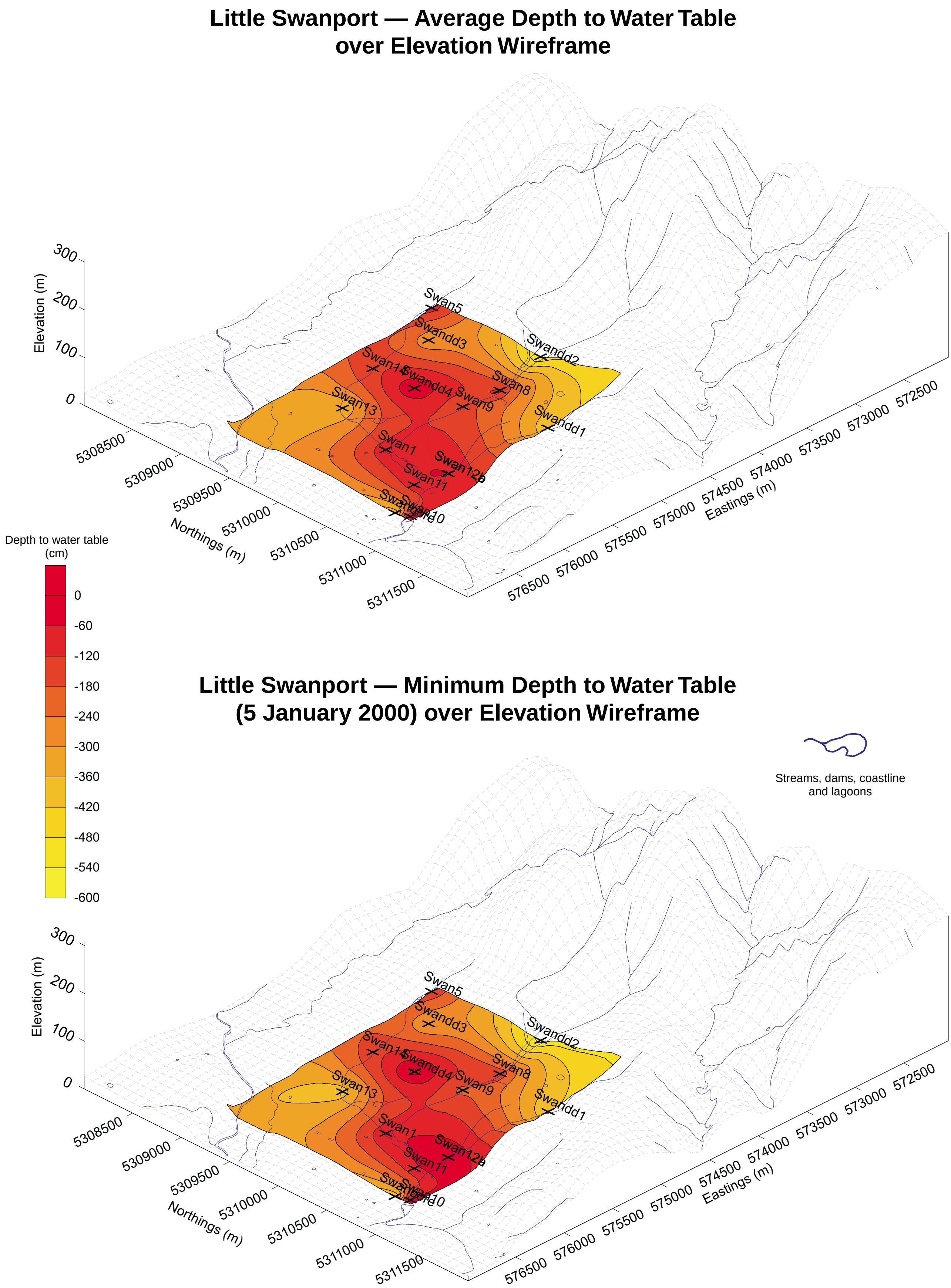
The diagram generated from the slug test data (fig. 54) shows a distinct area of high hydraulic conductivity, highlighted in red, centered about piezometer Swan13. This site is located within coarse sandy Quaternary alluvium and at a base of slope location.

Large areas of low hydraulic conductivity were also identified (particularly at piezometers Swan1, 5, 8, 9, 12 and SwanDD2 and DD4). This large area of low to

Table 9

Groundwater chemistry results

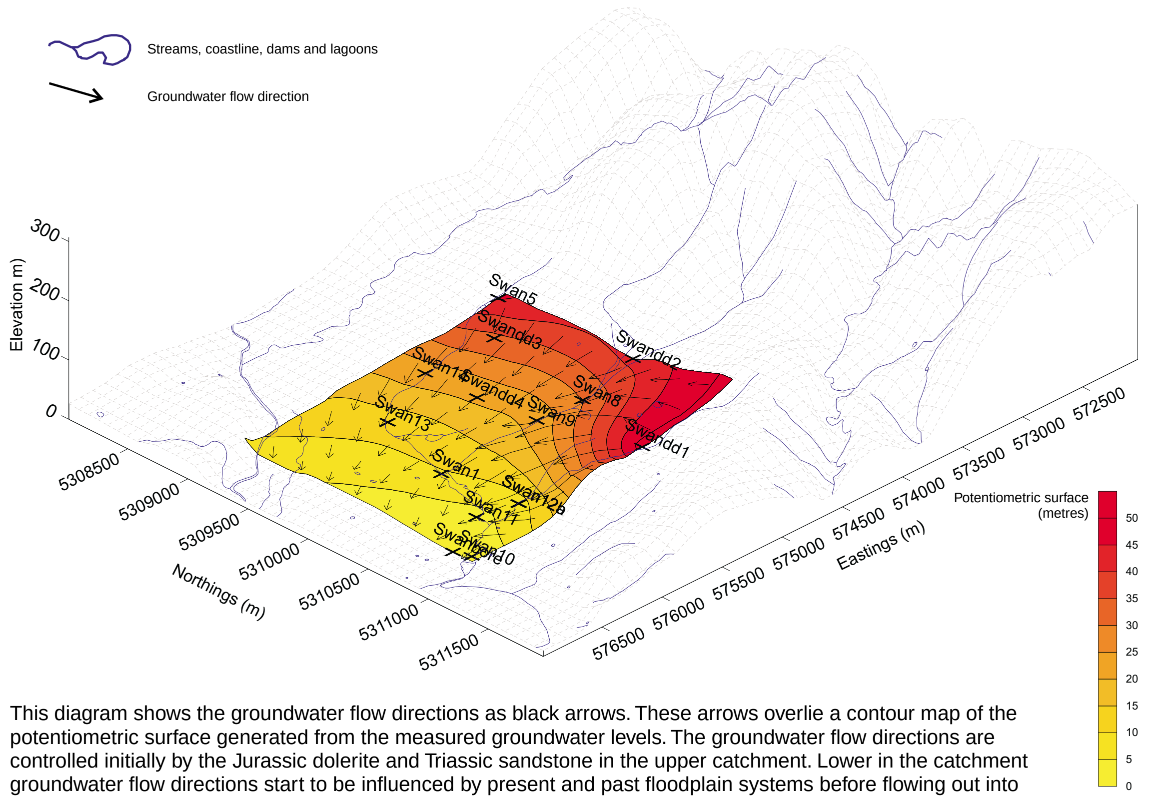
Piezometer Number	Ca^{++} (mg/l)	Mg^{++} (mg/l)	Na^{+} (mg/l)	K^{+} (mg/l)	HCO_3^{--} (mg/l)	CO_3^{--} (mg/l)	SO_4^{-} (mg/l)	Cl^{-} (mg/l)	TDS (mg/l)
SWAN BORE	112.9	107.1	420.4	19.8	96.7	0	12.2	1091.3	2240
SWAN1	115.0	122.7	750.4	2.0	207.4	0	88.1	1523.6	3220
SWAN5	92.6	128.4	728.3	6.3	137.2	0	119.6	1420.8	2890
SWAN8	105.4	96.7	338.7	4.5	324.3	0	52.9	751.2	1810
SWAN9	36.9	61.9	365.6	4.4	162.2	0	53.0	627.1	1360
SWAN10	841.5	1362.8	6087.9	192.1	235.4	0	997.1	13921.1	26700
SWAN11	118.3	127.4	1088.8	5.4	274.4	0	136.5	1849.5	3770
SWAN12A	16.9	25.0	140.7	3.5	70.2	0	21.7	251.6	571
SWAN12B	20.7	19.8	101.7	2.2	26.5	0	23.1	212.6	527
SWAN13	83.2	113.9	468.9	6.7	40.5	0	61.4	1070.0	2200
SWAN14	50.8	139.1	818.3	10.4	137.2	0	110.8	1481.0	2960
SWANDD1	136.2	193.9	853.4	15.1	366.4	0	168.0	1714.9	3830
SWANDD2	75.7	115.0	329.8	9.1	595.6	0	30.5	605.9	1640
SWANDD3	84.0	127.1	359.4	11.6	721.9	0	49.9	683.8	1830
SWANDD4	83.8	124.8	546.3	11.0	262.0	0	80.4	1055.9	2330



These diagrams illustrate the shallow depth at which the groundwater sits below the ground surface throughout much of the lower catchment. Groundwater is consistently within 1 to 2 metres of the surface at piezometers Swan5, 10, 11, 12a, and 12b. Groundwater levels in Swan DD4 averaged only 10 mm below the ground surface. The area surrounding Swan DD4 shows considerable signs of salinisation, with Bucks Horn Plantain and bare scalded ground over an area of 20–30 square metres.

Figure 52

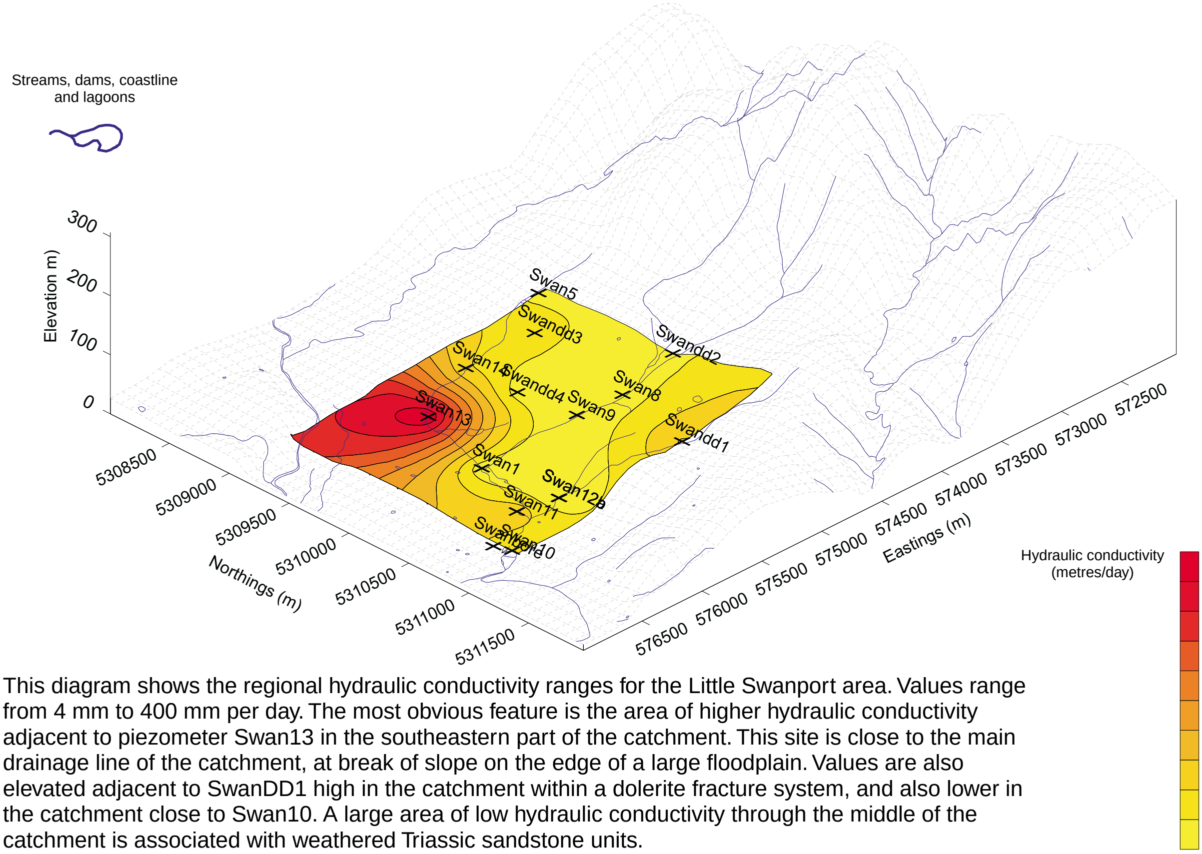
Little Swanport — Potentiometric Surface and Groundwater Flow Directions over Elevation Wireframe



This diagram shows the groundwater flow directions as black arrows. These arrows overlie a contour map of the potentiometric surface generated from the measured groundwater levels. The groundwater flow directions are controlled initially by the Jurassic dolerite and Triassic sandstone in the upper catchment. Lower in the catchment groundwater flow directions start to be influenced by present and past floodplain systems before flowing out into Little Swanport.

Figure 53

Little Swanport — Hydraulic Conductivity Contours over Elevation Wireframe



This diagram shows the regional hydraulic conductivity ranges for the Little Swanport area. Values range from 4 mm to 400 mm per day. The most obvious feature is the area of higher hydraulic conductivity adjacent to piezometer Swan13 in the southeastern part of the catchment. This site is close to the main drainage line of the catchment, at break of slope on the edge of a large floodplain. Values are also elevated adjacent to SwanDD1 high in the catchment within a dolerite fracture system, and also lower in the catchment close to Swan10. A large area of low hydraulic conductivity through the middle of the catchment is associated with weathered Triassic sandstone units.

Figure 54

very low hydraulic conductivity (from 3–40 mm per day) corresponds to sub-cropping Triassic sandstone units and recent clayey alluvial deposits close to drainage lines. This reduction in groundwater flow rates and corresponding increase in residence time tends to lead to increased groundwater and soil salinity, resulting from evaporation of near-surface pore waters. This effect can clearly be seen at piezometers SwanDD4 and Swan12a.

Water chemistry

Groundwater chemistry information for water samples extracted from all piezometers was determined by the MRT Laboratory. Analyses (Table 9, Appendix 5) showed that all waters had the same trace element components, with sodium (Na), magnesium (Mg), chloride (Cl) and bicarbonate (HCO_3) being the dominant ions. The significant level of Na and Cl components is consistent with near-coastal rainfall being a principal source of recharge to the catchment. Mg and HCO_3 are most probably derived from dissolution of silicate minerals in dolerite or its weathered derivatives.

Soil salinity

Drill cuttings recovered at 900 mm depth intervals during each piezometer installation were dried, crushed and placed in a mixture of five parts water to one part soil sample, mixed and then analysed for salt content. The average EC1:5 salinity values have been plotted on a contour map (fig. 55). The highest average salt concentration of 1558 µS/cm was centred around piezometer Swan10. This was located within a saline discharge site where the water table depth averages approximately 500 mm below ground level, and where considerable evaporation and concentration of salts would be likely to occur.

The surface soil salinity levels (fig. 55) are generally considerably higher than the averaged total soil salinity values for each piezometer. This is attributed to both the evaporation and concentration of salts from near-surface groundwater and the salt load likely to be present in the upper soil and which is deposited from sea mists and aeolian salts during easterly weather. Rainfall collected from the 'Ravensdale' property during the course of the project contained salt concentrations up to 90 µS/cm.

Hydrological observations

The main source of salt within the Little Swanport study area is from dissolved salts within wind, rain and salt spray. The low-lying and near-coastal nature of much of the study area suggests it may once have been subject to marine incursion, providing a further source of salt.

Groundwater drainage throughout the catchment is poor, due to the impermeable nature of recent clayey alluvium and associated sediments, and the low to very low relief throughout the middle and lower parts of the catchment. The impermeable sediments and low hydraulic gradient increase the residence time of the groundwater. This increases the dissolution rate of salts contained within the sediments, with further concentration resulting from evaporation when groundwater approaches within two to three metres of the ground surface.

Water budget calculations, with 599 mm of rain falling over the 7.8 km^2 catchment area each year, indicate an average water input of 4672.2 cubic metres per year. Based on an average rainfall salinity of 90 µS/cm or 57 mg/L, the annual salt input from rainfall into the catchment is 350 kilograms per hectare. Because of the lack of deep rooted vegetation to intercept or use the water, most of the rain water infiltrates as groundwater.

National catchment classification

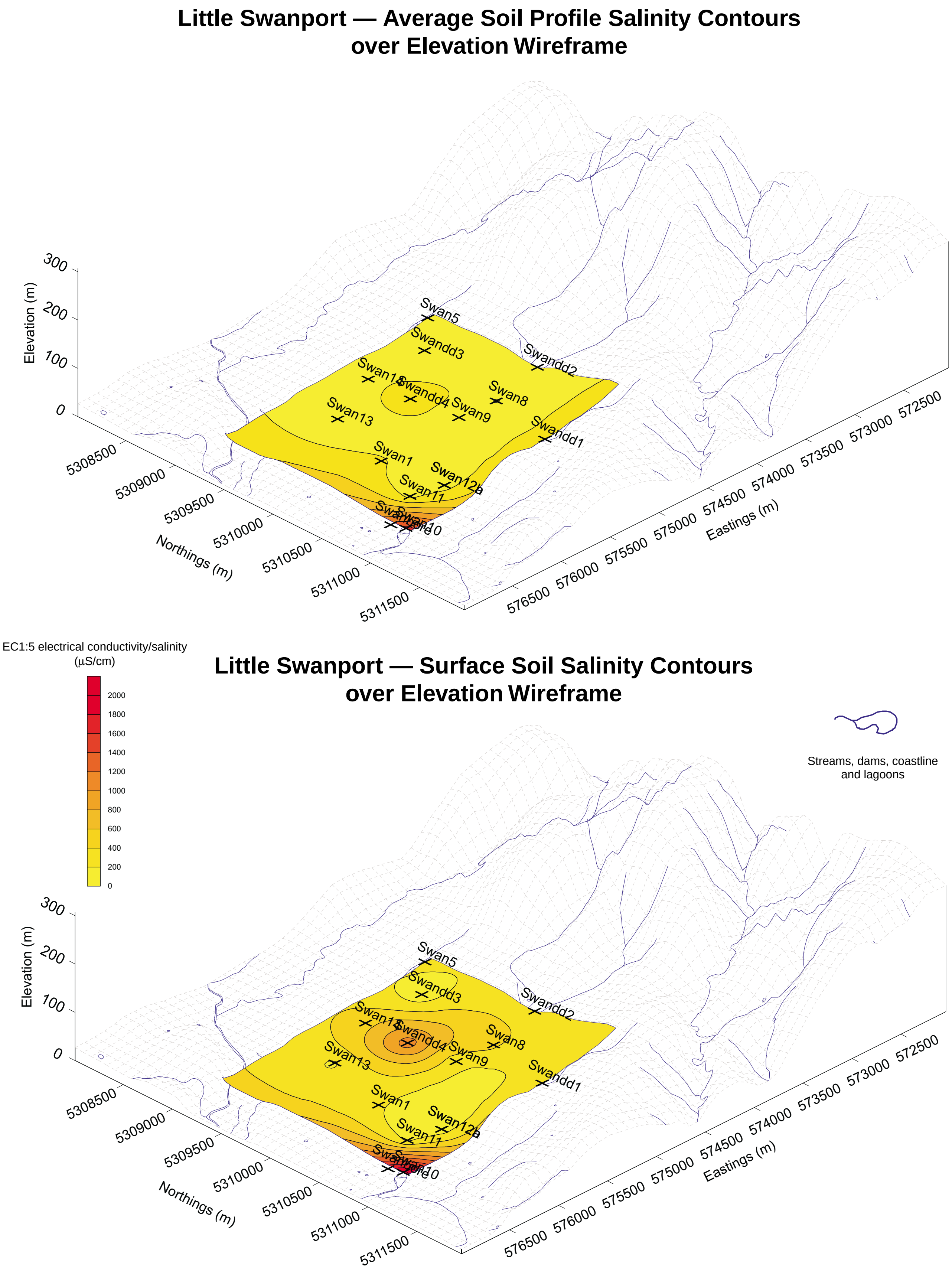
This Little Swanport case study area contains examples from a number of models as outlined in Coram (1998). Examples of *Local Model (viii) – Discharge from low hydraulic conductivity aquifers* were observed around piezometer Swan10 and SwanDD4. Examples of this type of model are documented in Western Australia at the Morilla swamp, in the northern wheatbelt, and in Victoria at Barwon Downs.

Examples of *Local Model (iv) – Discharge from colluvial/alluvial slopes* were observed around piezometers Swan12 and Swan13. Examples of this type of model are documented in Victoria in the Warrenbayne–Boho area, and in Queensland in the Burdekin Valley.

Recommended action

The Little Swanport study area has very saline groundwater, particularly lower in the catchment. A reduction of groundwater salinity, groundwater levels and a minimisation of soil and land degradation could be achieved by the following strategies:

- Maintain a good cover of vegetation and do not overgraze pastures.
- Revegetate areas identified as higher recharge with high water-using crops and deep-rooted native vegetation. By selecting appropriate native vegetation in these areas, healthy growth of the trees will help to utilise water, preventing excess groundwater recharge and salt mobilisation to lower slopes. This can be also incorporated into shelter belts, therefore helping to lower evaporation rates exacerbated by prevailing winds.
- Fence off all bare scalded areas from stock access, and plant with salt tolerant pasture species and saltbush. Species selection should be done in accordance with surface and near-surface salinity levels, in order to ensure successful establishment and future health and growth of the ground cover.



These diagrams clearly illustrate the very high salinity levels around Swan10, which appears red in the lower right-hand side of the study area. This site shows the highest surficial soil and average profile salinity levels and also has the highest average groundwater salinity level. Piezometer SwanDD4, located at a saline discharge site in the middle of the catchment, also shows elevated surface and average profile salinities. Saline groundwater is present to within one metre of ground level at both sites. The concentration of salt by near-surface evaporation of groundwater is the likely cause of the observed high soil salinity values.

Figure 55

- Investigate the chemistry of the soil and rocks to determine other possible salt sources, such as from Triassic sandstone or sediments from old lagoons or palaeochannels.
- Continue to monitor groundwater and surface soil salinity levels in the study region. This will provide long-term trends and changes that may result from implemented management, changes in land use.
- Irrigation water quality should be tested regularly prior to application, and careful scheduling adhered to in order to prevent additional recharge or runoff. Paddocks should not be left fallow for extended periods of time to minimise recharge during rainfall events.
- Improving current surface drainage may help to flush soils with low hydraulic conductivity and high salt storage levels. The disposal of this drainage water needs to be carefully considered.

Summary

The current salt inputs into the Little Swanport study area are derived from dissolved salts within wind, rain and salt spray. The close proximity to the coast results in the study area being subject to salt input from sea mists during easterly and northerly weather. Salt may also have been introduced into the lower catchment system during a marine incursion.

Salt is also contained, in varying amounts, within Triassic sandstone and Jurassic dolerite higher in the catchment and within Tertiary and Quaternary sediments lower in the catchment.

Salt within the groundwater is concentrated during the long residence time in the floodplain and colluvial sediments and through a process of evaporation in near-surface waters, especially around piezometer SwanDD4, where artesian conditions sometimes exist.

The highest salinity levels occur in areas of low hydraulic gradient, within the floodplain sediments and particularly within the lower catchment where groundwater is commonly less than five metres from mean sea level.

APPENDIX 1

Indicator Species for Identifying Saline Soils in Tasmania

Julie Finnigan
Department of Primary Industries, Water and Environment

The identification of saline soils in Tasmania is greatly aided by the presence of 'indicator species', plants that are associated with varying levels of salts in surface soils. While there are many plant types that can be listed, there are three main plant types that have been identified in Tasmania as being most reliable for identifying low, moderate and severe cases of surface salinisation.

Low to Moderate Surface Soil Salinity (0–4 dS/m and 4–8 dS/m)

One of the very first signs of low surface salinisation is a decline in pasture and crop productivity. This may be identified by the presence of stunted growth forms, yellowing of vegetation, poor or patchy germination and associated lower yields. Pastures affected by low levels of salinisation may also lack the presence of clover species, which are most sensitive to the presence of increasing levels of salts in soils.

Poor poppy growth and yield evident in salt affected drainage line, southern Tasmania. Reductions in yield can be seen in reduced poppy head size radiating up slope of the saline scalds (Photo by J. Finnigan)

Sea Barley Grass, *Hordeum marinum*, has been identified as a good indicator of the very early signs of surface soil salinity. The picture below shows Sea Barley Grass during the winter months where the flower heads are dead. During the spring months when the flower heads are growing, this indicator species can easily be mistaken for Barley Grass, *Hordeum leporinum*. While these species are very similar in appearance, Sea Barley Grass is a smaller plant with shorter flower heads.

Sea Barley Grass (Photo courtesy of Victorian NRE)

Buck's Horn Plantain, *Plantago coronopus*, has proven to be one of the most reliable indicators of low to moderate soil salinity in Tasmania. This picture highlights the growth form and colour variations of this plant. In areas where surface soil salinity levels are low, this plant will be green in colour, and can grow quite large with rosettes up to 20 cm in diameter. The more saline the soil conditions become, Buck's Horn Plantain becomes very stunted in growth (as small as a ten cent piece), and takes on a dark burgundy colour in the leaves. This is most noticeable when driving through affected agricultural areas where lower lying areas are often carpeted with the red tinge of Buck's Horn Plantain. The 'deer antler' shape of the leaves of this plant make it very easy to identify, hence the common name it has been given.

Buck's Horn Plantain (Photo by S. McMahon)

Landscape view of a low lying saline area in the northern midlands area of Tasmania. The presence of surface salting is most noticeable by the red colour that Buck's Horn Plantain has turned (Photo by J. Finnigan)

This photo shows water buttons growing in abundance on the periphery of a saline water hole in Northern Tasmania (Photo by J. Finnigan)

High to Severe Surface Soil Salinity (8–16 dS/m and >16 dS/m)

Where surface soil salinity levels continue to rise to very high and severe levels, associated vegetation continues to change. Buck's Horn Plantain will survive under high salinity levels, however as salinity climbs into the severe levels, most vegetation dies off leaving bare patches of soil. This is a devastating appearance that mars the landscape and leaves the soils most vulnerable to further forms of degradation.

Under very wet and highly saline conditions, yellow Water Buttons, *Cotula coronopifolia*, is often found throughout Tasmania. This is a very fleshy, or succulent plant, with distinctive 'button like' yellow flowers. Unlike many other flowers, this species does not have petals.

Yellow Water Buttons (Photo by S. McMahon)

Highly saline drainage lines are often thickly lined with these water buttons, whereas their presence in paddocks is usually more sparse. The size of Water Buttons plants tends to be controlled by both the degree of salinity and the frequency of waterlogging endured. In particular, the longer plants are inundated by water the larger they will grow.

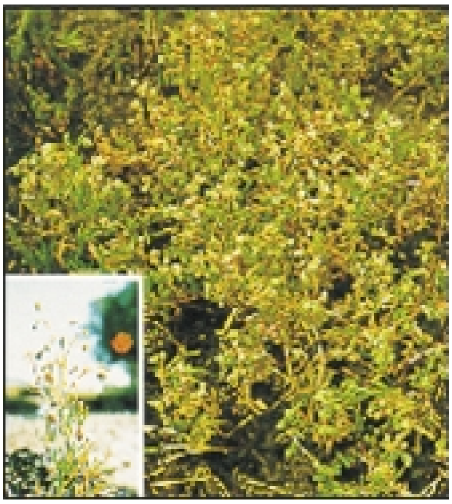
Other Plants in Tasmania that can be used for the identification of surface saline soils

Sea Barley Grass, Buck's Horn Plantain and Water Buttons are not the only plants that are used for the identification of saline surface soils in Tasmania, however they have proven to be the most reliable 'indicator species' for the range of soil types encountered across Tasmania's agricultural districts.

Other species that have been identified quite frequently in saline soils across Tasmania are listed below, however they do not occur as readily or frequently, and are therefore harder to identify in a landscape view.

Annual Beard Grass (Polypogon monspeliensis) (Photo courtesy of Victorian NRE)

Australian Salt Grass (Distichlis distichophylla)
(Photo courtesy of Victorian NRE)



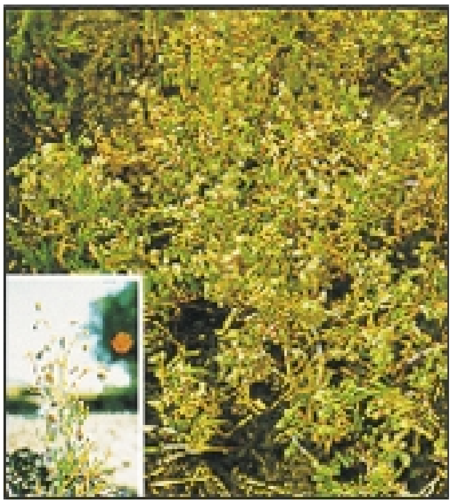
Australian Salt Grass (Distichlis distichophylla)
(Photo courtesy of Victorian NRE)

In agricultural regions that are close to Tasmanian coastlines, there are again a number of small plants and shrubs that have been identified under saline conditions. These include:

- Samphire (*Hallosarcia pergranulata*)
- Beaded Glasswort (*Sarcocornia quinqueflora*), and
- Pigface or Rounded Noonflower (*Disphyma crassifolium*).

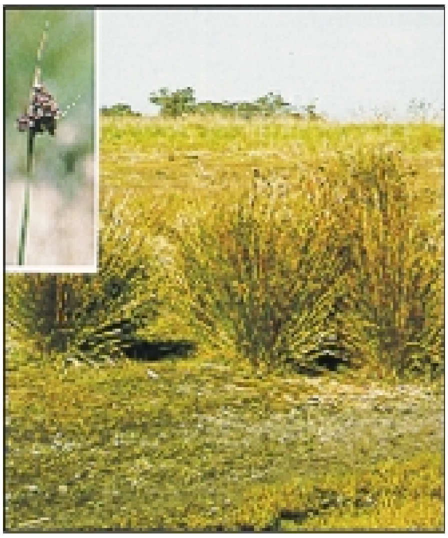
These plants are all succulants, with very fleshy leaves or stems.

There are some rushes that have also been observed in saline areas around Tasmania, however these have been more closely linked with waterlogging than with salinity. While waterlogging and salinity often go hand in hand, the rushes listed below are more reliable for indicating waterlogged soils, not highly saline soils.



Coastal Sandspurrey (Spurgularia media)
(Photo courtesy of Victorian NRE)

Toad Rush (Juncus bufonius)
(Photo courtesy of Victorian NRE)



Spiny Rush (Juncus acutus)
(Photo courtesy of Victorian NRE)

Appendix 2
Piezometer and rainfall data

This appendix contains basic data recorded from piezometers installed in the various study areas. These data include:

- AMG co-ordinates and elevations of installed piezometers;
- Salinity values and depth to water table of individual piezometers on all sampling dates (both tabulated and graphical);
- Meteorological data from representative stations.

The data are available in Microsoft Excel 97 format and are organised into individual files for each study area.

Study area	*File name*
Cape Portland	app2_port.xls
Longford Basin	app2_long.xls
Verwood	app2_ver.xls
University Farm	app2_uni.xls
Little Swanport	app2_swan.xls

Appendix 3
Salinity data

This appendix contains basic EC1:5 salinity data recorded from piezometers installed in the various study areas. These data include the EC1:5 values recorded at various depths in each hole and an average hole value. The data are presented in both tabular and graphical form.

The data are available in Microsoft Excel 97 format and are organised into individual files for each study area.

Study area	*File name*
Cape Portland	app3_port.xls
Longford Basin	app3_long.xls
Verwood	app3_ver.xls
University Farm	app3_uni.xls
Little Swanport	app3_swan.xls

Appendix 4
Logs of boreholes

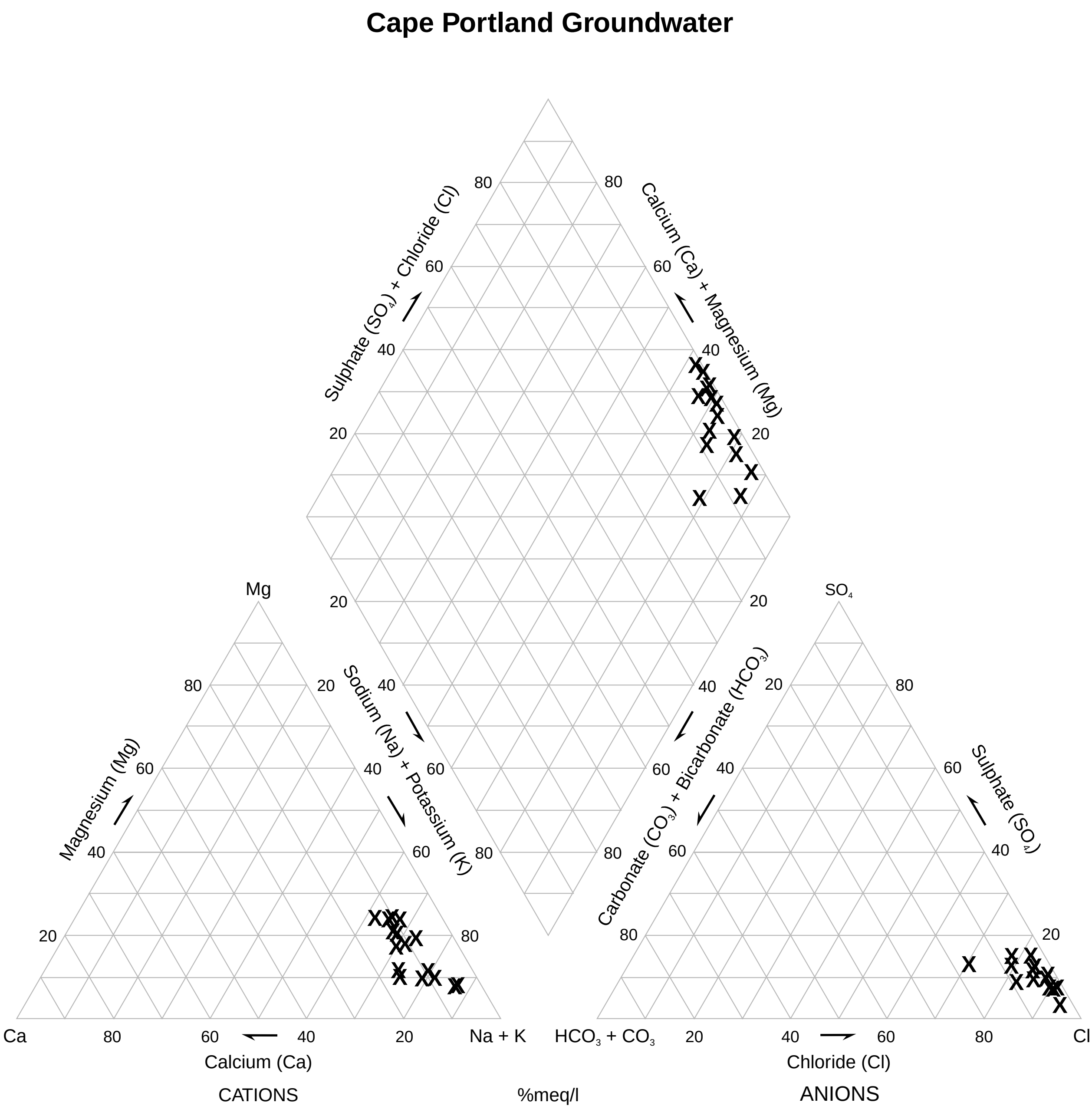
This appendix contains descriptive geological logs of each of the piezometers installed in the various study areas.

The data are available in Microsoft Excel 97 format and are organised into individual files for each study area.

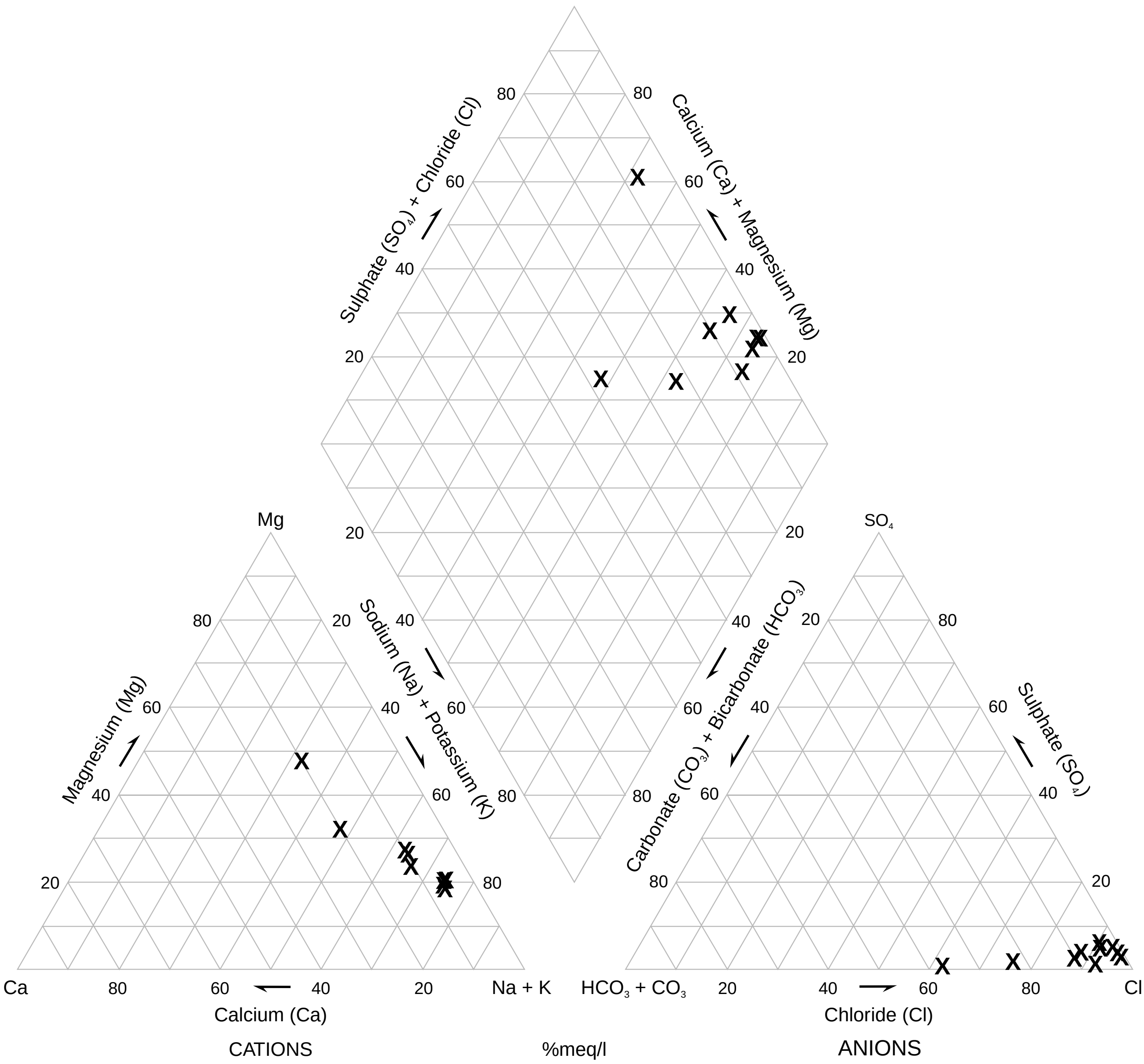
Study area	*File name*
Cape Portland	app4_port.xls
Longford Basin	app4_long.xls
Verwood	app4_ver.xls
University Farm	app4_uni.xls
Little Swanport	app4_swan.xls

Appendix 5

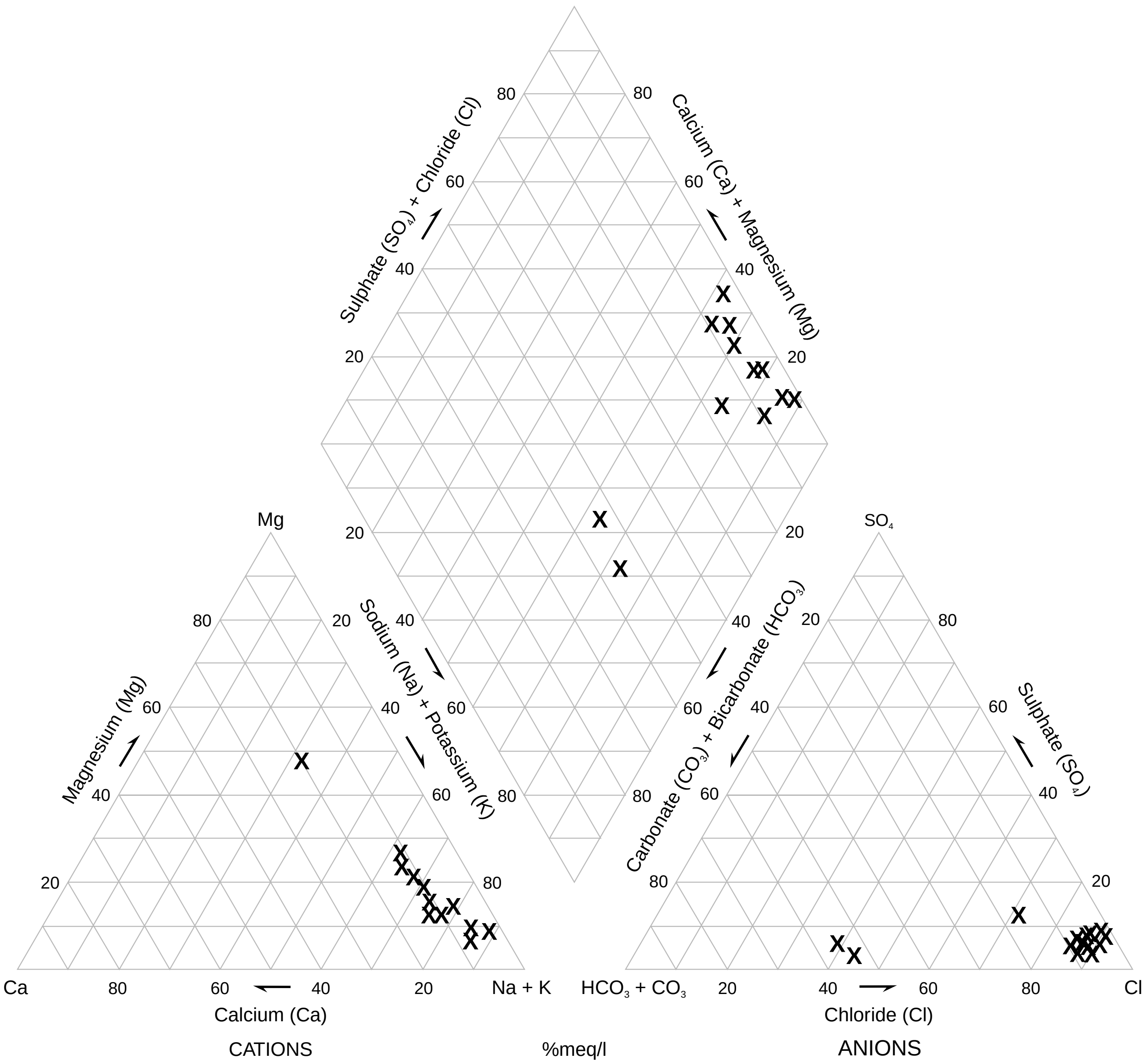
Piper diagrams of groundwater sample analyses results



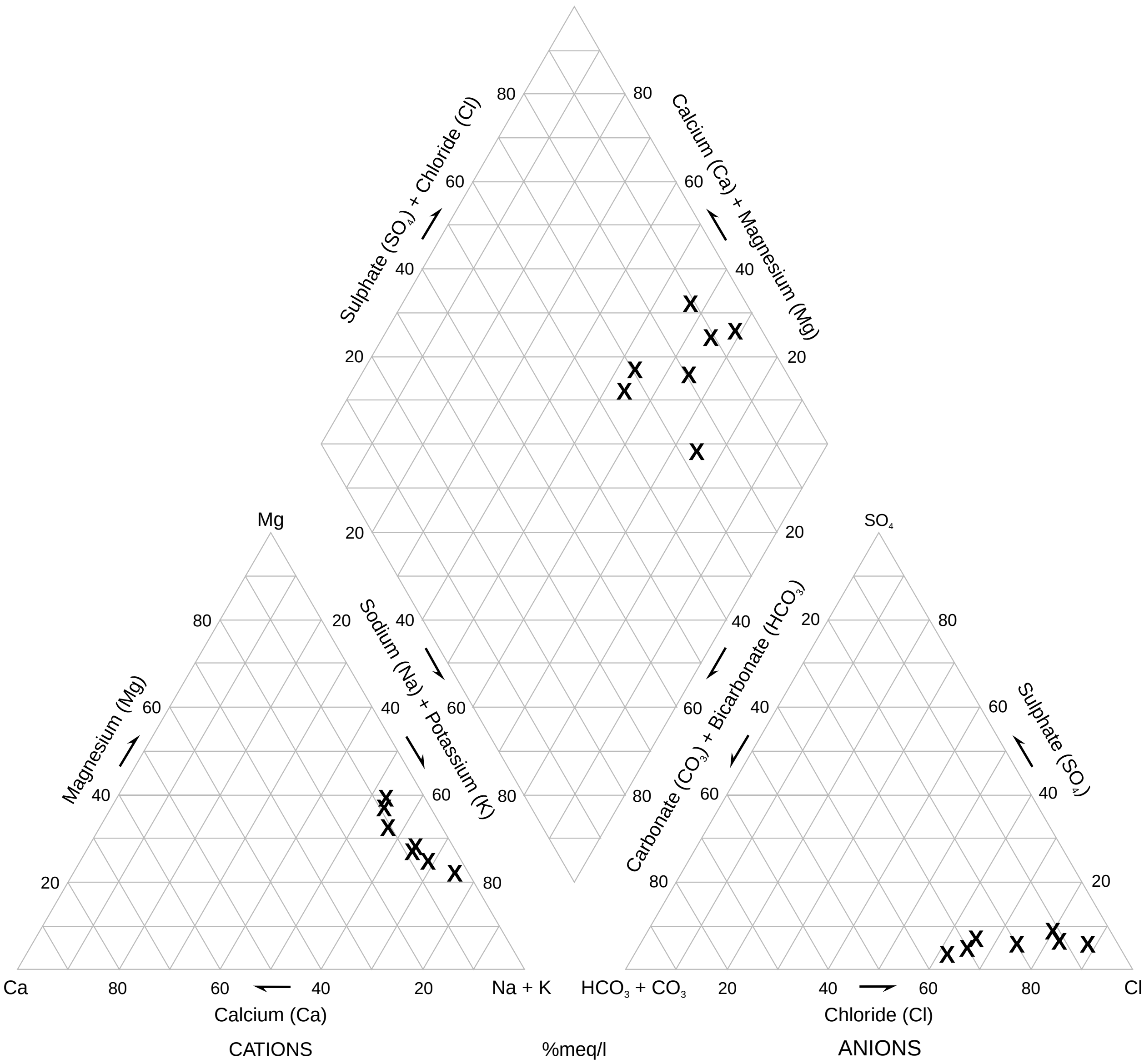
Longford Groundwater



Verwood Groundwater



University Farm Groundwater



Little Swanport Groundwater