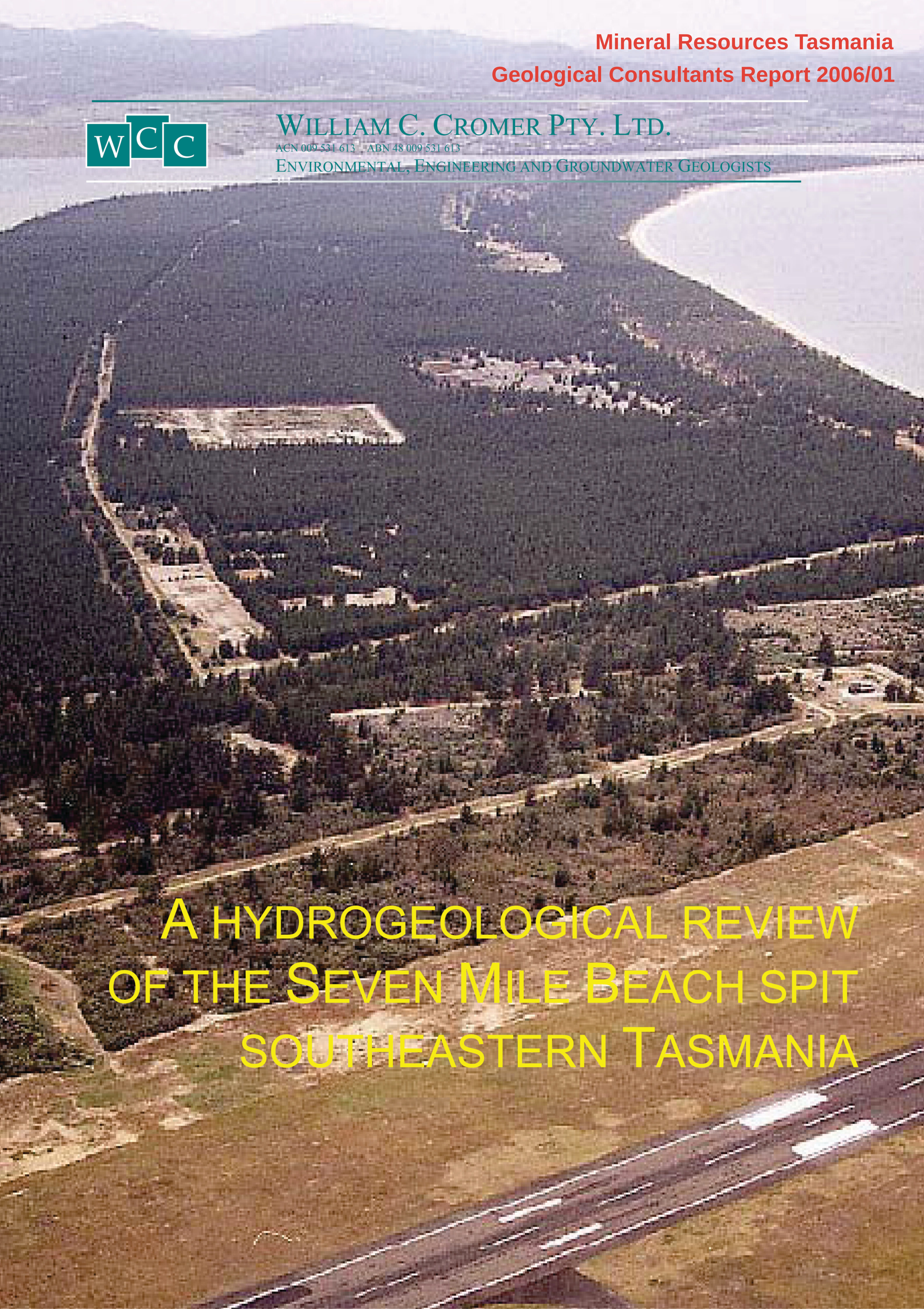
Mineral Resources Tasmania
Geological Consultants Report 2006/01

WILLIAM C. CROMER PTY. LTD.
ACN 009 531 613 , ABN 48 009 531 613
ENVIRONMENTAL, ENGINEERING AND GROUNDWATER GEOLOGISTS



A HYDROGEOLOGICAL REVIEW OF THE SEVEN MILE BEACH SPIT SOUTHEASTERN TASMANIA

Cover photo: The eastern half of the Seven Mile Beach spit, viewed from above Hobart Airport. Some of the *pinus radiata* in the middle of the plantation has since been harvested.
Photo: courtesy of Mineral Resources Tasmania

Refer to this report as:

Cromer, W. C. (2006). A hydrogeological review of the Seven Mile Beach spit, southeastern Tasmania. *Unpublished report for Mineral Resources Tasmania by William C. Cromer Pty. Ltd. (July 2006).*

SUMMARY

Background

Mineral Resources Tasmania requested this review of the geology and groundwater resources of Seven Mile Beach. Its aim is to provide an up-to-date statement of the hydrogeology of the area so that the potential impacts on groundwater of proposed sand mining – and vice versa – might be better understood and managed. Sand reserves for industrial purposes in southern Tasmania are nearing exhaustion, and Seven Mile Beach has long been recognised as the largest sand body closest to Hobart. About 95,000m^3 (150,000t) of sand is currently used each year.

A considerable amount of hydrogeological information has been collected from the area since the early 1970s, soon after the then Tasmanian Department of Mines instigated statewide investigations into groundwater in coastal sands. Seven Mile Beach was one of the first locations studied, and as a result three local golf courses, a nursery and other commercial ventures subsequently installed groundwater irrigation schemes. Some became major users, and several have since experienced salinity problems. Current groundwater extraction is estimated at 200ML a year.

Findings

This review of previous investigations and reports reveals that at Seven Mile Beach an unconfined upper aquifer of beach, aeolian and shallow marine sand extends the full length and width of the spit, covering about 15km^2. This aquifer is bounded to the south and north by Seven Mile and Five Mile Beaches (and the drainage lines passing from Milford in the east to the township of Seven Mile Beach in the southwest), and is bounded beneath by a thin (0.5m) semipermeable clay, sandy clay and clayey sand at depths ranging from about 10 – 15m below mean sea level. The clayey base to the upper aquifer also defines the top of a semiconfined aquifer.

The upper aquifer is completely full of low – moderate salinity groundwater except near lateral and basal boundaries where salinity appears to increase. It contains about 60,000ML of groundwater with salinities in the approximate potable range 100 – 1,000mg/L of Total Dissolved Solids. The water table is currently less than about one metre above mean sea level, which represents a fall of about a metre or more since the early 1970s. The fall is due to below average rain for the last 30 years or so. A range of factors causes water tables to rise and fall, and it is not possible to predict the timing or scale of future water table changes.

The upper aquifer has permeabilities up to 10m/day and a specific yield of about 0.25, and is capable of producing yields in individual shallow spear bores of up to about 2,000L/hour. It has a sustainable yield roughly equal to rain less evapotranspiration, which varies monthly and annually, but in normal rainfall periods may be 500ML/year (350,0000L/year/hectare, or about 1,000L/day/hectare).

The semipermeable basal clay of the upper aquifer inhibits but does not prevent vertical groundwater movement into and out of a lower, semiconfined aquifer beneath it. This aquifer contains moderate – high salinity groundwater with salinities generally higher than about 3,000 – 4,000mg/L of Total Dissolved Solids.

The upper aquifer is recharged mainly via infiltrating rain (the infiltrating portion is estimated to be about 7% of the annual total rain), but also at times by upward leakage of groundwater from the lower semiconfined aquifer.

Although annual extraction of about 200ML is less than the estimated recharge, the upper aquifer appears to be locally under stress where irrigation bores are lowering the water table sufficiently to induce upward and lateral leakage of more saline groundwater from the lower to the upper aquifer. This mixing creates an intermediate-salinity groundwater.

Issues for sand mining

Potential impacts from dry sand mining on groundwater conditions on RL8/1997 are relatively minor and easily addressed by standard risk management practices. This review instead suggests that hydrogeological issues relate more to the possible impacts of water table fluctuations on mining,

rather than to any impacts that mining might have on groundwater conditions. The most significant issue is the potential for the water table in the medium to long term to rise above the floor of the mined-out workings, impact on revegetation plans and cause local ponding of groundwater. In the short to medium term, this issue (if it occurs at all) will not be significant for mining, which will simply adjust its excavation depth to accommodate the water table changes. In the medium to long term (ie decades), this issue (if it occurs at all) might, by reducing the thickness of dry sand, affect the economics of the exercise or instigate a change towards both dry and wet mining techniques.

To understand the influences on water table fluctuations, and as an aid to future planning, environmental management at the mine ought to include a simple, long term groundwater monitoring programme.

CONTENTS

			Page
1	INTRODUCTION		8
	1.1	**Background and purpose of report**	8
	1.2	**The study area**	9
	1.3	**Previous hydrogeological investigations at Seven Mile Beach**	9
		1.3.1 Background	9
		1.3.2 Investigations at Seven Mile Beach	11
	1.4	**Current groundwater use at Seven Mile Beach**	16
2	GEOMORPHOLOGY, RAINFALL AND EVAPOTRANSPIRATION		19
	2.1	**Geomorphology**	19
		2.1.1 Seven Mile Beach bayhead spit	19
		2.1.2 Low lying backbarrier swamp and estuary	21
	2.2	**Rainfall and evapotranspiration**	21
3	GEOLOGY		23
	3.1	**Regional setting**	23
	3.2	**Basement rocks**	23
	3.3	**Tertiary sediments**	23
	3.4	**Quaternary sediments**	23
		3.4.1 General comments	23
		3.4.2 Seven Mile Beach stratigraphy	25
		3.4.3 Description of Units a to e at Seven Mile Beach	29
		3.4.4 Description of lagoonal units inland from Seven Mile Beach	31
		3.4.5 Quaternary history of the Seven Mile Beach area	32
4	GROUNDWATER		33
	4.1	**General principles**	33
		4.1.1 Origin of groundwater	33
		4.1.2 Unconfined and confined aquifers	33
		4.1.3 Storage capabilities of unconfined coastal sands	34
		4.1.4 Primary and secondary porosity	34
		4.1.5 Groundwater gradient	34
		4.1.6 Aquifer permeability and transmissivity	36
		4.1.7 Groundwater flow	36
		4.1.8 Rate of groundwater travel	36
	4.2	**Groundwater in hard fractured rocks near Seven Mile Beach**	36
	4.3	**Groundwater in Tertiary sediments**	37
		4.3.1 Groundwater in Tertiary sediments inland from Seven Mile Beach	37
		4.3.2 The lower semiconfined aquifer: groundwater in Tertiary? sediments beneath Seven Mile Beach	37
	4.4	**Groundwater in coastal sands at Seven Mile Beach**	39
		4.4.1 Occurrence	39
		4.4.2 Size of the aquifer at Seven Mile Beach	39
		4.4.3 Volume of groundwater stored in the Seven Mile Beach aquifer	39
		4.4.4 Origin and age of the groundwater	40
		4.4.5 The water table and its capillary fringe	40
		4.4.6 Water table fluctuations on RL8/1997	41
		4.4.7 Thickness of ‘dry’ sand on RL8/1997	44
		4.4.8 Groundwater flow directions and rate of flow	44
		4.4.9 Groundwater discharge from the aquifer	45
		4.4.10 The proportion of rain which recharges the aquifer	48
		4.4.11 Yields from shallow bores in the aquifer	49
		4.4.12 The effects of pumping on the aquifer at Seven Mile Beach	50
		4.4.13 Sustainable yield of the aquifer at Seven Mile Beach	52

Contents (cont'd)

Page
4.5 Groundwater quality 55
4.5.1 General comments 55
4.5.2 Variability in Type 2 groundwater in the upper aquifer 55
4.5.3 Suitability of the aquifer for agriculture and human consumption 55
4.5.4 Sea water intrusion 56
4.6 Groundwater contamination 57
4.6.1 Evidence for contamination of the Seven Mile Beach aquifer 58
4.6.2 Evidence for contamination of other unconfined coastal sand aquifers 59

5 POTENTIAL IMPACTS OF SAND MINING ON THE HYDROGEOLOGY OF THE SEVEN MILE BEACH SPIT 61
5.1 The sand mining proposal 61
5.2 Review of hydrogeological conditions on RL8/1997 61
5.3 Potential impacts on groundwater during sand mining on RL8/1997 62
5.3.1 General comments 62
5.3.2 Groundwater extraction for irrigation 63
5.4 Potential impacts of water table fluctuations on sand mining on RL8/1997 63

6 CONCLUSIONS AND RECOMMENDATIONS 65

7 REFERENCES 66

FIGURES
1. Location map of Seven Mile Beach 8
2. The study area at Seven Mile Beach, showing Retention Licence RL8/1997 10
3. The study area at Seven Mile Beach, showing the locations of exploration auger and drill holes, section lines and groundwater production and monitoring spear bores 15
4. Types of coastal sand bodies 19
5. Surveyed topographic sections A, B and C across Seven Mile Beach 20
6. Rainfall, temperature and evapotranspiration summary for Seven Mile Beach 22
7. Geology of the study area 24
8. Tasmanian glaciations and sea level changes in the Quaternary Period 25
9. Drill holes and transects 1, 2 and 3 at the Royal Hobart Golf Club 26
10. Schematic stratigraphy of the Seven Mile Beach spit beneath and near the Royal Hobart Golf Club 27
11. Comparison of interpreted stratigraphic cross sections 28
12. Grain size curves for sand samples from inferred Units b to e 31
13. Schematic water content distribution above a water table for various materials 41
14. Bores on RL8/1997 monitored for water level changes 43
15. Depth to the water table at Seven Mile Beach in 1975 45
16. Theoretical groundwater conditions near a beach in an unconfined aquifer 46
17. Cross section of the Seven Mile Beach aquifer near the beach on transect B 47
18. Comparison of the proportions of major dissolved ions in sea water, and in groundwater at different depths in bore 4 49
19. Comparison of the proportions of major dissolved ions in sea water, and in groundwater at different depths in bores 1 and 5 51
20. Fundamentals of pumping groundwater from an unconfined aquifer 53
21. Schematic hydrogeological model for Seven Mile Beach 54
22. Water table salinity distribution of Types 1 and 2 groundwater 56
23. Groundwater salinities at and near the Royal Hobart Golf Club 57
24. Vertical variability of groundwater salinity on transect B on RL8/1997 58
25. Schematic near-surface section showing the relationships between proposed depth of mining, the water table, capillary fringe and land surface 62

TABLES

1. Results of an informal July 2006 survey of major groundwater users at Seven Mile Beach 18
2. Rainfall, temperature and evaporation summary for Seven Mile Beach 21
3. Factors which cause changes in groundwater levels in the unconfined aquifer at Seven Mile Beach 35
4. Water table measurements at Seven Mile Beach, December 2005 to June 2006 42

APPENDIX

1. Water analyses from coastal sands at Seven Mile Beach 71

1 INTRODUCTION

1.1 Background and purpose of report

Seven Mile Beach (Figure 1) is a large sand spit near Hobart in southeastern Tasmania. Its significant resources of groundwater and sand have been the subject of various hydrogeological[1] investigations over the past few decades.

Groundwater from the spit is used by three golf courses, a nursery, commercial and recreational facilities and private individuals. Sand (an essential natural material used in the construction, building and glass industries) is currently not being mined, but interest in the resource is rapidly increasing as Hobart's existing supplies – mainly from the South Arm peninsula – will be exhausted in the next few years.

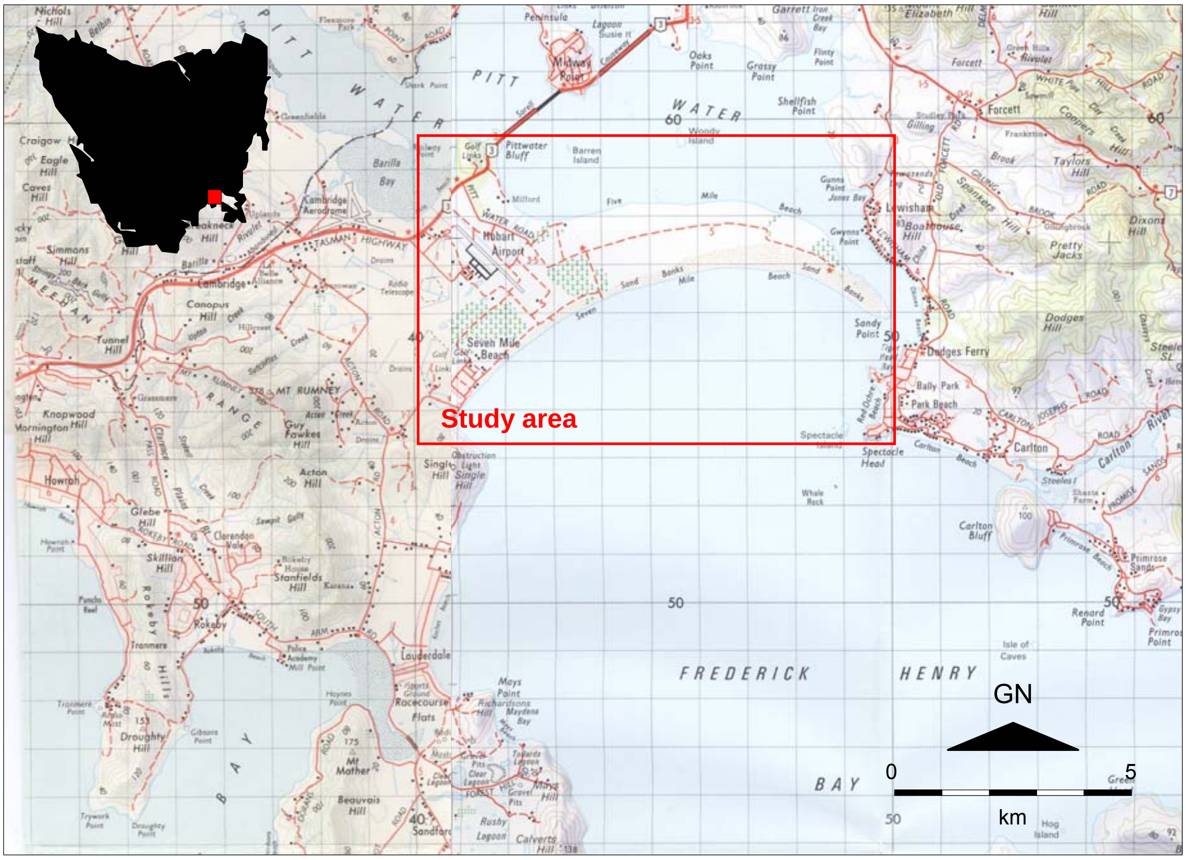


Figure 1. Location map of Seven Mile Beach
Sources: Tasmap 1:100,000 topographic series *Derwent* (1974) and *Prosser* (1980); Lands Department, Hobart

Mineral Resources Tasmania (MRT; formerly the Tasmanian Department of Mines) has long recognised the need to secure commercial resources of sand, and is actively promoting the Seven Mile Beach reserves as the largest and closest to Hobart.

The present independent report was commissioned by MRT. It is designed to provide hydrogeological information to regulatory authorities involved in determining whether or not sand extraction may proceed at Seven Mile Beach. As such, it is suitable for presentation as an appendix to a planning submission to rezone the City of Clarence Planning Scheme.

[1] Hydrogeology deals with the interrelationships between geology and groundwater conditions of an area. Groundwater is water contained within subsurface openings of unconsolidated (ie loose) materials like soils, or hard rocks. At Seven Mile Beach, the groundwater occupies interconnected pores between sand grains.

The Brief from MRT is that the report will:

- describe in detail the fundamentals of the hydrogeology of the Seven Mile Beach Protected Area, and

- examine all potential impacts of dry sand mining[2] on groundwater occurrence, movement, quality, and existing and future beneficial use.

Apart from informal interviews[3] with current groundwater users at Seven Mile Beach, no field investigations were conducted specific to the Brief. Instead, the report reviewed existing material, drawing heavily on published and unpublished hydrogeological investigations carried out by the Tasmanian Department of Mines and independently by exploration mining companies. This was supplemented by a large amount of groundwater information obtained principally from investigations at three local golf clubs and a commercial nursery which investigated the feasibility of groundwater use, and then, in the 1980s and 1990s, installed groundwater irrigation systems.

In format and scope, the report also closely follows that of Cromer (2003), a detailed study of the geology and groundwater resources of Nine Mile Beach near Swansea. Nine Mile Beach and Seven Mile Beach, and most other large coastal spits around the world, have many hydrogeological features in common.

Because this report is likely to be of interest to readers with little or no knowledge of hydrogeology, technical terms and concepts are kept to a minimum, or are explained in the text or footnotes where their use is unavoidable.

1.2 The study area

This report reviews hydrogeological conditions over the full length of the Seven Mile Beach spit, extending about 10km east from the Seven Mile Beach township in the west, to the Pittwater outlet (Figure 1). The spit is up to 1.5km wide, but the study area also includes areas inland of the sand body, in the vicinity of Milford and Hobart Airport, extending west behind the Llanherne and Royal Hobart Golf Clubs.

Dry sand mining is proposed over the middle sections of the Seven Mile Beach spit, on Retention Licence RL8/1997 (Figure 2) held by Sanbar Pty. Ltd.

1.3 Previous hydrogeological investigations at Seven Mile Beach

1.3.1 Background

Commencing in the 1960's and extending through the 1970's, the Department of Mines conducted statewide investigations into the distribution, quality and quantity of groundwater in coastal sand deposits. The impetus for this work was that unconsolidated sands contained large amounts of generally potable shallow groundwater, which although readily accessible and economically extractable by simple methods, was almost unused (Cromer, 1974a).

Some of the coastal localities studied by the Department included Nine Mile Beach[4] near Swansea (Cromer, 2003), Ocean Beach near Strahan (Cromer, 1974b), Seven Mile Beach (Cromer and

---

[2] Dry sand mining is the mining of sand deposits above a water table. The water table in a porous, permeable material like coastal sand at Seven Mile Beach is the level below which all the open spaces between the sand grains are saturated with water.

[3] Conducted by B. Cox for William C. Cromer Pty. Ltd. on 12 July 2006.

[4] Department of Mines groundwater investigations at Nine Mile Beach started as early as 1969 (Stephenson, 1969, Cromer, 1972), followed by much more detailed work in 1979 as a result of a request from the Glamorgan Council. At the time, the district was experiencing low rainfall (335mm in 1979) and water shortages, and Council hoped to supplement town surface water supplies with groundwater. Investigations were largely completed the same year, culminating in the installation and 21 day pump testing, in October-November 1979, of an array of 24 shallow bores which collectively yielded 34,000L/hour. Council did not proceed with groundwater use, principally due to the legal difficulty of ensuring a reliable groundwater supply

Figure 2. The study area at Seven Mile Beach, showing Retention Licence RL8/1997 where dry sand mining is proposed.
<u>Sources</u>
Tasmania 1:25,000 series *Carlton*. Lands Department, Hobart (1985)
Photo courtesy of Mineral Resources Tasmania.

---

if, for example, neighbouring landowners installed their own bore systems which might have interfered with Council's. Nevertheless, the bore system remains available for use to this day.

Sloane, 1976), Greens Beach[5] at the mouth of the Tamar River (Cromer, 1979), Chinamans Bay (Maria Island), Swanwick, Coles Bay, Currie on King Island (Cromer and Matthews, 1973) and Lady Barron on Flinders Island.

1.3.2 Investigations at Seven Mile Beach

Groundwater (1958)
Consulting engineers Griggs Valentine were commissioned by the Royal Hobart Golf Club to investigate the feasibility of using groundwater for fairway irrigation (Anon, 1958). Ten shallow wells were dug, and water quality presumably tested. Groundwater on the eastern side of the property was judged suitable, but that on the western side was unsuitable, for irrigation. The excavation of soaks[6] was recommended, and this was subsequently done.

Groundwater (1963)
The earliest Mines Department report on groundwater at Seven Mile Beach was a brief published note by Matthews (1963) concerning the Royal Hobart Golf Club at the western end of the beach. The club relied on groundwater for the clubhouse, greens and fairways, obtained from three soaks. Matthews noted the variable quality of the groundwater in them: the eastern soak had groundwater with a salinity[7] of 750 parts per million (ppm) of total dissolved solids (TDS), the western soak showed 1,500ppm, and the soak in the northwestern corner showed a salinity of 3,000ppm. Matthews hinted that groundwater quality might be vertically variable as well, included comments about the potential for salt water intrusion, and suggested a series of test holes and water analyses ought to be done to explore the hydrogeology further.

Groundwater (1971)
The Seven Mile Beach area was mentioned briefly by Leaman (1971) in his study of the hydrogeology of the Coal River valley.

Sand resources (1974)
Threader (1974) estimated that about 45 million cubic metres of Quaternary dune and beach sand were present over a 5km^2 area at Seven Mile Beach, to a depth of nine metres (ie mostly below sea level. Of this, about 9 million cubic metres were available above the water table for dry sand mining.

Groundwater (1976)
The first detailed hydrogeological investigations at Seven Mile Beach were conducted over the period 1973 – 1975 (Cromer and Sloane, 1976). The work aimed to assess the lateral and vertical variability of groundwater quality, and to use recharge/discharge estimates combined with aquifer properties to determine a general groundwater regime for the area. The survey consisted of:

- hand-augering 150 shallow holes to the water table on a rough grid over the spit, and electrical conductivity[8] (related to salinity) measurements of the groundwater in each hole,
- surveying three cross sections (called 'transects') across, and one along, the spit,

[5]The groundwater system, installed in 1976, is still used by the caravan park. The golf club next door has its own separate groundwater irrigation system.
[6] A soak is a waterhole excavated to or below the water table, so that groundwater in the soak stands at the level of the water table.
[7] 'Salinity' of water is due to dissolved chemicals. All natural waters on earth contain dissolved chemicals derived from air, water, soil and rocks. The most common dissolved constituents are chloride, carbonate, bicarbonate, sulphate, potassium, sodium, calcium, magnesium, iron, aluminium, silica, nitrate, phosphate, fluoride. A range of trace elements is also usually present. One measure of salinity is parts per million (ppm) of total dissolved solids (TDS), which is the same as milligrams per litre (mg/L). Rainwater may have salinities less than 50 – 100mg/L. Sea water has a salinity of about 34,000 mg/L. 500mg/L is commonly regarded as a desirable maximum salinity for human consumption, although up to 1,000mg/L is acceptable. Acceptability varies between consumers, however, and many commercially-available mineral waters have higher salinities.
[8] Electrical conductivity describes how readily the water conducts an electric current. The current is conducted by dissolved chemicals in the water. The higher the concentration of dissolved chemicals, the higher the conductivity and the more 'saline' the water. Pure water, with no dissolved constituents, does not conduct electricity. Electrical conductivity is commonly measured in millisiemens/centimetre (mS/cm) or microsiemens/centimetre (µS/cm). As a rough guide, to convert from µS/cm to Total Dissolved Solids (TDS or 'salinity') measured in milligrams/litre (mg/L), multiply the former by 0.65. Example: an electrical conductivity of 1,000µS/cm is a salinity of about 650mg/L TDS. The preferred upper salinity limit for drinking water of between 500 and 1,000mg/L corresponds to an electrical conductivity of between about 800 and 1,600µS/cm.

- drilling several deeper stratigraphic holes, including one to 80m, and pump testing of the aquifer,
- chemical analyses of the groundwater, and
- grain size analysis of 100 sand samples.

The locations of the auger and drill holes are shown in Figure 3. The main results of the work were:

- Mottled green-white clay of presumed Tertiary age underlies the whole spit at depths ranging from 10 – 12m. Drilling near the southern end of the airport showed the clay was at least 70m thick.
- The clay is overlain by Quaternary-age sands, which from the surface down consist of a yellow-buff coloured aeolian quartz sand up to 3m thick, over yellow-grey shelly marine sand and (to the northwest of the sand spit), slightly clayey estuarine quartz sand.
- Groundwater was encountered in all holes, at depths of about 2 – 3m below ground. The water table is a gently convex surface with a maximum height (in 1976) of about 2.5m above mean sea level; the slope (gradient) of the water table was about 1 in 400 (ie 0.0025). The base of the aquifer corresponded to the base of the Quaternary sand sequence (ie to depths of 10 – 12m, or up to 5 – 8m below mean sea level.
- Groundwater quality varied laterally and vertically. Salinities at the water table were less than 200mg/L over most of the spit, but increased rapidly inland on the low-lying ground east and southwest of Hobart Airport, and inland from the Seven Mile Beach township.

Sand exploration (1977 – 1978)
Louisa Mining Corporation NL held exploration licence EL7/75 over Seven Mile Beach and Pittwater during the period April 1975 – April 1978 (Forster, 1977, 1978). The company explored principally for heavy minerals contained within the sand. Its main activities included:

- a scout hand-augering programme on a broad grid to depths of 7 – 14m, and analyses of sand samples by heavy liquid separation to isolate the heavy mineral fraction, and
- with partner Mineral Deposits Limited, a July – September 1976 drilling programme of some 37 holes to depths of 10 – 16m along a transect of the spit.

Hole locations on the transect are shown in Figure 3. The exploration results included:

- all holes were in 'clean' sand to depths of around 12m, where a shelly horizon sat on green clay,
- yellow aeolian (windblown) sand extended to the water table, below which the sand colour turned to grey,
- the heavy minerals present in the sand ranged up to about 0.2% by weight. They included rutile, zircon, ilmenite, magnetite, topaz and garnet[9]. Rutile made up more than half the heavy mineral component. Reserves of about 150,000t of 88% rutile were indicated. Heavy minerals were concentrated along the centre of the spit east of Hobart airport.

The market for heavy mineral sands was depressed in the late 1970s, and the company did not proceed further. However, it recognised the potential for industrial sand mining.

---

[9] Rutile = titanium dioxide TiO_2; zircon = zirconium silicate $ZrSiO_4$; ilmenite = Iron titanium oxide $FeTiO_3$; magnetite = iron oxide Fe_3O_4; topaz = aluminium silicate $Al_2SiO_4.(OH, F)_2$; garnet = iron, magnesium and calcium silicates $(Fe, Mg, Ca)_3.(Al, Fe)_2.(SiO_4)_3$. The heavy minerals at Seven Mile Beach are all derived from the weathering of older rocks, including the Jurassic-age dolerite (rutile, ilmenite, magnetite), Triassic sedimentary and older granites (topaz, garnet, zircon).

Groundwater (Tasmania Golf Club, 1980)
By the late 1970s, the Tasmania Golf Club was interested in groundwater for fairway irrigation, to minimise high mains water costs. Groundwater from the Seven Mile Beach spit about 3km to the south was favoured, but initial investigations focussed on a less expensive potential source of water on Milford Farm next to the club (Cromer, 1980). Results from 18 shallow bore holes (Figure 3) were discouraging: the aeolian sand cover was relatively thin, with underlying marine and fine-grained estuarine sediments of low permeability[10] and poor quality groundwater.

Groundwater (Royal Hobart Golf Club, 1981)
Detailed hydrogeological investigations were conducted at the Royal Hobart Golf Club between August 1980 and January 1981 (Cromer, 1981). The purpose was to investigate the stratigraphy of the sand body and clarify water quality variability across the site. The work included:

- the drilling and logging of 25 mechanically augered holes to depths of 7 – 14m (to the base of the aquifer),
- installation of spear bores[11] and conducting pump tests in several holes, and
- groundwater analyses.

Hole locations are shown in Figure 3. The main results were:

- three types of groundwater existed beneath the course, two of which were suitable for fairway irrigation, and
- the aquifer was capable of increased groundwater extraction, and a linear array of 20 spear bores was suggested.

Green (1981) conducted isotopic studies on groundwater samples collected from the 1981 investigations. He was able to show that groundwater used for irrigation also contained a significant proportion of piped town water.

The 20 production bores were subsequently installed to depths of about 6m below ground, and pumping started in May 1982[12]. The design flow rate was about 10L/sec (36,000L/hour, or 0.85ML/day), and the combined groundwater quality was about 1,500mg/L TDS. The system worked well for many years, but by the mid-1990s the groundwater salinity had increased to about 1,750 – 1,900mg/L TDS, and yields from individual spears had decreased (Cromer, 1995). The club abandoned the system to instead pump from the original three soaks and several later concrete-lined wells. Additional spears were installed later on the practice fairway.

Geological mapping (1982)
The Tasmanian Department of Mines published the *Sorell* geological map sheet, Gulline (1982) and followed with the explanatory notes for the area (Gulline, 1984). The *Sorell* map, and adjacent maps, has been combined to produce the geology of the Seven Mile Beach area in Figure 4.

Groundwater (Tasmania Golf Club, 1982 – 1983)
The hydrogeology of Seven Mile Beach was thought to be sufficiently understood by the early 1980s for the Tasmania Golf Club to install a linear array of 20 spear bores immediately east of Hobart Airport (Figure 3). Work was completed in November 1982 (Cromer, 1983a). Bores were 20m apart and about 8m deep, extending 5 – 6m below mean sea level. During the first 50 days of almost continuous operation, the system yielded 56.3 million litres of groundwater (1.25ML/day, 47,000L/hour or 13L/sec) which was pumped 3km north to a plastic-lined holding dam at the club.

[10] Throughout this report, permeability means the same as hydraulic conductivity.

[11] Spear bores are relatively inexpensive and therefore very common in coastal sands around Tasmania. Although there are design variations, a typical spear consists of a length of 50mm diameter PVC pipe which is slotted for a metre or more at its base, and capped on the bottom. The best way to installed a spear is to lower it down previously-installed larger casing (which is then removed) to depths of one to three metres below the water table. A suction pump is then fitted at the surface. In coastal sand, a single well-installed spear can supply groundwater at the rate of 2,000L/hour or more.

[12] Article and photograph, Hobart *Mercury*, 19 May 1982 (page 9).

Groundwater quality decreased from about 800mg/L in November 1982, to 1,500mg/L in January 1983. Water levels during pumping were measured in a series of monitoring bores stretching several hundred meters from the production array. Maximum drawdown[13] after 50 days was 0.34m in a bore next to the pump shed in the centre of the array. The drawdown about 150m east across Pittwater Road, was 0.12m. The spear bore system remains in use, pumping groundwater with a salinity (June 2006) of about 3,000mg/L[14].

Groundwater (Westlands Nurseries, 1983)
Westlands Nursery installed a linear array of five or six spears in late 1983 (Cromer, 1983b), and doubled the number soon after. The system (Figure 3) experienced iron oxide issues, and was abandoned in preference for soaks. Another array of spears was placed near Surf Road, but later also abandoned. A 113m deep exploratory water bore drilled in the early 1990s was unsuccessful. Soaks currently provide all of Westlands groundwater.

Sand resources (1984)
The Department of Mines (Threader, 1984) investigated sand resources near the Royal Hobart Golf Club.

Groundwater (Honours thesis, 1988)
Groundwater occurrence and salinity was investigated by indirect geophysics (resistivity[15]) methods at four foreshore sites on the spit, as well as drilling seven bores at and inland from one of the sites, in the late 1980s (Roberts, 1988). The work formed part of an honours thesis in conjunction with Mines Department personnel. The resistivity work included 40 soundings, but was of limited use in determining the position of the water table and variability in groundwater salinity[16]. Of considerably more value were the drilling results and water analyses, with six logged bores to depths of 20m below sea level on a 280m long line extending inland from near high water mark (Figure 3). These confirmed the occurrence of low – moderate salinity groundwater in the upper aquifer, and suggested the possible presence of a lower, locally confined or semiconfined, higher-salinity aquifer beneath a thin (0.5m thick) dark-coloured clayey sand at depths between about 12 – 16m below high water mark.

Groundwater (Llanherne Golf Club, 1990)
The then-relocating Llanherne Golf Club investigated supplementing mains irrigation water with groundwater in 1990 (Cromer, 1990a, 1990b). Six investigation drill holes were completed in a roughly NW-SE direction across the undeveloped course, six production spears were installed (Figure 3) and the system was commissioned in May 1991. Under test, it yielded about 0.5L/sec (40kL/day). The club later extended the system, which remains in use.

Sand exploration and reserves (1993)
CSR Readymix (Miedecke, 1993) prepared an environmental a management plan for sand mining over part of Seven Mile Beach. At about the same time, MRT independently continued to investigate sand reserves near Hobart (Sloane and Weldon, 1993).

[13] Drawdown is the lowering of the water table during pumping, measured relative to the initial water table depth.

[14] From a water analysis kindly provided by Mr. D. Gilligan, Tasmanian Golf Club.

[15] The resistivity method involves hammering short metal rods into surface soil, connecting them as a circuit to a source of electric current, and measuring the ground resistance between them at known distances apart. The further apart the rods, the deeper the current travels in the ground, depending on subsurface conditions. Materials with a high resistance to current include dry surface soil, and unjointed, fresh rock. High conductivities are exhibited by sea water or saline water, and wet clay. Intermediate resistances are shown by a wide range of materials and groundwater salinities.

[16] Indirect methods like resistivity (in contrast to direct methods like drilling and water sampling) require mathematical modelling and various assumptions which generate numerous possible solutions and equivocal interpretations. Similar issues were found in interpreting resistivity results at Nine Mile Beach (Palfreyman, 2002). This work, also part of a geology Honours project at the University of Tasmania, included water table monitoring, groundwater sampling, electrical geophysical techniques to assess sea water-freshwater interfaces and potential contamination from on-site, in-ground domestic wastewater disposal, and groundwater and water balance modelling.

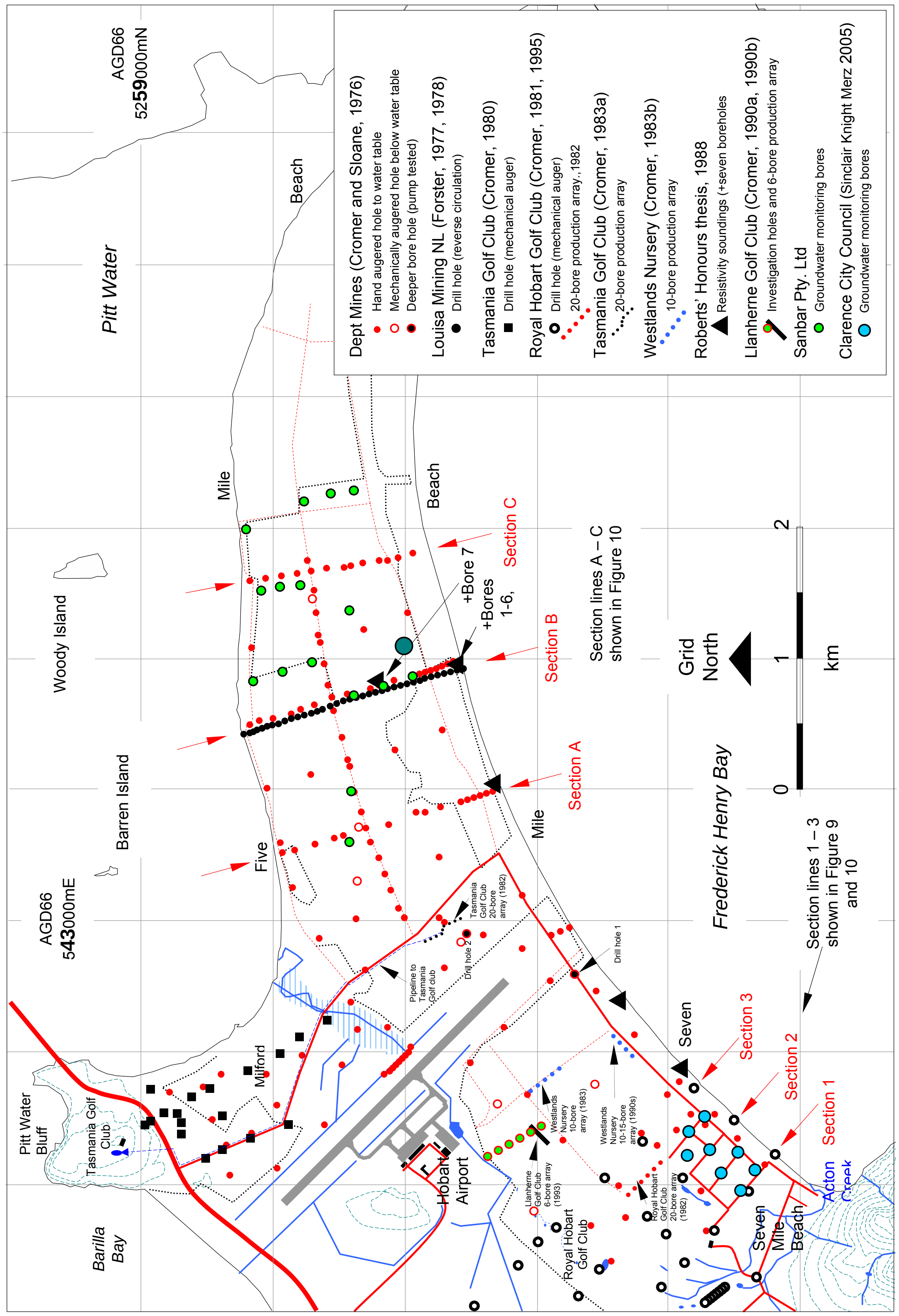


Figure 3. The study area at Seven Mile Beach, showing the locations of exploration auger and drill holes, section lines (transects) and groundwater production and monitoring spear bores.

Sand resources (1993, 1994)
Matthews and Donaldson (1994) reviewed earlier work by Threader (1984) and Sloane and Weldon (1993), noting that available sand resources for Hobart appeared to be 'approaching exhaustion within the next few years.', and that Seven Mile Beach appeared to be the largest on-shore resource closest to Hobart.

Sand and heavy mineral exploration (1993)
North West Bay Company Pty. Ltd. was granted the 5km^2 exploration licence EL20/89 over much of the area previously explored by Louisa Mining NL in the 1970s and now held by Sanbar as RL8/1997 (Figure 2). The first year's exploration by Northwest included an extra 10 auger holes added to the 37 drilled by Mineral Deposits in 1975 – 1976 (Figure 3). Anticipated heavy mineral grades did not eventuate and in 1993 Northwest assigned exclusive rights to Sanbar Pty. Ltd. effective from January 1994 (Morrison, 1994) to assess the ground for sand mining. Sand analyses were done on previous drill holes, and in 1994 16 hand-drilled holes were completed and 80 samples tested (Morrison, 1995). The work established that:

- a fine grained sand deposit 8-15m thick blanketed the EL,
- the sand is very similar to construction sand currently supplied to the Hobart area, and that
- mined to a mean depth of 10m, 50 hectares would yield about 50 years supply at the then current demand.

Groundwater monitoring (Clarence City Council, 1999 – present)
In 1999, consultants Sinclair Knight Merz were commissioned by the Clarence City Council to install eight groundwater monitoring bores in the Seven Mile Beach township. The work was intended to investigate the effects, if any, of domestic wastewater disposal on groundwater quality. Samples are tested every six months for pH, electrical conductivity, salinity, nutrients, biochemical oxygen demand (BOD[17]) and bacteria. Bore locations are shown in Figure 3. Groundwater salinities from the bores are superimposed on Figure 23, and the results of the investigations (Sinclair Knight Merz, 2005) are discussed in Section 4.6.2.

Groundwater monitoring (Sanbar, 2005, 2006)
Sixteen groundwater monitoring bores were installed by consulting engineers Pitt & Sherry for Sanbar Pty. Ltd. on RL8/1997 (I. Woodward, *pers. comm*., 2006). Locations are shown on Figures 3 and 14. Each bore was surveyed relative to Australian Height Datum (AHD[18]), and groundwater levels measured on several occasions. Results are summarised and discussed in Section 4.4.6.

1.4 Current groundwater use at Seven Mile Beach

There is currently no reliable long term monitoring information on groundwater usage at Seven Mile Beach.

A brief and informal visit in July 2006 to known existing major users elicited the information summarised in Table 1, from which the current annual usage is estimated to be 200ML. Domestic and other groundwater use is trivial in comparison.

[17] BOD is commonly used as an indicator of pollution by organic matter. The test involves diluting a portion of a water sample with oxygenated water for an incubation period of usually 5 days at 20^{0}C, and measuring how much oxygen is used up in oxidising the organic matter. Results are usually expressed in mg/L. The higher the BOD, the higher the level of organic matter.

[18] This report includes information spanning more than 30 years, with height data variously expressed relative to AHD, MSL (Mean Sea Level) and high and low tides. AHD and MSL are interchangeable, since MSL in Tasmania (based on tide gauges at Hobart and Burnie) is equal to 0m AHD. High and low tides of course vary. The highest and lowest tides that are possible based on sun-moon alignments are called the High Astronomic Tide (HAT) and Low Astronomic Tide (LAT) respectively. HAT would approximate the highest strand line on a beach. HAT = 0.8m AHD, and LAT = – 0.8mAHD.

About a quarter of the 200ML is pumped off-site by the Tasmania Golf Club, but almost all of the balance of 150ML is irrigated on land from which it is obtained. A proportion of this irrigated water recharges the shallow aquifer, and so the 150ML does not fully represent the total net volume extracted. Section 4.4.9 investigates the proportion of rain (perhaps 7%) which recharges the aquifer, but the figure is probably higher (possibly 10 – 20%) for irrigation water.

Of the 50ML or so pumped off-site, evidence suggests that perhaps most of it is not from the unconfined aquifer, but is higher-salinity groundwater derived by primarily upward flow through its semipermeable base from the lower aquifer (Sections 4.3.2 and 4.4.12). This water is not included in extraction figures for the unconfined aquifer.

As a first approximation, current *net* annual groundwater extraction is as follows (numbers are rounded):

Total extraction reported in Table 1	200ML
Less (say) 20% of 150ML which is recycled	30ML
Less pumped off site (25% of 50ML)	10ML
Net extraction (say)	**160ML, but round to 150ML**

Table 1. Results of an informal July 2006 survey of major groundwater users at Seven Mile Beach

Oganisation	Groundwater system	Installation history	Est. current groundwater capability	Application	Est. annual groundwater use
Royal Hobart Golf Club	Spear bores, wells andsoaks	Soaks late 1950's to present; 20 spear bores early 1980s; 3 wells 2001; 4 spear bores 2003	8,000L/hr from 3 wells; 4,000L/hr from 3 spears; all pumped to Soak 1 (Figure 9); System pumped 'continuously' for 6-7 months per year	Irrigation	50ML
Tasmania Golf Club	Spear bores on leased land east of airport; pumped to holding dam at club	20 spear bores early 1980s	Groundwater mixed with town water	Irrigation	50ML
Llanherne Golf Club	Spear bores pumped to 4 holding tanks on site	7-8 spear bores early 1990s; 5 extra spears adder later	15,000 – 20,000L/hr; System pumped 'continuously' for 6-7 months per year	Irrigation	50ML
Westlands Nursery	Soaks, spear bores	3 soaks; 10 spear bores early 1990s'; 10-15 later spear bores (all spear bores since abandoned)	4,000 – 5,000L/hr from soaks; pumped 'continuously' all year	Irrigation; garden watering	40ML
Whispering Sands	Spear bores to on-site holding tanks	1 operating system (9 spear bores to 2 x 22,500L tanks); 3 other sets totalling 13 spears not used)	1,500 – 2,000L/hr; pumped for 3 – 4 hours a day	Irrigation; garden watering; toilets; horse troughs	3 – 4ML
J. James	Spear bores	Installed 1993	1,000 – 1,500L/hr pumped for 8 hours a day in summer; 2 hours a day at other times	Irrigation; horse troughs	1ML

2 GEOMORPHOLOGY, RAINFALL AND EVAPOTRANSPIRATION

2.1 Geomorphology

The main coastal geomorphological features of the study area include the Seven Mile Beach/Five Mile Beach spit, and the low-lying land extending west from near Milford to Acton. At the western end of the study area, the spit ends abruptly against rising ground underlain by older Permian and Triassic sediments intruded by Jurassic dolerite. Isolated outliers of Triassic sedimentary rocks (mainly sandstone) crop out at Pittwater Bluff (Tasmania Golf Club) and at the Hobart Airport control tower.

2.1.1 Seven Mile Beach bayhead spit

Seven Mile Beach is the dominant landform in the study area. It is a large bayhead spit (Figure 4) formed by the accumulation of sand moving both onshore, and in a west to east direction, under conditions of varying sea level during about the last 6,000 – 10,000 years BP (Before Present).

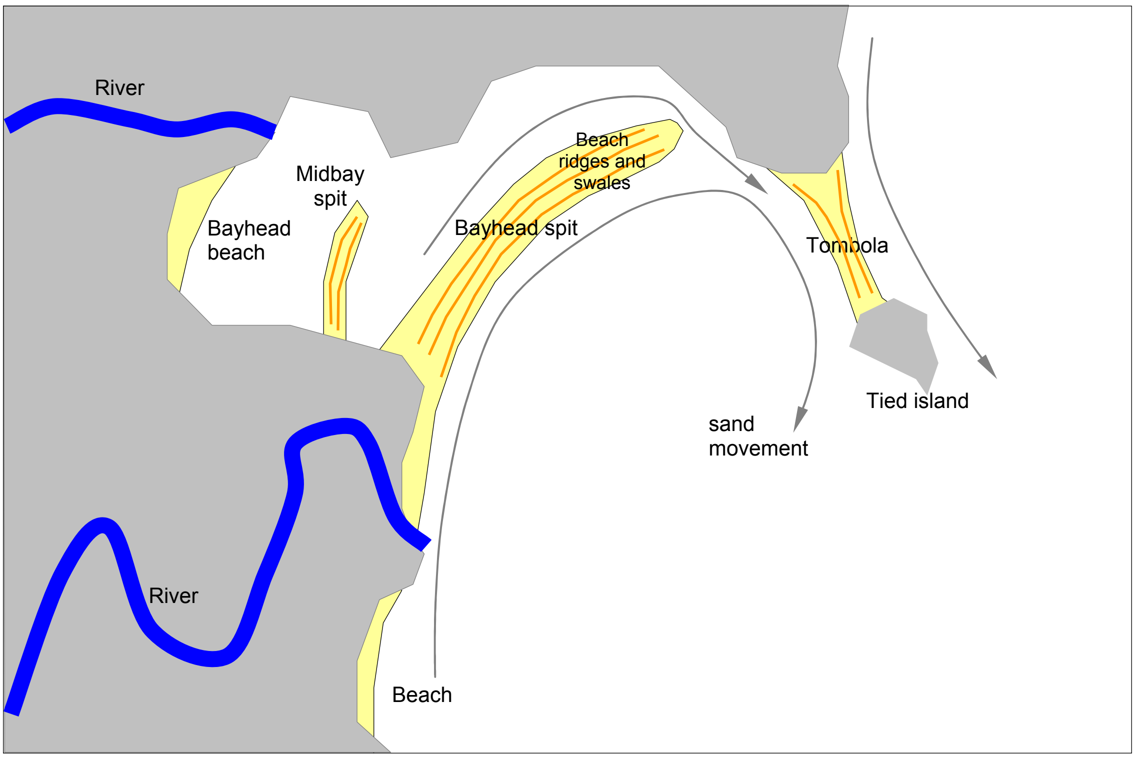


Figure 4. Types of coastal sand bodies. Seven Mile Beach is a typical bayhead spit. Other examples include Nine Mile Beach near Swansea, and Ocean Beach at Strahan. The isthmus at Wineglass Bay, and the necks on Maria and Bruny Islands, are tombolas, and Mt. Freycinet, north and south Maria Island, north and south Bruny Island, and South Arm are examples of tied islands.

In a landward direction from its southern boundary along Frederick Henry Bay, the middle section of the spit near transects A, B and C (Figure 3; in the general area proposed for sand mining) comprises (Figure 5):

- a modern *beach* at or near mean sea level (MSL),
- a *foredune system* comprising one to five partly vegetated dunes ranging in height from about 3m above mean sea level (AMSL), to 6m AMSL, and in width from 75m to 150m inland from high water mark (HWM), and

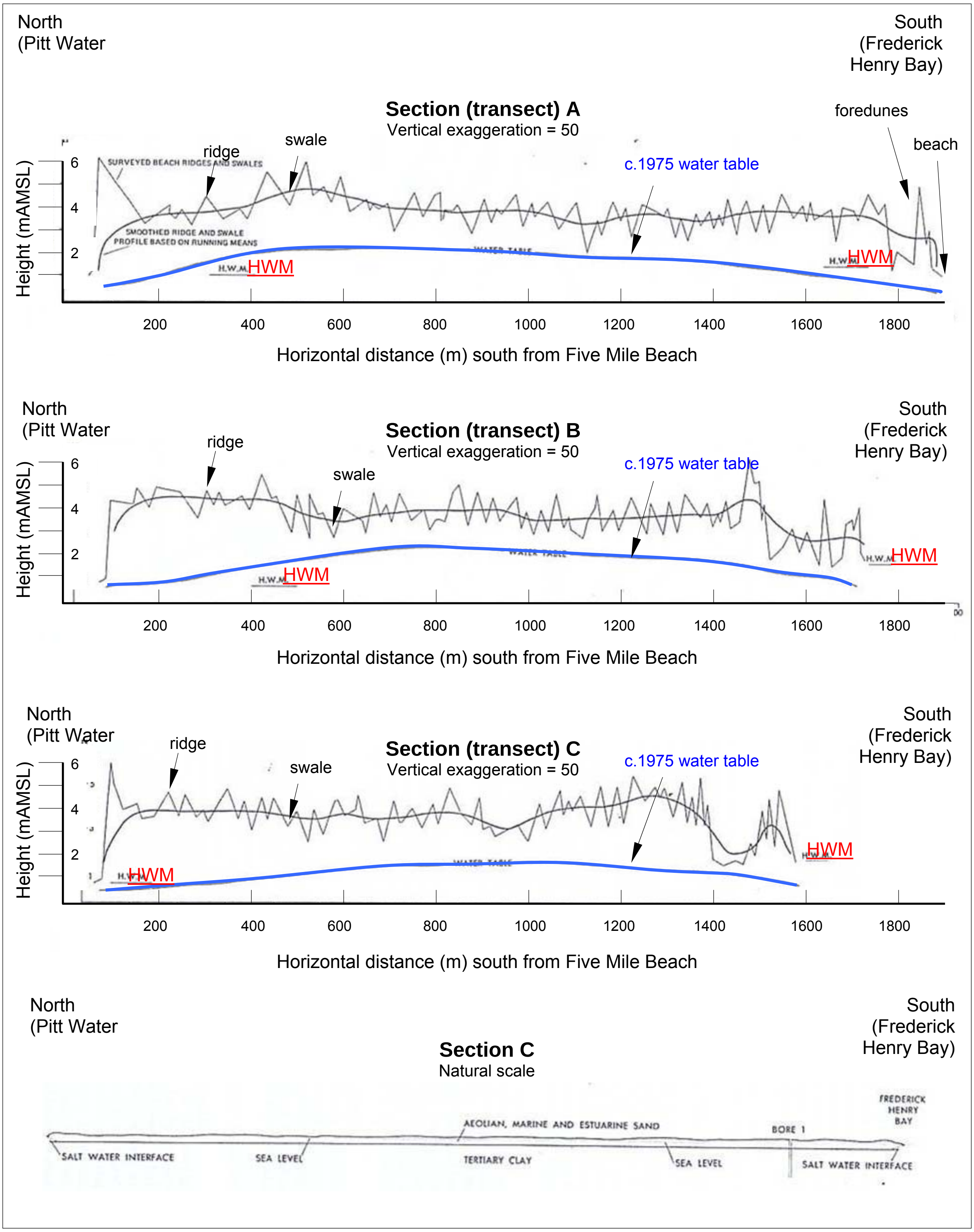


Figure 5. Surveyed topographic sections A, B and C across Seven Mile Beach (modified from Cromer and Sloane, 1976). The vertical exaggeration is 50, except for the bottom section at natural scale. The locations of the sections are shown in Figure 3. The razor-tooth pattern is a surveyed series of ridges and intervening swales, totalling about 35– 40 in number. The smoothed black line is the average height of the ridges and swales (based on running averages). The blue line is the measured water table in 1974 – 75. HWM = high water mark at the time of survey.

- a series of 35 – 40 subparallel *beach ridges and swales*, the former averaging about 2.5m AMSL in the south but rising to about 5m AMSL towards the north, and the intervening swales lower than adjacent ridges by about 0.5m to 1.5m.

Further east, the spit narrows and heightens, with the destruction of the beach ridge system and its replacement by blowouts and actively migrating dunes. The ridge and swale system has been levelled on the southern half of Hobart Airport, but further west its integrity has been largely maintained in the built-up township area, and the Royal Hobart Golf Club.

2.1.2 Low lying backbarrier swamp

The northern and northwestern border of the spit, extending from Milford Farm, past Hobart Airport to Seven Mile Beach township, is backed on its inland side by a strip of low-lying swampy ground which in places has been artificially drained. Behind the Royal Hobart and Llanherne Golf Clubs, the poorly drained land rises gently towards Acton and Cambridge.

2.2 Rainfall and evapotranspiration

Mean monthly figures for Seven Mile Beach are summarised in Table 2 and Figure 6a. Evapotranspiration has been estimated using a Forestry Tasmania technique based on mean maximum daily temperature. On this basis, evapotranspiration exceeds mean rainfall in all months of the year.

In coastal sands, there is effectively no runoff, so that any rain excess to evapotranspiration is available for infiltration below the root zone of plants to contribute to soil moisture and to recharge groundwater. In abnormally dry years there is likely to be little or no recharge. Conversely, abnormally wet years result in additional groundwater recharge.

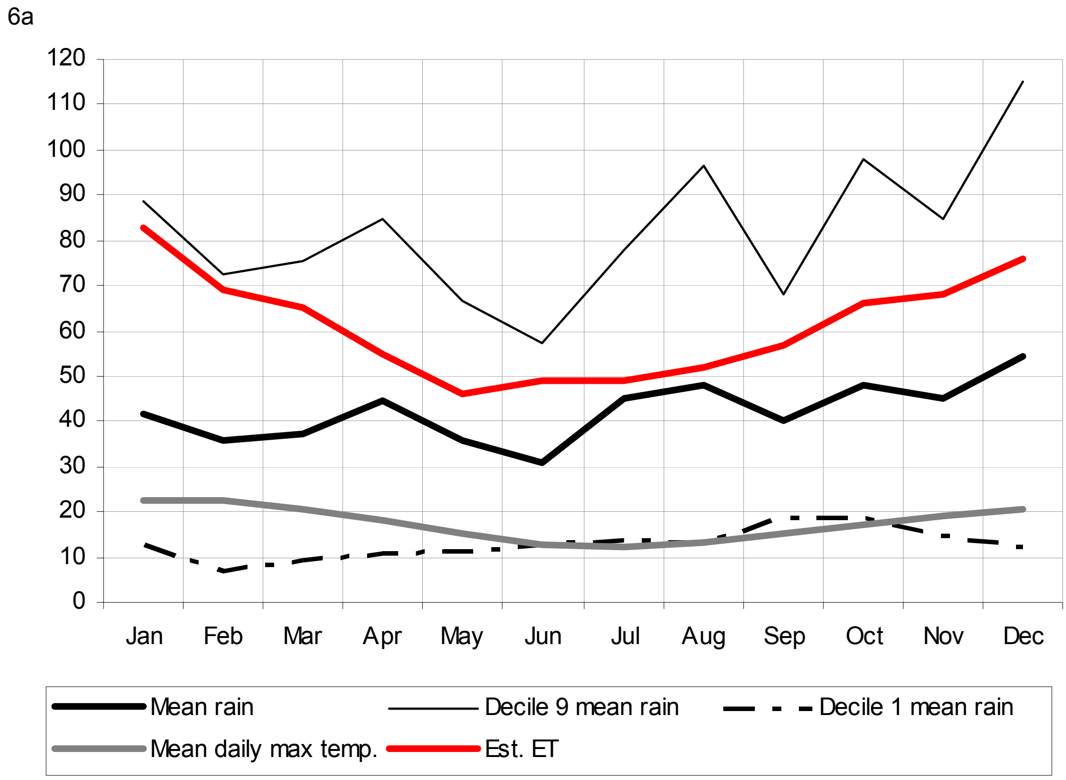
Table 2. Rainfall, temperature and evaporation summary[1] for Seven Mile Beach

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Mean rain (mm)[2]	42	36	37	45	36	31	45	48	40	48	45	54	**507**	Total
Decile 9 rainfall (mm)[3]	89	72	75	85	67	57	78	97	68	98	85	115		
Decile 1 rainfall (mm)[4]	13	7	9	11	11	13	14	13	19	19	15	12		
Mean daily maximum temperature (^{0}C)	22	22	21	18	15	13	12	13	15	17	19	21	**17**	Average
Mean daily evaporation (mm)	6.2	5.6	4.2	2.9	1.8	1.3	1.4	2.0	3.0	4.0	5.0	6.0	**3.6**	Average
Mean monthly evaporation (mm)	192	157	130	87	56	39	43	62	90	124	150	186	**1316**	Total
Est. evapotranspiration (mm)[5]	83	69	65	55	46	49	49	52	57	66	68	76	**735**	Total
Est. evapotranspiration excess (mm)	41	33	28	10	10	18	4	4	17	18	23	22	**228**	Total

Notes
1. Covers the period 1958 to 2004. Latitude: 42.8389S, Longitude 147.4992E. Elevation 4.0m.
2. Rainfall, temperature and evaporation data from Bureau of Meteorology at www.bom.gov.au/climate/averages/tables/cw_094008.shtml. Figures (except daily evaporation) have been rounded to nearest whole number.
3. 90% of all the recorded rainfall figures for a particular month are equal to or less than the Decile 9 rainfall.
4. 90% of all the recorded rainfall figures for a particular month are equal to or greater than the Decile 1 rainfall.
5. Evapotranspiration (ET) is estimated using a Forestry Tasmania method based on maximum mean daily temperature (T).
   For the months June-Jan, the relationship is ET = 0.12T mm/day
   For the months Feb-May, the relationship is ET = 0.13T - 0.4 mm/day

Figure 6b shows annual rainfall at Hobart Airport for the period 1959 – 2005. The five-year running average (red line) reveals that annual rain increased to well above average (blue line) between the mid-1960s to mid-1970s, but has been mostly below average for the past 30 years.

Irrespective of any effects of water pumped for irrigation, groundwater levels in the Seven Mile Beach aquifer have therefore probably been steadily falling since the mid-1970s.



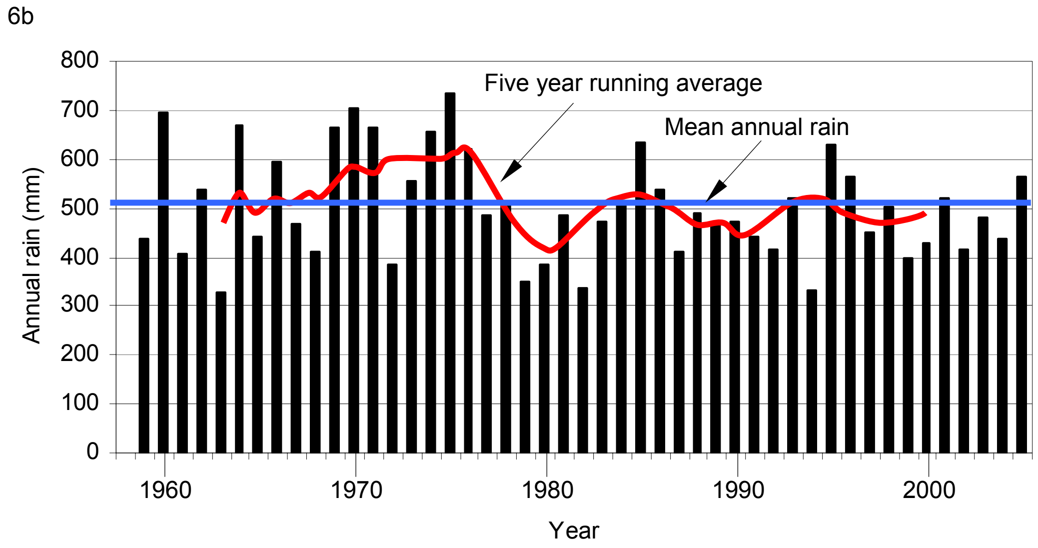


Figure 6. (a) Rainfall, temperature and evaporation summary for Seven Mile Beach; (b) Annual rainfall at Hobart Airport 1959 – 2005.

3 GEOLOGY

3.1 Regional setting

Pitt Water and Frederick Henry Bay are part of a down-faulted basin called the Coal River Graben (Leaman, 1971; Baillie and Leaman, 1989) bordered by uplifted older basement rocks and filled with unconsolidated sediments deposited since Tertiary times. The graben includes the Seven Mile - Penna-Sorell area in the south, extending north northwest to Richmond and Campania. A drill hole near the southern end of Hobart Airport (Figure 3) established that the inferred Tertiary clays were at least 70m thick (Cromer and Sloane, 1976), and based on similar structures elsewhere in Tasmania (eg the Great Oyster Bay graben near Nine Mile Beach) a thickness of several hundred metres of Tertiary materials may be present beneath the Seven Mile Beach spit.

The spit itself is composed entirely of Quaternary-age aeolian (windblown), beach, marine and estuarine sands.

3.2 Basement rocks

Basement rocks in the study area are mainly confined to Single Hill, which rises abruptly from sea level at the western side of the graben and includes a complex system of Jurassic dolerite dykes intruding Permian sandstone and siltstone. None of these rocks has a significant bearing on the hydrogeology of the Seven Mile Beach spit. Outliers of Triassic sandstone crop out at the Hobart Air[port control tower, on Pitt Water Bluff, and on Woody and Barren Islands in Pitt Water.

3.3 Tertiary sediments

Unconsolidated clay, sand, silt, gravel and combinations of these materials occur on the extensive, gently sloping hillsides north and west of the Royal Hobart Golf Club, and (as discussed above) probably dip eastwards and seawards beneath the sand body.

The sand body itself rests on a dark-coloured, often shelly, clay, sandy clay or clayey sand between about 8 – 14m below sea level. The material, inferred to be Quaternary in age, is termed Unit a in Cromer (1981) and Unit c in Roberts (1988), and appears to be present everywhere beneath the spit. Underlying Unit a is at least several metres of dark coloured sand, gravelly sand and clayey sand which may be Quaternary or Tertiary in age. These sediments contain groundwater which from available evidence is more saline than, and possibly largely separated from, the better quality groundwater in the Quaternary aquifer.

3.4 Quaternary sediments

3.4.1 General comments

Quaternary-age[19] sediments are widespread in the study area (Figure 7). Of most interest to the present study are the beach, near-shore (shallow) marine, estuarine and backbarrier swamp deposits laid down in the Late Pleistocene and Holocene Epochs, and which now form or border the Seven Mile Beach spit.

Figure 8 is a schematic time scale showing the relationships between the Pleistocene and Holocene Epochs in the Quaternary Period in Tasmania, and the inferred rises and falls of sea level occasioned by waning and waxing glaciations. By inference with dated coastal sand bodies elsewhere in southeastern Australia (including Tasmania), the Seven Mile Beach spit is thought to have been formed during the Holocene Epoch (Thom, *et. al*., 1981).

---

[19] The Quaternary Period of geological time is the last two million years. Of this, the first 99.5% is called the Pleistocene Epoch, and the rest (0.5%, or the last 10,000 years) is the Holocene Epoch.

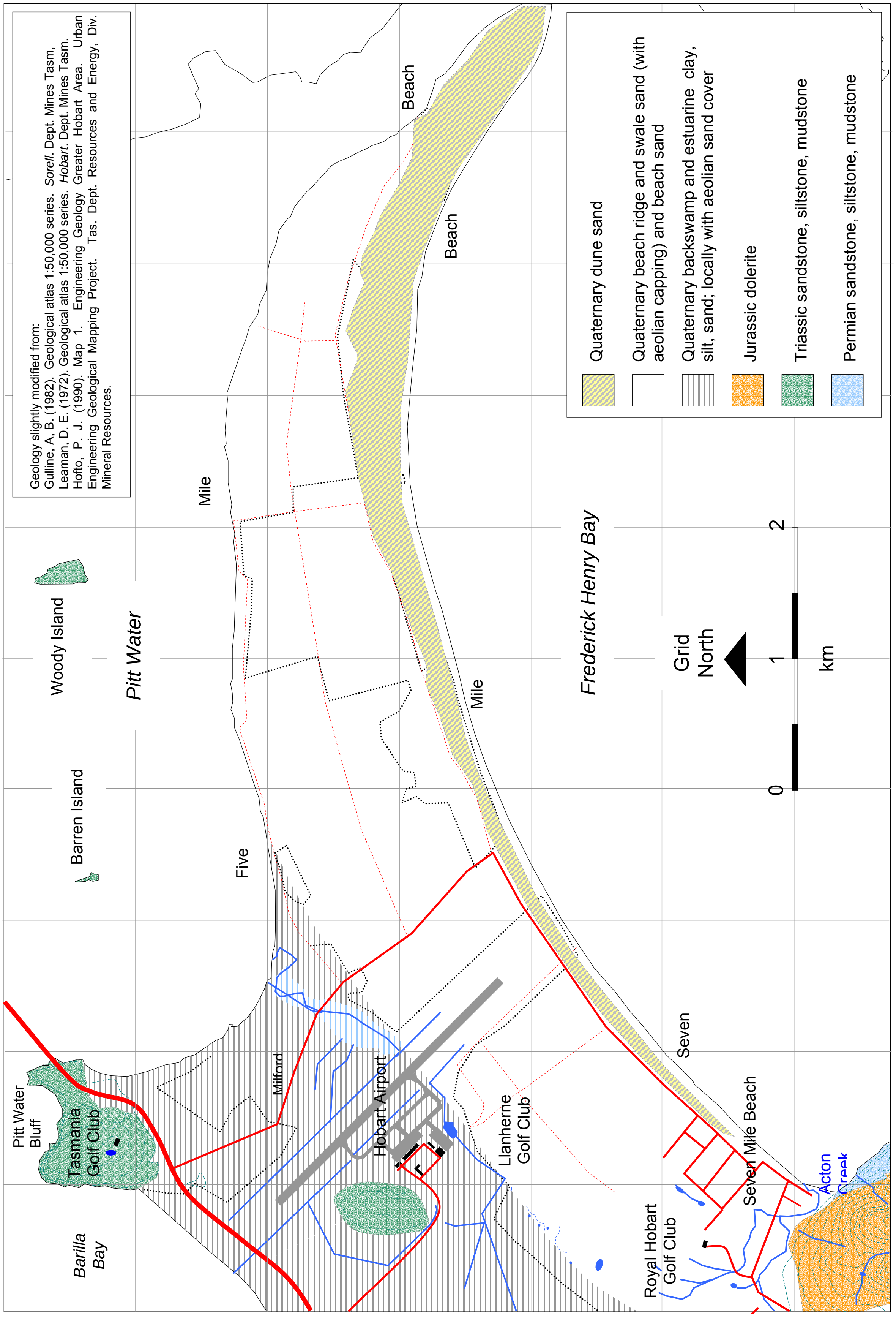


Figure 7. Geology of the study area

3.4.2 Seven Mile Beach stratigraphy

Materials exposed at the surface and inferred to be Holocene in age include beach sand on the modern beach, aeolian sand in the foredunes, aeolian sand and beach sand in the ridge and swale system behind the foredunes, and backbarrier clay, silt, sand and combinations of these along the landward edge of the sand spit.

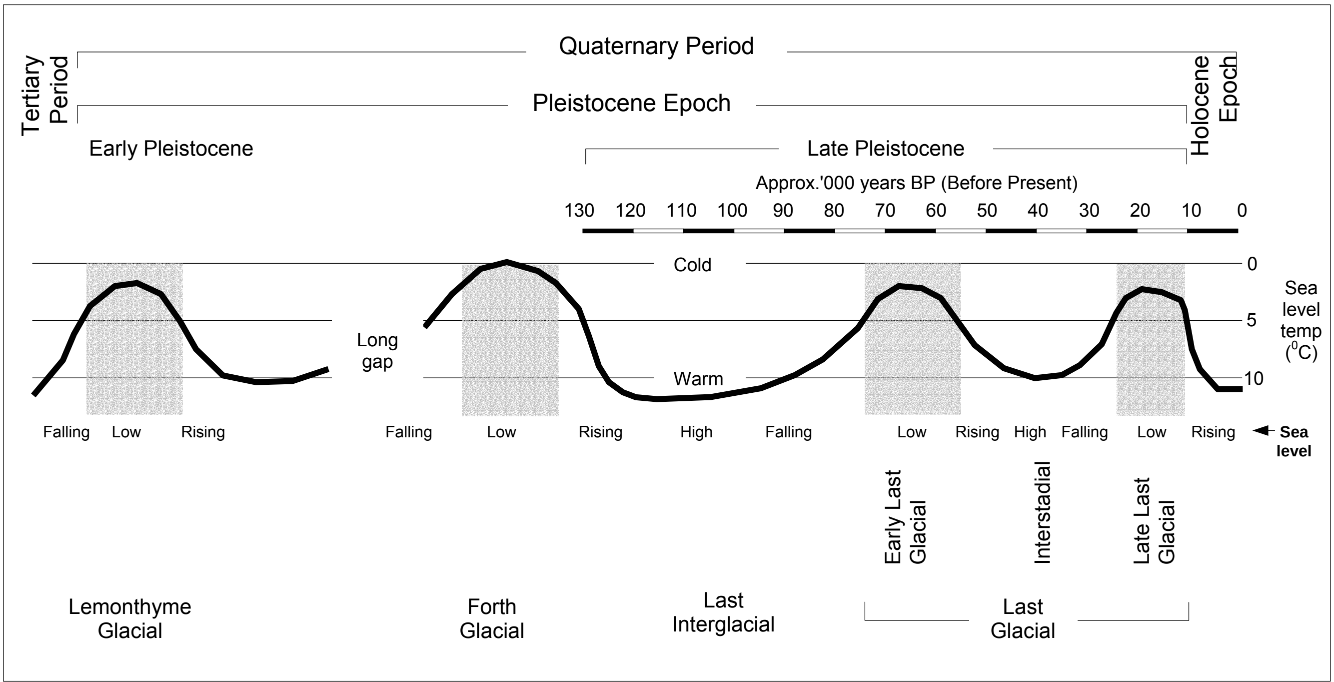


Figure 8. Tasmanian glaciations and sea level changes in the Quaternary Period, adapted from Colhoun (1975). The heavy black line represents inferred approximate sea level temperature. Low temperatures correspond to times of maximum glacial activity and lower sea level; higher temperatures correspond to times of minimum glacial activity and higher sea level. In between, sea level is either rising (transgressing) or falling (regressing). The Last Interglacial sea level may have been 10 to 20m higher than at present. The Late Last Glacial sea level may have been 70m lower than at present. Tasmania was then connected to mainland Australia by a dry Bass Strait, and the Tasmanian coastline was about halfway across the continental shelf. From about 15,000 to 12,000 years BP (Before Present), ice caps started to melt and sea level rose. It reached its highest point (about one metre above present mean sea level) about 6,000 years BP, during the Holocene Epoch, when the Seven Mile Beach spit (and other similar coastal deposits) was forming. After a brief period of falling level, sea level has remained fairly constant over the past few thousand years.

The subsurface distribution of materials has been reasonably established to depths of around 10 – 12m below sea level beneath the Royal Hobart Golf Club near the western end of the spit (Cromer, 1981). Similar materials have been found to depths of around 10 – 20m below sea level along transect B of Cromer and Sloane (1976), which corresponds to the line of auger holes installed by Louisa Mining in 1976 (Forster, 1977), some of the investigation holes of Roberts (1988), and the 2005 monitoring bores of Sanbar (I. Woodward, *pers. comm*., 2006). Valuable depth information has also been obtained from the production spear bores of the three golf courses, and Westlands Nursery.

Stratigraphic cross sections at the Royal Hobart Golf Club

These three section lines (Figure 9) extend in a northwesterly direction from near high water mark, over the low foredunes, across the beach ridge system (including club fairways), over the low-lying backbarrier (lagoonal) deposits at the rear of the spit, onto the gently-sloping ground inferred to be underlain by Tertiary sediments.

Figure 10 shows the interpreted stratigraphy across the three section lines (transects) based on the detailed bore logs of investigation holes presented in Appendix 1 of Cromer (1981). All the sediments beneath and near the golf course are considered to be Holocene in age, with the possible exception of the 'basal' clay layer, which may in part be Pleistocene. The clay layer forms the lower, relatively impermeable boundary to the unconfined aquifer.

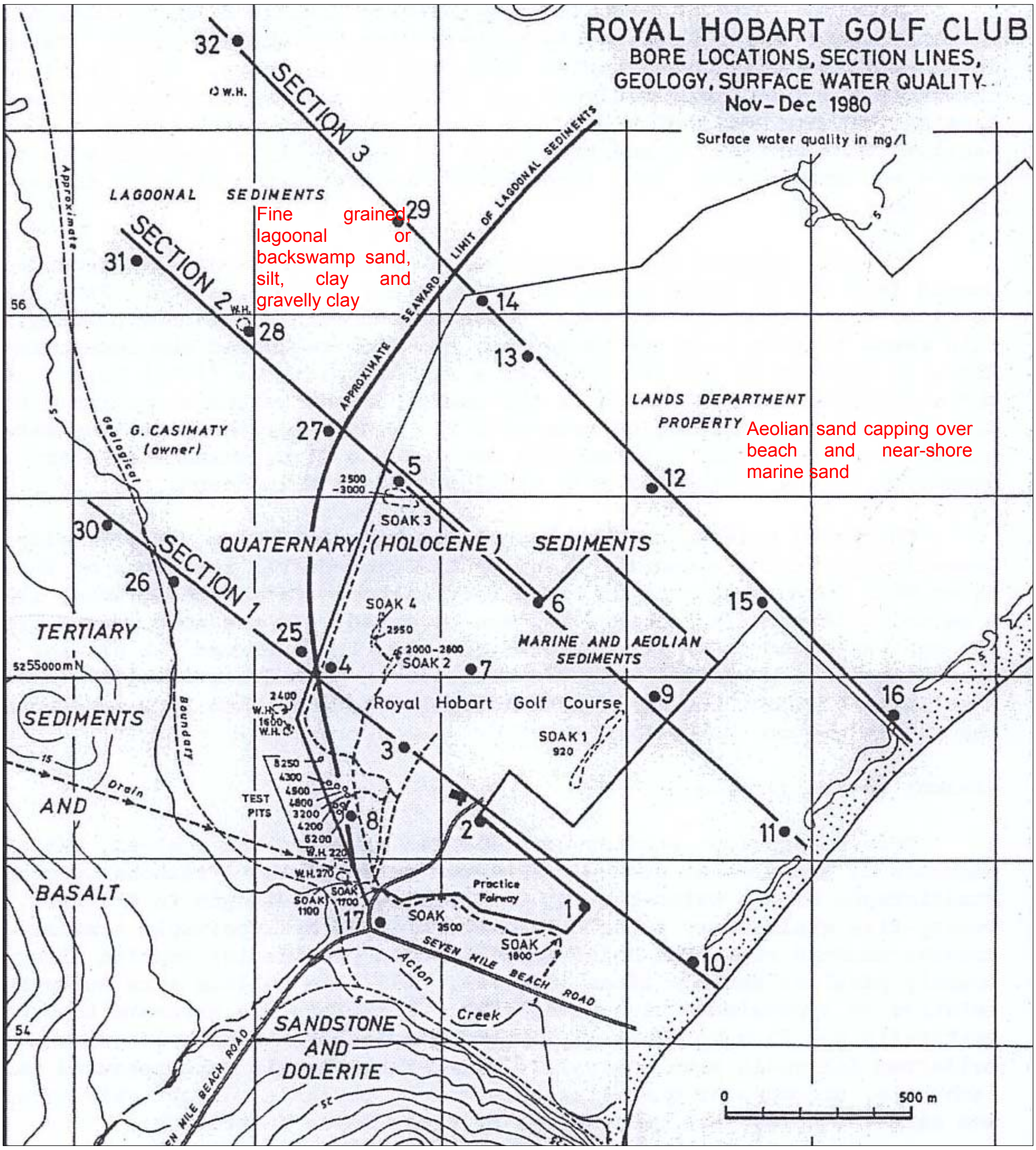


Figure 9. Drill holes and transects 1, 2 and 3 at the Royal Hobart Golf Club (after Cromer, 1980). The yellow shaded area (see also Figure 6) comprises Quaternary aeolian, beach and near-shore marine sand of the Seven Mile Beach spit. Also shown are the salinities in mg/L of surface waters (not groundwater) in 1980.

The main stratigraphic points arising from Figure 10 are:

- On the spit itself, the youngest materials are buff to light yellow aeolian sand and beach sand, overlying grey and brown sand locally enriched in shelly layers; these materials are collectively up to 10 – 15m thick, rest on the basal clay at about 8 – 12m below sea level, and extend from the coast inland almost to the western edge of the golf course.

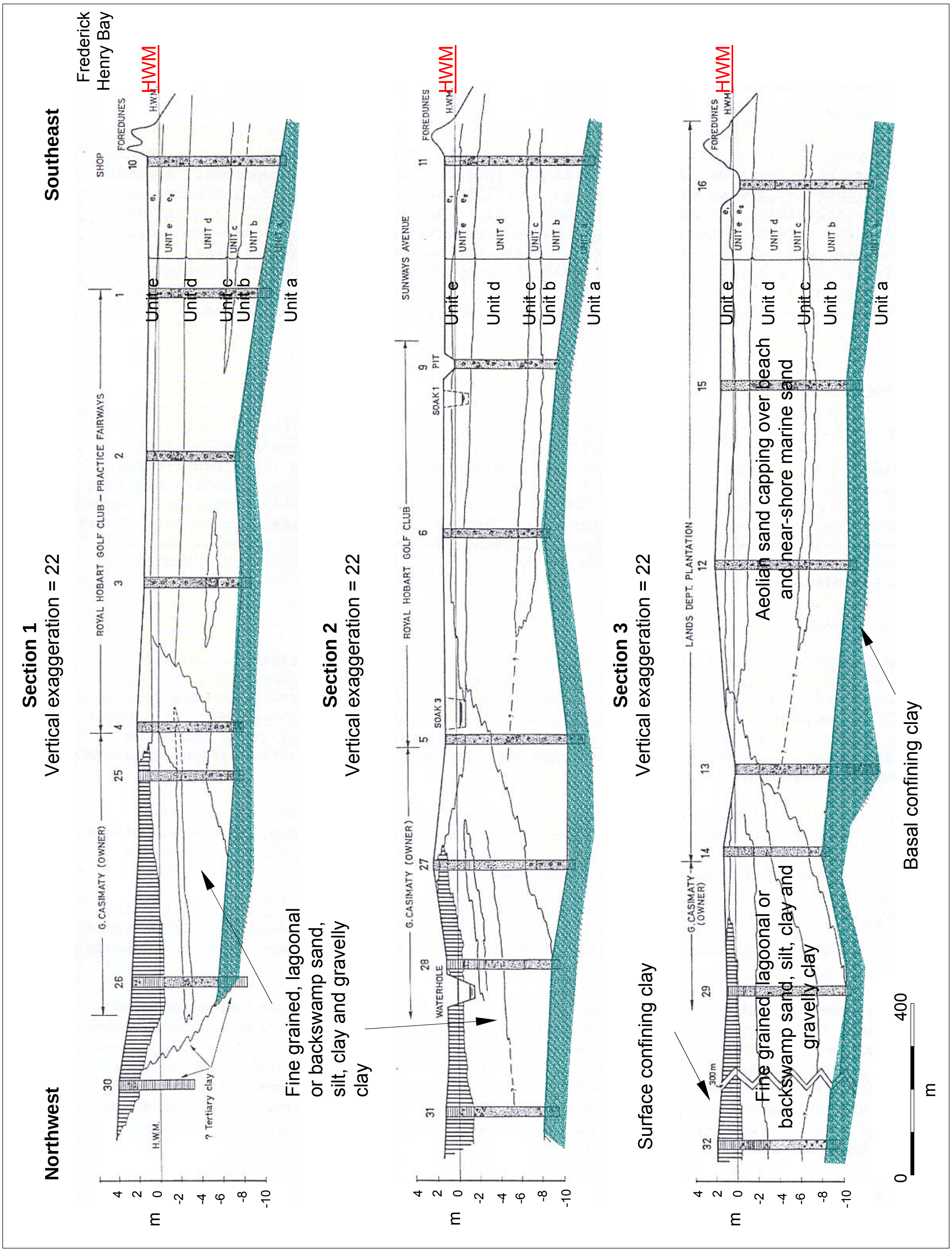


Figure 10. Schematic stratigraphy of the Seven Mile Beach spit beneath and near the Royal Hobart Golf Club. See Figure 9 for locations of the three transects. The yellow shaded area (see also Figure 6) comprises Units b, c, d and e – Quaternary aeolian, beach and near-shore marine sand of the Seven Mile Beach spit. Unit a is a distinctive, stiff, green sandy clay or clayey sand.

- West and northwest of the golf course the Holocene sediments consist not of relatively 'clean' aeolian, beach and marine sand, but of finer grained, lagoonal or backswamp sand, silt, clay and gravelly clay (including a surface clay layer) which extends from the club's western boundary to about the 3 – 5m contour.

Cromer (1981) recognised up to five separate materials (Units a to e in Figure 10). Their mode of formation is discussed in more detail in Section 3.4.5.

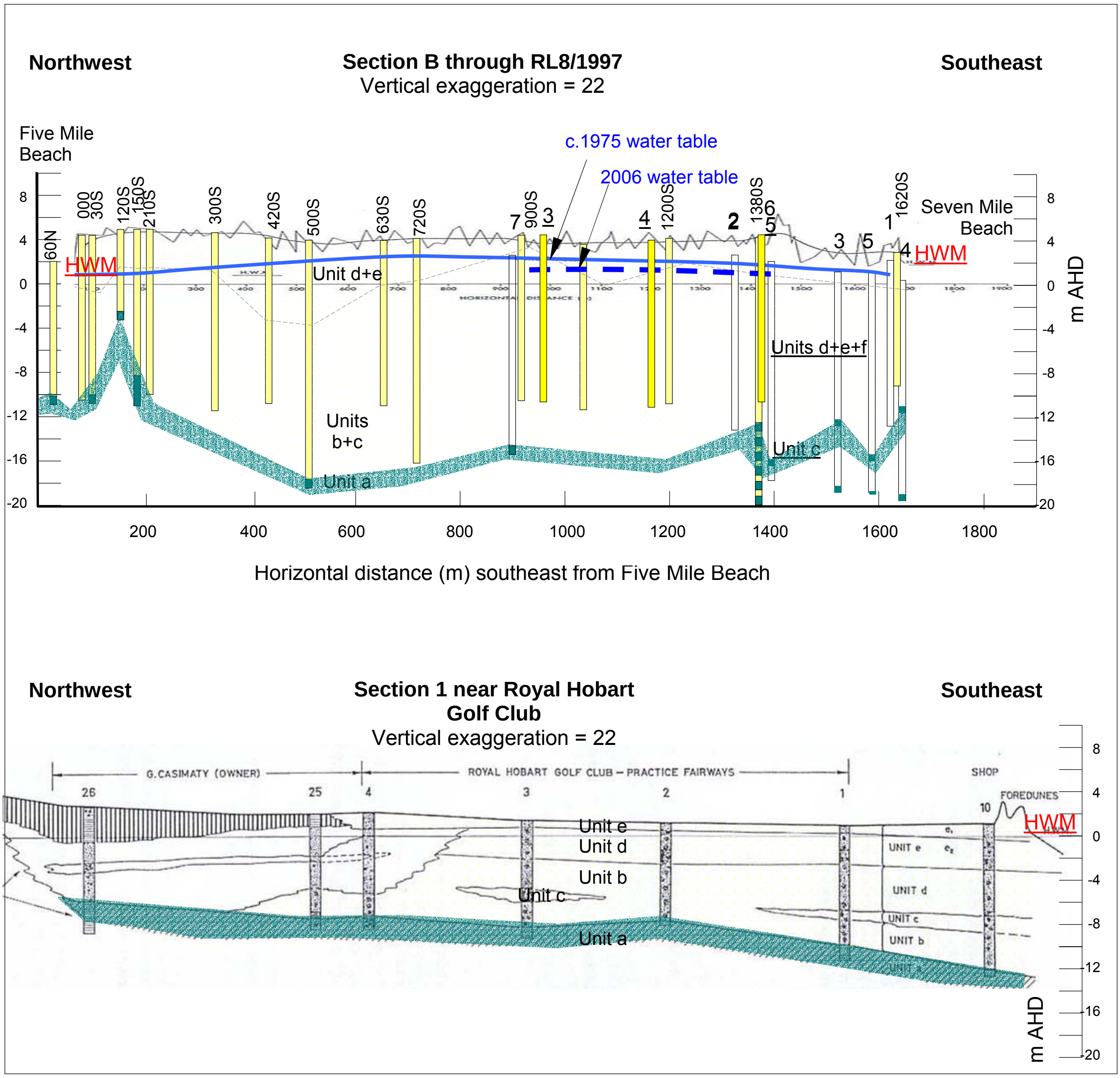


Figure 11. Comparison of interpreted stratigraphic cross sections from near the middle of the spit (top; through RL8/1997) and the southwestern corner near the Royal Hobart Golf Club. See Figure 7 for locations. The surveyed transect at top is from Cromer and Sloane (1976). Hole numbers 60/N, 000, 30S, 120S…. are Forsters (1977) hand augered holes drilled in 1976; numbers refer to the metreage northwest and then southeast from Five Mile Beach. Hole numbers and locations 1 – 7 are from Roberts (1988). Units a, b+c and d+e are Cromer's interpretations (this report) of the materials encountered, which probably correspond to those in the bottom diagram. Units c, and d+e+f, on the right of the top diagram are Robert's 1988 interpretation, where his Unit c corresponds to Unit a (this report). The 3 bores (3, 4, 5) with underlined numbers are Pitt and Sherry's 2005 monitoring holes (I. Woodward *pers. comm*. 2006; depths not reported).

Stratigraphic cross section in Retention Licence RL8/1977
Surveyed transect B of Cromer and Sloane (1976), logs of augered holes from Forster (1977), and logs of drilled holes from Roberts (1988) have been combined to compile the interpreted cross section of RL8/1997 in Figure 11. Transect 1 (at the same scale and vertical exaggeration; Figure 11) from near the Royal Hobart Golf Club has been added for comparison.

3.4.3 Description of stratigraphic units a to e at Seven Mile Beach

The following comments are taken largely from Cromer (1981). They refer to stratigraphic units a to e at Seven Mile Beach (Figures 10 and 11) and probably correspond to Roberts' (1988) units c, d, e and f[20].

With the exception of Unit a (shaded green), the materials described in Section 3.4.4 are collectively shaded light yellow in Figures 3, 9, 10 and 11.

Unit a – Quaternary-age estuarine clay
Unit a (the lowest in Cromer's 1981 sequence; shaded green in Figures 10 and 11) is described as a stiff, impermeable clay. Its upper surface shows minor relief, and near Royal Hobart Golf Course it dips gently seawards from about 7m below sea level at its landward boundary, to 11 to 13m below sea level at the coast. Over a distance of about 2km, this is an average slope of a mere 0.15^{0}, so it is almost flat. The clay is generally dark greenish grey, brownish black or olive black, mottled and streaked in places with lighter colours, highly plastic and moist. Locally, it contains sand and sandy clay patches (which probably become more abundant with depth), and in holes 4, 5, 14 and 25 (Figure 9) it contains a trace of white to cream shell (bivalve) fragments. Locally, Unit a grades to gravelly clay (eg in hole 1) and rarely it contains a trace of rock fragments and pebbles.

Because of its dark, presumably organic nature, the local presence of shelly material, and by analogy with basal clays beneath marine sequences elsewhere (eg Thom *et. al*., 1978), the clay is regarded as estuarine and formed behind a rising seaward sand barrier. In a Tasmanian context, similar greenish clay has been established beneath surface sands by drilling at Lauderdale (Cromer and Stephens, 1992), at Nine Mile Beach (Cromer, 2003), and at Greens Beach (Cromer, 1979).

Further east, at Section B in Figure 11, Forster's (1977) drill logs describe "green sand and clay", "sand and clay", and in hole 1380S from 18m to 24.2m below ground, "grey clay bound sand". This material is here also interpreted as Unit a. Along the seaward side of the same transect Roberts (1988) describes a thin (0.5m thick) moist greenish clayey sand with an upper surface showing a relief of about 5m, at depths between 11 and 15m below sea level.

It is likely that Robert's deeper Unit a (described as an "estuarine" sandy clay) and Unit b (a dark coloured sand) both represent lagoonal deposition, and that his Unit c (Cromer's 1981 Unit a) is the clayey, estuarine upper surface which was later covered with sandy materials beneath a rising sea level.

In any case, a sharp stratigraphic boundary (the top of Cromer's Unit a; Robert's Unit c) appears to be present in all holes drilled deep enough, and by inference with similar sand bodies elsewhere in Tasmania, is likely to underlie the whole spit. Accordingly, this thin clayey horizon separates the overlying beach and marine sand from underlying lagoonal clayey sand and sand horizons, and so influences the hydrogeology of Seven Mile Beach:

- its inferred low permeability means it acts at least as an aquitard[21] and
- its presence at shallow depth means that, from a hydrostatic viewpoint, the Seven Mile Beach aquifer above it is largely full of low – moderate salinity groundwater (Section 4.4).

[20] The reason for the different nomenclature is that Roberts drilled deeper at his Site 4 near the middle of Seven Mile Beach, and identified two lower units (his Units a and b) below Cromer's (1980) Unit a basal clay.
[21] An aquitard is a layer or horizon which retards, but does not fully inhibit, the vertically downward or upward movement of groundwater. See Section4.1.2 for more details.

It is noted that drill hole 2 (Figure 3, and Cromer and Sloane, 1976) near the southeastern end of the airport runway penetrated up to 70m of materials recorded as mainly clay beneath the Unit a level. It is likely that the drilling method prevented the identification of thin sandier horizons which may well have been present. More recently, in the early 1990s, private water boring drillers explored to a depth of 113m below ground at Westlands Nursery. The hole reportedly intersected greyish yellow muddy sand for most of its depth, had a relatively low yield of poor quality water, and remains unused[22]. Probably most of the material drilled in both holes was Tertiary rather than Quaternary is age, and indeed, Robert's (1988) Units a and b are also possibly Tertiary.

Unit b – Holocene-age marine sand
Unit b is a distinctive olive black, grey or olive grey, very fine to fine grained (Figure 12), well sorted sand overlying the estuarine clay. Beneath the Royal Hobart Golf Club, it is a wedge-shaped deposit, 1 to 6m thick, thickening seawards. The sand is flecked with very fine shell fragments, and locally contains a trace of calcareous cemented sand patches, well rounded dolerite pebbles, and local rich pockets of shells. Further east, at Section line B, Roberts (1988) described similar sand as grey, greyish olive and greenish grey, well sorted, with traces of silt, wood and charcoal fragments, and locally, a shelly base. Forster (1977) describes shelly grey or green sand, and in places his augering was stopped by rich shelly horizons directly above the estuarine clay.

A relatively quiet, nearshore transgressive[23] marine environment of deposition is suggested for this unit because of its grain size and degree of sorting, its biota, and because it rests directly on materials inferred to be estuarine.

Unit c – Holocene-age marine sand
Overlying the transgressive sheet beneath the western end of the sand spit is a thin but distinctive grey to olive grey shelly sand from 0 to 2m thick, opening out seawards and displaying a gently seawards dip on its upper surface. The sand fraction is fine to medium grained, well sorted to poorly sorted, with a high proportion of constituents coarser than 2mm. Large whole shells are locally abundant, and the unit contains well rounded quartzite gravel and occasional dolerite pebbles. Beneath Section B further east, Roberts (1988) describes similar materials as his Unit e.

The unit is interpreted as a near-shore marine deposit. Thom *et. al.* (1978, page 29) described a similar thin shelly sand bed from Moruya on the southern New South Wales coast as a 'regressive shore facies[24] sequence associated with progradation of the beach-ridge plain'. It is therefore possible that Unit c at Seven Mile Beach is a regressive facies between two transgressive facies (Units b and d) deposited during a temporary fall of sea level, possibly during mid-Holocene times.

Unit d – Holocene-age marine sand
Unit d overlies the Unit c shelly sand and is an olive black, grey or greyish olive, very fine to medium grained, well sorted sand 2.5 to 5m thick beneath the Royal Hobart Golf Club. It is very similar to Unit b, flecked with white fine grained shell fragments, and containing a trace of fine quartzite gravel, well rounded dolerite pebbles, and possibly thin sand lenses locally enriched in fine shell fragments[25]. The unit becomes finer towards its base, and is considered to be a transgressive, quiet, nearshore marine deposit.

This unit probably includes the lower part of Roberts (1988) Unit F further to the east.

---

[22] *Pers. comm*. A. van der Staay (7 July 2006)

[23] See Figure 8 for a discussion of transgressive and regressive deposits. The former were formed under net rising sea levels, typically advancing inland, or 'prograding'. Regressive deposits form when net sea levels are falling. The word 'net' is used advisedly here, since in different parts oft the world, the land surface may be rising or falling due to tectonic forces independently of, and at different rates to, any rise or fall of sea level. The difference between the two is the net sea level rise or fall.

[24] Facies: a geological term describing the sum total of features of a sedimentary unit or body which characterise it as having been deposited in a given environment. Thus, beach facies, near-shore facies, lagoonal facies, estuarine facies, etc. Studies of the distribution of facies leads to an understanding of past geographies and geomorphologies.

[25] At Nine Mile Beach, a similar Unit (Unit 2 of Cromer, 2003) contained the following biota: *Donacilla nitida*, *Fulvia*, *Glycimeris striatularis*, *Clanculus*, *Austroginella muscaria*, *Polymices*, *Scaeoleda crasea* and *Bankivia fusciata*, *Zeacumantuo diemeinsio, Nassarius pauperatus*, *Guratens pictus*, *Subminella undulata*, *Tawera gallinule*, and echinoderm spines., *Mactra rufencens*, *Pullastra fabayella*, *Nastid* spp., *Placenen flaccida*, *Fulvia tennicostata* and *Mytilus flamulatus*.

Unit e – Holocene-age beach and aeolian sand

The uppermost facies at Seven Mile Beach is a tabular, fine to medium grained, well sorted sand sheet of relatively uniform thickness (3 – 4m), generally coarser at the base, and fining vertically. The sand is generally bright yellowish brown to dull yellowish orange, leached of carbonate in the upper levels, but containing fine shell fragments (and locally enriched in larger, whole shell) towards the base. This unit hosts the water table, where irregular patches of calcareous cemented sand have locally accumulated via dissolution and precipitation. Soil profiles have developed on this unit, with seemingly increased profile differentiation and leaching in a landwards direction. Locally (eg near Soak 3 at the Royal Hobart Golf Club), 'sandrock' ('hardpan' or 'coffee rock') has developed. The absence of such materials towards the coast suggests less soil profile development and that the unit becomes younger in that direction. This is turn supports the interpretation of the facies as sand deposited by beach processes (including beach ridge formation) and capped by an irregular, thin aeolian sand.

3.4.4 Description of lagoonal units inland from Seven Mile Beach

Inland from the Seven Mile Beach sand spit, and stretching from east of Hobart Airport southwesterly towards the Royal Hobart Golf Club, is a complex series of lensing, interbedded shell-free sand, clay and silt (and combinations of these) interpreted as lagoonal or swampy deposits. They occupy a shallow, basin-shaped depression (in part marked by the drainage lines and swampy ground in Figure 7) immediately landwards of the marine sequence described in Section 3.4.3.

Beneath the Royal Hobart Golf Club, it is difficult to correlate individual facies between boreholes, but most appear to dip and thicken seawards. In general, the grain size fines upwards, and the clay fraction increases to the top. The sediments are usually brightly coloured olive brown, bright olive, yellow brown and grey. The youngest facies is a stiff surface clay west of the golf course and inland from the neighbouring pine plantation.

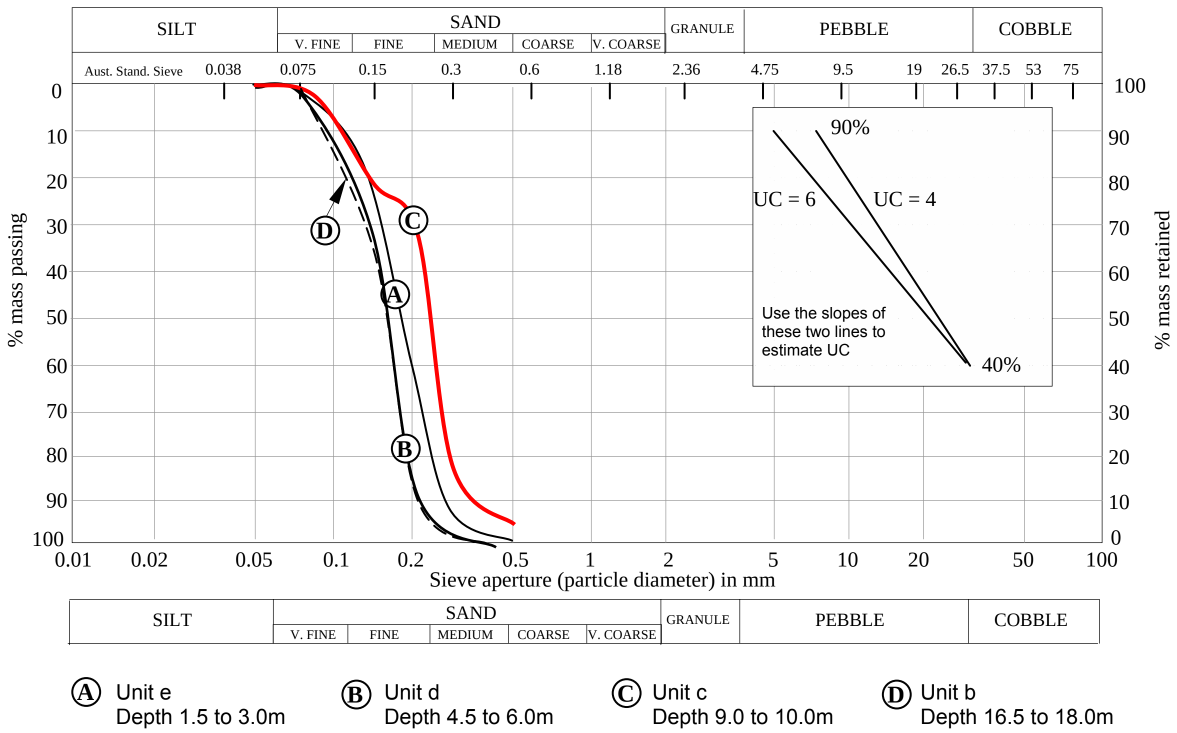


Figure 12. Grain size curves for sand samples from inferred Units b – e in hole 720S on Section line B, compiled from data in Morrison (1994). The samples all fall into the medium to very fine sand range, with very little material finer than 0.075mm, or larger than 0.5mm. The irregular shape of sample C is due to two and possibly three distinct size populations, probably reflecting shell concentrations.

The sequence is probably Holocene in age, formed at the same time as the marine sequence behind a rising sand barrier developed in the nearshore zone. The rising barrier blocked the then existing seaward-draining creeks and caused the deposition, in fresh water, of sediments inland of the coastline.

3.4.5 Quaternary history of Seven Mile Beach

In the absence of radiocarbon dating[26] of the Seven Mile Beach marine, beach and aeolian sediments, it is difficult to give more than an approximate account of the sequence of Holocene events which formed the spit.

At the height of the Late Last Glacial about 18,000 to 20,000 years BP (Figure 8), sea level is thought to have been about 70m lower than at present. Everywhere, coastlines stood out on continental shelves or rises. In the Tasmanian region, Bass Strait was dry land, and northern Tasmanian rivers like the Tamar, Mersey and Leven meandered across an almost flat grassland to join the ancestral Yarra River and flow westward north of present day King Island. In eastern Tasmania, Schouten and Maria were isolated uplands on a coastal plain which stretched east for 10km or so across an almost flat continental shelf. Further south, Bruny Island was some 50 or 60km inland from the coastline. The Carlton and Coal Rivers flowed over a dry Frederick Henry Bay, probably to join the ancestral Derwent River on what is present day Storm Bay before it discharged down the continental rise. Seven Mile Beach and Pitt Water did not exist.

Colhoun (1975) has attempted a reconstruction of landforms types, geomorphic processes, climate and vegetation for Tasmania during the Last Glacial. In eastern Tasmania, the probable vegetation was grassland, coastal scrub and light eucalypt savannah. Winters were probably cool, with snow on high ground. Deposits included valley fills and slope deposits, and the accumulation, from adjacent dry river beds or swamps, of windblown sand and clay to form lunettes.

Possibly from as early as 15,000 years BP, but at a quickening pace from about 10,000 – 12,000 years BP, global sea levels started to rise as ice caps and glaciers melted. As the Tasmanian shoreline moved inland, available sand supplies were worked into nearshore barriers. Inland from these barriers, estuarine conditions started to develop in what is now Frederick Henry Bay, and Unit a started to form. The Carlton and Coal Rivers were separated by rising (transgressing) waters, and the latter flowed into a broad wet depression similar to the present day Pitt Water. As transgression continued, and sea level rose to about a metre above present day levels by about 6,000 – 6,500 years BP[27], the estuarine conditions were pushed inland, or disappeared, contemporaneous with the nearshore deposition of grey shelly sand (Unit b).

During the mid-Holocene, sea level receded slightly to present day levels. As the beach ridges accumulated under the slight fall of sea level, backbarrier clay, clayey sand and sandy clay were deposited in the low-lying zone behind the innermost beach ridge at the western end of the spit.

Most recently, the present outlets of the Coal and Carlton Rivers were established. At Seven Mile Beach, a system of aeolian foredunes has developed, and some of this material has been blown inland to form a thin aeolian capping on the underlying beach materials.

---

[26] Shell samples for radiocarbon dating were collected from several Tasmanian beaches (Rheban, Greens Beach, Seven Mile Beach and Anthonys Beach near Smithton) in July 1979. The sampling was part of a programme of dating of Holocene coastal landforms in southeastern Australian, conducted by the Department of Geography at the University of New South Wales (Thom *et. al*., 1981). The samples from Seven Mile Beach proved unsuitable for testing. However, five dates were obtained from samples of shell hash (fragmented shell) from Nine Mile Beach. All were in excess of 8,500 ^{14}C years BP (Before Present). These were considered "anomalously old', resulting from the mixing (by beach and near-shore marine processes) of shell fragments of different ages from early to late Holocene, perhaps with some Pleistocene detritus. Similar problems were encountered with shell hash dates from the other Tasmanian sites, although a young age of 3,650+/-270 years BP was obtained from one of the Greens Beach samples.

[27] A rise of (say) 100m in sea level in 5,000 years is an average rate of one metre in 50 years, or 2cm a year. On a coastal plain sloping seawards at (say) 1^0, this rate of sea level rise would cause the coastline to move landwards at the rate of a metre a year – rapid enough to be readily apparent to indigenous communities.

4 GROUNDWATER

4.1 General principles

The following comments are drawn largely from Cromer (1993), to provide interested readers with a basic background in hydrogeological principles.

4.1.1 Origin of groundwater

With the exception of 'new' water formed underground from magmatic and other volcanic process, all groundwater is derived from that part of precipitation which, after surface runoff and evaporation, infiltrates the soil. Some of the infiltrating water is transpired by plants, some is drawn upward by capillary action and evaporated, and some remains indefinitely in microscopic voids in the soil profile. During and after continuous and wetting rain, the remainder infiltrates downwards, intermittently and successively saturating the material through which it passes, until the water reaches the *zone of saturation*. Here, the soil or rock *voids* (openings) are completely filled with water. The water is then called *groundwater*, and the upper surface of the zone of saturation is known as the *water table*. The water table is usually a subdued replica of the land surface, being almost flat under gently undulating ground (like Seven Mile Beach), and deeper and sloping under hills.

The proportion of rain entering the soil is very variable, ranging from a few percent on steep, rocky slopes, to perhaps 50% or more in sandy or gravelly areas with little runoff. The proportion also changes seasonally, and infiltration into sands like those at Seven Mile Beach, for example, would be expected to be a maximum when evaporation is least – at night in winter. Of the water which enters the soil, only a fraction avoids transpiration or retention in soil voids, and infiltrates to the water table.

Groundwater is therefore a part of the general hydrological cycle, and is directly related to the surface movement of water.

4.1.2 Unconfined and confined aquifers

An *aquifer* is a body of rock, or unconsolidated material such as sand, capable of supplying useful[28] amounts of groundwater.

An aquifer has two purposes: it *stores*, and *transmits*, groundwater. The relative importance of each function is determined by the nature of each aquifer. Some aquifers (eg hard sandstone) may store only a small amount of water in a network of thin fractures, but might transmit it freely, and remain reliable suppliers, if the fractures are sufficiently interconnected. Other materials like fine-grained and porous clays may contain larger amounts of water, but yield only small amounts because the water is not transmitted easily through their microscopic voids.

Aquifers may be *unconfined* (like Units b – e at Seven Mile Beach) *confined*, or *semiconfined*. An unconfined or water table aquifer exists in unconsolidated sediments or other materials whenever the water table is in contact with air at atmospheric pressure. Unconfined aquifers therefore receive recharge from infiltrating rain over their full areal extent. Groundwater in a bore, well or soak tapping an unconfined aquifer remains at the level of the water table.

By contrast, a confined aquifer is a saturated, permeable zone bounded above (and sometimes below) by relatively impermeable material called an *aquiclude*. The aquifer cannot receive recharge by directly infiltrating rain, but must get it from a more elevated recharge area elsewhere, where the permeable zone is exposed at the land surface, and where at least local unconfined conditions exist. The infiltrating groundwater in the zone of recharge moves downslope beneath the confining impermeable layer. The water in confined aquifers is therefore not in contact with the atmosphere, and is at a pressure greater than atmospheric. Water in bores tapping confined aquifers rises up the bore under pressure, and may overflow at the land surface. Instead of a water table, the water level in bores tapping confined aquifers indicates the piezometric level or piezometric surface of the aquifer.

[28] What might be regarded as a *useful* groundwater supply by some might be inadequate for others.

Sometimes, the low permeability material is sufficiently permeable so as to permit the slow vertical movement of groundwater, but not permeable enough to allow its lateral transport as in an aquifer. These materials, like Unit a at Seven Mile Beach, are called *aquitards*, and an aquifer bound on its top (and sometimes its bottom) by an aquitard is called a *semiconfined aquifer*.

The water level in an unconfined aquifer, and the piezometric surface in a confined aquifer, may fluctuate (rise and fall) on a range of time and size scales for a variety of reasons[29], summarised in Table 3. Groundwater movement vertically up or down through an aquitard occurs whenever there is a driving pressure of water, at a rate governed by Darcy's Law (Section 4.1.7).

4.1.3 Storage capabilities of unconfined coastal sands

Unconsolidated sands like those at Seven Mile Beach are reliable aquifers. They have good storage capabilities, and are also relatively good transmitters. The water is stored in voids between the sand grains, and the voids are interconnected (ie the aquifer is intergranular). The voids may constitute from about 25% to 35% of the volume of sand (ie the *porosity,* θ*,* of the sand is 25% to 35%, or 0.25 to 0.35 expressed as a fraction). Each cubic metre of saturated sand below the water table therefore contains 250L to 350L of groundwater. A proportion of this is held tightly around the sand grains, and cannot easily be removed. A measure of the extractable volume of water in an unconfined aquifer is its *specific yield* (S), defined as the ratio of (a) the volume of groundwater which the saturated aquifer will yield by gravity, to (b) the volume of the aquifer. It is equivalent to the porosity minus the firmly-held water (*specific retention*), or

Porosity = specific yield + specific retention

34

The specific yield is essentially equivalent to the *effective porosity*.

4.1.4 Primary and secondary porosity

The voids between sand grains in a coastal sand body like Seven Mile Beach constitute *primary porosity*, because they were formed at the same time as the sand was deposited. Over time, as the sand becomes progressively cemented and consolidated in the process of becoming hard rock, the primary porosity is reduced. Most hard rocks have very little remaining primary porosity. However, if the hard rock becomes jointed and otherwise fractured, the fractures constitute *secondary porosity*.

4.1.5 Groundwater gradient

Groundwater is rarely stationary. It moves in response to gravity, and hydrostatic and lithostatic pressures, from recharge areas to discharge zones. Discharge occurs wherever the water table intersects the land surface in springs, swamps, rivers and the sea, provided the water table slopes towards the feature. If the water table is lower than the feature, water may flow from the spring or river to the groundwater body. The slope of the water table is called the water table *gradient*[30], which determines the direction and rate at which groundwater moves. The greater the gradient, the more rapid the flow. Groundwater flows in the direction of steepest gradient. In coastal sand bodies, the gradient is usually very low (often less than 1:100) so that even though the materials may be relatively permeable, the groundwater is slow-moving.

[29] Of these, sea level rise is of topical concern. Tide gauge records show net global sea level has risen 0.1 – 0.2m during the twentieth century (Sharples, 2002, page 23). Moreover, the trend appears to be accelerating (Sharples 2002, Figure 8c). The average global rise is supported by local tide gauges which indicate sea levels relative to the land in southeastern Tasmania have risen by about 0.14m since the 1840s, and most of that possibly since the 1880s (Sharples, 2004, page 8). Assuming the rise is linear, the average rate since the late 1880s has been 1.2mm per year. If this is applied to Seven Mile Beach, sea level has risen about 0.05m (50mm) since the mid 1960s. The global average sea level rise projected to 2100 is between 0.08 and 0.88m (Sharples, 2004, page 65) but based on historical Tasmanian data the low end of this range would appear to be too low.

[30] The gradient is usually expressed as the difference in elevation of the water table between two points, divided by the distance between them. For example, a fall of one metre in water table elevation over a horizontal distance of 50 metres is a gradient of 1:50 (ie 0.02, expressed as a fraction).

Table 3. Factors which cause changes in groundwater levels in the unconfined aquifer at Seven Mile Beach. Similar causes also affect confined and semiconfined aquifers.

Cause	Effect	Time frame	Areal extent of effect relative to size of Seven Mile Beach aquifers	Relative effect on groundwater levels	Remarks
Groundwater extraction, domestic-scale	Lowering of groundwater level	Short (hours)	Minor. Effects not measureable after several metres from extraction point	Minor to major	
Wastewater disposal, domestic scale	Raising of groundwater level	Short (hours) to medium term	Minor. Effects not measureable after several metres from discharge point	Minor to moderate	
Wastewater disposal, community scale	Raising of groundwater level	Long term	Minor to moderate. Effects measureable for tens to hundreds of metres from application area	Moderate to major	
Groundwater extraction, irrigation-scale	Lowering of groundwater level	Short to medium term (days to months)	Minor to moderate. Effects measureable for tens to hundreds of metres from extraction area	Moderate to major	
Rainfall	Raising of groundwater level	Short (rain events), medium (seasonal) and long term	Aquifer wide	Minor to major	Est. less than 10% of rain annually reaches water table. 1cm of rain reaching table cause about a 4cm rise. Long term effects may be significant.
Ocean tides	Raising and lowering of groundwater level	Short (hours); cyclic	Minor; less than a few tens of metres inland, depending on tide range and aquifer permeability. Involves no physical transfer of sea water in and out of aquifer	Minor to moderate. Effect Is equal to full tide range on beach, but is rapidly dampened inland from high water mark	Rising tide causes water levels to increase, and vice versa. The effect relative to the tidal range is the tidal efficiency of the aquifer.
Atmospheric pressure changes	Raising and lowering of groundwater level	Short (hours); in part cyclic; to medium (seasonal)	Aquifer wide	Minor to moderate. 1cm (mercury) change in atmospheric pressure causes 13.6cm change in water table.	Pressure decreases cause water levels to increase by water transfer from capillary fringe. The extent relative to atmospheric pressure change is the barometric efficiency of the aquifer.
Vegetation changes	Lowering of groundwater level	Medium to long term	Variable	Minor to major	Pinus radiata may extract several hundred mm of water annually from the water table or capillary fringe, or may prevent similar volumes of soil water recharging th ewater table
Sea level rise (or fall)	Raising (or lowering) of groundwater level	Long term (decades)	Aquifer wide	Minor to moderate, potentially major	All other influences being equal, a 1cm rise in sea level causes a 1cm rise in groundwater level
Land surface rise or fall	Raising (or lowering) of groundwater level	Very long term (decades to centuries)	Aquifer wide	Minor to moderate, potentially major	All other influences being equal, a 1cm rise in land level causes a 1cm lowering in groundwater level

4.1.6 Aquifer permeability and transmissivity

Permeability (symbol K) is a measure of how readily an aquifer transmits water, and is defined as the rate at which groundwater will flow from a unit area (eg one square metre) of aquifer under a unit gradient (ie the gradient is 1). It is expressed as cubic metres per day per square metre ($m^3/day/m^2$, which reduces to m/day). Typical coastal sands have permeabilities in the approximate range 2 to 20 m/day, depending on the size and interconnectedness of the voids between the sand grains, and whether the sand is poorly-sorted or well-sorted. Permeability usually varies horizontally and vertically in an aquifer. *Transmissivity* (T) is defined as the product of permeability and saturated aquifer thickness, and is therefore the rate at which groundwater will flow laterally from a vertical, one-metre wide strip of the aquifer under a unit hydraulic gradient.

4.1.7 Groundwater flow

The groundwater flow through a unit area (eg one vertical square metre) of an aquifer is determined by the aquifer permeability and the water table gradient, and is calculated from Darcy's Law:

Flow = permeability x gradient[31].

Groundwater flow is often expressed in m^3/day.

4.1.8 Rate of groundwater travel

The rate at which groundwater moves through an aquifer is determined by the aquifer permeability, the water table gradient, and the aquifer porosity (expressed as a fraction):

Rate of flow = permeability x gradient ⁄ effective porosity[32].

In coastal sand bodies where gradients are low, the rate of groundwater movement is usually low. Water falling as rain and entering the water table in the centre of a large sand spit like Seven Mile Beach may take 10 to 20 years to travel the 500 metres or so to the coast.

4.2 Groundwater in hard fractured rocks near Seven Mile Beach

The groundwater resources of hard fractured rocks in the study area are outside the scope of this report, but some general comments are useful.

All hard rocks in the study area, including Permian and Triassic sedimentary rocks, and Jurassic dolerite, are fractured-rock, usually unconfined, aquifers. Groundwater below the water table is contained within fractures (secondary porosity), so that the yield (flow rate when pumped) from bores drilled into these rocks depends on whether the drill holes intersect water-bearing fractures, and to what extent the fractures are interconnected. The sustainability of the yield depends on the storage capability of the aquifer, the annual rainfall and the proportion which recharges the aquifer.

Mineral Resource Tasmania holds records of bores drilled into hard in the general area. Some of this information is summarised by Matthews and Donaldson (2001) on a 1:500,000 map of Tasmania. Bores drilled in fractured rock aquifers in the vicinity of Seven Mile Beach are shown as having a range of yields, mostly less than about 0.5 – 1L/sec (1,800 – 3,600L/hour).

Groundwater quality is related to rainfall in that, usually, the lower the rainfall, the poorer the quality. The same map indicates that the salinity of groundwater in the fractured rock aquifers near Seven Mile Beach tends to be relatively high, with Total Dissolved Solids usually above 2,000 – 3,500mg/L.

[31] For example, assuming a permeability of $10m^3/day/m^2$ and a gradient of 1:100 (ie 0.01), the flow through a single square metre of sand is 10 x 0.01 = $0.1m^3$/day (100L/day). If the sand permeability is $2m^3/day/m^2$, and the gradient remained at 0.01, the flow would be 2 x 0.01 = $0.02m^3$/day (20L/day). On a one hectare property, with a 100m boundary parallel to a beach, the groundwater flow across the boundary would be 100m x $0.02m^3$/day (ie $2m^3$/day, for each one metre depth of saturated sand).
[32] For example, if the sand permeability is $2m^3/day/m^2$, the gradient is 0.01 and the effective porosity is 0.25, the rate of flow would be 2 x 0.01 ⁄ 0.25 = 0.08m/day (ie 8cm/day).

4.3 Groundwater in Tertiary sediments

4.3.1 Groundwater in Tertiary sediments inland from Seven Mile Beach

Tertiary sediments in Tasmania are mainly intergranular aquifers with both unconfined and confined examples. Materials mapped as Tertiary inland from Seven Mile Beach underlie parts of the ground rising gently towards Acton Road, just outside the study area. Few bores have been drilled in these sediments: yields are generally low, and water quality is usually poor (salinities higher than about 3,000 – 4,000mg/L TDS), as a consequence of the relatively low rainfall and the fine grained nature of much of the sediments[33].

4.3.2 The lower semiconfined aquifer: groundwater in Tertiary? sediments beneath Seven Mile Beach

Field evidence for the lower aquifer

Evidence on the Seven Mile Beach spit for groundwater of a different quality to that in the unconfined aquifer comes historically from several sources: groundwater extracted by the Royal Hobart Golf Club, the groundwater quality pumped from the spear array used by the Tasmania Golf Club, and Robert's (1988) seven investigation bores drilled on transect B (Figure 3):

- The evidence from the Royal Hobart Golf Club (Cromer, 1981) clearly indicated different groundwater types but none of the investigation bores intersected groundwater in the basal clay (Unit a) or pointed to the presence of a deeper aquifer. The basal clay appeared to be an aquiclude, and it was inferred that pumping of soaks and spear bores had induced lateral (not vertical) movement of poorer quality water seawards beneath the property.

- The Tasmania Golf Club experience was different: water salinity increased fairly soon after large-scale pumping started, but this was taken as evidence that groundwater in the aquifer became more saline with depth, with no influences from any other water.

- The clearest evidence is that of Roberts (1988). Five of his seven bores penetrated the 0.5m thick dark coloured clayey base of the Quaternary unconfined aquifer and intersected a few metres of water-bearing, dark coloured sand, gravelly sand, clayey sand, sandy clay and clay. These relatively shallow materials may be Quaternary or Tertiary in age, but they presumably overlie a considerable thickness of Tertiary sediments[34]. In any case, the bores demonstrate the presence of water-bearing materials below what has been assumed to be the base of the unconfined aquifer.

In their upper levels at least, these sediments below the clayey base of the unconfined aquifer contain moderate – high quality groundwater (Roberts, 1988, and Figure 17, this report). Salinities ranged as follows: Bore 3 3,250mg/L TDS; Bore 5 9,200 – 10,400mg/L TDS; Bore 6 4,220mg/L TDS and Bore 7 8,280mg/L TDS. The waters are also principally sodium chloride waters (Section 4.6) which are chemically different to the predominantly calcium bicarbonate groundwater in the overlying Quaternary aquifer, and which, in the proportions of their major dissolved ions (but not salinity), resemble sea water. As Roberts (1988) has inferred, a proportion of the sodium chloride groundwater in this lower aquifer[35] may in fact be connate sea water (ie trapped in the sediments at the time of their deposition), diluted by recharge from elsewhere.

Inferences from the field evidence

All available evidence suggests the base to the Quaternary upper unconfined aquifer underlies the entire Seven Mile Beach spit. Its mainly clayey but varying texture suggests it is of probably variable

---

[33] Compared to relatively coarse materials like beach sands, finer grained sediments (eg silt and clay) affect water quality in two ways: the finer particles have greater surface areas which results in increased dissolving of soluble components in the water. Finer particles usually have relatively low permeability, so that groundwater flow rates are lower and the water stays in contact with the sediments for longer periods.

[34] It is presumed that the mostly clay materials in the 80m deep Hole 1 of Cromer and Sloane (1976) are Tertiary, as were 'muddy sands' reported from the 113m deep exploratory water bore drilled in the early 1990s at Westlands Nursery.

[35] It is arguable that in the strictest sense, the lower, water-bearing materials do not constitute an *aquifer*, since the high salinity groundwater is of very limited use.

(and mainly low) permeability, and instead of being an aquiclude throughout is likely, at least in places, to be an aquitard, semiconfining the groundwater beneath. It will therefore allow the passage of groundwater through it, either vertically upwards or downwards, at a volumetric rate of flow which is determined by its permeability and the total head difference[36] between the two aquifers (Darcy's Law; Section 4.1.7 and Figure 21). Semiconfined aquifers are also called leaky aquifers.

The head of the semiconfined aquifer is determined by the elevation of its recharge area, which is probably the low lying Acton – Cambridge area only a few metres above mean sea level. Similarly, the head of the unconfined aquifer is between about one and two metres above mean sea level. It is therefore likely that the total head difference between the two aquifers is quite small[37], and varies continuously from place to place in a complicated response to the many subtle and not-so-subtle causes of water level fluctuations listed in Table 2. If that of the upper aquifer exceeds that of the lower aquifer, groundwater from the former will move down through Unit a into the latter until the head difference is eliminated. The converse is true (Figure 21). That the two groundwaters remain largely chemically distinct suggests the process is slow.

Upward leakage could occur after long periods of below-average rain (like the present) when the water table falls. It could be locally induced by groundwater extraction, and may be occurring at the both the Royal Hobart and Tasmania Golf Clubs. The Tasmanian Golf Club spear bore array in the centre of the spit east of Hobart Airport taps only the unconfined aquifer. However, groundwater salinity increased soon after the system was commissioned, and a May 2006 analysis[38] revealed the water has a salinity of 3000mg/L TDS and is of the sodium chloride type of the lower aquifer.

Estimating the permeability of the aquitard, and the leakage through it
It would be useful to try and estimate the permeability of the aquitard and thereby gain an idea of the magnitude of the leakage through it.

An indirect method of estimating a permeability range[39] is to use the Tasmania Golf Club data from its spear array. The salinity of the groundwater currently being pumped is perhaps three times the average salinity of the groundwater in the upper aquifer, but also perhaps only a third of the salinity of the lower aquifer. Assuming that:

- 10% of the 50ML (5ML) pumped each year comes from the lower aquifer.
- the aquitard is 0.5m thick,
- the Tasmania Golf Club spear array has a radius of influence of 400m (so it is drawing water from an area of 50ha), and
- the total head difference during pumping is 6m (a difference of 3m between the pumped water table elevation and the piezometric head of the lower aquifer).

then (from Darcy's Law) to produce the 5ML of upwards leakage the aquitard would need to have a permeability of 0.00005m/day. If the leakage was 10ML/year, the permeability would need to be 0.0001m/day. Applying a permeability range of 0.0001 – 00001m/day to the full extent of the aquitard beneath the spit, and assuming a smaller (unpumped) total head difference of 1m, results in an annual leakage rate through the aquitard of between about 100ML and 1,000ML. A more precise assessment is not possible. Indeed, irrespective of the permeability of the aquitard, fluctuations in the total head difference might mean the leakage is largely non-existent at times, and reversed at others.

---

[36] The total head of the unconfined aquifer at Seven Mile Beach is equal to the sum of the pressure head, and the elevation head. The pressure head at a point in the aquifer is the height to which water will rise in a bore at that point. The elevation head is vertical distance of the same point above an arbitrary datum. The same applies to a confined aquifer.
[37] This is also evident from Robert's (1988) bores. There is no evidence of a head higher than the unconfined water table in the bores which penetrated the lower aquifer.
[38] Kindly provided by Mr. D. Gilligan, Tasmania Golf Club
[39] Bouwer (1989, page 38) suggests deep clays might exhibit permeabilities in the range 10^{-8} – 10^{-2}m/day, and clay, sand and gravel mixtures in the range 0.001 – 0.01m/day.

4.4 Groundwater in coastal sands at Seven Mile Beach

4.4.1 Occurrence

All the Holocene materials (the yellow-shaded Units b to e in Figure39s 9, 10 and 11) in the Seven Mile Beach spit contain groundwater.

These sands constitute the Seven Mile Beach upper, unconfined aquifer. Their relatively good storage capacities and permeabilities mean they have the ability to supply useful quantities of useable groundwater.

The unconsolidated sediments inland from the aquifer (Figures 9 and 10) contain groundwater, but these finer grained, lagoonal or backswamp sand, silt, clay and gravelly clay are generally too impermeable. Some higher-permeability horizons do exist, but the fine-grained nature of most of the material results in groundwater of generally poorer quality than in the spit itself.

4.4.2 Size of the aquifer at Seven Mile Beach

The intergranular and unconfined aquifer at Seven Mile Beach extends the full length (about 10km) and width (up to 1.5km) of the sand body, and therefore covers an area of some 15km^2. East of Milford (Figure 7), the spit is bounded on both sides by sea water. Extending west and southwest from Milford to the Seven Mile Beach township, its inland limit is marked by the edge of the beach ridge and swale system abutting swampy ground, tidal channels, artificial drains and Acton Creek.

Figure 10 shows that at its western end the aquifer extends vertically from the water table in Units d and e, to the top of the low-permeability Unit a. The saturated thickness therefore varies from about 10m along the landward edge of the spit, to about 15m along the seaward edge. Further east, transect B in Figure 11indicates the average saturated thickness is approximately 14 – 15m.

Assuming an average overall saturated thickness of 13m, the volume of the upper aquifer[40] is about 0.2km^3, or 200 million m^3. This is not the volume of the water stored in the aquifer.

Approximate volume of the Seven Mile Beach upper aquifer: 200 million m^3

4.4.3 Volume of groundwater stored in the Seven Mile Beach aquifer

Apart from a narrow mixing zone near the coast where fresh groundwater and sea water mix (the fresh water – sea water interface; see Section 4.4.9), useable groundwater exists throughout most of the lateral extent and thickness of the aquifer.

The volume of fresh groundwater stored in the Seven Mile Beach aquifer is readily estimated from:

Groundwater volume = aquifer volume x aquifer porosity

Cromer and Sloane (1976) estimated that the aquifer had a specific yield of 0.24. Porosity equals specific yield plus specific retention, and a reasonable porosity for Seven Mile Beach is about 30% (ie 0.30),

Groundwater volume = 200 million m^3 x 0.30 = 60 million m^3 = 60,000ML

If it were possible to remove all this water, extraction would require a grid of at least 50,000 bores, at say 20 metre centres, spaced evenly across the whole aquifer. If each were pumped at 1,000 L/hour, it would take about two months to completely remove the fresh water resource.

---

[40] In this and similar estimates of aquifer or groundwater volumes, it is best to round the figures up or down to reflect their inherent uncertainty.

Approximate volume of groundwater stored in the Seven Mile Beach upper aquifer: 60,000ML or 60 million m^3

4.4.4 Origin and age of the groundwater

South and east of the tidal channel near Milford, the groundwater in the Seven Mile Beach upper aquifer is derived mainly from infiltrating rain.

West of Milford and Hobart Airport, groundwater additions to the aquifer may occur from time to time along its inland boundary where the artificial drainage line separates the lagoonal and backswamp materials from the beach and marine sands. This would happen whenever the water table in the former was higher than in the latter. For example, unusually heavy rain runoff from the west might build up in the drains, or groundwater pumping near the drainage line might lower the water table in the aquifer below that in the backswamp materials, and induce poorer quality water into it. Historically, this appears to have happened at Royal Hobart (Cromer, 1981).

As discussed, depending on the total head difference between the upper and lower aquifers, groundwater may also leak slowly up or down through the semipermeable Unit a which separates them.

Some of the groundwater may be relatively old. As soon as the spit started to grow and stabilise above mean sea level, rain water displaced sea water, and started accumulating in the sands. This commenced during the progradation (seawards-growing) stage when sea levels fell from about one metre above present levels, in mid-Holocene times approximately 6,000 years BP. Since then, rain has constantly recharged the aquifer from above, and groundwater has discharged on all sides, so that some of the groundwater is continually being replenished. However, this flushing is more effective at and near the water table, where the water is youngest and as a result groundwater salinity is the lowest.

4.4.5 The water table and its capillary fringe

Groundwater in the Seven Mile Beach upper aquifer is at depths slightly above mean sea level, except to within a few tens of metres inland from the coast where the water table fluctuates in response to tides. Elsewhere, the groundwater is deepest under the foredunes and shallowest in swales.

At and below the water table, all the intergranular openings between sand grains are filled with water at atmospheric pressure, and the sand is saturated. At increasing heights above the water table, the pores contain both water and air (with the water under negative pressure head) in the unsaturated vadose zone. Air is continuous between the pores at a point above the water table called the air-entry value. The vertical distance between the water table and the air entry value is essentially equal to the capillary fringe for the material in question (Figure 13).

The existence of the capillary fringe has practical implications for dry sand mining. Excavations will be in dry sand through most of the vadose zone until the top of the capillary fringe is encountered. The sand will then start to feel and appear slightly damp. The dampness will increase until saturated conditions are met at the water table.

Field experience indicates that the thickness of the capillary fringe at Seven Mile Beach is in the range 0.3 – 0.5m, depending on the grain size distribution of the sand near the water table. This is in general accord with Figure 13.

As the water table rises and falls in response to infiltrating rain, so does the capillary fringe (whilst maintaining its thickness).

4.4.6 Water table fluctuations on RL8/1997

As summarised in Table 3, water tables fluctuate continuously and unpredictably in response to conflicting influences.

No information is available on a continuous basis about the way the Seven Mile Beach water table changes with time. However, data are available for the 1970s, and 2006 which give some insight into the scale of fluctuations over decades. As Figure 6a shows, the fifteen years ending about the mid 1970s had above average annual rain, whereas the 30 or so years since have had below-average annual rain. Not unexpectedly, the 1970s water table elevation was higher than at present.

The water table in the 1970s

Figure 5 shows the approximate 1975 water table position in transects A, B and C across the spit (Cromer and Sloane, 1976). In all three sections, the water table displayed a convex shape, reaching a maximum elevation of about 2.5m AMSL (2.5m AHD) in transect B, and falling to about 1m AMSL at the coast. The average gradient towards both Seven Mile and Five Mile Beaches was about 0.001. Steeper gradients can be expected closer to the coast.

On the present RL8/1997, depths to the water table in 1975 ranged from about 1.5 – 2.5m (Figure 14).

2006 monitoring

The most recent data[41] (Table 4) records water levels in 16 bores on five occasions between December 2005 and July 2006 (In January 2006, water levels were measured at both high and low tides). Bore locations are shown in Figure 3, and repeated (with annotation) in Figure 14. Several of these bores were located on the 1975 transects B and C, so that the data can be compared.

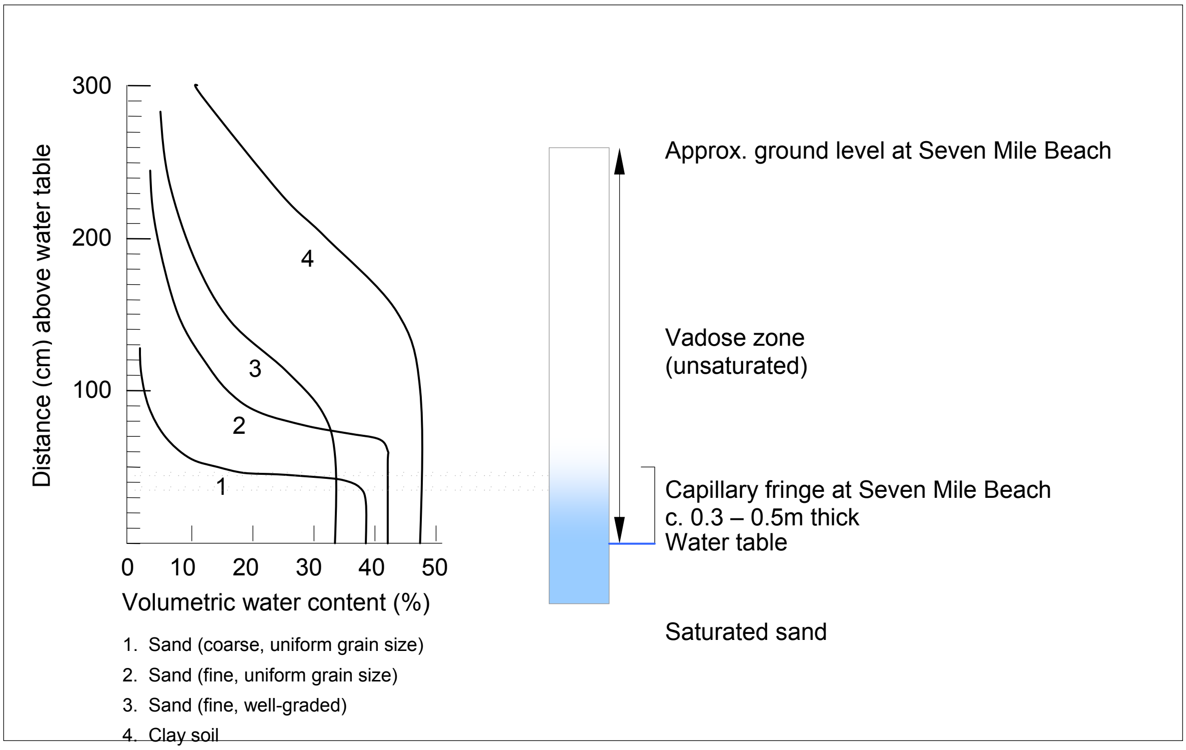


Figure 13. Schematic water content distribution above a water table, for various materials (after Bouwer, 1978).

[41] Kindly provided by I. Woodward of Pitt & Sherry.

All bores showed a drop in water level over January – July 2006, which is not surprising since during the same period, southeastern Tasmania received below average rain, particularly in June 2006[42]. The average fall in the water table was 0.19m (range 0.12 to 0.28m). There is no clear spatial pattern to the numbers. The smallest falls were recorded at bores 1 (not shown on Figure 14) and 8, with similar low numbers at bores 7 and 12. These bores are close to the Nine Mile Beach foreshore, but so are bores 9 and 10 which recorded about twice as much water table fall.

Table 4. Water table measurements at Seven Mile Beach, December 2005 to July 2006

	Coordinates and elevation			Water table RL (mAHD)					
	GDA94 Easting	GDA94 Northing	Ground elevation (mAHD)	Dec-05	Jan-06	Jan-06	Jun-06	Jul-06	Fall January to July
BH1	543773	5257600	3.13	0.73	0.68	0.70	0.58	0.56	0.12
BH2	544161	5257555	3.09	0.72	0.72	0.72	0.52	0.54	0.18
BH3	544876	5257494	3.15	0.98	0.98	0.98	0.73	0.80	0.18
BH4	544936	5257215	3.28	1.00	1.01	1.01	0.78	0.79	0.22
BH5	545004	5257017	3.77	0.85	0.86	0.86	0.61	0.67	0.19
BH6	545107	5257799	3.09	1.20	0.99	0.99	0.79	Vandalised	
BH7	545049	5258051	3.37	1.06	0.74	0.74	0.59	0.60	0.14
BH8	544989	5258278	4.06	0.61	0.62	0.64	0.52	0.48	0.14
BH9	545752	5257916	3.62	0.68	1.38	1.38	1.08	1.10	0.28
BH10	545735	5258110	3.01	1.23	0.98	1.03	0.73	0.74	0.24
BH11	545715	5258271	3.66	0.61	0.60	0.62	0.40	Vandalised	
BH12	546179	5258314	3.75	0.75	0.75	0.72	0.60	0.60	0.15
BH13	546422	5257871	3.61	0.91	0.92	0.92	0.48	0.69	0.23
BH14	546451	5257691	3.26	0.85	0.84	0.84	0.64	0.61	0.23
BH15	546450	5257500	3.93	0.80	0.73	0.78	0.58	0.56	0.17
BH16	545563	5257562	3.34	0.64	1.16	1.16	0.94	Dry	
			Tide Range	High 1.54 m	High 1.37 m	Low 0.18 m	High-Low 16 Jun 1.1 - 1.0 Low-High 19 Jun 0.9 - 1.3	1.38	

Comparing the water table elevations in 1975 (Figure 5) and 2006 (Table 4) shows:

Transect B Bore 3 (near the centre of the spit)
1975 water table elevation (Figure 5) 2.5mAHD
2006 water table elevation (Table 4) 0.8mAHD
Difference 1.7m fall

Transect B Bore 5 (south of centre)
1975 water table elevation (Figure 5) 1.5mAHD
2006 water table elevation (Table 4) 0.7mAHD
Difference 0.8m fall

Transect C Bore 9 (north of centre)
1975 water table elevation (Figure 5) 1.4mAHD
2006 water table elevation (Table 4) 1.1mAHD
Difference 0.3m fall

[42] From Bureau of Meteorology at www.bom.gov.au/climate. Southeastern Tasmania received between 60% and 80% of mean average rain for the period 1 January 2006 to 30 June 2006, with departures from the mean ranging from 100 to 200mm for the period. June rain was "very much below average".

Transect C	**Bore 10 (north of bore 9)**	
1975 water table elevation (Figure 5)		1.1mAHD
2006 water table elevation (Table 4)		0.7mAHD
	Difference	0.4m fall

Transect C	**Bore 11 (north of bore 10, near Five Mile Beach)**	
1975 water table elevation (Figure 5)		0.9mAHD
2006 water table elevation (Table 4)		0.4mAHD
	Difference	0.5m fall

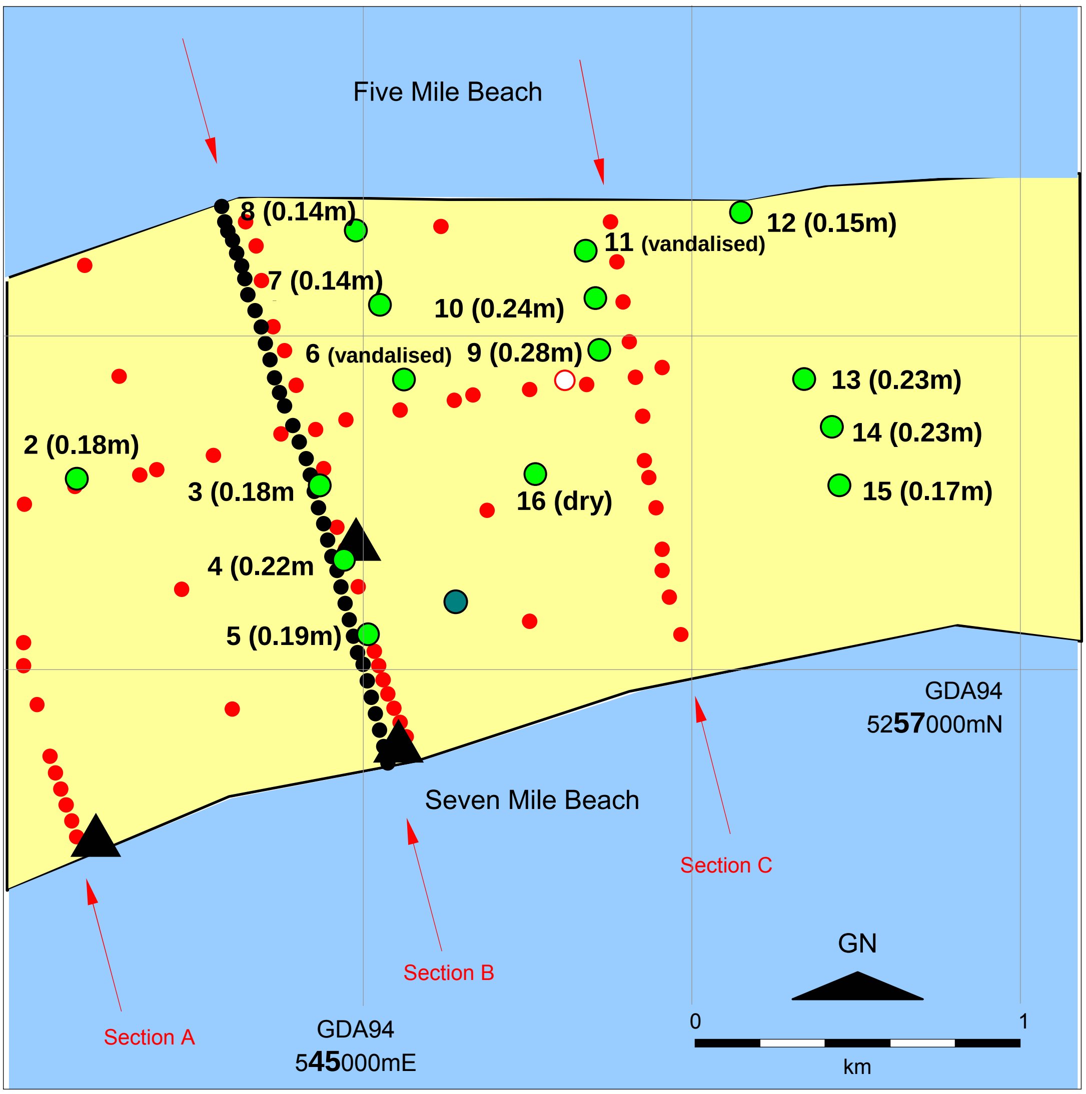


Figure 14. Bores (green circles) on RL8/1997 monitored for water level changes five times between December 2005 and July 2006. Other symbols are as shown in Figure 3. Values beside each of the monitored bores are the bore number, and (in brackets) the fall in the level of the water table during Jan – July 2006. Data from Table 4.

These results indicate an overall fall in the water table elevation over thirty years; the range is 0.3 – 1.7m (average 0.8m). The largest fall has occurred near the centre of the spit where the water table elevation is greatest.

As an approximation, it is estimated from Table 4 that in a year of average rain in all months, the annual maximum natural rise or fall of the water table throughout the Seven Mile Beach aquifer will not exceed about 0.5m ie it will fluctuate 0.25m above and below a mean level.

Estimated short-term (annual) fluctuation of the water table in the Seven Mile Beach upper aquifer: 0.5m (0.25m above and below a mean)

4.4.7 Thickness of 'dry' sand on RL8/1997

The thickness of dry sand on RL8/1997 varies at any location depending on water table fluctuations. The (constant) height of the capillary fringe is also relevant in that perhaps half the fringe thickness could arguably be subtracted from the water table depth.

Figure 15 shows that the thickness of sand above the water table on part of RL8/1997 in 1975 ranged from 1.5 – 2.5m.

Since the 1970s, the water table has fallen, so that the thickness of sand has increased. Table 4 reveals:

- The average height of the ground surface at the bores was 3.4m AHD (range 3.0 – 4.1mAHD)
- The thickness of sand above the water table[43] therefore varied as the water table altered, averaging 2.6m (range 1.8 – 3.5m) in December 2005, and 2.8m (range 2.3 – 3.6m) in July 2006.

Average dry sand thickness available on RL8/1997 in July 2006 = 2.8m

4.4.8 Groundwater flow directions and rate of flow

As discussed in Section 4.1, groundwater moves in the direction of maximum gradient. East of Milford, movement is north and south to both Seven Mile and Five Mile Beaches. At the western end of the spit, groundwater flows to Seven Mile Beach, to Acton Creek, and inland to the drainage line. The speed at which the groundwater moves (Section 4.1) is governed by aquifer permeability and porosity, and the water table gradient.

Permeability[44] in a sand aquifer is related to the particle size distribution of the sand grains within it, and the degree of compaction of the material. Permeability therefore varies horizontally and vertically.

Cromer and Sloane (1976) reported permeability (K) in the range 11 – 12m/day, and transmissivity (T) of 110 – 120m^2/day, from Bore 2 (Figure 3) near Hobart Airport. Little further information is available specific to the study area, but other coastal sands aquifers have been tested as follows:

Greens Beach (Cromer, 1979):	K = 5 – 10m/day; T = 55 – 100m^2/day
Nine Mile Beach (Palfreyman, 2002)	K = 2 – 8m/day (implying T of about 20 – 80m^2/day

[43] For practical mining purposes, half of the estimated 0.3 – 0.5m thickness of the capillary fringe should perhaps to be subtracted from these figures.
[44] An indication of bulk permeability can be measured in the field by pump testing bores and observing the way the water table responds with time during and after pumping.

Nine Mile Beach (Cromer, 2003) K = up to 30m/day (implying T up to about 250m^2/day
Lauderdale (Cromer, 2001b) K = 1 – 5m/day (implying T of about 10 – 50m^2/day
Assuming an average permeability of 10m/day, a gradient of 0.001, and effective porosity of 25% (0.25) for the Seven Mile Beach aquifer,

Average rate of flow = 10m/day x 0.001 ⁄ 0.25 = 0.04m/day = 4cm/day = 15m/year

In practice, a range of flow rates is likely to be occurring at any time in the aquifer because of differing permeabilities, porosities and gradients.

Assumed properties of the Seven Mile Beach upper aquifer:
Effective porosity = 0.25
Average permeability = 10m/day
Average gradient (slope on water table) = 0.001 (0.06^0)
Average rate of groundwater movement towards coastlines = 15m/year

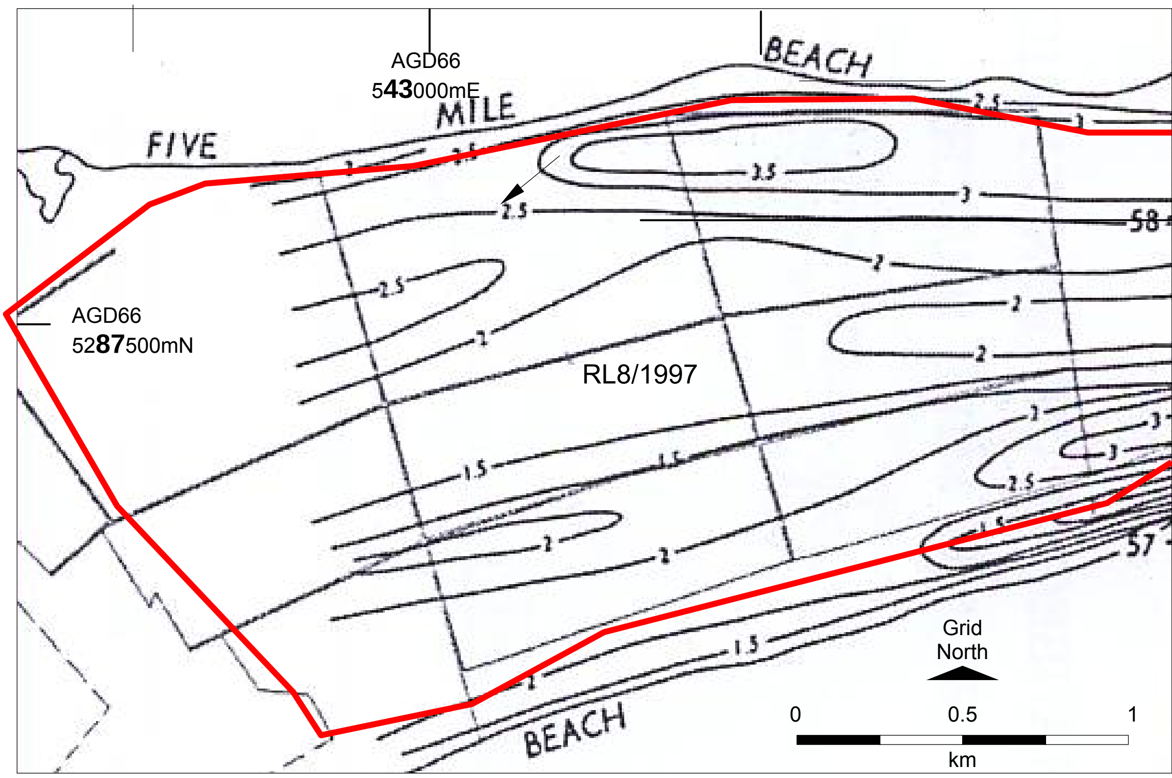


Figure 15. Depth (in metres) to the water table at Seven Mile Beach in 1975 (modified from Cromer and Sloane, 1976). Retention Licence RL8/1997 is shown bordered in red. The average thickness of dry sand has increased in 2006 to about 2.8m because the water table elevation has decreased.

4.4.9 Groundwater discharge from the aquifer

Groundwater discharges naturally from the unconfined aquifer at Seven Mile Beach between high and low water level along Seven and Five Mile Beaches, and to the drainage lines along its landward limit. The rate of discharge is highest when the water table and its gradient is highest, and is lowest when the water table and its gradient is lowest. Along coastlines, the fresh groundwater is in contact with sea water in a landward-dipping, relatively narrow zone of mixing called the fresh water – sea water interface.

Two methods are available to estimate the discharge from the aquifer.

Using water table monitoring

Assuming that rainfall was sufficiently low so as not to recharge the water table during the monitoring period, the average fall of 0.2m in Table 4 and Figure 14 represents a loss of *water* of about a quarter of this (say, 5mm), because the effective porosity of the aquifer is about 25% (0.25; Section 4.4.3). It is reasonable to assume as a first approximation that as stated above, this loss occurred throughout the aquifer, and was discharged to the boundaries at Five Mile and Seven Mile Beaches, and to the artificial drains at the landward side west of Milford. Applied to 15km^2, a 6mm column of groundwater represents 75ML, which discharged from the aquifer over 180 days. This is an annual rate of about 150ML (say, 0.5ML/day). If the boundaries to the aquifer are about 20km long, the discharge rate is 0.5ML/20km, or about 25L/day/metre of coast and drainage line[45].

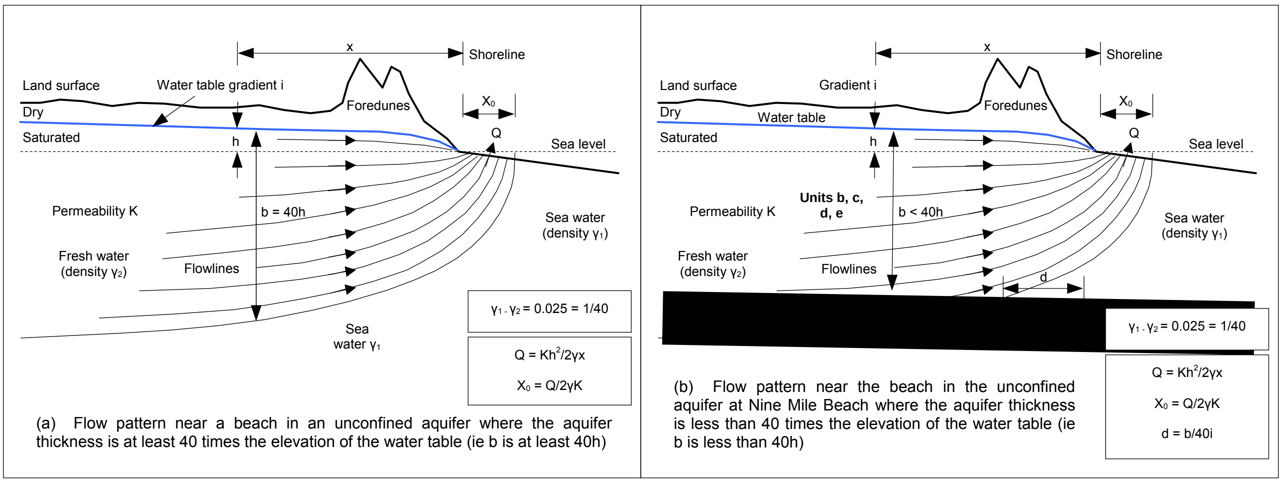
If the discharge rate remained unchanged, the annual discharge of about 150ML represents about 0.25% of the 60,000ML of groundwater estimated to be stored in the aquifer (Section 4.4.3).

It is worth emphasising that these are rough figures. In nature, the rate at which groundwater is discharged from the aquifer varies with the water table gradient, which changes from time to time and from place to place. Since the 2006 monitoring period was unusually dry, the discharge rate of 150ML/year would be lower than usual, and would have been declining exponentially with time as the elevation of the water table decreased.

Further water level monitoring on RL8/1997 will refine this estimated discharge rate, which might easily double during periods of above average rain.

Theoretical calculations about the fresh water – sea water interface

All coastal sands unconfined aquifers exhibit a 'fresh' water – sea water interface at the coast, which is in practice a narrow mixing zone of brackish water dipping inland from beach level (Figure 16). The shape of the interface is mathematically predictable, and depends only on the elevation of the water table, the permeability of the aquifer, and the density difference between the two water types. Because water table gradients are continually changing in response to recharge and discharge, and tidal effects near the coast, the shape and location of the interface are also continually changing[46].



(a) Flow pattern near a beach in an unconfined aquifer where the aquifer thickness is at least 40 times the elevation of the water table (ie b is at least 40h)

(b) Flow pattern near the beach in the unconfined aquifer at Nine Mile Beach where the aquifer thickness is less than 40 times the elevation of the water table (ie b is less than 40h)

Figure 16. Theoretical groundwater conditions near a beach in an unconfined aquifer (from Glover, 1964, and Cromer, 1979). The figure at right applies to Seven Mile Beach .

At Seven Mile Beach, and all other Tasmanian coastal sands bodies which have been investigated, the aquifer is thin enough, and the elevation of the water table is sufficient, so that more than a short

---

45 Cromer (2003) did similar calculations for Nine Mile Beach near Swansea, obtaining a discharge of about 125L/day/m of coastline. However, this was probably a higher than average figure, and other data showed an average fall in the water table of about 0.1mm/day – an order of magnitude less. In extended dry periods, the rate would decrease further.

46 The fresh water – sea water interface occurs naturally, and is not an example of "sea water intrusion". In this report, sea water intrusion means sea water replacing fresher groundwater in an aquifer, as a result of human intervention (usually by overpumping one or more coastal bores). I am not aware of any demonstrated examples of sea water intrusion in Tasmania.

distance inland, the aquifer is completely filled with fresh water ie the dipping interface is interrupted by the top of Unit a (Figures 10 and 11).

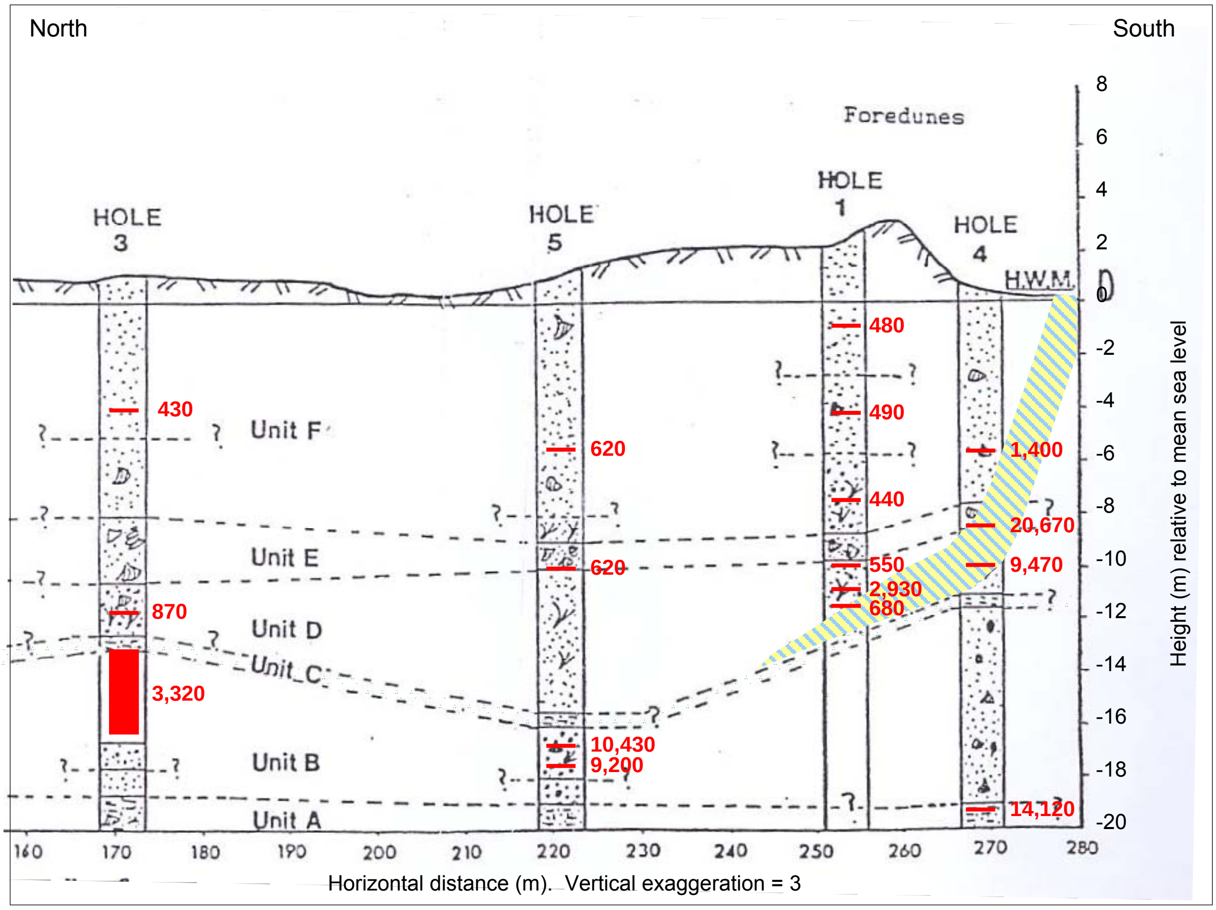


Figure 17. Cross section of the Seven Mile Beach aquifers near the beach on transect B (Figure 3). The base diagram has scanned from Figure 4 of Roberts (1988), with the following additions: the fresh water upper aquifer (Units b to e, this report) is shaded light yellow, the semipermeable base to the aquifer (Unit a, this report) is shaded green; the numbers in red type are groundwater salinities (mg/L of Total Dissolved Solids, TDS, taken from Appendix 5 of Roberts) at various depths in Robert's bores 1, 3, 4 and 5 (the red line or box marks the depth or interval sampled), and the light blue shading beneath Seven Mile Beach is intended to indicate sediments saturated with sea water. The interpreted fresh water – sea water interface (in reality a diffuse zone) is shown by the yellow-blue dashed region.

In a static (stationary water) situation, one metre of fresh water above sea level will support a 40m high column of fresh water below sea level[47]. Two important implications arise from this:

- If the upper aquifer at any point is at least 40 times thicker than the elevation of the water table, then the aquifer will contain a lower zone of sea water beneath the fresh groundwater body (Figure 16a).

- If the upper aquifer at any point is less than 40 times as thick as the elevation of the water table, then the aquifer will contain only fresh groundwater (Figure 16b).

Information compiled from Roberts (1988) supports the inference that Figure 16b applies to Seven Mile Beach.

[47] This relationship arises because fresh water is slightly less dense than sea water. The difference is about 0.025, or one-fortieth. To be in hydrostatic equilibrium, the weight of adjacent columns of water in an aquifer must be equal. For example, a column of sea water 40m high weighs the same as a column of fresh water 41m high.

Figure 17 is the coastal section of transect B (which passes through RL8/1997), superimposed with groundwater salinities from Robert's water analyses in Appendix 5. Bore 4, sited on the beach, intersected relatively fresh water to at least 6m; at 8.7m, salinity had increased to 20,670mg/L[48], and below that, ranged from about 9,500 – 14,000mg/L.

Figures 18 and 19 compare the proportions of major ions in the groundwater samples with the same ions in sea water. Collectively, the data suggest that:

- bore 4 and probably bore 1 passed through the fresh water – sea water interface,
- the fresh water – sea water mixing zone extends inland at the base of the aquifer at about -14 to -16mAHD to at least bore 1 (20m inland), but not bore 5 (50m inland),
- the average slope on the interface is therefore between about 15^0 and 35^0.
- no undiluted sea water was found in any of the bores,
- Unit a, shaded green and inferred to be the semipermeable base of the unconfined aquifer, inhibits (to an unknown but probably large extent) the mixing of low salinity water in the upper aquifer with underlying poorer quality water. In its proportions of major ions, the latter resembles sea water (albeit of lower salinity).

Assuming a range of reasonable gradients, the theoretical model can be used to estimate the corresponding range of groundwater flows at the beach (Q in Figure 16b), and the gap between high and low water mark (x_0) through which the flow occurs.

Assuming an average July 2006 water table gradient between the centre of the spit and the coast of 0.00073 (Table 4 and Figure 14), a density difference between fresh water and sea water of 0.025, and an average permeability of 10m/day, the flow rate for each metre length of coastline is 0.1m^3/day. If the coastline length is 15km, this is a total daily discharge of 1.6ML, or about 600ML per year. The theoretical width of the gap on the beach through which the flow occurs is 0.2m. The distance d in Figure 16b is the inland extent of the sea water lens at the base of the fresh water aquifer. Under the above assumptions, it is about 70m, which is not inconsistent with field observations.

The flow rate obtained by using the theoretical model in Figure 16b is higher than the estimated range obtained from water table fluctuations in Table 4. Also, the width of the gap through which the discharge occurs seems much too narrow to be realistic. These discrepancies highlight the difficulty of estimating groundwater flows in aquifers where basic parameters such as permeability, porosity and gradient vary unpredictably. Furthermore, the theoretically static groundwater system is dynamically changing with the tides. Near the beach, the tide-induced diurnal variations in water table level are a significant proportion of the tidal range, but the fluctuations are dampened out rapidly in a landwards direction at a rate determined by the permeability of the aquifer.

4.4.10 The proportion of rain which recharges the aquifer

No data are available on the proportion of rain which infiltrates the sandy soils at Seven Mile Beach, survives uptake by vegetation, and eventually reaches the water table. However, crude estimates are available for Nine Mile Beach, where continuous water table measurements were obtained in a bore in 1979, together with local rainfall records (Cromer, 2003). Since coastal sand bodies share many hydrogeological attributes, the following relevant observations are taken largely from the Nine Mile Beach results.

Sufficient rain must fall before any recharge effect is noticeable at the water table. At Nine Mile Beach in 1979, rain events of less than about 2mm spaced more than a few days apart had no measurable effect, but the total of about 50mm between 26 September and 15 October raised the water table approximately 20mm. Assuming the porosity of the aquifer is about 25 – 30% (Cromer,

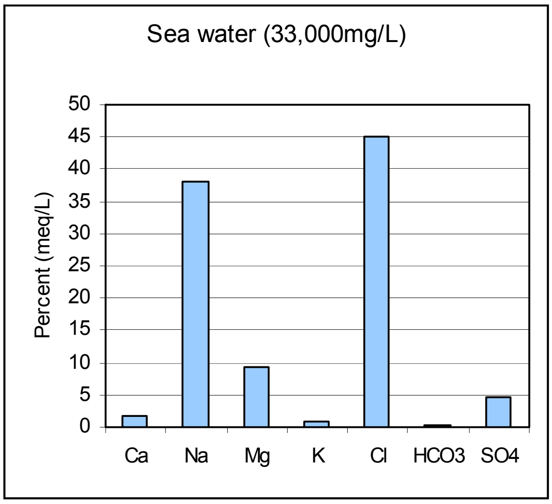
[48] Sea water has a salinity of about 33,000mg/L.

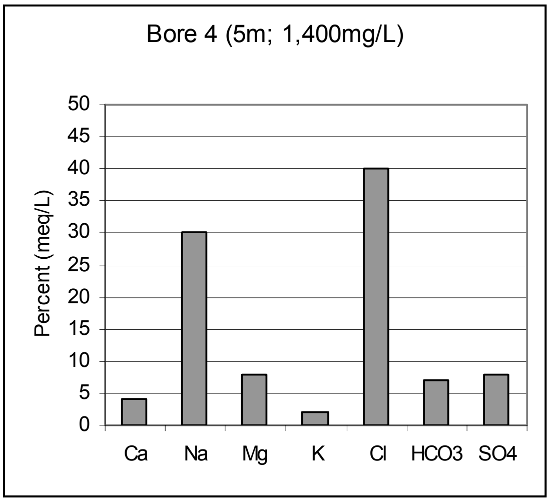
2003, used 25%), only about 5 – 7mm of the 20mm rise represents infiltrating water, which (neglecting water retained between sand grains) fills up the intergranular spaces between grains.

Therefore, of the 50mm of rain which fell, perhaps 10% reached the water table in the monitored period. This estimate can be reasonably extended over a full year of normal rainfall. There were 45 rain days in the 161 day monitoring period, but only 13 (say, 30%) were events of more than 2mm. Nevertheless, they accounted for 95mm, or 70% of the rain. It can reasonably be assumed that in a normal rainfall year, with twice as much rain, the proportion of effective rain events would at least be similar (ie 70%) as in the drier monitoring period. Accordingly, as a first approximation, 10% of 70%, or 7%, of mean annual rain recharges the Nine Mile Beach aquifer.

It is likely that similar infiltration figures apply to Seven Mile Beach. Since the mean annual rainfall for Hobart Airport and neighbouring districts is about 500mm (Table 1), about 35mm may replenish the aquifer in an average year[49]. Over 15km^2, this is equivalent to slightly more than 500ML/year (350kL/hectare/year).

Est. annual rainfall recharge to the unconfined aquifer in a normal year: 500ML





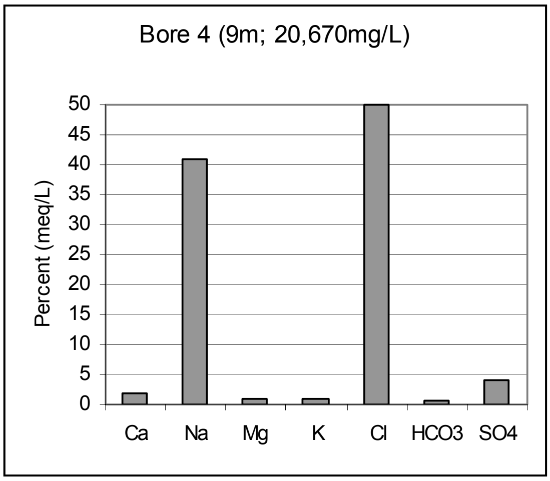


Figure 18. Comparison of the proportions of major dissolved ions in sea water, and in groundwater at different depths in bore 4 (data from Appendix 5 of Roberts, 1988). Bore 4 is on the beach on transect B at Seven Mile Beach (Figure 3). Ca = calcium; Na = sodium; Mg = magnesium; K = potassium; Cl = chloride; HCO3 = bicarbonate; SO4 = sulphate. The groundwater at 5m and 9m both resemble sea water in the proportion of major ions. The shallower, fresher water, and to a greater extent the deeper, more saline water, are probably in the mixing zone between sea water and fresh groundwater.

4.4.11 Yields from shallow bores in the aquifer

[49] Cromer (2003) estimated that at Nine Mile Beach, in an average rainfall year, 7% of rain recharges the water table. This this represents about 40mm of groundwater, or 400,000L/hectare/year.

A large number of shallow bores (spear bores) have been installed at Seven Mile Beach over the past 30 years or so. Some have been installed for private individuals, but most have been as multiple bore arrays for golf clubs and commercial facilities.
These installations show conclusively that individual spear bores, appropriately screened and installed up to several metres below the summer water table, are capable of sustained yields of up to about 2,000L/hour.

Similar or higher yields may be obtained simply from excavations (soaks) dug below the water table.

4.4.12 The effects of pumping on the aquifer at Seven Mile Beach

Background fundamentals

When groundwater is pumped from a bore (Figure 20a) which intersects the water table in an unconfined aquifer, the water level in the bore is lowered (drawn down). This in turn induces groundwater to flow into the bore from all directions, causing a lowering (drawdown) of the water table immediately around the bore. As pumping continues, the water level in the bore continues to fall, and the area around the bore affected by drawdown (the cone of depression) continues to expand outwards. Depending on the pump rate, both the water level in the bore and the expansion of the cone of depression may slow down or even stabilise (radial drainage to the bore is sufficient to provide the pump flow rate).

Pumped bores placed close together may interfere: their cones of depression overlap and the drawdown in each bore is greater than it would have otherwise have been (Figure 20b). The separation distance required to avoid this situation depends on the depth and pump rate of each bore, the characteristics of the aquifer, and the time for which pumping continues.

Pumping a single bore at Seven Mile Beach

Cromer and Sloane (1976) pumped bore 2 (Figure 3) for 420 minutes at a rate of 0.9L/sec (53L/min). Drawdown in the bore after that time was 6.23m. At a distance of 2.4m from the pumped bore, the drawdown after the same time in an observation bore was 0.28m, indicating the cone of depression was very steep-sided and narrow.

Multiple bore arrays at Seven Mile Beach

Several multiple systems have been installed at Seven Mile Beach over the past 25 years (Section 1.3.2) at or for the Royal Hobart, Tasmania and Llanherne Golf Clubs, and commercial operations Westlands Nursery and Whispering Sands.

None of these arrays, however, has been subjected to detailed pump testing and monitoring in a manner similar to that described by Cromer (1979) and Cromer and Leaman (1980) at Greens Beach in northern Tasmania, or by Cromer (2003) at Nine Mile Beach.

As discussed in Section 4.3.2, pumping (and thereby locally lowering the water table) around the Tasmania Golf Club spear bore array appears to have induced upward leakage of higher salinity groundwater through the semipermeable base of the unconfined aquifer (Figure 21). It is possible that other spear bore installations, including individual spears, are having the same effect.

Pump testing a 24 – spear array at Nine Mile Beach

Observations about the Nine Mile Beach pump test are applicable to Seven Mile Beach because of the similarities in aquifer characteristics. A summary of results is:

- In August and September 1979, a 24-spear-bore array was installed near the Dolphin Sands Road – close to the centreline of the Nine Mile Beach spit.

- The array comprised two concentric circles of spear bores, with radii of 48m and 74m. Spears were connected in groups of four to each of six main radial lines, in turn connected to a single pump. The 148m diameter array covered a circular area of 1.7 hectares. The water table prior to the pump test was approximately 2.4m below the ground surface.

- Each spear comprised a vertical length of 65mm diameter PVC casing, the lower two metres of which were slotted.

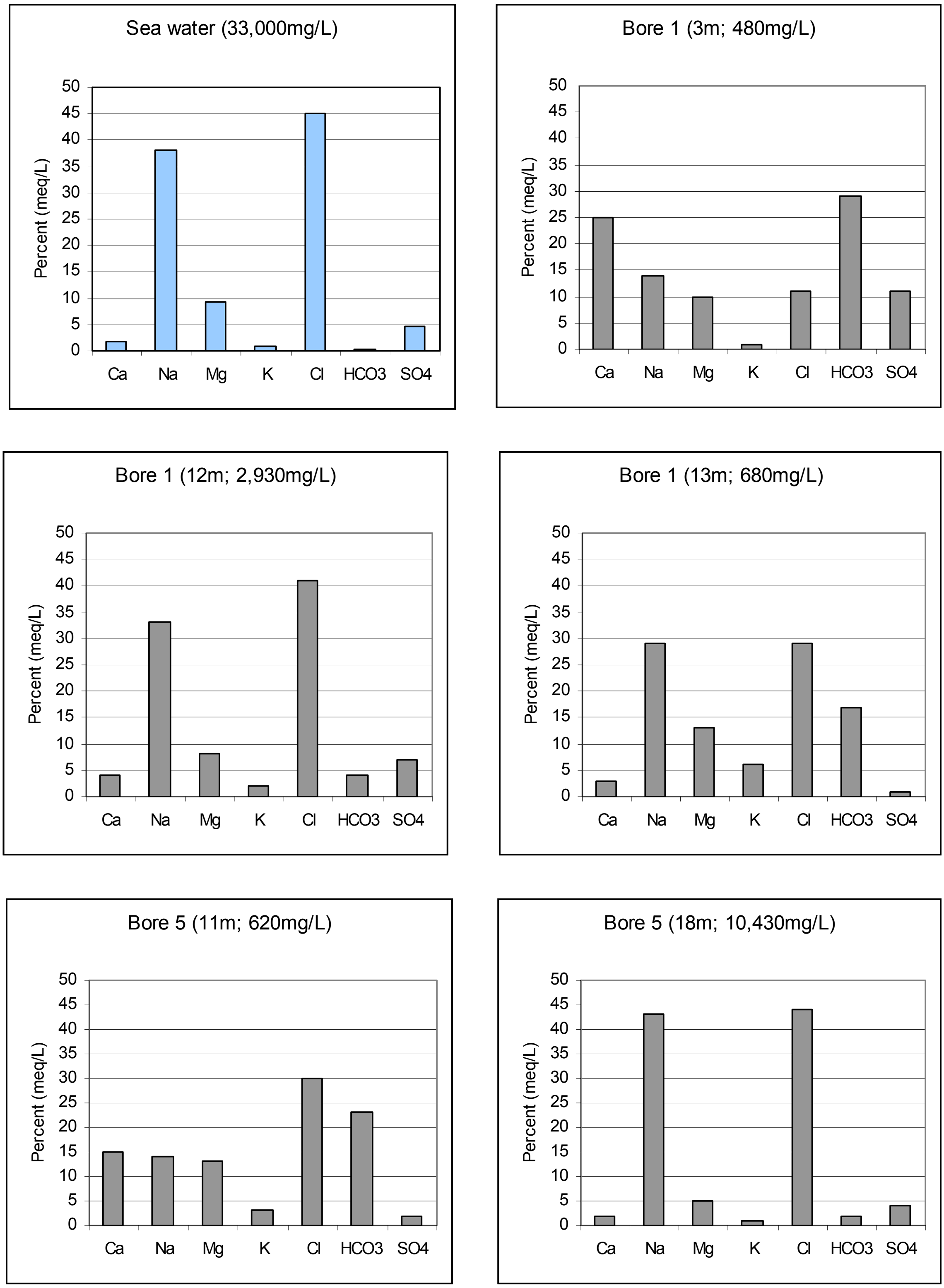


Figure 19. Comparison of the proportions of major dissolved ions in sea water, and in groundwater at different depths in bores 1 and 5 (data from Appendix 5 of Roberts, 1988). Bores 1 and 5 are about 20m and 50m inland respectively from high water mark on transect B at Seven Mile Beach (Figure 3). Ca = calcium; Na = sodium; Mg = magnesium; K = potassium; Cl = chloride; HCO3 = bicarbonate; SO4 = sulphate. The groundwater in bore 1 at 3m shows no sea water influence, but the samples from 12m and to a lesser extent 13 m both suggest mixing. The groundwater in bore 5 at 11m shows no sea water influence, but the sample from 18m (below the Unit a base to the unconfined aquifer) has a diluted sea water signature.

- Nine observation bores monitored the effects of pumping. The bores were arranged in two roughly radial lines at right angles to each other, at varying distances from the array centre.

- In October 1979, the 24 spear bores in the array were simultaneously pumped at a combined flow rate of approximately 9.5L/sec (34,000L/hour). This rate was equivalent to 1,400L/hour/spear, or 23L/min/spear. Water samples were collected for chemical analysis.

- Water levels were measured in all observation bores for the next 21 days (31,100 minutes) during which a total of 17ML of groundwater was pumped from the aquifer.

- Maximum drawdown in the four closest observation bores was 0.6m after 21 days pumping. At 129m from the array centre, the final drawdown was 0.37m; at 291m, it was 0.2m; at 400m, it was 0.1m, and at 548m, the furthest observation bore, it was 0.04m (4cm). As a rough approximation, this latter distance could be regarded as the radius of influence of the array.

4.4.13 Sustainable yield of the aquifer at Seven Mile Beach

The sustainable yield of an aquifer is the total amount of groundwater which can be extracted without reducing average groundwater reserves or affecting groundwater quality. In unconfined aquifers isolated from other groundwater influences this is usually taken to mean the long-term average annual recharge to the aquifer from infiltrating rain, which, from Section 4.10, is of the order of 500ML per year[50].

Current net usage (Section 1.4 and Table 1) is about 150ML, or about 30% of the annual rain recharge. While this appears sustainable, it may not be if, as discussed in Section 4.3.2, local relatively high extraction rates are compromising water quality in the upper aquifer by inducing upwards or lateral flow of poorer quality water.

The 500ML annual recharge represents about 330kL/hectare or (say) 1,000L/day/hectare. Similar figures were obtained from Nine Mile Beach (Cromer, 2003).

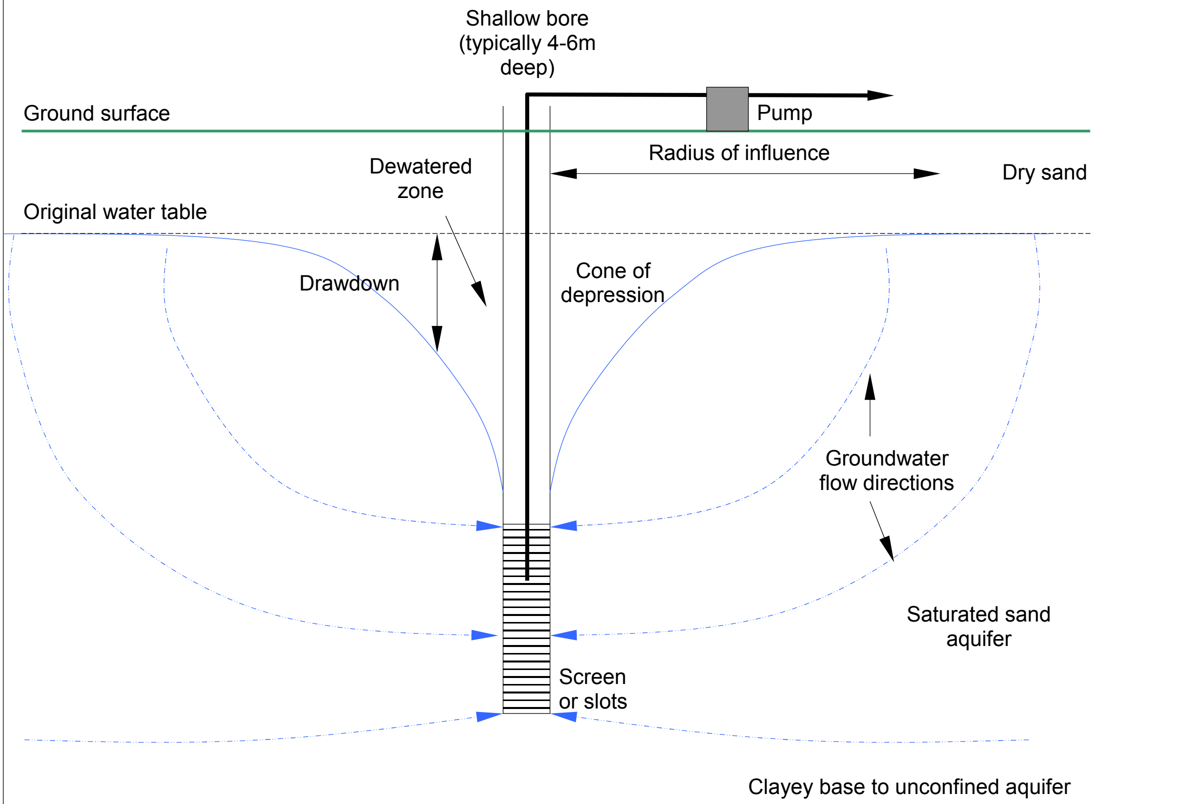
A few permanent residences use groundwater for domestic uses (garden watering, and in toilets and laundries). Daily usage might exceed the estimated 1,000L/day/hectare. This is unlikely to lead to unacceptable environmental effects, however, because (a) the area affected by pumping is relatively small on each lot, (b) the combined area of the lots is only a small proportion of the total aquifer area, and (c) part of the water on each lot is recycled[51], therefore reducing effective groundwater use.

Est. sustainable yield of Seven Mile Beach upper aquifer: 500ML/year

[50] It is interesting to speculate on the fate of the annual recharge volume. All figures are rough estimates. Of the 500ML, 150ML is extracted by pumping for irrigation, and 150ML discharges at the coast. The balance of 150ML might represent leakage through Unit a to the lower aquifer.

[51] In relation to groundwater recycling, water pumped from the aquifer, perhaps temporarily stored in tanks, and reapplied as garden irrigation, is partly evapotranspired and partly infiltrated. Infiltration back to the aquifer is a maximum at night, when evaporation is least, so night watering is best. Groundwater used in toilets connected to septic tanks is almost fully recycled, since after discharge from the tank (perhaps to absorption trenches) it re-enters the aquifer closer to the water table and beneath the root zone of many plants.

20a. Outside its radius of influence, a bore has no effect on the water table



20b. If neighbouring bores are sited sufficiently close to each other, their cones of depression will overlap. Drawdowns of overlapping cones of depression are additive.

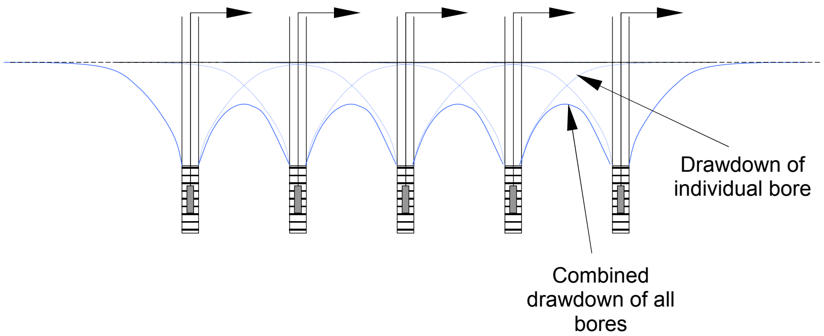


Figure 20. Fundamentals of pumping groundwater from an unconfined aquifer: a) single bore; (b) multiple bores.

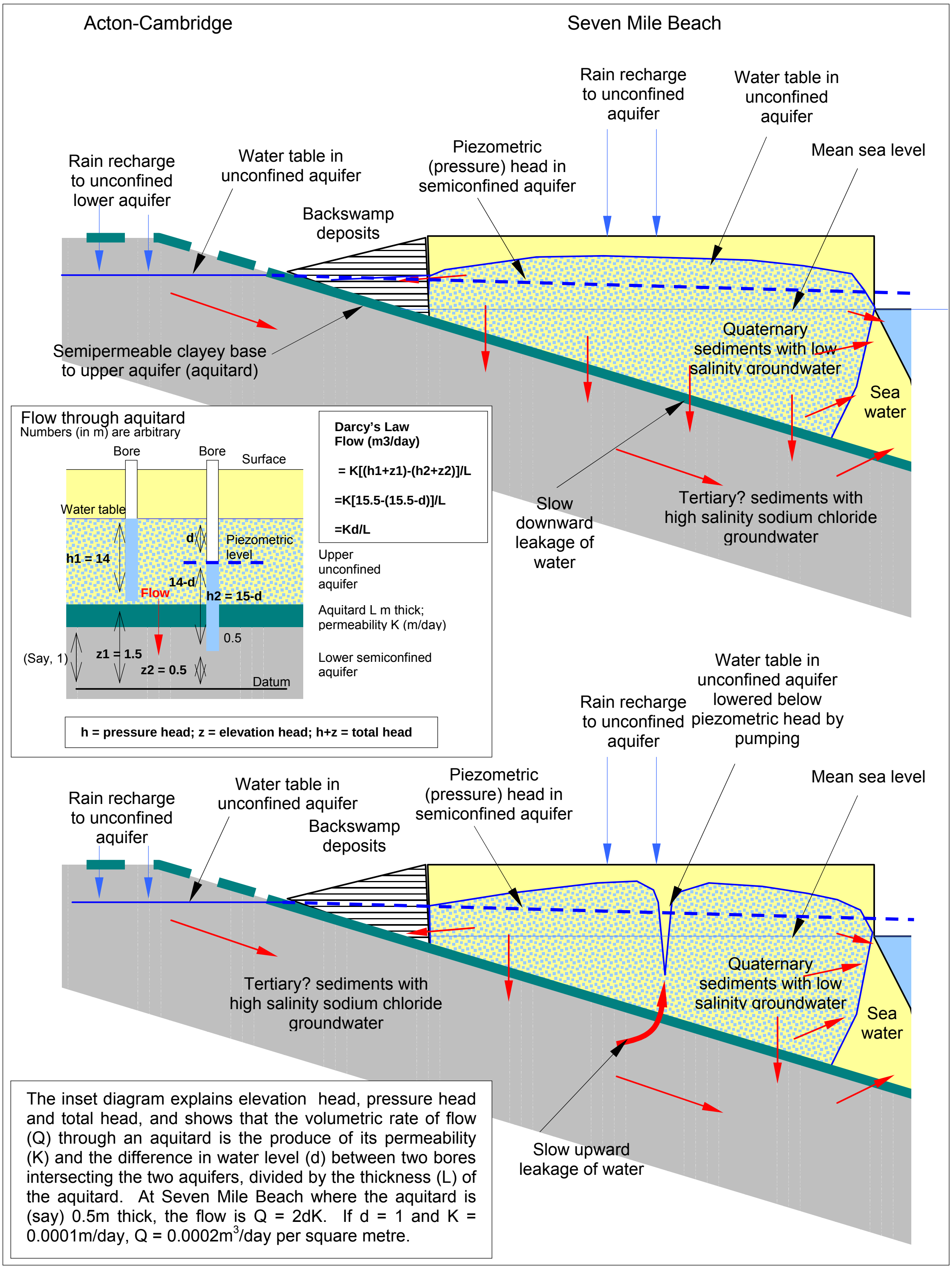


Figure 21. Schematic hydrogeological model for Seven Mile Beach arising from the current review. The upper unconfined aquifer is separated from the lower semiconfined aquifer by a thin low permeability clayey layer (an aquiclude). In the upper diagram, the total pressure head (inset) in the unconfined aquifer is greater than that in the semiconfined aquifer, so that the unconfined aquifer leaks water into the lower aquifer. In the lower diagram, the situation is locally reversed (in this case, by pumping), permitting upwards leakage of more saline water into the upper aquifer.

4.5 Groundwater quality

4.5.1 General comments

Cromer (1981) identified three types of groundwater at and near the Royal Hobart Golf Club, and it appears from subsequent work (particularly Roberts, 1988), that the same situation applies over most of the Seven Mile Beach spit.

The three groundwater types are:

- Type 1: A moderate – high salinity sodium chloride groundwater occurring in the lagoonal and backswamp sediments landward of the spit, and also beneath it in the lower, semiconfined aquifer. Salinities are generally higher than 3,000 – 4,000mg/L TDS.

- Type 2: A low – moderate salinity groundwater of the calcium bicarbonate type, occurring mainly in the upper unconfined aquifer (ie in the beach, marine and aeolian sediments of the spit itself). Salinities range from 100 – 1,000mg/L TDS.

- Type 3: A moderate salinity mixture, in varying proportions, of Types 1 and 2 groundwaters, present wherever the two are in contact (ie along the lateral and lower boundaries of the unconfined aquifer. Salinities range from 1,000 – 2,000mg/L TDS.

Appendix 1 reproduces various water analyses to illustrate the different water types. The differences are also shown by graphing the relative proportions of major ions (sodium, chloride, calcium, bicarbonate, sulphate) in Figures 18 and 19.

4.5.2 Variability in Type 2 groundwater in the upper aquifer

The salinity of Type 2 groundwater varies laterally and vertically in the upper unconfined aquifer.

Lateral variability

In the early – mid 1970s, salinity ranged from about 100mg/L at the water table in the middle of the spit, to about 300 – 500mg/L TDS near Seven Mile and Five Mile Beaches (Figure 22).

Lateral (and vertical) mixing was recognised at the Royal Hobart Golf Club (Cromer, 1981; Figure 23), probably due to pumping for irrigation, but complicated by the use of fresh mains water (salinity less than 50mg/L) as well.

In Figure 23, the salinities of recent groundwater samples tested by Sinclair Knight Merz (2005) have been superimposed on the 1981 contours over the Seven Mile Beach township. While there are differences between the two sets of data (the latest figures probably more closely match the 1976 contours in Figure 22), the situation appears essentially as it did a quarter of a century ago.

Vertical variability

Salinity increases with depth in the unconfined aquifer, ranging up to about 1,000mg/L TDS near its base, and reflecting the longer time the water has spent in contact with the sediments. Salinities higher than this probably indicate Type 2 or Type 3 water (ie the latter caused by Type 2 water mixing with Type 1 water).

Figure 17 shows Type 1 and 2 salinities with depth in Roberts' (1988) bores on transect B. Recent monitoring by Pitt and Sherry (I. Woodward, *pers. comm*. July 2006) in the sixteen bores on RL8/1997 show an average electrical conductivity (EC) of about 950µS/cm (range 442 – 1556µS/cm), corresponding to an average salinity of about 625mg/L (range 300 – 1,000mg/L).

The results from Roberts (1988) and Pitt and Sherry are combined in Figure 24.

4.5.3 Suitability of the groundwater for agriculture and human consumption

Previous reports (eg Cromer, 1979, 1981, 2003) have discussed in detail the suitability of coastal sands groundwaters for agricultural and human consumption. Interested readers are referred to these.

Type 1 groundwater
Type 1 groundwater is too saline for human potability and of very limited agricultural use.

Type 2 groundwater
This low – medium salinity, near-neutral groundwater is very hard, but suitable for all agricultural uses, and, subject to satisfactory bacteriological analysis, suitable for human consumption[52].

Type 3 groundwater
This medium salinity groundwater is suitable for most agricultural uses, but generally too saline for human consumption.

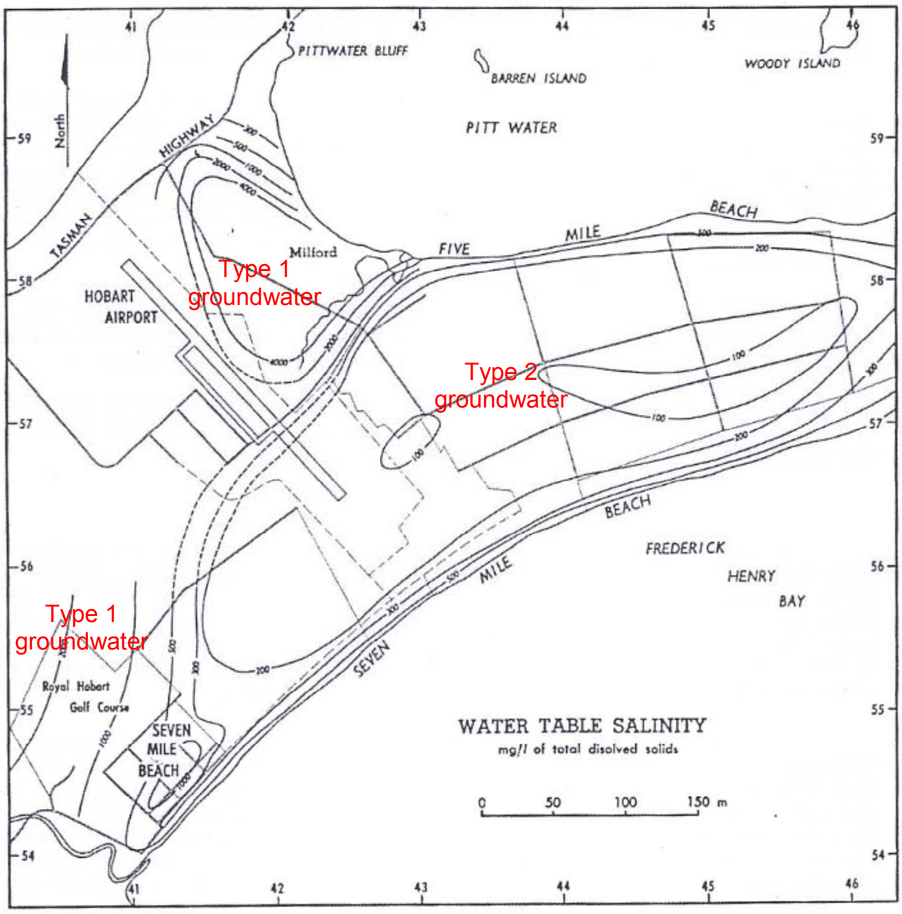


Figure 22. Water table salinity distribution of Types 1 and 2 groundwater at and near Seven Mile Beach in the early – mid 1970s, from Cromer and Sloane (1976).

4.5.4 Sea water intrusion

There are no documented instances of sea water intrusion[53] in Tasmania, despite the widespread extraction of groundwater from coastal sands aquifers for both domestic and large-scale irrigation uses. However, as discussed in previous sections, groundwater extraction on a scale for irrigation purposes appears to have locally caused the mixing of Type 1 with Type 2 water. The process possibly happens naturally at various times.

[52] 500mg/L TDS is commonly regarded as a desirable maximum salinity for human consumption, although up to 1,000mg/L is acceptable. Acceptability varies between consumers, however, and many commercially-available mineral waters have higher salinities.

[53] Sea water intrusion means the invasion of existing groundwater with sea water of a salinity around 33,000 – 34,ooomg/L TDS. At Seven mile Beach, the mixing of Type 2 water with Type 1 water is not considered part of this process.

Section 4.4.9 discussed the theoretical shape and inland extent of the fresh water – sea water interface which exists in all unconfined coastal aquifers – whether they comprise sand, or fractured solid rock. Roberts' (1988) bores on transect B appear to have penetrated the interface, which extends up to about 50m inland from high water mark.

Sea water intrusion is unlikely for most current domestic-scale uses at Seven Mile Beach, and for large-scale extraction as well if it is located at sufficient distance from the coast. Intrusion could be induced at any time by pumping from one or more bores close enough to the coast for water table drawdowns to have a hydraulic effect on the sea water – fresh water interface.

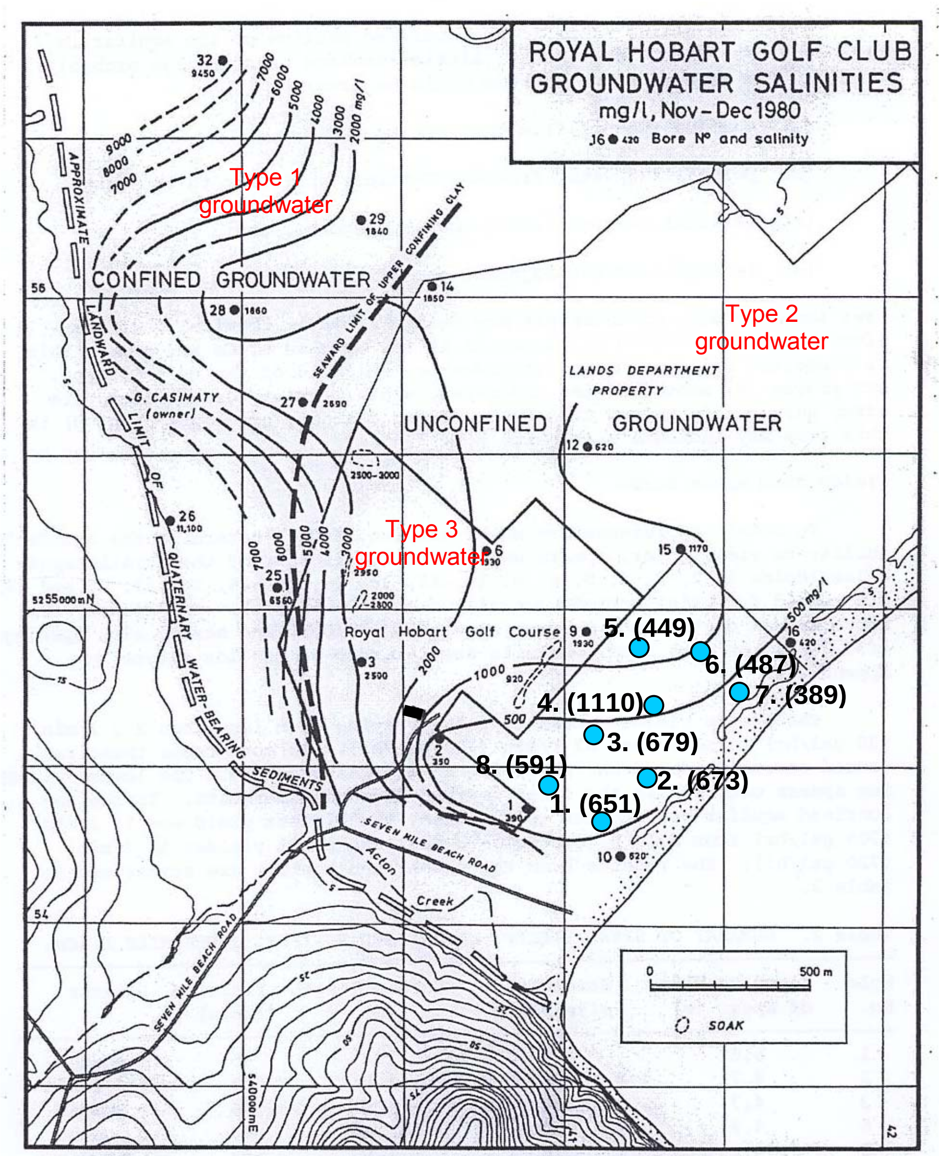


Figure 23. Groundwater salinities and contours (mg/L) at and near the Royal Hobart Golf Club in Nov – Dec 1980, (from Cromer, 1981), and in eight monitoring bores (blue circles; installed 1999) in June 2005 (Sinclair Knight Merz 2005).

4.6 Groundwater contamination

The potential exists to affect groundwater quality and use at Seven Mile Beach through a variety of sources, including sea water intrusion, pumping which induces mixing of different groundwater types, garden and agricultural chemicals, domestic wastewater disposal, runoff from metal roofs and bitumen roads, accidental spills of oils, greases, fuels, and deliberate burial of solid or liquid wastes.

4.6.1 Evidence for contamination of the Seven Mile Beach aquifer

General comments

Groundwater contamination at Seven Mile Beach is likely to concern at least some of the issues listed above that have affected Type 2 groundwater in the unconfined aquifer. For example,

- the area is unsewered, and domestic wastewater is disposed of on-site at each house,
- as discussed in this report, there is evidence of mixing of groundwater types, and
- there is a known history of localised hydrocarbon contamination of groundwater on Commonwealth land at Hobart Airport.

These actual and potential effects can only be assessed by monitoring and analysis – principally of groundwater, but in some instances also of soil or air.

Monitoring groundwater for the effects of domestic wastewater disposal

Since 1999, Sinclair Knight Merz (2005) has been monitoring groundwater in eight bores in the Seven Mile Beach township, to assess whether the disposal of domestic wastewater – principally from septic tank absorption trenches – was affecting groundwater quality.

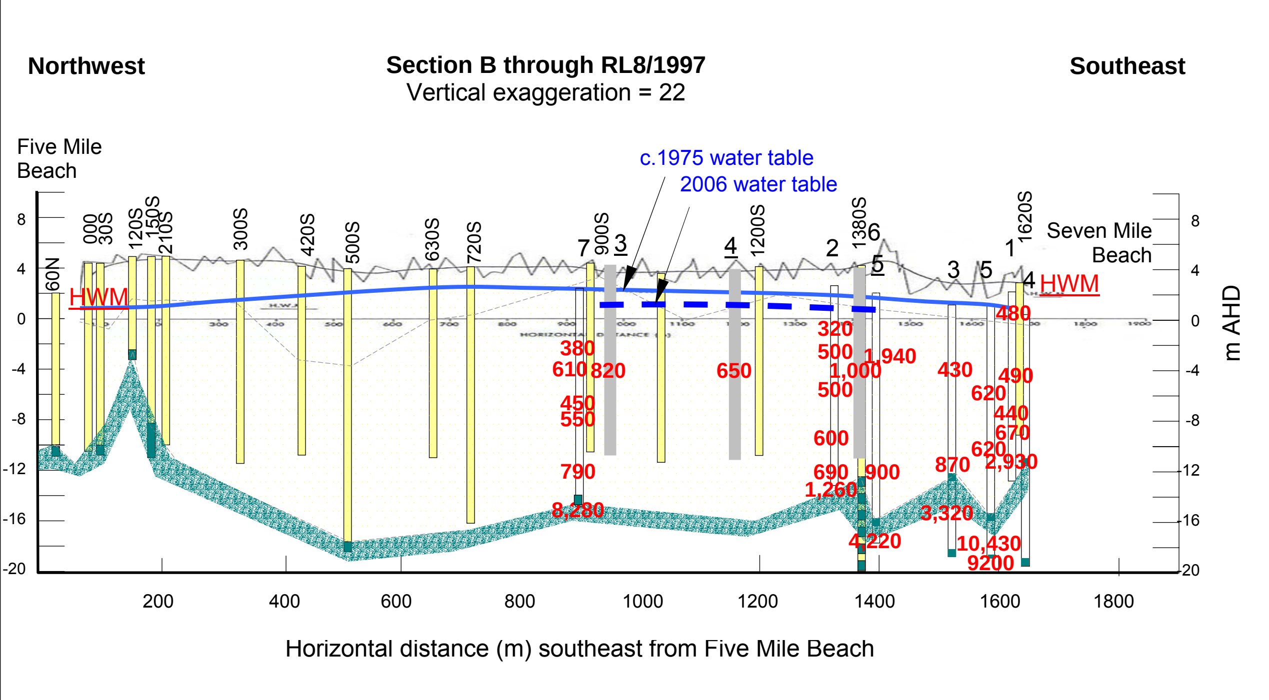


Figure 24. Vertical variability in groundwater salinity on transect B on RL8/1997 at Seven Mile Beach. Salinities (in red type) are in mg/L TDS. Bores as per Figure 11. Source: Roberts (1988) and Pitt and Sherry (I. Woodward *pers. comm*. July 2006).

The 2005 report concluded that "As observed with the previous monitoring episodes at Seven Mile Beach, the groundwater sampled from the monitoring bores contains very low levels of Thermotolerant Coliforms (TC) and *Faecal Streptococci*. However, these levels are representative of those that would occur within a natural stream environment and are therefore not of concern." In fact, of the many separate TC results from nine sampling episodes, TC was detected only twice (1cfu/100mL in bore 4 in November 1999, and 40cfu/100mL in bore 6 in December 2003).

A review of the data shows that there is a fair degree of variability in some tested analytes, both between sampling episodes and within single episodes. For example:

- salinity of individual bores differed by as much as 30% between some runs: the salinity of the groundwater in bore 4 was 1,500mg/L in October 2002, and 934mg/L six months later.

- Total nitrogen since 1999 averaged 3mg/L (range 0.4 to 39mg/L) but within individual episodes values between bores typically varied by a factor of ten,
- Total phosphorus since 1999 averaged 0.6mg/L (range 0.02 to 5mg/L) but within individual episodes values between bores also typically varied by a factor of ten,

The report went on to state: "…it is not necessary to sewer Seven Mile Beach in the immediate future…"

With these comments in mind, it is instructive to review contamination issues in similar coastal sand aquifers elsewhere in Tasmania.

4.6.2 Evidence for contamination of other unconfined coastal sand aquifers

Nine Mile Beach

The following is taken from Cromer (2003).

Although some groundwater part-analyses (electrical conductivity, pH) are currently being done by Nine Mile Beach residents in association with the Glamorgan Spring Bay Landcare Committee, no systematic sampling programme has been attempted to measure a full range of potential contaminants. Data are therefore very limited.

Domestic wastewater disposal is a potential source of contamination (principally bacteria and nutrients) which has received some attention at Nine Mile Beach, and elsewhere where shallow groundwater resources exist.

The first indication of possible bacteria in groundwater was a single water analysis collected during the 21 day pump test of the 24-spear array in 1979. It returned detectable bacteria at low levels, but this single unrepeated result may have been due to surface contamination during sampling.

Palfreyman (2002) investigated groundwater quality in the vicinity of an operating septic tank and absorption trench at the eastern end of the Nine Mile Beach spit. Seven sampling bores were installed in a north-south line extending from the trench coastwards for about 55m, and the groundwater from each was analyses for bacteria and nutrients (nitrogen and phosphorus species). The depth to groundwater was between 3.6m and 5.5m. The water table gradient in the vicinity of the trench was about 0.1 (which seems unusually high), but less than 0.01 at greater distances downgradient.

Bacteria (*E. coli*) in the trench at levels of 400,000/100mL were reduced to 5,000/100mL in groundwater immediately below the trench. Bacteria were undetected (<1/100mL) in groundwater at greater distances, except for a presumptive[54] 300/100mL reported from a bore about 15m downgradient. Ammonia nitrogen at 200mg/L in the trench was converted to nitrate nitrogen during vertical infiltration to the water table beneath the trench, and thereafter, nutrient levels in the groundwater attenuated in a downgradient direction. The author suggested that wastewater impacts on groundwater are restricted to small areas around operating absorption trenches and similar installations, but recommended more monitoring of these effects, and suggested that drinking water bores be located either upgradient (rather than downgradient) from disposal systems, or be placed ('set back') at least 40m downgradient from disposal systems.

Setback distances between water bores and disposal systems in unconfined aquifers can also be estimated using the viral die-off method, suggested by Beavers and Gardner (1993), extended by Cromer *et. al.* (2001), and routinely used in the computer programme Trench®3.0 (Cromer 1999a, 1999b).

A range of wastewater disposal methods other than standard septic tanks and absorption trenches would be acceptable at Nine Mile Beach. These include low water (eg composting) toilets and separate greywater disposal in beds or trenches, and aerated treatment systems and spray or

[54] A *presumptive* result lacks a confirmation analysis, and so may not necessary be accurate.

shallow surface drip irrigation of secondary treated (ie chlorinated) effluent. Each of these would impact on the aquifer to different degrees.

Lauderdale and Roches Beach

In relation to Palfreyman's wastewater sampling at Nine Mile Beach, Cromer (2001b) reported similar but more definitive results from the shallow coastal sand aquifer at Lauderdale near Hobart[55]. About 500 houses on small suburban lots disposal of domestic wastewater in septic tanks and absorption trenches. In addition, all stormwater, including roof and bitumen road runoff, discharges directly to the aquifer via soakage pits. The potential clearly exists for groundwater contamination from a wide range of domestic sources, including wastewater, garden chemicals, detergents and other household chemicals, and fuels. There is minimal groundwater usage, so the risk of sea water intrusion is absent.

Despite the high residential density at Lauderdale, testing within the township for bacteria, nutrients, metals, organics including petroleum hydrocarbons, and pesticides, showed no significant effects on the groundwater or marine environment. Within the aquifer, bacteria, petroleum hydrocarbons and pesticides were not detected in any of the groundwater samples.

These results were explained by follow-up, detailed sampling in and near a single septic tank absorption trench. Bacteria levels in the trench ranged up to 8,600,000cfu/100mL. After one metre of wastewater infiltration through unsaturated sand to the water table, bacteria were reduced to non-detectable levels, total nitrogen was reduced by 90%, nitrogen as ammonia (NH_3-N; 140mg/L) was reduced to around 1mg/L, and nitrogen as nitrate (NO_3-N) increased from about 0.01mg/L to 10 to 30mg/L. Importantly, downgradient from the trench, NO_3-N decreased with distance, so that after 10 to 20m, it was reduced to 1mg/L. Orthophosphate (PO_4-P) at 15mg/L in the trench decreased to 5mg/L beneath the trench, to 1mg/L after 10 to 20m of groundwater travel, and to 0.1mg/L after 50m. These results indicate that each absorption trench is probably underlain by a restricted halo of groundwater with elevated nitrate and phosphate and little else, and that a short distance downgradient (probably less than a few tens of metres) the contaminants merge with background levels.

The 2001 report commented that "…it is contrary to current environmental dogma that a high septic tank density could result in relatively minor changes in groundwater quality. Furthermore, the environmental and economic benefits of such wastewater disposal outweigh the beneficial uses of the groundwater."

Similar results were found by Geary *et. al*. (1999), who investigated possible groundwater contamination of shallow sand aquifers at Dodges Ferry in southeastern Tasmania. The residential density is locally high, and there is no reticulated water supply. An initial survey of bore waters showed low levels of bacteria, and some isolated but relatively high nitrate levels, but generally the effect of wastewater disposal on groundwater quality was limited.

---

[55] The sand spit at Lauderdale is very similar to that at Seven Mile Beach. It comprises unconsolidated Quaternary beach sand with a capping of wind-blown sand, but sand permeability is lower at about 5 m/day. The sands extend vertically to a clay basement about 8 to 10 metres below sea level. Unconfined groundwater at depths of 1 to 2 metres is moving coastwards at 5 to 15 metres/year. Investigations involved sampling twelve shallow groundwater bores and six surface waters in the town, and a more detailed survey, involved sampling of seven water bores, a well, and effluent from an absorption trench, at a selected house. Water samples were collected in June and December 1997, and in May 1998.

5 POTENTIAL IMPACTS OF SAND MINING ON THE HYDROGEOLOGY OF THE SEVEN MILE BEACH SPIT

5.1 The sand mining proposal

Sanbar Pty. Ltd. has prepared a draft mining plan in conjunction with their consultants Pitt and Sherry Pty Ltd who will be drafting an Environmental Management Plan for use in any future development application. It proposes to extract sand by dry mining techniques from RL8/1997 to meet current demand of about 95,000m^3 (150,000t). The main issues from a hydrogeological viewpoint are:

- The first 20 years' mining will occur on a 150ha area recently harvested of *pinus radiata* and left unplanted.
- Rehabilitation of mined areas would include native tree plantings.
- Only dry sand will be extracted. A buffer of 0.7m is proposed between the base of the mine workings, and the highest expected water table level.
- Mining will occur along a 350m long face, with a maximum of 4ha open and not rehabilitated at any time.
- No on-site facilities will be present other than a crib room and portable toilet. A mobile tanker will be used for equipment refuelling.

5.2 Review of hydrogeological conditions on RL8/1997

The following hydrogeological observations and inferences (Figure 25), discussed previously in this report, are relevant:

- The unconfined aquifer underlies all of the retention licence to depths of about -14m AHD
- The average height of the ground surface is 3.4m AHD (range 3.0 – 4.1mAHD)
- The average water table elevation was 0.7m AHD (range 0.4 – 1.1m AHD) in July 2006
- Based on short to medium term measurements (Dec 2005 – July 2006) the estimated short term (annual) fluctuation in the elevation of the water table on RL8/1997 is 0.5m (ie 0.25m above and below the July 2006 levels,
- The average thickness of dry sand over RL8/1997 in July 2006 was 2.8m (or 2.6m assuming the lower half of the capillary fringe is saturated), leaving 1.9m available for mining if a 0.7m buffer to the water table is maintained. Allowing for a 0.25m increase in the water table annually, the available thickness reduces, on average, to 1.65m.
- The groundwater in the unconfined aquifer is Type 2, of low to moderate salinity and containing mainly calcium bicarbonate with subordinate sodium chloride; its average salinity is about 600mg/LTDS (range 300 – 1,000mg/L TDS).
- Several natural and man-induced factors will, or might, alter the elevation of the water table on RL8/1997, over various time scales, in a complicated, unpredictable manner (Table 3). During the life of the mine (decades) the net change at any time might be no change, or a lowering or raising of the water table, compared to current levels.

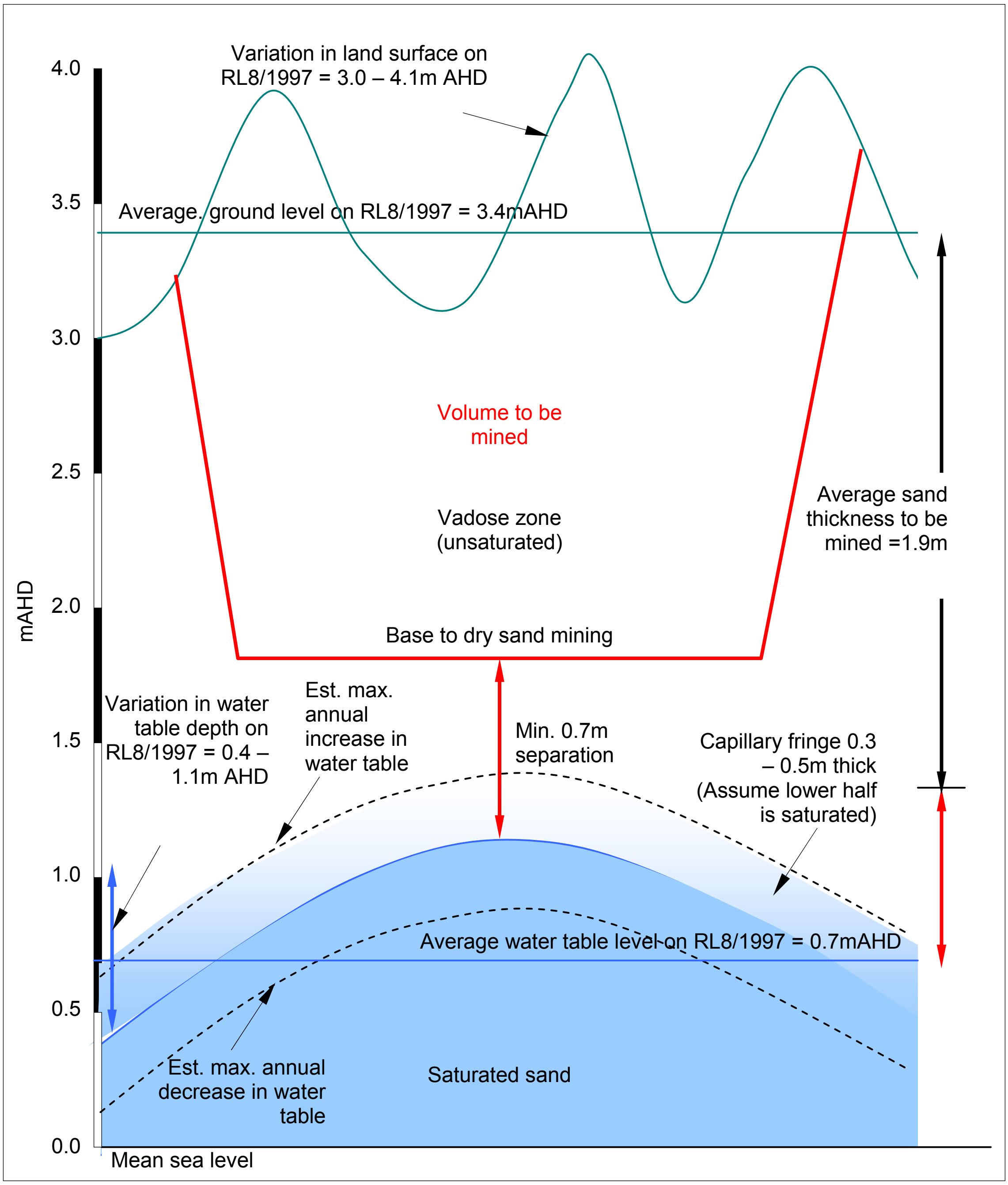


Figure 25. Schematic near-surface section showing the relationships between proposed depth of mining, the water table, capillary fringe and land surface. Water table elevations and available depth of mineable sand are for July 2006, and may fluctuate unpredictably.

5.3 Potential impacts on groundwater during sand mining on RL8/1997

5.3.1 General comments

The potential exists to affect groundwater conditions on RL8/1997 through a variety of causes, including:

- accidental spills of oils, greases, fuels, and burial of solid or liquid wastes, and
- groundwater extraction for irrigation.

This report presumes that the first group of these issues will be managed in an environmentally acceptable manner in accordance with the draft mining plan and any conditions attached to the operating permit for the mine.

5.3.2 Groundwater extraction for irrigation

It is possible that groundwater may need to be extracted for irrigation during progressive revegetation of the mined areas. A maximum of 15ha might require irrigation at any one time, and then only if rainfall was insufficient.

The draft mining plan estimates that in dry years about 45ML would be required annually for irrigation[56]. If so, the general effects on the unconfined aquifer will be minimised if:

- The water is extracted from shallow spear bores, soaks or horizontal bores over a wide enough area to reduce water table drawdown and minimise the potential to induce Type 1 water into the aquifer from beneath, and

- As far as is feasible, the water is extracted from beneath the mined areas to enhance recycling (an uncertain but probably significant proportion of the irrigation water will quickly infiltrate the 0.7m thickness of buffer sand and recharge the shallow water table).

The water quality near the water table everywhere in the unconfined aquifer beneath RL8/1997 will generally be suitable for irrigation. With no or minimal fertiliser use, it is not expected that groundwater quality will be adversely affected in any significant manner by irrigation.

5.4 Potential impacts of water table fluctuations on sand mining on RL8/1997

Fluctuating water table levels have the potential to affect sand mining operations in a more significant way than sand mining will affect groundwater conditions. A list of possible causes of water level changes is summarised in Table 2.

The key issue is that future water table elevations are unpredictable, but they may be substantial; for example, this report has shown that, largely due to below average rain, the water table over RL8/1997 has fallen on average by about 0.8m since the mid 1970s. It is possible that a similar rise in water table elevation will occur in the medium to long term.

In a practical sense, mining will be conducted against a continuous net change in water table elevation from a variety of causes, but the effect will be generally minor and not noticeable in the short term unless careful and continuous water table measurements are taken. Operations will maintain a nominal 0.7m thickness of sand buffer above the water table, but over time, the elevation of the floor of the mine may need to alter from place to place in response to water table changes. The result may be a series of different floor levels recording where the water table was at the time the areas were mined. This effect would barely be noticeable over the areal extent of the mine.

In the medium to long term, the water table may remain essentially constant, or may fall (it cannot, however, fall below 0mAHD). If so, no impacts on mining operations are expected. However, if the water table rises to and above the floor of previously mined areas these sites will first become swampy, with temporary ponded water after rain (and attendant impacts on revegetated species), and then more permanent ponds of groundwater. The areal extent of any ponding will be influenced by the floor levels of the mine as well as the rate and extent of water table rise. This exposed groundwater will evaporate at a rate approximating the pan evaporation rate for the district, but the net loss from the aquifer compared to pre-mining conditions is difficult to quantify because the ponded water also receives 100% recharge from rain (rather than the 7% or so which is inferred to infiltrate to the water table under current conditions).

[56] The 45ML per year of irrigation water is not an every-year demand but a worst-case-year scenario to return a 10%ile rainfall year to a 50%ile irrigation amount, ie. It would only be required in a very dry year and not every year.

The level and areal extent of ponded groundwater will continue to fluctuate in an unpredictable manner, but it is not expected the ponds will be associated with significant deleterious issues. It is common in nature for shallow water tables to temporarily or permanently approach, or even lie above, the ground surface and so cause ponding.

Trying to control or eliminate ponded groundwater, if it occurs during or after mining, is likely to be expensive, time-consuming and unnecessary.

6 CONCLUSIONS AND RECOMMENDATIONS

This review of previous investigations and reports has shown that at Seven Mile Beach an upper unconfined aquifer of beach, aeolian and shallow marine sand extends the full length and width of the spit, and covers about 15km^2. This aquifer:

- is bounded to the south and north by Seven Mile and Five Mile Beaches, and the drainage lines passing from Milford in the east to the township of Seven Mile Beach in the southwest,
- is bounded beneath by a thin (0.5m) semipermeable clay, sandy clay and clayey sand aquitard at depths ranging from about 10 – 15m below mean sea level (AHD),
- is completely full of low – moderate salinity (Type 2) groundwater except where salinity appears to increase near aquifer boundaries,
- contains about 60,000ML of groundwater with salinities in the approximate range 100mg/L to 1,000mg/L of Total Dissolved Solids, which is within the potable range provided it contains no deleterious constituents (eg bacteria),
- is recharged mainly via infiltrating rain (it is estimated that about 7% incident rain infiltrates to groundwater) but also possibly by upward leakage of moderate – high salinity groundwater (Type 1; salinities higher than about 3,000 – 4,000mg/LTDS) from a lower aquifer semiconfined by the aquitard and underlying the full lateral extent of the spit and beyond,
- has permeabilities up to 10m/day and a specific yield of about 0.25,
- is able to produce yields in individual shallow spear bores of up to 2,000L/hour depending on bore construction and installed depth,
- has a sustainable yield roughly equal to rain less evapotranspiration, which varies monthly and annually, but in normal years may be 500ML/year, (350,0000L/year/hectare, or about 1,000L/day/hectare),
- is under stress from current levels of groundwater use which total about 200ML a year but which appear (locally at least) to be lowering the water table sufficiently so as to induce upward and lateral leakage of Type 1 groundwater into the unconfined aquifer,
- is not significantly affected by small-scale domestic wastewater disposal in the vicinity of on-site disposal systems.

Hydrogeological issues for proposed dry sand mining on RL8/1997 in the middle of the spit relate more to the possible impacts of water table fluctuations on mining, than to any impacts that mining might have on groundwater conditions. The most significant issue is the potential for the water table in the medium to long term to flood the mined-out workings, impacting on revegetation plans and causing local ponding of groundwater. In the short to medium term, this issue (if it occurs at all) will not cause significant concerns for on-going mining operations, which will simply adjust its excavation depth to accommodate the water table changes. In the medium to long term (ie decades), this issue (if it occurs at all) might, by reducing the thickness of dry sand, affect the economics of the exercise or instigate a move towards both dry and wet mining techniques.

To understand the influences on water table fluctuations, and as an aid to future planning, environmental management at the mine ought to include a simple, long term groundwater monitoring programme. This should involve the collection of at least the following information within RL8/1997:

- Weekly depth to groundwater in the existing monitoring bores,
- Six monthly groundwater quality from several of the bores (tested at least for TDS, electrical conductivity, pH, chloride, bicarbonate, sulphate, sodium and calcium)
- Installation and other details of any irrigation bores and associated new observation bores, and
- Full records of groundwater irrigation use

7 REFERENCES

Anon (1958). Summary of investigations on ground water on Royal Hobart Golf Club property at Seven Mile Beach. *Unpublished report for the Royal Hobart Golf Club by consulting engineers Griggs Valentine (February – April 1958).*

Anon (1993). EL 20/89 Llanherne Sand Project – Review of Environmental Issues. *Unpublished report for Sanbar Pty. Ltd. (November 1993).*

Bacon, C. A. (1992). Sand at Dysart. *Report Dept. Mines Tasm., 1992/05.*

Baillie, P. W. and Leaman, D. E. (1989). Southeastern Tasmania, *in* Burrett, C. F. and Martin, E. L. (Eds), (1989). Geology and Mineral Resources of Tasmania. *Geol. Soc. Australia Inc. Special Publication 15*; pp365 – 366.

Beavers, P. D. and Gardner, E. A. (1993). Prediction of virus transport through soils. *Australian Water and Wastewater Association, Technical Papers of the 15th Federal Convention*, Gold Coast, Australia, 18-23 April 1993 (Volume 2, pp 530-535).

Benyon, R. Theiveyanathan, S and Doody, T (2006). Impacts of tree plantations on groundwater in south-eastern Australia. *Australian Journal of Botany* 54(2) 181–192

Bouwer, H. (1978). *Groundwater Hydrology*. McGraw-Hill, New York. pp480.

Colhoun, E. (1975). A Quaternary Climatic Curve for Tasmania. *Australasian Conference on Climate and Climatic Change. Royal Meteorological Society, Monash University, December 1975.*

Cromer, W. C. (1972). Groundwater prospects, Nine Mile Beach. *Tech. Report 17, Dept. Mines Tasm.,* pp 157-163.

Cromer, W. C. (1974a). Water in coastal sands. *Tech Report 19 Dept. Mines Tasm. pp 128 – 135.*

Cromer, W. C. (1974b). Groundwater prospects, Cape Sorell and Braddon Point, Western Tasmania. *Unpublished Report Dept. Mines Tasm. 1974/13.*

Cromer, W. C. (1976). Determination of aquifer parameters in unconsolidated coastal sands. *Unpublished Report Dept. Mines Tasm. 1976/9.*

Cromer, W. C. (1979). Groundwater from Coastal Sands at Greens Beach, Northern Tasmania. *Bull. Geol. Surv. Tasm*. 57.

Cromer, W. C. (1980). Groundwater investigations at Milford for the Tasmania Golf Club. *Unpublished Report Dept. Mines Tasm. 1981/30.*

Cromer, W. C. (1981). Groundwater investigations at Seven Mile Beach for the Royal Hobart Golf Club. *Unpublished Report Dept. Mines Tasm. 1981/3*

Cromer, W. C. (1983a). Tasmania Golf Club Groundwater Irrigation Scheme. *Unpublished Report by William C. Cromer Pty. Ltd. for the Tasmania Golf Club (January 1983).*

Cromer, W. C. (1983b). Proposed groundwater irrigation scheme, Westlands Nursery, Seven Mile Beach. *Unpublished Report for Westlands Nursery by William C. Cromer Pty. Ltd. (June 1983).*

Cromer, W. C. (1990a). The feasibility of supplementing mains irrigation water with groundwater at the proposed new Llanherne Golf Club. *Unpublished Report for the Llanherne Golf Club by Environmental & Technical Services Pty. Ltd. (July 1990).*

Cromer, W. C. (1990b). Preliminary investigations for a proposed groundwater irrigation scheme at the Llanherne Golf Club. *Unpublished Report for the Llanherne Golf Club by Environmental & Technical Services Pty. Ltd. (September 1990).*

Cromer, W. C. (1993). Geology and groundwater resources of the Devonport-Port Sorell-Sassafras Tertiary Basin. *Bull. Geol. Surv. Tasm. 67.*

Cromer, W. C. (1995). Groundwater irrigation system, Royal Hobart Golf Club – Review and Recommendations. *Unpublished Report for the Royal Hobart Golf Club by Environmental & Technical Services Pty. Ltd. (August 1995).*

Cromer, W. C. (1999a). Trench™3.0: An AIEH computer software application for managing on-site wastewater disposal. *Environmental Health Review*, May 1999, pp 23-25.

Cromer, W. C. (1999b). Trench™3.0: A computer application for site assessment and system sizing, in Patterson, R. A. (Ed.) *On-site '99 – Proceedings of the On-Site '99 Conference: Making on-site wastewater systems work*. University of New England, Armidale, 13-15 July 1999, pp 85-88.

Cromer, W. C. (2001a). Proposed subdivision, Acton Road, Seven Mile Beach: Domestic wastewater management. *Unpublished report for estate of G. Casimaty (June 2001).*

Cromer, W. C. (2001b). Treating domestic wastewater in a coastal sand aquifer near Hobart. *in* Patterson, R. A. (Ed.) *On-Site '01 – Proceedings of the On-Site '01 Conference: Advancing On-site Wastewater Systems; Design and Maintenance*. University of New England, Armidale, 25-27 September 2001.

Cromer, W. C. (2003). The geology and groundwater resources of Nine Mile Beach, eastern Tasmania. *Tasmanian Geological Survey Record 2003/07. Mineral Resources Tasmania.*

Cromer, W. C. and Leaman, D. E. (1980). Comparative pump test analysis of a multiple bore array in a thin unconfined aquifer. *J. geol. Soc. Aust.*, 27, pp105 – 116.

Cromer, W. C. and Matthews, W. L. (1973). Groundwater investigations at Currie, King Island. *Unpublished Report Dept. Mines Tasm. 1973/94.*

Cromer, W. C. and Sloane, D. J. (1976). The hydrology of Seven Mile Beach. *Unpublished Report Dept. Mines Tasm. 1976/10.*

Cromer, W. C. and Stephens, J. R. (1992). *Lauderdale Tip: Development Proposal and Environmental Management Plan.* Report prepared by Environmental & Technical Services Pty. Ltd. for Clarence City Council, May 1992.

Cromer, W. C., Gardner, E. A. and Beavers, P. D. (2001). An improved viral die-off method for estimating setback distances. *in* Patterson, R. A. (Ed.) *On-Site '01 – Proceedings of the On-Site '01 Conference: Advancing On-site Wastewater Systems; Design and Maintenance*. University of New England, Armidale, 25-27 September 2001.

Duncan, D. McP. (1999). A study of the sand resources of Southern Tasmania. Unpublished Report Dept. Mines Tasm 1999/03.

Forster, M. C. (1977). EL 7/75 Pittwater – Progress Report. *Unpublished report for Louisa Mining Corp. N. L. (January 1977).*

Forster, M. C. (1978). EL 7/75 Pittwater – Final Report. *Unpublished report for Louisa Mining Corp. N. L. (July 1978).*

Geary, P. M., Robertson, G. and Whitehead, J. H. (1999). On-site systems and catchment management. *in* Patterson, R. A. (Ed.) *On-Site '01 – Proceedings of the On-Site '01 Conference: Advancing On-site Wastewater Systems; Design and Maintenance*. University of New England, Armidale, 25-27 September 2001.

Glover, H. H. (1964). The pattern of fresh water flow in a coastal aquifer. *Wat. Supply Pap. US geol. Surv. 1613-C, pp32-35.*

Green, D. C. (1981). Stable Isotope Investigation of Groundwater at Seven Mile Beach. *Unpublished Report Dept. Mines Tasm. 1981/54.*

Gulline, A. B. (1982). Geological atlas 1:50,000 Series. Sorell. *Dept. Mines Tasm.*

Gulline, A. B. (1984). Geological Survey Explanatory Report, Geological atlas 1:50,000 Series. Sorell. *Dept. Mines Tasm.*

Jacob, C. E. (1963). Determining the permeability of water-table aquifers. *in* Bentall, R (comp) Methods of Determining Permeability, Transmissibility and Drawdown. *US Geological Survey Water-Supply Paper 1536-I*, pp. 245-271.

Leaman, D. E. (1971). The geology and ground water resources of the Coal River Basin. *Underground Wat. Supply Pap. 7, Dept. Mines Tasm*

Matthews, W. L. (1963). Underground water at Seven Mile Beach Golf Course. *Tech. Report 8 Dept. Mines Tasm. Pp144 – 145.*

Matthews, W. L. and Donaldson, R. C. (1994). A review of sand resources in the Hobart area. *Mineral Resources Tasmania Rept 1994/10.*

Matthews, W. L. and Donaldson, R. C. (2001). Groundwater Prospectivity of Tasmania (1:500,000 map). Tasmanian Geological Survey, *Mineral Resources Tasmania*

Miedecke, J. A. (1993). ELA 29/89, Seven Mile Beach – Preliminary Environmental Management Plan. *Prepared for CSR Ready Mix.*

Mills, J. (2000). A review of the socio-economic and environmental issues relating to the potential extraction of sand in the Hobart region. *Unpublished Report Dept. Mines Tasm. 2000/03.*

Morrison, K. C. (1994). EL 20/89 – Annual Report Year 2 (25/9/93 – 25/9/94). *Unpublished report for North West Bay Co. Pty. Ltd. (September 1004).*

Morrison, K. C. (1995). EL 20/89 – Annual Report Year 3 (25/9/94 – 25/9/95). *Unpublished report for Sanbar Pty. Ltd. (September 1995).*

Palfreyman, C. (2002). Hydrogeology and contamination potential of the Dolphin Sands aquifer. *Unpublished Honours thesis, School of Earth Sciences, University of Tasmania, November 2002.*

Roberts, P. (1988). Groundwater salinity at Seven Mile Beach. *Unpublished Honours thesis, Department of Geography, University of Tasmania.*

Sharples, C. (2002). *Geomorphology of the South Eastern Region of Tasmania. Explanatory report to accompany digital mapping dataset.* Prepared for the Integrated South East Coastal Management Authority.

Sharples, C. (2004). *Indicative Mapping of Tasmanian Coastal Vulnerability to Climate Change and Sea Level Rise: Explanatory Report.* Prepared for the Department of Primary Industries, Water and Environment, Hobart (December 2004).

Sinclair Knight Merz (2005). Seven Mile Beach Groundwater Monitoring – June 2005. *Report prepared by consulting engineers Sinclair Knight Merz Pty. Ltd. for Clarence City Council, June 2005.*

Sloane, D. J. and Weldon, B. D. (1993). Sand resources in the Hobart area (Revision 1). *Report Div. Mines Tasm. 1993/01.*

Stephenson, P. C. (1969). Groundwater prospects at Nine Mile Beach. *Unpublished Report Dept. Mines Tasm.*

Thom, B. G., Polach, H. A. and Bowman, G. M. (1978). Holocene age structure of coastal sand barriers in New South Wales, Australia. *Unpublished report, Department of Geography, Faculty of Military Studies, University of New South Wales, Duntroon, Australian Capital Territory.*

Thom, B. G., Bowman, G. M., Gillepsie, R., Temple, R. and Barbetti, M. (1981). Radiocarbon dating of Holocene beach-ridge sequences in south-east Australia. *Monograph No. 11, Department of Geography, University of New South Wales, Duntroon, Australian Capital Territory*

Threader, V. M. (1974). Sand resources, Sandford – South Arm Peninsula. *Tech. Report 17 Dept. Mines Tasm. pp 49 – 54.*

Threader, V. M. (1984). Sand resources on a 24 hectare extension to the Royal Hobart Golf Club, Seven Mile Beach. *Unpublished Report Dept. Mines Tasm. 1984/32.*

APPENDIX 1

Water analyses from coastal sands at Seven Mile Beach

Explanatory Notes to Appendix 1

Typical analytes
Groundwater analyses are typically tested for the following:

- pH, electrical conductivity (EC), total dissolved solids (TDS), silica (SiO_2)

- Major cations
- Calcium (symbol Ca), magnesium (Mg), Potassium (K), Sodium (Na), iron (Fe)

- Major anions
- Carbonate (CO_3), Bicarbonate (HCO_3), Chloride (Cl), Sulphate (SO_4)

The following can be calculated from the above: temporary and permanent hardness (as $CaCO_3$), alkalinity (as $CaCO_3$), percent sodium, sodium adsorption ratio, etc.

A wide range of minor constituents may be tested for specific purposes, including nutrients (nitrogen and phosphorus species), bacteria, trace or heavy metals (eg copper, lead, zinc, etc), and a wide range of organics.

Units of measurement
EC is measured in millisiemens/cm (mS/cm) or microsiemens/cm (µS/cm).

TDS, anions and cations are usually measured in milligrams/litre (mg/L), or for trace elements, micrograms/litre (µg/L)

Chemical equivalence of dissolved species
Cations (positively charged) and anions (negatively charged) should be present is roughly equal combining proportions in water. Their concentrations expressed as mg/L will not balance, but their concentrations expressed by their combining power as milliequivalents/litre (meq/L) should.

Concentrations expressed as mg/L indicate the salinity of a water analysis as well as the constituents present. Analyses can be more easily compared to others if constituents are expressed in meq/L, or as %meq/L. For example, the third column of following analysis shows that the predominant dissolved species is sodium, even though its concentration in parts per million is les than both bicarbonate and chloride.

Constituent	mg/l	meq/l	% meq/l
Silica (SiO_2)	<5	-	-
Iron (Fe)	<0.1	0.0	0.0
Calcium (Ca)	12	0.60	2.13
Magnesium (Mg)	26	2.14	7.58
Sodium (Na)	240	10.44	37.00
Potassium (K)	24	0.61	2.16
Bicarbonate (HCO_3)	450	7.38	26.15
Sulphate (SO_4)	<5	<0.1	0.0
Chloride (Cl)	250	7.05	24.98
Total dissolved solids	780	28	

Table 1a
Groundwater analyses from the upper, unconfined aquifer at Seven Mile Beach (from Cromer and Sloane, 1976)

Table 1. CHEMICAL ANALYSES[1] OF GROUNDWATER FROM SEVEN MILE BEACH
Expressed as milligrams per litre (mg/l), milligram equivalents per litre (meq/l), and percentage milligram equivalents per litre (% meq/l).

Constituent	Sea Water[2] mg/l	Sea Water[2] meq/l	Sea Water[2] % meq/l	751661[3] 15/10/75[4] mg/l	751661[3] 15/10/75[4] meq/l	751661[3] 15/10/75[4] % meq/l	751662 15/10/65 mg/l	751662 15/10/65 meq/l	751662 15/10/65 % meq/l
Silica (SiO_2)	0.04	-	-	12.	-	-	17	-	-
Iron (Fe)	0.0	0.0	0.0	<0.1	0.0	0.0	<0.1	0.0	0.0
Calcium (Ca)	400	20	1.0	51	2.55	2.0	53	2.65	2.33
Magnesium (Mg)	1 272	104.3	8.7	96	7.9	6.6	98	8.04	7.07
Sodium (Na)	10 560	464.6	39.0	980	43.12	36.0	1 030	45.32	39.84
Potassium (K)	380	9.88	1.0	49	1.27	1.0	50	1.30	1.14
Bicarbonate (HCO_3)	142	2.27	0.1	700	11.2	9.0	710	11.36	9.99
Sulphate (SO_4)	2 560	53.80	5.0	77	1.62	1.0	80	1.68	1.48
Chloride (Cl)	18 980	531.40	44.5	1 860	52.10	44.0	1 550	43.40	38.15
Total dissolved solids	34 380	1 186		3 200	120		3 310	114	
Hardness (as $CaCO_3$)				520			540		
Alkalinity (as $CaCO_3$)				510			580		
pH		8.0-8.4			7.6			7.8	
% difference in equivalents of cations and anions[5].		1.89			15.5			4.4	
Per cent sodium		79.2			80.9			81.3	
Sodium absorption ratio		58.9			18.9			19.6	

1. Analyses by Department of Mines Laboratory, Launceston, unless otherwise indicated.
2. Average composition; from Hem (1959), p. 10.
3. Department of Mines registered number.
4. Date of collection. Samples 751661, 751662, 751663, 751664 collected during pump test of Bore Hole 1 [EN426558] at 60, 120, 180 and 300 minutes respectively after start of test. Each sample represents a mixture of water from all levels in the aquifer, and is an average composition. Al <0.2 meq/l.
5. A check on the accuracy of the analysis. Percentage difference of cation, and anion, equivalents should be zero if all major constituents have been determined.

Sea water

Groundwater from the lower parts of the upper, unconfined aquifer in hole 1 (Figure 3), showing possible mixing with water from lower aquifer

Table 1b
Groundwater analyses from the upper, unconfined aquifer at Seven Mile Beach (from Cromer and Sloane, 1976)

Table 1. (continued)

Constituent	751691[6] 20/10/75 mg/l	meq/l	% meq/l	742648[7] 13/11/74 mg/l	meq/l	% meq/l	661[8] 15/10/65 mg/l	meq/l	% meq/l
Silica (SiO_2)	<5	-	-	10	-	-	n.d.	-	-
Iron (Fe)	<0.1	0.0	0.0	<0.1	0.0	0.0	n.d.	-	-
Calcium (Ca)	12	0.60	2.13	42	2.10	24.6	92	4.59	-
Magnesium (Mg)	26	2.14	7.58	10	0.82	9.6	17	1.40	-
Sodium (Na)	240	10.44	37.00	23	1.01	11.82	55	2.39	-
Potassium (K)	24	0.61	2.16	4.1	0.10	1.17	4	0.10	-
Bicarbonate (HCO_3)	450	7.38	26.15	207	3.39	39.68	n.d.	-	-
Sulphate (SO_4)	<5	<0.1	0.0	16	0.34	3.97	n.d.	-	-
Chloride (Cl)	250	7.05	24.98	28	0.78	9.13	72	2.03	-
Total dissolved solids	780	28		260	8.5		445	10.5	
Hardness (as $CaCO_3$)	140			146			300		
Alkalinity (as $CaCO_3$)	370			170			250		
pH		8.0			8.3			7.2	
% difference in equivalents of cations and anions[5]		4.4			10.6				
Per cent sodium		80.1			27.5			29.4	
Sodium absorption ratio		8.9			0.83			1.4	

5. A check on the accuracy of the analysis. Percentage difference of cation, and anion, equivalents should be zero if all major constituents have been determined.
6. Samples collected during pump test at Bore Hole 2 [EN428566], at 60 and 180 minutes after start of test. Al <0.2 meq/l.
7. Collected during brief pump test of shallow spear bore at site of Proline Hole 1 [EN415563].
8. Partial analysis by Government Analyst Laboratory, Hobart. Results supplied by CSIRO Forest Research Institute. Locality uncertain, collected from water table.

10-11

Groundwater from the lower parts of the upper, unconfined aquifer in hole 2 (Figure 3)

Table 1c
Groundwater analyses from the upper, unconfined aquifer at Royal Hobart Golf Club, Seven Mile Beach (from Cromer, 1981)

638

TASMANIAN DEPARTMENT OF MINES
WATER ANALYSIS

Field No. RH 1
Lab. reg. no. 802942
Surface sample?
Groundwater sample? YES

Project ROYAL HOBART GOLF CLUB
Location Practise Fairway, SE corner.

Co-ordinates 540890mE 5254390mN
Date sampled: 10.12.80
Sampled by: W. Cromer
Date analysed: 6.1.81
Analysed by: Dept. Mines, Launceston

Sampling conditions From spear bore installed to 5.0m and pumped at 45 litres/min (600 gph)

Landowner and address (if applicable)

Field observations
Colour clear
Odour slight H_2S
Taste slight
pH 8.2
Eh
Temperature (°C)
Specific conductance (μS/cm at 25° C) 500
Turbidity
Precipitates
Other

LABORATORY ANALYSIS

	mg/l	meq/l	% meq/l
Carbonate (CO_3)	Nil		
Bicarbonate (HCO_3)	285	4.67	38.6
Chloride (Cl)	51	1.44	11.9
Sulphate (SO_4)	18	0.37	3.1
Silica (SiO_2)	14	–	
Calcium (Ca)	81	4.04	33.4
Magnesium (Mg)	9.8	0.81	6.7
Iron in solution (Fe)	<0.1	–	
Aluminium (Al)	<0.2	–	
Potassium (K)	1.7	0.04	0.3
Sodium (Na)	16	0.70	5.8
Total dissolved solids (TDS)	390	12.1	
Permanent hardness as $CaCO_3$	8		
Temporary hardness as $CaCO_3$	235		
Alkalinity as $CaCO_3$	235		
Other TDS: conductance ratio = 0.70			

pH	7.3
Specific conductance (μS/cm at 25°C)	560
Colour	
Turbidity	
% difference in anion and cation meq/l	7.3

Previous chemical analysis available?	NO
Date	
Lab. ref. number	
Bacteriological analysis available?	NO
Date	
Lab. reg. number	

HARDNESS SCALE
(Total hardness as Calcium Carbonate)

Soft	0—60 mg/l
Moderately Hard	61—120
Hard	121—180
Very hard	more than 180

IONIC RATIOS

Ca: Mg = 5.0	Cl: total = 0.12
Na: total = 0.06	SO_4: total = 0.03
Na: Cl = 0.49	SiO_2: total = 0.04

SUITABILITY
a = no problems, b = doubtful, c = excessive

DOMESTIC		DRINKING	
Total dissolved solids	a	pH	a
Total hardness	b–c	Iron	a
Chloride	a	Sulphate	a
Sodium	a	Magnesium	a
Colour	a		

DOMESTIC HOT WATER CYLINDER

Total dissolved solids	b	Chloride	b
Cl/alkalinity ratio = 0.22	a	pH	a

AGRICULTURAL USE

	Value	Suitability (a,b, or c)
Salinity class (C1—C4)	C2	a
Sodium class (S1—S4)	S1	a
Percent Sodium	13	a
Sodium adsorption ratio	0.5	a
Residual sodium carbonate	Nil	a

Remarks A predominantly calcium bicarbonate type water of medium salinity; very hard, neutral pH, suitable for drinking and agricultural purposes

3–62

Table 1d
Groundwater analyses from various depths in the upper, unconfined aquifer in bore 2 on transect B (Figure 3 and 17) at Seven Mile Beach (from Roberts, 1988)

WATER QUALITY - HOLE 2

Depth (m)	4.0	6.0	8.0	12.0	14.5	
R.L. (m)	1.3	3.3	5.3	9.3	11.8	
Constituent						
pH	7.4	7.8	7.5	7.9	8.2	
conductance (μS)	530	820	780	970	1200	
CO_3 (mg/l)	0.0	0.0	0.0	0.0	0.0	
HCO_3 "	250	280	250	330	240	
Cl "	39	110	120	170	240	mg/L
SO_4 "	7.4	54	16	5.3	22	
Ca "	55	78	66	76	27	
Mg "	6.0	8.6	11	18	21	
Fe "	<0.1	0.23	<0.1	<0.1	<0.1	
Al "	<0.2	<0.2	<0.2	<0.2	<0.2	
K "	4.0	6.0	6.0	10	27	
Na "	37	70	67	115	190	
TDS "	320	500	500	600	690	
Hardness Perm.	125	4	0.0	0.0	0.0	
Hardness Temp.	210	230	185	260	155	
Alk. as $CaCO_3$	210	230	210	270	195	
CO_3 (meq/l)	0.0	0.0	0.0	0.0	0.0	
HCO_3 "	4.10	4.59	4.10	5.41	3.94	
Cl "	1.10	3.10	3.38	4.79	6.77	
SO_4 "	0.15	1.12	0.33	0.11	0.46	
Ca "	2.74	3.89	3.29	3.79	1.35	meq/L
Mg "	0.49	0.71	0.90	1.48	1.73	
Fe "	0.0	0.0	0.0	0.0	0.0	
Al "	0.0	0.0	0.0	0.0	0.0	
K "	0.10	0.15	0.15	0.26	0.69	
Na "	1.61	3.05	2.91	5.00	8.27	
Sum (meq/l)	10.29	16.61	15.06	20.84	23.21	
% diff. of anion and cation equivalents(1)	4.0	6.1	3.7	1.1	3.7	
Sodium Adsorpt. Ratio	1.27	2.01	2.01	3.08	6.66	
% Sodium	34.62	41.03	42.21	49.95	74.42	
Residual Sodium Carb.	0.87	0.0	0.0	0.14	0.86	
CO_3 (%meq/l)	0.0	0.0	0.0	0.0	0.0	
HCO_3 "	39.84	27.63	27.22	25.96	16.97	
Cl "	10.69	18.66	22.44	22.98	29.17	
SO_4 "	1.46	6.74	2.19	0.53	1.98	
Ca "	26.63	23.42	21.85	18.18	5.82	%meq/L
Mg "	4.76	4.27	5.98	7.10	7.45	
Fe "	0.0	0.0	0.0	0.0	0.0	
Al "	0.0	0.0	0.0	0.0	0.0	
K "	0.97	0.90	1.00	1.25	2.97	
Na "	15.65	18.36	19.32	23.99	35.63	

(1) An indication of the accuracy of the analysis. Should approach zero if all major species have been determined.

William C Cromer Pty. Ltd.
74A Channel Highway Taroona, Tasmania 7053 Australia
Mobile 0408 122 127 Fax 03 6227 9456 E-mail billcromer@bigpond.com

Table 1e
Groundwater analyses from five depths in the upper, unconfined aquifer in bore 7 on transect B (Figure 3 and 17) at Seven Mile Beach (from Roberts, 1988)

WATER QUALITY - HOLE 7

Depth (m)	5.0	6.0	8.0	9.5	14
R.L. (m)	2.9	3.9	5.9	7.4	11.9
Constituent					
pH	7.8	8.0	7.5	8.0	8.0
conductance (µS)	670	800	810	800	1400
CO_3 (mg/l)	0.0	0.0	0.0	0.0	0.0
HCO_3 "	340	380	280	300	340
Cl "	62	110	130	135	280
SO_4 "	15	29	35	9.7	30
Ca "	65	71	72	61	19
Mg "	10.5	15.5	13	16	23
Fe "	<0.1	<0.1	<0.1	<0.1	0.9
Al "	<0.2	<0.2	<0.2	<0.2	<0.2
K "	5.7	6	10	1.2	10
Na "	49	66	56	61	210
TDS "	380	610	450	550	790
Hardness Perm.	0.0	0.0	3.2	0.0	0.0
Hardness Temp.	210	240	230	220	145
Alk. as $CaCO_3$	280	310	230	250	280
CO_3 (meq/l)	0.0	0.0	0.0	0.0	0.0
HCO_3 "	5.58	6.23	4.59	4.92	5.58
Cl "	1.75	3.10	3.67	3.81	7.90
SO_4 "	0.31	0.60	0.73	0.20	0.62
Ca "	3.24	3.54	3.59	3.04	0.95
Mg "	0.86	1.27	1.07	1.32	1.89
Fe "	0.0	0.0	0.0	0.0	0.0
Al "	0.0	0.0	0.0	0.0	0.0
K "	0.15	0.15	0.26	0.03	0.26
Na "	2.13	2.87	2.44	2.65	9.14
Sum (meq/l)	14.02	17.76	16.35	15.97	26.34
% diff. of anion and cation equivalents(1)	9.0	11.8	10.0	11.8	7.1
Sodium Adsorpt. Ratio	1.49	1.85	1.60	1.79	7.67
% Sodium	35.74	38.57	36.68	38.07	76.80
Residual Sodium Carb.	1.48	1.42	0.0	0.56	2.74
CO_3 (%meq/l)	0.0	0.0	0.0	0.0	0.0
HCO_3 "	39.80	35.08	28.07	30.81	21.19
Cl "	12.48	17.46	22.45	23.86	30.00
SO_4 "	2.21	3.38	4.46	1.25	2.35
Ca "	23.11	19.93	21.96	19.04	3.61
Mg "	6.13	7.15	6.54	8.27	7.18
Fe "	0.0	0.0	0.0	0.0	0.0
Al "	0.0	0.0	0.0	0.0	0.0
K "	1.07	0.84	1.59	0.19	0.99
Na "	15.19	16.66	14.92	16.59	34.70

(1) An indication of the accuracy of the analysis. Should approach zero if all major species have been determined.

Mobile 0408 122 127 Fax 03 6227 9456 E-mail billcromer@bigpond.com

Table 1f
Groundwater analyses from two depths in the upper, unconfined aquifer, and two (right) in the lower aquifer, in bore 5 on transect B (Figure 3 and 17) at Seven Mile Beach (from Roberts, 1988)

WATER QUALITY – HOLE 5

Depth (m)	6.0	11.0	17.7	18.3
R.L. (m)	5.0	10.0	16.7	17.3
Constituent				
pH	7.8	7.9	7.4	7.5
conductance (µS)	680	780	12000	10500
CO_3 (mg/l)	0.0	0.0	0.0	0.0
HCO_3 "	200	220	480	470
Cl "	115	165	5080	4570
SO_4 "	13.5	16	580	510
Ca "	65	47	105	91
Mg "	8.7	25	190	170
Fe "	<0.1	<0.1	<0.1	<0.1
Al "	<0.2	<0.2	<0.2	<0.2
K "	6.9	20	110	100
Na "	29	49	3200	2800
TDS "	620	620	10430	9200
Hardness Perm.	36	39	75	540
Hardness Temp.	160	180	190	380
Alk. as $CaCO_3$	160	180	190	380
CO_3 (meq/l)	0.0	0.0	0.0	0.0
HCO_3 "	3.28	3.61	7.87	7.71
Cl "	3.24	4.65	143.26	128.87
SO_4 "	0.28	0.33	12.06	10.61
Ca "	3.24	2.35	5.24	4.54
Mg "	0.72	2.06	15.62	13.97
Fe "	0.0	0.0	0.0	0.0
Al "	0.0	0.0	0.0	0.0
K "	0.18	0.51	2.82	2.56
Na "	1.26	2.13	139.20	121.80
Sum (meq/l)	12.20	15.64	326.07	290.06
% diff. of anion and cation equivalents(1)	11.5	9.8	0.1	1.5
Sodium Adsorpt. Ratio	0.90	1.43	43.10	40.04
% Sodium	26.67	37.45	87.19	87.04
Residual Sodium Carb.	0.0	0.0	0.0	0.0
CO_3 (%meq/l)	0.0	0.0	0.0	0.0
HCO_3 "	26.89	23.08	2.42	2.66
Cl "	26.56	29.73	43.98	44.46
SO_4 "	2.30	2.11	3.70	3.66
Ca "	26.56	15.03	1.61	1.57
Mg "	5.90	13.17	4.80	4.81
Fe "	0.0	0.0	0.0	0.0
Al "	0.0	0.0	0.0	0.0
K "	1.48	3.26	0.87	0.88
Na "	10.33	13.62	42.73	42.02

(1) An indication of the accuracy of the analysis. Should approach zero if all major species have been determined.

Upper aquifer Lower aquifer

Table 1g
Groundwater analyses from two depths in the upper, unconfined aquifer, and one (right) in the lower aquifer, in bore 3 on transect B (Figure 3 and 17) at Seven Mile Beach (from Roberts, 1988)

WATER QUALITY - HOLE 3

Depth (m)	5.0	12.5	14.0-17.0
R.L. (m)	4.0	11.5	13.0-16.0
Constituent			
pH	7.7	8.9	8.1
conductance (μS)	740	1500	5500
CO_3 (mg/l)	0.0	27	0.0
HCO_3 "	290	380	420
Cl "	76	240	1560
SO_4 "	23	<5	92
Ca "	50	3.7	22
Mg "	8.0	4.4	46
Fe "	<0.1	0.6	<0.1
Al "	<0.2	0.26	<0.2
K "	6.0	26	53
Na "	78	330	1050
TDS "	430	870	3320

Hardness Perm.	0.0	0.0	0.0
Hardness Temp.	160	30	190
Alk. as $CaCO_3$	240	360	350

CO_3 (meq/l)	0.0	0.9	0.0
HCO_3 "	4.76	6.23	6.89
Cl "	2.14	6.77	43.99
SO_4 "	0.48	<0.10	1.91
Ca "	2.50	0.18	1.10
Mg "	0.66	0.36	3.78
Fe "	0.0	0.0	0.0
Al "	0.0	0.0	0.0
K "	0.15	0.67	1.36
Na "	3.39	14.36	45.68

Sum (meq/l)	14.08	29.57	104.71
% diff. of anion and cation equivalents(1)	4.8	5.6	0.8
Sodium Adsorpt. Ratio	2.70	27.64	29.24
% Sodium	52.84	96.53	90.60
Residual Sodium Carb.	1.60	5.69	2.01

CO_3 (%meq/l)	0.0	3.04	0.0
HCO_3 "	33.81	21.07	6.58
Cl "	15.20	22.90	42.01
SO_4 "	3.41	0.34	1.82
Ca "	17.76	0.61	1.05
Mg "	4.69	1.22	3.61
Fe "	0.0	0.0	0.0
Al "	0.0	0.0	0.0
K "	1.07	2.27	1.30
Na "	24.08	48.57	43.62

(1) An indication of the accuracy of the analysis. Should approach zero if all major species have been determined.

Upper aquifer   Lower aquifer

Table 1h
Groundwater analyses from probably three depths in the upper, unconfined aquifer in bore 1 on transect B (Figure 3 and 17) at Seven Mile Beach (from Roberts, 1988). The middle analysis suggests sea water mixing, presumably as part of the sea water – fresh water interface.

WATER QUALITY - HOLE 1

Depth (m)	11.0-12.0	12.0	13.0
R.L. (m)	8.9-9.9	9.9	10.9
Constituent			
pH	7.9	7.9	8.5
conductance (µS)	840	4800	1300
CO_3 (mg/l)	0.0	0.0	6.5
HCO_3 "	200	220	260
Cl "	190	1320	250
SO_4 "	15	290	17.5
Ca "	48	80	17
Mg "	29	91	38
Fe "	0.23	<0.1	0.12
Al "	<0.2	<0.2	<0.2
K "	17	62	57
Na "	65	690	165
TDS "	550	2930	680
Hardness Perm.	72	390	0.0
Hardness Temp.	165	185	200
Alk. as $CaCO_3$	165	185	220
CO_3 (meq/l)	0.0	0.0	0.22
HCO_3 "	3.28	3.61	4.26
Cl "	5.36	37.22	7.05
SO_4 "	0.31	6.03	0.36
Ca "	2.40	3.99	0.85
Mg "	2.38	7.48	3.12
Fe "	0.0	0.0	0.0
Al "	0.0	0.0	0.0
K "	0.44	1.59	1.46
Na "	2.83	30.02	7.18
Sum (meq/l)	17.00	89.94	24.50
% diff. of anion and cation equivalents(1)	5.3	4.2	2.9
Sodium Adsorpt. Ratio	1.83	12.54	5.10
% Sodium	40.62	73.38	68.52
Residual Sodium Carb.	0.0	0.0	0.29
CO_3 (%meq/l)	0.0	0.0	0.90
HCO_3 "	19.29	4.01	17.39
Cl "	31.53	41.39	28.78
SO_4 "	1.82	6.71	1.47
Ca "	14.12	4.44	3.47
Mg "	14.00	8.32	12.74
Fe "	0.0	0.0	0.0
Al "	0.0	0.0	0.0
K "	2.59	1.77	5.96
Na "	16.65	33.38	29.31

(1) An indication of the accuracy of the analysis. Should approach zero if all major species have been determined.

Table 1i
Groundwater analyses from probably three depths in the upper, unconfined aquifer, an done (the last) in the lower aquifer in bore 4 on the beach on transect B (Figure 3 and 17) at Seven Mile Beach (from Roberts, 1988). The middle two analyses suggests sea water mixing, presumably as part of the sea water – fresh water interface.

WATER QUALITY - HOLE 4

Depth (m)	5.0	9.0	11.0	20.0
R.L. (m)	4.7	8.7	10.7	19.7
Constituent				
pH	8.0	7.4	7.8	7.2
conductance (µS)	2400	22400	10600	15000
CO_3 (mg/l)	0.0	0.0	0.0	0.0
HCO_3 "	240	195	250	380
Cl "	800	11800	4900	6630
SO_4 "	220	1160	1180	920
Ca "	46	310	108	200
Mg "	56	95	93	290
Fe "	<0.1	<0.1	<0.1	0.2
Al "	<0.2	<0.2	<0.2	<0.2
K "	34	175	96	115
Na "	390	6250	3350	4100
TDS "	1400	20670	9470	14120
Hardness Perm.	150	1010	450	1380
Hardness Temp.	195	160	200	320
Alk. as $CaCO_3$	195	160	200	320
CO_3 (meq/l)	0.0	0.0	0.0	0.0
HCO_3 "	3.94	3.20	4.10	6.23
Cl "	22.56	332.76	138.18	186.97
SO_4 "	4.58	24.13	24.54	19.14
Ca "	2.30	15.47	5.39	9.98
Mg "	4.60	7.81	7.64	23.84
Fe "	0.0	0.0	0.0	0.0
Al "	0.0	0.0	0.0	0.0
K "	0.87	4.48	2.46	2.94
Na "	16.97	271.88	145.73	178.35
Sum (meq/l)	55.82	659.73	328.04	427.45
% diff. of anion and cation equivalents(1)	11.4	9.2	1.7	0.6
Sodium Adsorpt. Ratio	9.14	79.69	57.09	43.37
% Sodium	72.11	92.23	91.92	84.28
Residual Sodium Carb.	0.0	0.0	0.0	0.0
CO_3 (%meq/l)	0.0	0.0	0.0	0.0
HCO_3 "	7.06	0.49	1.25	1.46
Cl "	40.40	50.58	42.14	43.75
SO_4 "	8.20	3.67	7.48	4.48
Ca "	4.12	2.35	1.64	2.34
Mg "	8.24	1.19	2.33	5.58
Fe "	0.0	0.0	0.0	0.0
Al "	0.0	0.0	0.0	0.0
K "	1.56	0.68	0.75	0.69
Na "	30.39	41.33	44.45	41.73

(1) An indication of the accuracy of the analysis. Should approach zero if all major species have been determined.

Table 1j
Groundwater analyses from the lagoonal, backswamp sediments in bore 26 on transect 1 at Royal Hobart Golf Club, Seven Mile Beach (from Cromer, 1981)

7/80

TASMANIAN DEPARTMENT OF MINES

WATER ANALYSIS

Field No. RH26
Lab. reg. no. 802902
Surface sample?
Groundwater sample? YES

Project ROYAL HOBART GOLF CLUB   Location G. Casimaty's property.

Co-ordinates 539900 m E, 5255250 m N
Date sampled: 26.11.80   Sampled by: W. Cromer
Date analysed: 19.12.80   Analysed by: Dept. Mines, Launceston

Sampling conditions From spear bore installed to 4.6 m and pumped at 14 litres/min (180 gph)

Landowner and address (if applicable) G. Casimaty, "Acton View", Seven Mile Beach

Field observations
Colour pale yellow   Odour   Taste
pH   Eh   Temperature (°C)   Specific conductance (µS/cm at 25° C) 16000
Turbidity high   Precipitates   Other

LABORATORY ANALYSIS

	mg/l	meq/l	% meq/l
Carbonate (CO_3)	Nil		
Bicarbonate (HCO_3)	860	14.1	3.5
Chloride (Cl)	6250	176	43.7
Sulphate (SO_4)	515	10.7	2.7
Silica (SiO_2)	27	–	
Calcium (Ca)	415	20.7	5.1
Magnesium (Mg)	800	65.8	16.3
Iron in solution (Fe)	<0.1		
Aluminium (Al)	<0.2		
Potassium (K)	19	0.49	0.1
Sodium (Na)	2650	115	28.6
Total dissolved solids (TDS)	11,100	403	
Permanent hardness as $CaCO_3$	3625		
Temporary hardness as $CaCO_3$	705		
Alkalinity as $CaCO_3$	705		
Other TDS : conductance ratio = 0.62			

pH	7.4
Specific conductance (µS/cm at 25°C)	18000
Colour	
Turbidity	
% difference in anion and cation meq/l	0.3

Remarks
A predominantly sodium chloride type water of very high salinity; very hard, of near neutral pH. Unsuitable for most uses except some stock watering.

Previous chemical analysis available?	NO
Date	
Lab. ref. number	
Bacteriological analysis available?	NO
Date	
Lab. reg. number	

HARDNESS SCALE
(Total hardness as Calcium Carbonate)

Soft	0—60 mg/l
Moderately Hard	61—120
Hard	121—180
Very hard	more than 180

IONIC RATIOS

Ca: Mg = 0.31	Cl: total = 0.44
Na: total = 0.29	SO_4: total = 0.03
Na: Cl = 0.65	SiO_2: total = 0.002

SUITABILITY
a = no problems, b = doubtful, c = excessive

DOMESTIC DRINKING

Total dissolved solids	c	pH	a
Total hardness	c	Iron	a
Chloride	c	Sulphate	c
Sodium	c	Magnesium	c
Colour	b		

DOMESTIC HOT WATER CYLINDER

Total dissolved solids	c	Chloride	c
Cl/alkalinity ratio = 8.9	c	pH	a

AGRICULTURAL USE

	Value	Suitability (a,b, or c)
Salinity class (C1—C4)	C4	c
Sodium class (S1—S4)	S4	c
Percent Sodium	57	b
Sodium adsorption ratio	17.5	b
Residual sodium carbonate	Nil	a

3–73