THE MOURQUONG DISCHARGE COMPLEX AND DISPOSAL BASIN, MURRAY BASIN, SE AUSTRALIA

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Geological Controls on the Permeability and Hydrodynamics of
Groundwater Discharge Complexes and Disposal Basins

The Mourquong Discharge Complex and Disposal Basin, Murray Basin, SE Australia

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James Ferguson and Bruce M. Radke publish with the permission of the Director, AGSO.

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3. ABSTRACT

The Mourquong Groundwater Discharge Complex is located about 1km north of the Murray River, in the Mallee region of the Murray Basin. It is a topographic depression with a semi-circular outline some 10km in diameter. The complex lies over the faulted western side of the Koorlong Trough, against the Danyo Fault. The trough has been subsiding and consequently the discharge complex has been a depocentre since at least the Pleistocene, accumulating over the Pliocene Parilla Sand, which is now the regional unconfined aquifer. Development of the complex followed widespread deposition of the Blanchetown Clay initially and predominantly under low-salinity lacustrine conditions in the paleo-lake, Lake Bungunnia. Parilla Sand on the Merbein Ridge to the west of the Danyo Fault was predominantly emergent within the lake, and contributed intermittent colluvial and fluvial sands to the Blanchetown Clay along the western margin of the discharge complex. At some later stage the Mourquong depression was invaded to form part of the River Murray floodplain. Erosion into the Blanchetown Clay formed channels which were later infilled with Shepparton Formation overbank deposits of thin beds of sands and clays. After deposition of the Blanchetown Clay ceased a number of deflation and accumulation events produced the lacustrine and aeolian deposits of the Yamba Formation before, synchronously, and after the main mobilisation event which produced the aeolian sand dunes of the Woorinen Formation. The lacustrine deposits have a high gypsum sand content, interlaminated with clays and muds. The aeolian deposits are quartz sand intervals which form thin but extensive sheets.

This interaction of differential tectonism and salina deposition has produced a relatively thick (typically 2 to 3 m) wedge of permeable Yamba Formation sediments which are enclosed by Blanchetown Clay in the northwest of the discharge complex. The Blanchetown Clay is generally of low permeability but at the western margin of the complex, the enclosing clay unit is thin and permeable from intercalated colluvial sand deposits. This permeable mixed facies is a potential conduit for movement of groundwater between the Yamba Formation in the discharge complex and the adjacent regional aquifer in the Parilla Sand. There is a centrally-distributed permeable interlaminated sand and clay facies, probably Shepparton Formation, which may represent former meander channels of the Murray River which entered the discharge complex from the south.

Since 1969, the western side of the Mourquong complex has been used as an active disposal basin for the Buronga Interception Scheme, which is designed to reduce

salinisation of the nearby Murray River. Preceding the disposal use of the complex, the natural hydrodynamics in the northwestern area of the discharge complex involved the following processes. (1) Inflow of groundwater at the western margin through the sandy horizons of the Blanchetown Clay. This groundwater is a mixture of regional groundwater, local rainfall recharge through the overlying sandy Woorinen Formation dune and entrained brine from deeper areas of the Parilla Sand. (2) Capillary evaporation of the incoming Parilla Sand groundwater at the lake margin forming sub-surface brine and surface efflorescences which are partly removed by aeolian deflation and partly redissolved by rainfall. The saline water formed by dissolution of the efflorescences flows towards, and accumulates in the topographically lower parts of the discharge complex. (3) Development of an evaporative groundwater brine in the permeable Yamba Formation sediments towards the centre of the discharge complex from a combination of lateral flow of the marginal evaporated groundwater brine, and infiltration of the saline water containing redissolved efflorescences. (4) Downwards diffusion of salt from the brine pool in the Yamba Formation through the Blanchetown Clay towards the underlying lower salinity Parilla Sand groundwater.

Establishment of the disposal basin resulted in the discharge of saline disposal water (e.g. 34,000 mg/L) at the southern end of the basin. From there, the water flows westwards and northwards where it spreads to form a large shallow pond about about 5 km^2 in area. Evaporation along this flow-path has produced a disposal brine of whose salinity fluctuates widely (e.g. 91,500 to >350,000 mg/L), depending on the season and the rate of discharge of disposal water. At the centre of the innundated area hydraulic gradients are vertically downwards and, during the 13 years the disposal basin has been in operation the surface brine has moved into the Yamba Formation sediments creating a disposal brine - saturated zone at least 4 m in thickness and an underlying broad (ca. 1.5 m) mixing zone in the Blanchetown Clay. The rapidity of downward movement indicates advective flow and the width of the mixing zone suggests that the upper part of the Blanchetown Clay is not sufficiently impermeable for diffusion to be rate limiting. The lateral hydraulic gradient to the north is directed away from the disposal basin into the pristine area of the discharge complex and, as a result, high salinity, which is indicative of disposal water, has been detected 150 m from the regularly innundated area. To the west, there is a minimum in the hydraulic head near the basin margin in summer. Under these conditions, water will tend to flow towards the marginal area from both the disposal basin and the natural recharge/regional groundwater system beneath the Woorinen Formation dune. In winter, ephemeral perched water tables complicate the situation. The western hydraulic gradient away from the disposal basin appears lower than that to the northward and, as a result, the rate of lateral flow of disposal water is lower and it is detectable 10 m, but not 70 mfrom the innundated area. Lateral movement of the the disposal brines in both the north and west is horizontal from an elevation close to the base of the disposal water-saturated zone. To the west the brines have flowed without obvious perturbation into the laterally enclosing Blanchetown Clay. The significant extent of intrusion of the disposal brines into the Blanchetown Clay in both the lateral and vertical directions suggests that this unit is not yet fulfilling its anticipated role as a clay aquitard.

The Mourquong data have emphasised the critical but diverse role of the Blanchetown Clay in determining the permeability and hydrodynamics of the overlying groundwater discharge complexes. The Mourquong Complex represents the higher permeability end of the spectrum in which the regional groundwater has ready access through the Blanchetown Clay to the discharge complex. As a result, an increase in the regional groundwater table is closely followed by an increase in the water table and concomittant sediment accumulation in the discharge complex. This synchronicity has allowed the development of the relatively thick sequence of Yamba Formation sediments and groundwater heads in the underlying Parilla Sand which are below ground level in the discharge complex. Nulla Spring Lake in the Nulla Discharge Complex in the Murray Mallee represents the low permeability end of the Blanchetown Clay spectrum. Groundwater input is severely restricted both vertically and laterally and occurs in the form of numerous small springs. Because the permeability and not the regional groundwater head is the major control, there is a considerable lag in the response of the water table and sediment accumulation in the lake to increases the the groundwater head in the regional aquifer. Consequently, only a thin sequence (about 0.5 m) of lacustrine Yamba Formation sediments has been deposited and the groundwater heads in the underlying Parilla Sand are 1 to 2 m above ground level in the lake. It is predicted that disposal water would be effectively contained in these low permeability Blanchetown Clay sites.

4. GENERAL OBJECTIVES AND METHODOLOGY

4.1 General Objectives

The investigation of the Mourquong Discharge Complex and disposal basin is part of an NRMS - funded project " Groundwater dynamics of evaporative brines and their application to saline wastewater disposal".

This project which aims to facilitate the siting and management of disposal basins by determining the geological controls on the permeability and hydrodynamics of natural and developed groundwater discharge sites.

4.2 Background

Natural groundwater discharge complexes in the Murray Basin are commonly used for the disposal of saline groundwater from salt interception schemes. A major factor in the siting and management of these disposal basins has been the need to understand and, if necessary, control the way in which brines generated by evaporation of the saline water leak laterally into adjacent areas and/or vertically into the underlying regional aquifer.

The fate of the vertically-moving brines which reach the regional aquifer can be a major factor in determining the efficiency and environmental impact of a disposal basin. The brines may be partly dispersed and swept down gradient, or they could form relatively stable brine pools which remain beneath the disposal site. Clearly, the latter situation is preferable because not only is the vertically leaking disposal water contained, but the capacity of the disposal basin would be increased many-fold if the evaporated disposal water could be stored mainly in the underlying aquifer. The extent of this increased disposal capacity is evident from the work of Macumber (1991), who showed that there is a highly saline brine in the regional Parilla Sand aquifer beneath Lake Tyrrell which contains about 1 to 2% of the total salt in the Murray Basin.

There is abundant evidence that the hydrodynamic processes in natural groundwater discharge complexes can increase the salinity in the underlying aquifers to various degrees, but the nature of the processes involved, and the factors which determine the extent of the increase in salinity are not well understood. Numerical models indicate that the situation should be relatively straightforward. Brine pools will develop where high sediment permeability favours advective reflux of lacustrine brines and, conversely, low permeability substrates restrict groundwater flow and salt moves by diffusion.

A preliminary examination of the situation at Lake Tyrrell suggests that application of this concept to natural systems requires some knowledge of the geological evolution as well as the present-day lithostratigraphy of the area. The bed of Lake Tyrrell is not obviously permeable because most of the lake is underlain by 20m thickness of Blanchetown Clay. The present-day hydraulic heads are directed upwards from the brine in the Parilla Sand aquifer to the lake, which suggests that the brine was emplaced during hydrodynamic regime(s) different to the present. Current suggestions to resolve the discrepancy between the theoretical predictions and the inferred low present-day permeability distribution of the lake include the possibility that brine reflux occurred through fractures in the Blanchetown Clay or through a small area at the southern end of the lake where the underlying Parilla Sand is exposed at the lake surface.

4.3 Selection of Study Areas

Natural groundwater discharge complexes at Scotia and Nulla in the Murray Mallee of western NSW (Figure **4.1**) were selected as likely representatives of the brine pool and brine containment end-members, respectively. The lacustrine sediments of the Scotia Discharge Complex were known to have a high sand content and potentially high permeability. In contrast, Nulla Spring Lake within the Nulla Discharge Complex has a substrate of potentially low-permeability Blanchetown Clay.

The Mourquong Groundwater Discharge Complex (Figure **4.1**), now actively used as the disposal site for the Buronga Salt Interception Scheme, was selected for study of modified natural hydrodynamics. It should lie towards the brine-containment part of the spectrum, because it is sited on the Blanchetown Clay. In this sense the Mourquong and Nulla Discharge Complexes are comparable, but in other respects they offer a strong lithostratigraphic and hydrodynamic contrast.

4.4 Methodology

For each site the present-day and historical features of the system have been considered because an historical context is necessary to explain a number of the existing hydrodynamic signatures.

The present-day lithostratigraphy and hydrodynamics provide information on the current processes by which water and salt are moving. This information is a basis for classifying the natural environments and disposal basins in terms of their potential for brine retention or reflux, and for assessing the limits and rates of future groundwater movement.

The stratigraphic and hydrodynamic history of groundwater discharge complexes is accessible through information on the lithostratigraphy of the lacustrine sediments, and from the distribution and geochemistry of the saline waters retained from previous regimes. The method has been to reconstruct the pre-existing regional hydrodynamic context and the processes of discharge development. This has been done by using the results of a detailed stratigraphic study to help model the hydrodynamic history of each complex from its initiation to present state.

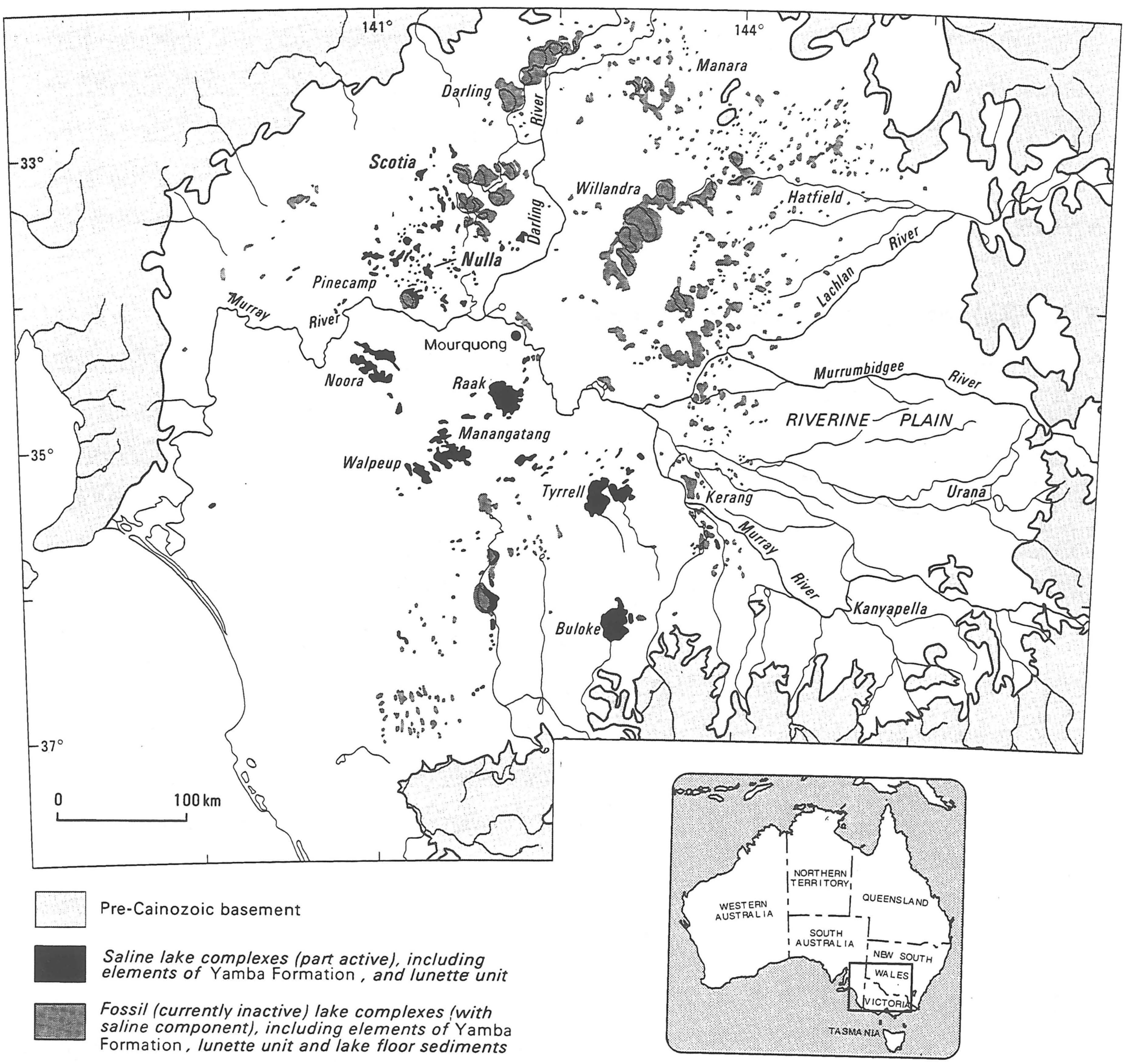

Fig. 4.1 Location of Nulla and Scotia Discharge Complexes and the Mourquong Discharge Complex and Disposal Basin

5.MOURQUONG DISCHARGE COMPLEX AND DISPOSAL BASIN

5.1 Introduction

The Mourquong Groundwater Discharge Complex is located due north of Mildura, in New South Wales between 4 and 8 kilometres north of the Murray River. It is adjacent to and directly north of the Stanley Wines vineyards on the Buronga-Dareton highway (Figure **5.1**).

This discharge complex is the site of one of at least 150 operating disposal basins in the Murray Basin (Evans, 1989; Hostetler and Radke; 1995). The disposal basin covers an area of about 320 ha in the western area of the complex, in what was formerly a partly vegetated playa containing worked-out gypsum pits. Since 1979, when it began operation, about 2.2 x 10^6 m^3 of saline wastewater has been disposed of annually at this site. The wastewater is pumped about 3 km from the Buronga Salt Interception Scheme (Figure **5.1**) , which is a line of interception bores protecting the Murray River from saline groundwater inflow (Merrick and Middlemis, 1993). This groundwater is derived from the Parilla Sand aquifer, and is discharged at a point in the south of the evaporation basin at a salinity of about 34,ooo mg/L Total Dissolved Solids (TDS).

The climate in the Mallee region, where Mourquong is situated, is semi-arid. Annual rainfall at Mildura, 10 km from Mourquong, is about 270-320 mm, and pan evaporation is about 2200 mm.

The objectives of this preliminary investigation of Mourquong are: (1) to provide information on the permeability (as indicated by interparticle porosity) of the various lithostratigraphic units and the natural hydrodynamic conditions prior to flooding, and to compare these features to those of the Nulla Discharge Complex, which is also sited on Blanchetown Clay; and (2) to determine the effects of flooding by disposal water. These effects include: the changes in salinity and chemical

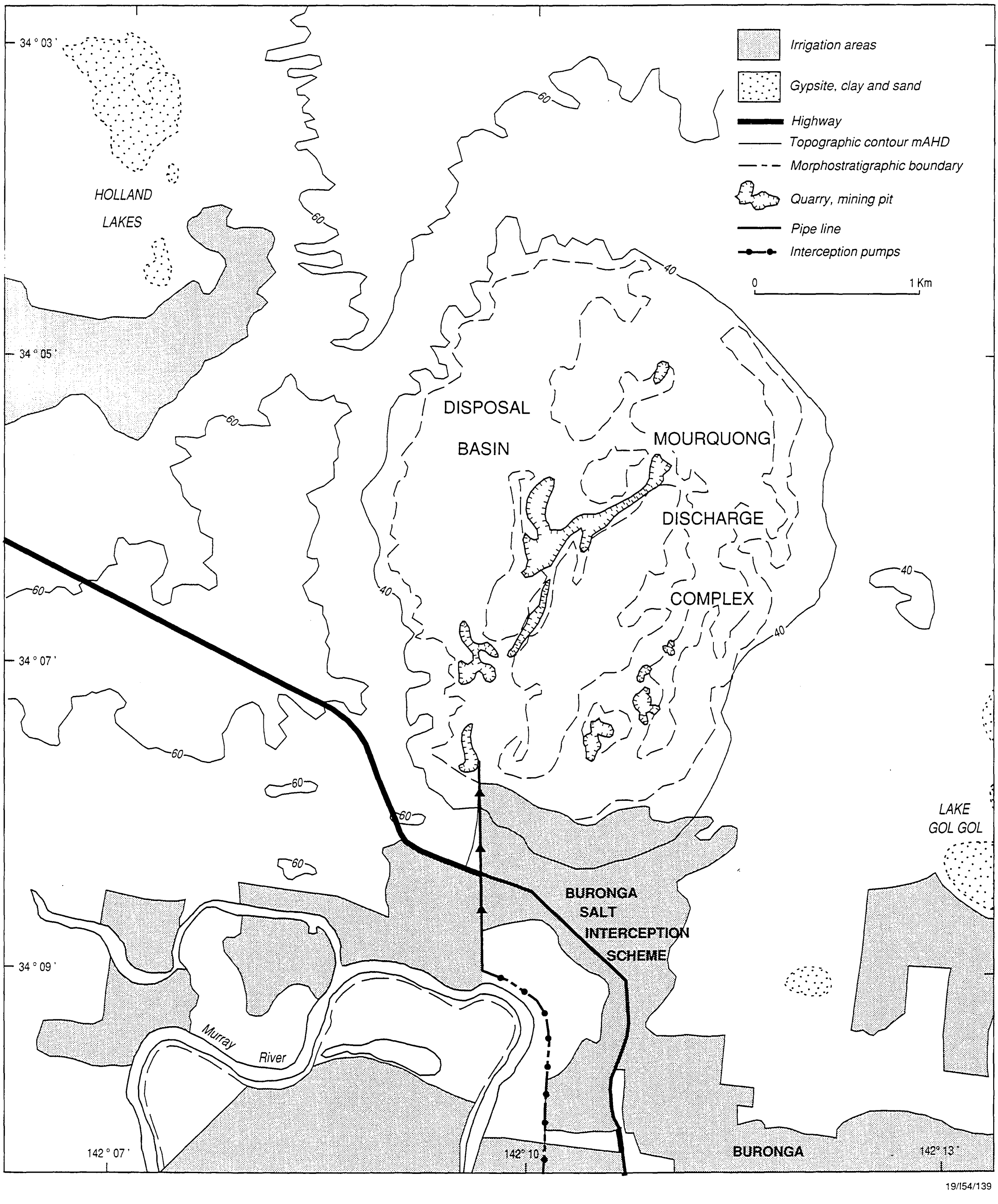

Fig. 5.1 Location and topography of the Buronga Salt Interception Scheme and the Mourquong Disposal Basin

composition of the disposal water during its time at the surface; the distribution of disposal water in the groundwater in and around the basin; and, the direction, extent and mechanism of groundwater flow. No attempt has yet been made to produce a mathematical model of the disposal basin, calculate flow rates, or predict the future direction and extent of disposal groundwater flow.

5.2 Methods

Drilling was undertaken at the Mourquong site in March and August 1992. Conditions for drilling and for the identification of disposal water were particularly unfavourable at the southern end of the complex, near where the disposal water is discharged. In this area the sediment is very soft and, because the salinity is relatively low, it seems unlikely that there is a strong, easily-measurable, contrast in salinity between the disposal water and the natural groundwater of the discharge complex. For these reasons, drilling was restricted to the northern area of the disposal basin.

Two transects (Figure **5.2**) were established, one orientated east-west (E-W) and the other north-south (N-S). The E-W transect has two components. (1) The western transect, which extends from a site (M1) in the centre of the flooded area to the western margin of the exposed lacustrine sediments and then (M4 to M12) up the face of a large Woorinen Formation dune which exends along (and partly overlies) the western margin of the discharge complex (Figure **5.1**). (2) The eastern transect, which starts at M1 and includes two sites (M18 and M13) in a topographically complex area at the eastern margin of the disposal basin

The N-S transect extends along the north-south axis of the disposal basin northwards from M1 through a site within the flooded area (M3), a site the intermittently flooded zone (M16), and then crosses an area of low strandline dunes (M15 and M14) before terminating (M17) in the topographically slightly higher northern area of the discharge complex.

Salinity of porewaters was measured at the base of each 0.4 m core section. The sections were then split for lithostratigraphic examination.

Drillholes were cased as piezometers, and subsequently levelled relative to a point on an establised Department of Water Resources (DWR) piezometer on the western margin.

The salinity, piezometric and lithostratigraphic data provided the database for preparation of stratigraphic sections containing information on the distribution of the disposal water and the hydraulic gradients. The locations of the piezometers, the midpoint of the piezometer slots and the salinity measuring points are superimposed on simplified stratigraphic sections for the E-W transect (Figure **5.3**), the western transect (Figure **5.4**) and the N-S transect (Figure **5.5**).

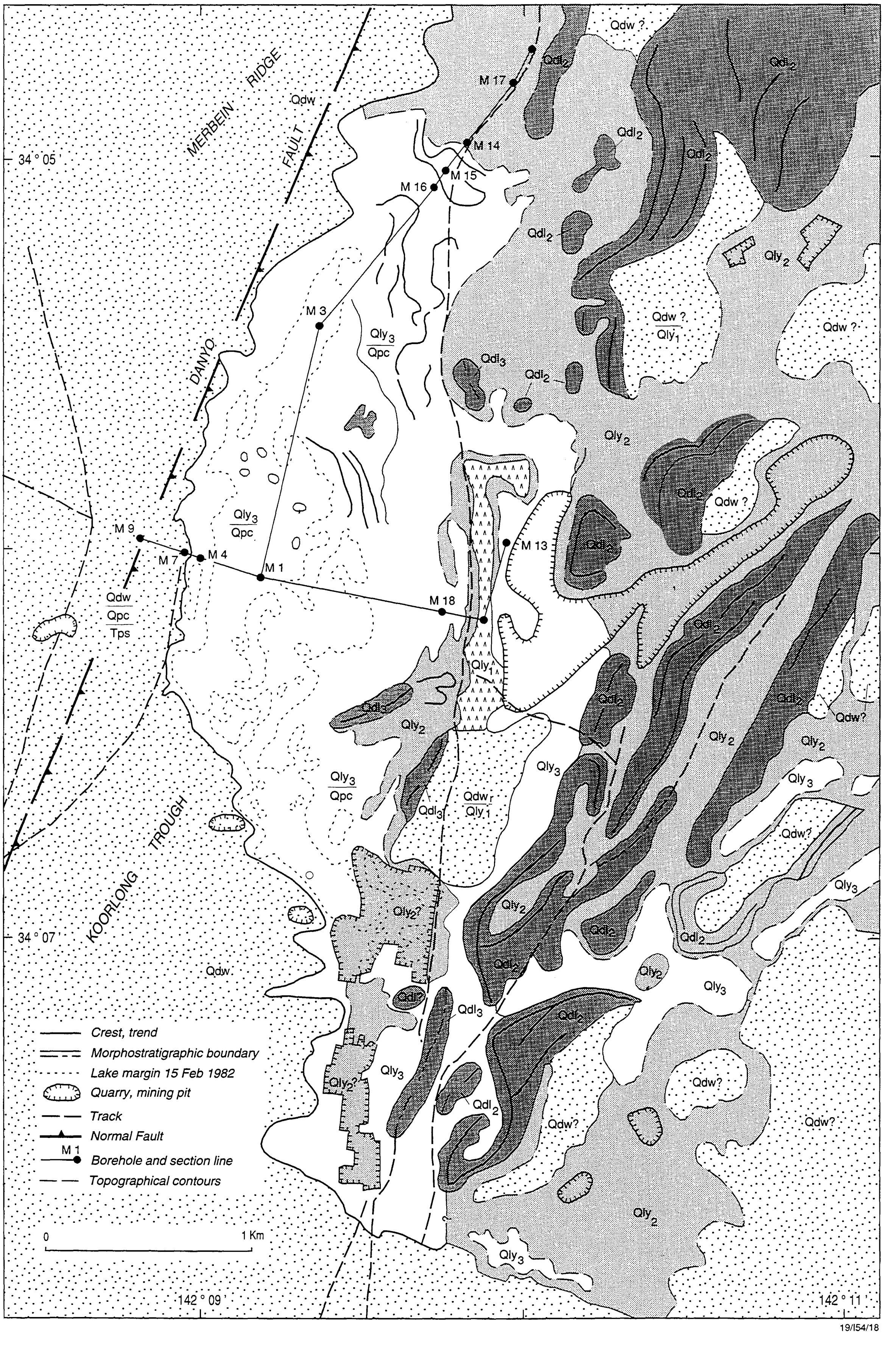

Fig 5.2 Drilling transects across the Mourquong Disposal Basin: the east-west (E-W) transect (M9 to M13)- including the western (M1 to M9) and eastern (M1 to M13) transects; and the north-south transect (M17 to M1).

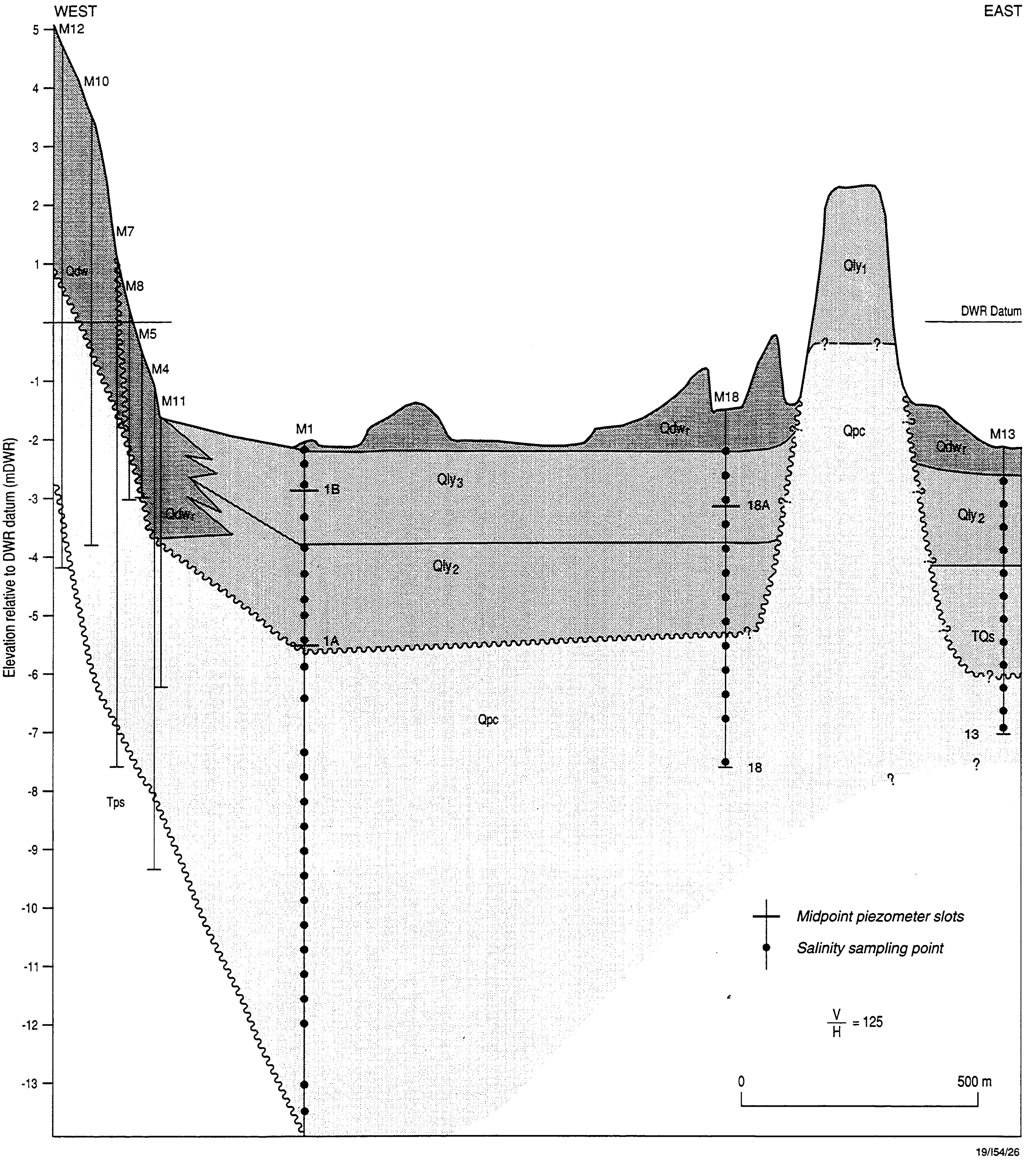

Fig. 5.3 Piezometer locations and depths, and groundwater salinity sampling points on the E-W transect.

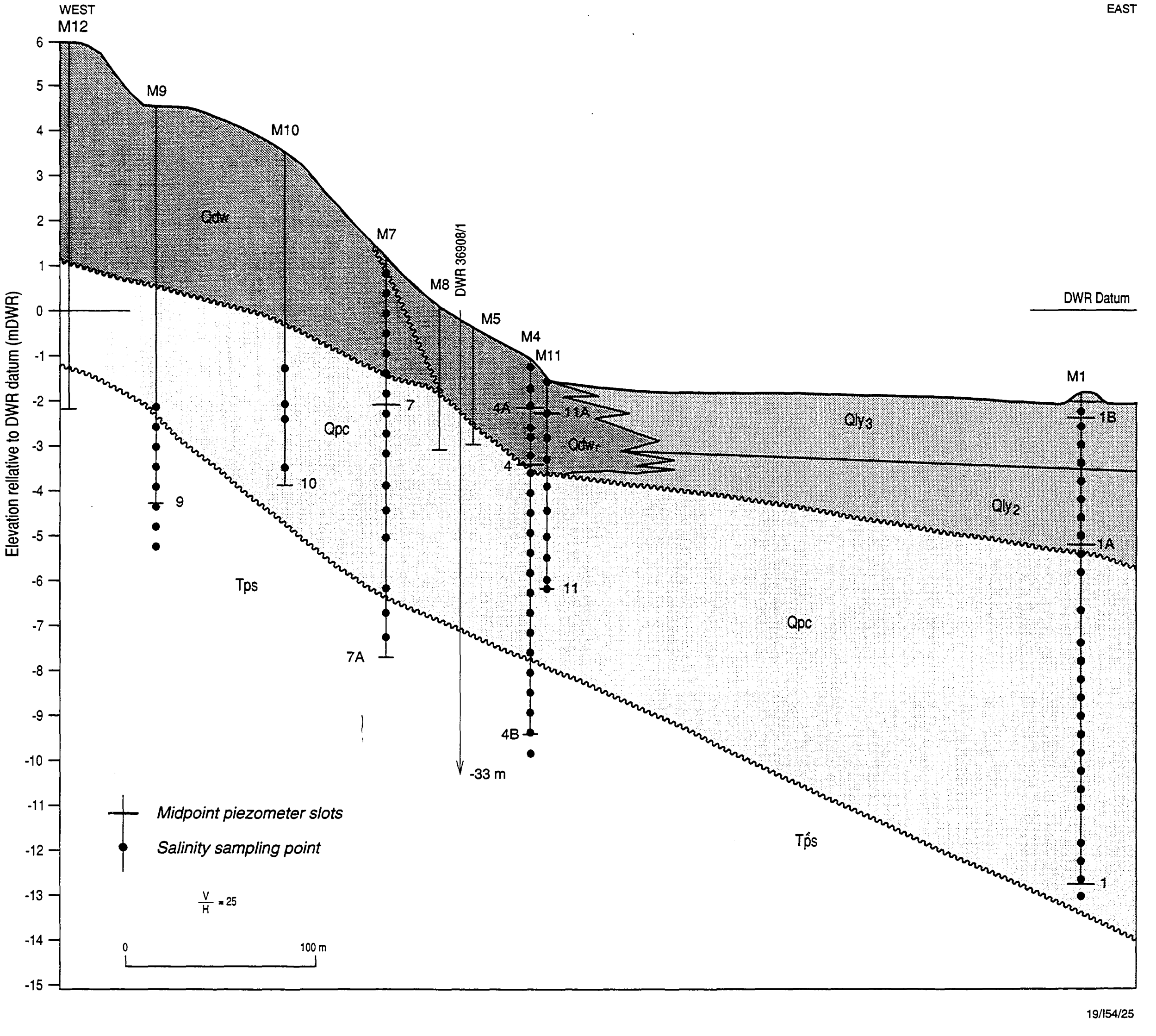

Fig. 5.4 Piezometer locations and depths, and groundwater salinity sampling points on the western transect.

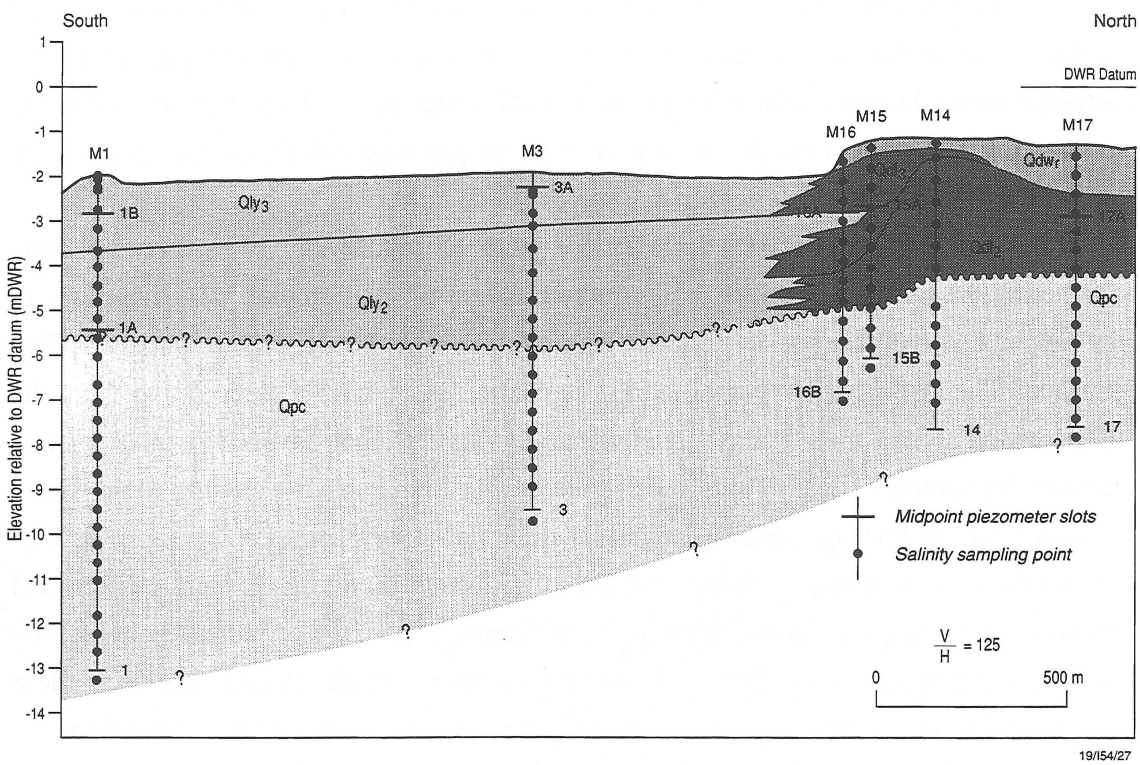

Fig. 5.5 Piezometer locations and depths, and groundwater salinity sampling points on the N-S transect.

Systematic monitoring of surface water levels, salinty and geochemistry was beyond the scope of the investigations, and measurements were limited to periods when drilling was in progress.

Details of the methods are in Appendix.

5.3 Physiography and Lithostratigraphy

5.3.1 Physiographic Features

The discharge complex is a topographic depression with a semicircular outline some 10 kilometres in diameter, with its gently arcuate western margin apparently adjacent to the Danyo Fault, which strikes north north-east. This fault separates the underlying Koorlong Trough and a low ridge to the west which corresponds to the structural Merbein Ridge (Figure **5.2** and **5.6**).

The complex contains a distinctive suite of landforms. A crescentic dune delineates the northern, eastern, and southern extent of the complex which appears to be entrenched within a fossil stranded lake complex on the upper Blanchetown Clay surface. The less arcuate western margin is delineated by both a slope down from the ridge which defines the western margin of an active salina that covers a relatively small area of the complex. East of this salina, and within the outermost circular dune, lies a complex topography comprising pedestals of a flat-topped gypsite terrace. Most of these pedestals have one or more generations of lunette accretion on their western and northwestern margins. Some pedestals are additionally covered or partially covered by subdued hummocky sand dunes. A lower pervasive surface extends between these pedestals from the lunette margins of the existing lake to the outermost circular dune.

Longitudinal sand dunes of the Woorinen Formation overlie the sandy ridge to the west, and the older component of the outer circular dune. Within the complex, no longitudinal dunes are recognized, but subdued hummocky sand dunes partially cover some of the pedestals.

Although less apparent, there appears to be a series of strandlines of low lunettes bordering the existing lake. Between these lunettes and the pedestals, a slightly higher surface, with relict strandlines, extends eastwards.

5.3.2 Stratigraphy

Lithostratigraphic data is presented in the detailed lithological logs of Appendix I of Radke (1992b). This information is summarized in cross-sections of the complex along west-east and south-north sections (Figures **5.7** to **5.9**). Interpretation of this sequence is presented in Figures **5.10** and **5.11**).

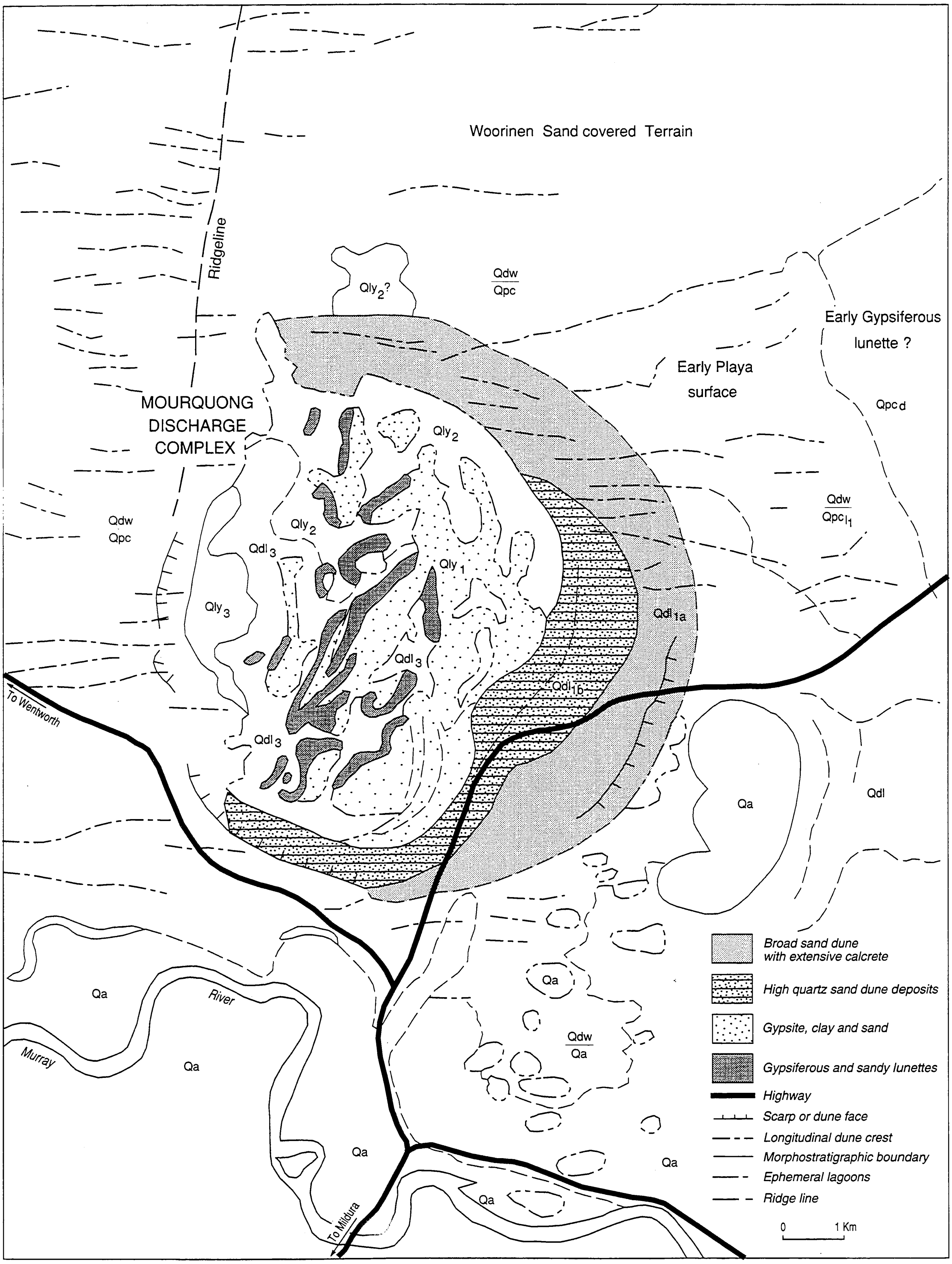

Fig. 5.6 Morphostratigraphic units of the Mourquong Discharge Complex. Three interpreted deflation-lacustrine cycles of Yamba Formation are: 1. Qdl_{1a}, Qdl_{1b} -deflation lunettes; Qly_1 - lacustrine deposits: 2. Qdl_2 (darktone); Qly_2: 3. Qdl_3; Qly_3.

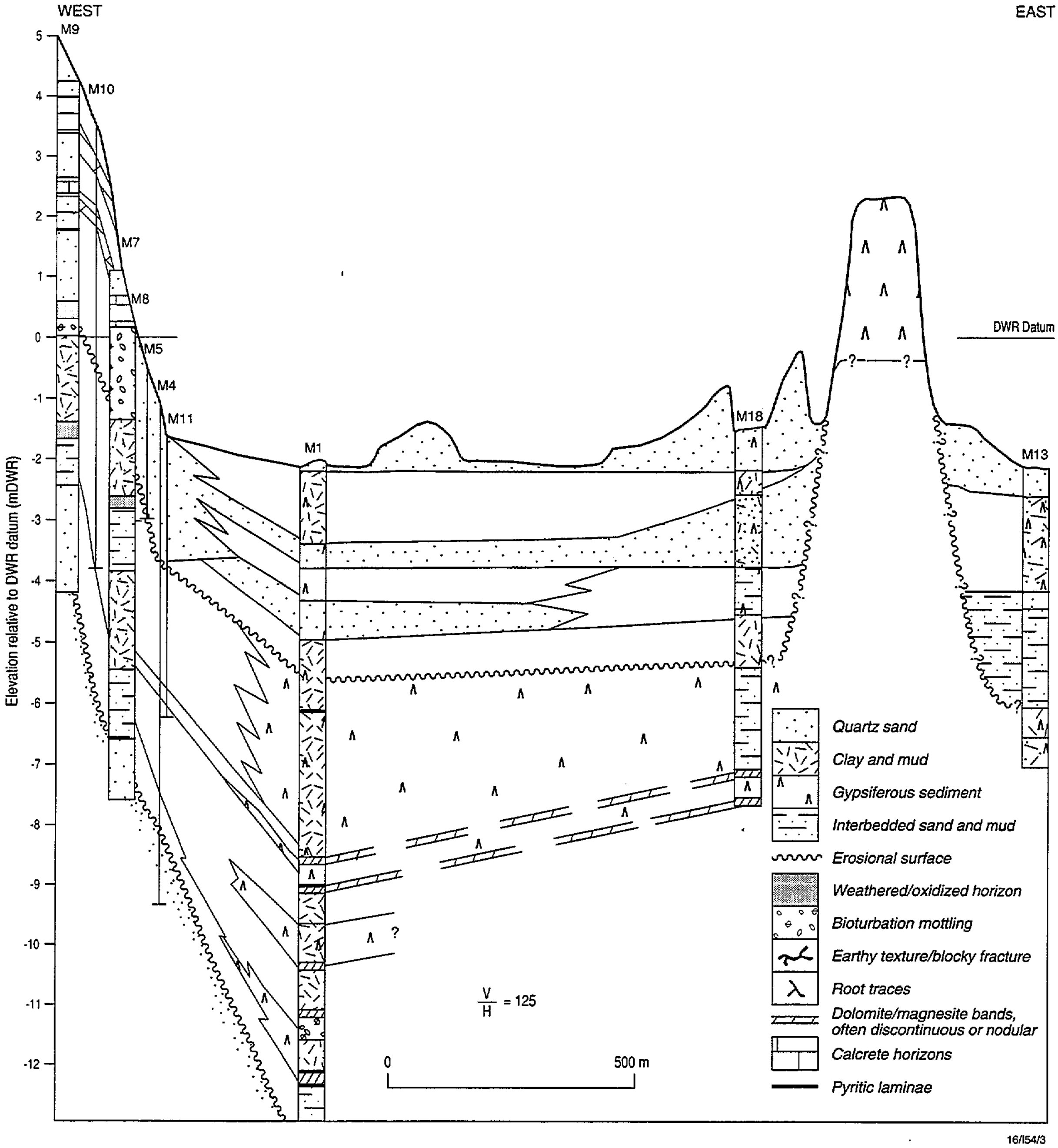

Fig. 5.7 Lithostratigraphy of the Mourquong Disposal Basin; E-W section

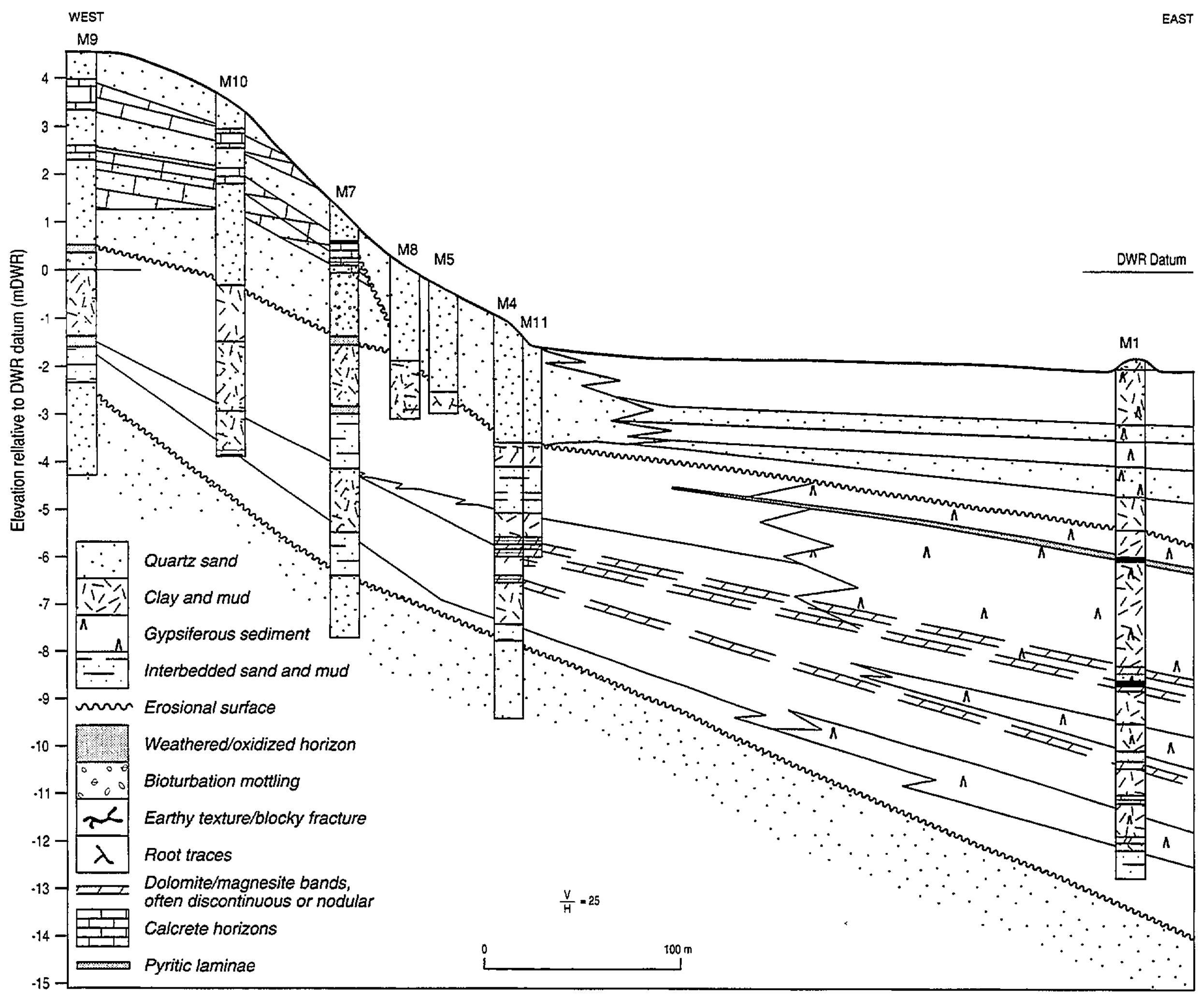

Fig. 5.8 Lithostratigraphy of the Mourquong Disposal Basin; western section

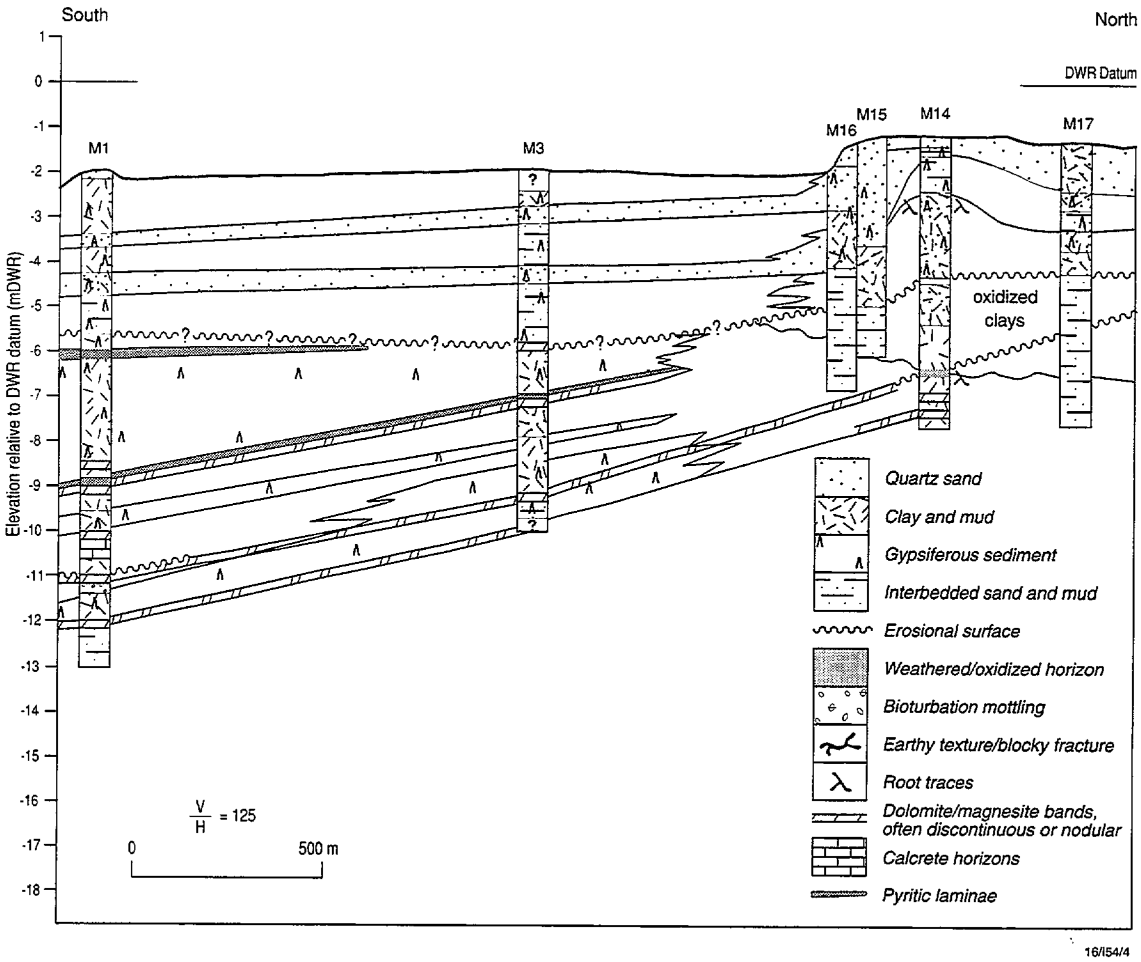

Fig. 5.9 Lithostratigraphy of the Mourquong Disposal Basin; N-S section

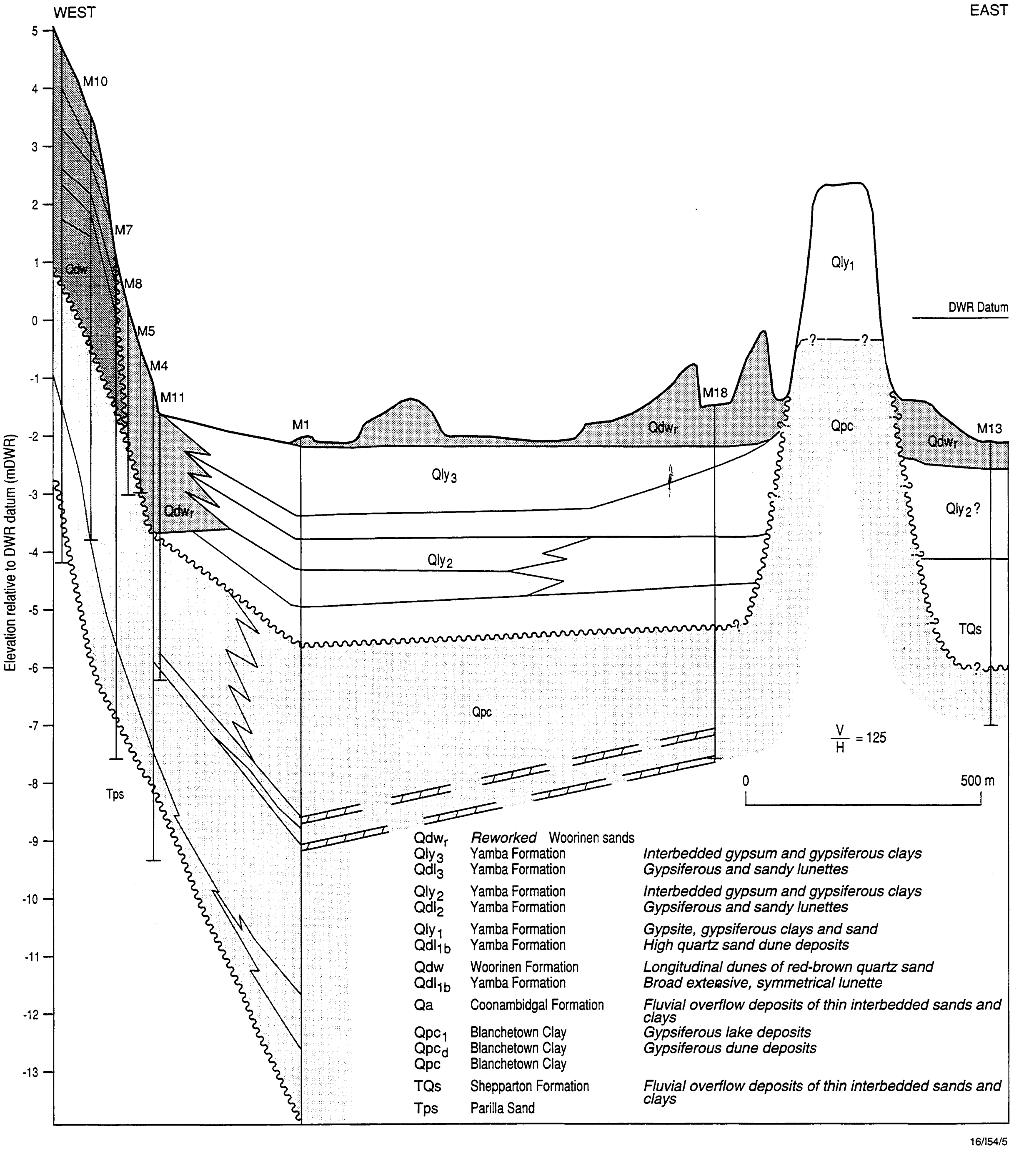

Fig. 5.10 Stratigraphy of the Mourquong Disposal Basin; E-W section

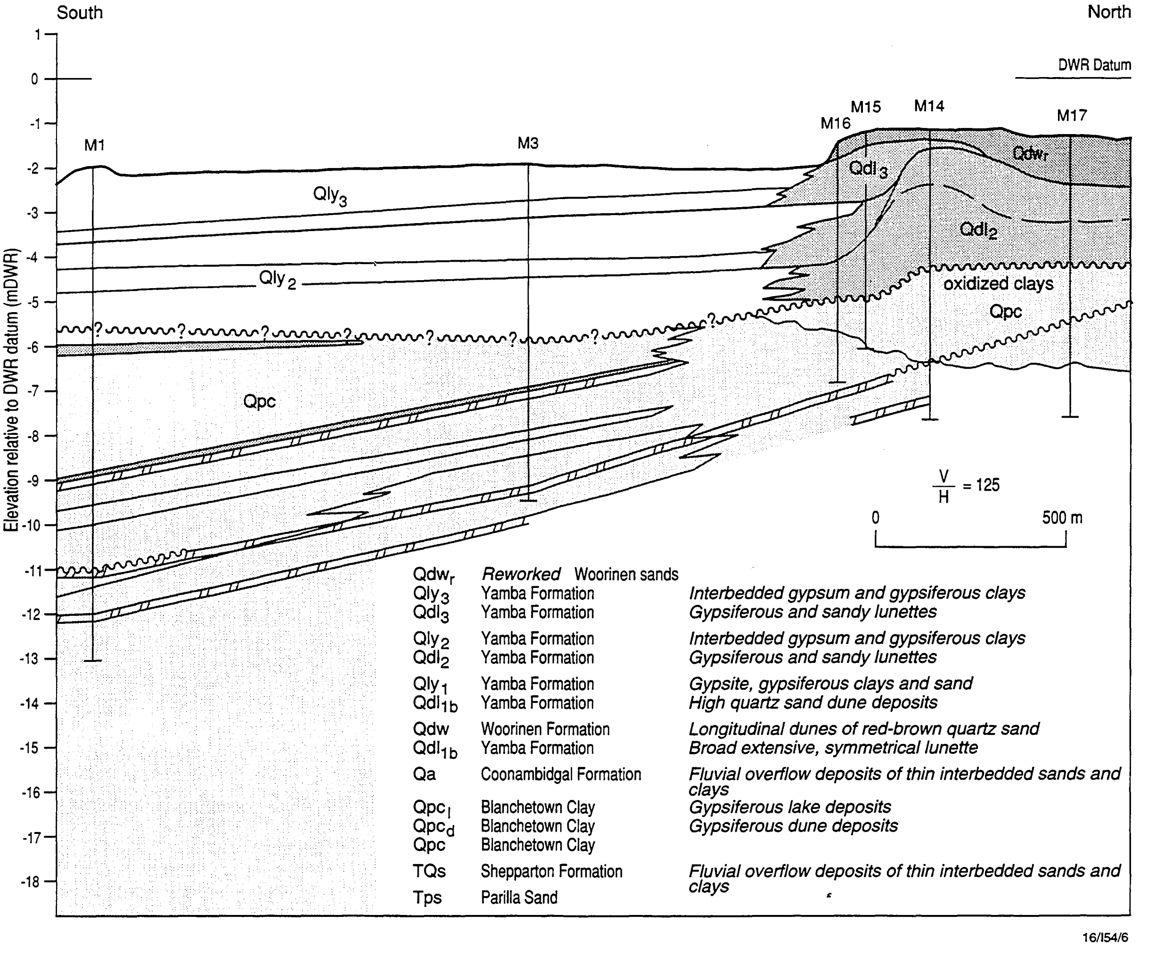

Fig. 5.11 Stratigraphy of the Mourquong Disposal Basin; N-S section.

5.3.2.1 Parilla Sand

The Parilla Sand was intercepted in the bottom 2 metres of Mourquong drillholes M4, M7, and M9, and comprises semiconsolidated light olive grey, variably sorted to bimodal, quartz sand. Large colour mottling (reddish brown, yellowish grey and light grey) intensifies upwards with increasing clay-matrix content, down-filtered from the overlying Blanchetown clay, and with apparent bioturbation. The Parilla Sand is regionally continuous and extends beneath the Mourquong Discharge Complex (Scott et al., 1991; Rural Water Commission, 1991).

Stratigraphic Relationships: The upper Parilla Sand has a porosity-modified transition into Blanchetown Clay from the erosion, reworking, of its unconsolidated sands, and from infiltered clay.

5.3.2.2 Blanchetown Clay

The Blanchetown Clay is continuous beneath the discharge complex, apparently draping gently over the former Parilla topography. This, as well as superimposed differential subsidence, is generally echoed in the present land surface. Within the west-east and south-north transects, the Blanchetown Clay ranges from 3 to in excess of 8 metres thickness in M1, at the lake centre. The unit thins to the west, towards and beyond the lake margin, and northwards along the axis of the lake to M3 and M14.

The lower 1.2 metre interval is an intermixture of underlying Parilla Sand and Blanchetown mud as thin-bedded sand-mud alternations. Where unweathered, the Blanchetown is predominantly bluish-grey mud and clay with stratiform gypseous mud facies and thin interbedded carbonates. The gypsiferous mud facies occurs in three separate lenses which are progressively thicker upsection from 0.75m to 3.5m thick at the top of the unit. This gypsiferous facies is apparently restricted to the central axis of the existing lake (M1 and M3), however there is no subsurface data under an extensive area to the east which is interpreted as having a spatial and stratigraphic admixture of saline lacustrine and lunette deposits (Figure **5.2**). Both the lenses of gypseous facies and stratigraphic thickness between carbonate horizons indicate a uniform thickening of the whole unit eastwards. Northwards the thinning is only apparent in the upper gypseous facies and an erosional hiatus is interpreted at the top of the Blanchetown Clay in M3 and M14, on the upper erosional surface of a magnesitic micrite band within weathered mud.

Thin dolomicrite bands (laminae to thin beds) and horizons of indistinct to discrete dolomicrite nodules occur within the lowerpart of the unit, some having associated evidence of exposure and weathering, or erosion.

Fine framboidal pyrite is ubiquitous, imparting darker-coloured wisps and lamination. One horizon has distinctive varve-like lamination emphasized by the pyrite and has been used as a marker horizon identified throughout the unit except in M14. In

M9, a dense limonitic ochre within oxidation-mottled sediments is interpreted as the same horizon.

On the raised sloping section west of the lake margin, additional mixed sands, sandy muds and muddy sands constitute a middle sandy facies which overlies and is overlain by "typical" Blanchetown muds. These sediments may be intercalated Shepparton Formation deposits, deposited in alluvial or possibly floodplain deposits that may have flanked the proto lake Bungunnia. Another interpretation of this facies is that it is Blanchetown Clay with an intermixture of sand from the Parilla Sand that may have been introduced by colluvial input from a nearby exposure of Parilla Sand, or from lacustrine onlap and shoreline reworking of exposed Parilla Sand nearby.

Stratigraphic Relationships: Blanchetown Clay overlies the Parilla Sand with a partially reworked zone of the underlying Parilla. The unit has an apparent conformable junction with the overlying Yamba Formation under Mourquong lake (disposal basin).

5.3.2.3 Shepparton Formation

Sediments of this unit are recognized in M13 where they are presumed to disconformably overlie Blanchetown Clay. The Shepparton sediments comprise repeated thin interbeds of unconsolidated light grey(N7) to light olive grey (5Y 6/2) muddy sand and muds, with very light olive grey (5Y 7/1) to rust-coloured (10YR 5/6) quartz sands of varying bimodality and sorting. The sands are high in heavy minerals adjacent to the muds. The muds are very thin beds with gradational fining-upwards textures.

Stratigraphic Relationships: The Shepparton Formation is incised into and overlies disconformably the Blanchetown Clay in the central part of the Mourquong Discharge Complex. The unit is disconformably? overlain by the second cycle of lake sediments of the Yamba Formation. To the west of the Danyo Fault, the uppermost Parilla and lower Blanchetown sequence have repeated sand/clay interbeds. This occurrence may also be Shepparton Formation.

5.3.2.4 Woorinen Formation

These dune sands are recognized in M7, M9 and M10. Semiconsolidated and calcareous dark reddish-brown quartz sands of the Woorinen Formation are distinctive, with sesquioxide staining on the quartz, calcrete profiles, bioturbation, and root traces. The sands range from 4m in M9 to 2.5m in M7 and are completely eroded at M5. The unit is variably indurated with calcrete intervals. Two profiles, 0.5 to 1.5m thick, are recognized in M9 and M10. These drape over the western ridge and generally conform to the topography. The upper calcrete is thinner but more compact and probably crops out between M10 and M7 where the easterly slope of the ridge steepens. The eastern extent of the lower interval is probably erosional, buried by a downslope unconsolidated sand derived from the Woorinen cover.

That the calcretes partially follow the surface into the Mourquong depression indicates that the Woorinen sand sheet extended over an already deflated surface. This is in agreement with the distribution of Woorinen longitudinal dunes on the eastern side of the complex, draping over the dominant and outermost semicircular lunette ridgelines (Figure **5.6**).

Stratigraphic Relationships: The Woorinen Formation unconformably overlies a weathered and oxidized Blanchetown surface. It is eroded and partly covered on the slope down to Mourquong lake by the Woorinen sand derivative.

Younger, remobilized reddish quartz sands contrast the Woorinen in their absence of induration and are interpreted as a reworked dune sand, synchronous with and post-Yamba in deposition. This is referred to as the Woorinen sand derivative.

5.3.2.5 Yamba Formation (Brown and Stephenson, 1991)

The sequence overlying the Blanchetown Clay has a contrasting high clastic gypsum sand content as beds and laminae, interlaminated with clays and muds. These lake deposits also thicken eastwards into the discharge complex. On the south-north section the unit thickens slightly to M3, and then thins considerably towards M14 with a corresponding increase in thickness of interbedded quartz-sand bodies.

These brown gypseous quartz-sand intervals are interpreted as Woorinen sand derivative, and form two thin (0.5 metre) but extensive sheets which thicken suddenly in M14. They are apparent aeolian equivalents of the lake deposits, and are transitional with gypsum-rich lunettes which have been delineated on aerial photography (Figure **5.2**). In the cross-sections, these lunettes have been differentiated (Qdl) from the host Yamba Formation. No lithostratigraphic information is available on these lunettes.

The Woorinen sand derivatives probably indicate deflation events within the current discharge history and are probably equivalent chronostratigraphically with the deflation events proposed for the Nulla Discharge Complex (Radke, 1992).

Stratigraphic Relationships: The Yamba Formation overlies the Blanchetown Clay with apparent conformity under Mourquong Lake (disposal basin) except at the northern end where a hiatus is inferred in M3 and M14. On the western margin of the lake it lenses out under the Woorinen sand derivative. At least two intervals of the Woorinen sand derivative intertongue with the unit and, within the area of section lines, appear to extend over the whole area. Because of the type of lake accumulation, there are numerous breaks and micro-deflation events within the Yamba Formation.

5.3.3 Diagenesis

5.3.3.1 Carbonate

Bands and horizons of concretions of chalky white micritic carbonate occur within the Blanchetown Clay. Most occurrences are chalky dolomicrite but to the northern end of the transect, the upper eroded surface of the unit in M14 and M3 appears to be magnesite (no effervescence in 10% hyrochloric acid).

Generally the Woorinen Formation is slightly calcareous. Calcrete profiles of varying maturity occur in the middle and upper Woorinen Formation. Where fully developed, the profile has a distinct and indurated upper boundary, mottled calcite-rich pinkish matrix in the host sand, scattered pisolites and reworked calcrete fragments. Extra cementation may occur in root traces. Two calcrete profiles are recognized, the upper one apparently eroded on the western slope between M7 and M10.

5.3.3.2 Gypsum

Gypsum is present in the Blanchetown Clay as scattered laminae of clastic sands within muds and clays. This gypseous facies is only present under Mourquong lake (disposal basin) but is apparently absent laterally to the west into sandier Blanchetown facies beyond the lake.

In the overlying Yamba Formation, gypsum is prolific as laminae and thin beds of primary clastic sands. These indicate seasonal or regular episodic origin. At a few upper horizons, hardpan layers of variable continuity and induration, indicate static groundwater levels when the lake was dry.

5.3.3.3 Pyrite

Within the Blanchetown Clay, much of the lamination within the predominantly blue-grey mud sequence is colour-enhanced by fine black framboidal pyrite which appears restricted to fine interparticle porosity in thin silty or sandy interbeds within gypseous facies. This suggests sulphate reduction occurred where organic matter and iron-rich porewaters were closely associated in porous gypseous laminae.

5.3.3.4 Discussion

Syndepositional diagenesis has been predominant in the sequence. Significant early diagenetic overprints occur in the Yamba Formation in gypsum hardpans where the lake has been dry, and groundwater levels have left indurated gypsum crystal crusts within the sequence. Pedogenic processes in the sands of the Woorinen Formation have also remobilized wind-blown carbonate into calcrete horizons.

5.3.4 Porosity

5.3.4.1 General Statement

Lateral permeability within the complex is significant within the Parilla Sand, Woorinen Formation, Woorinen Formation derivative, and the lowermost and uppermost intervals of the Yamba Formation.

There are no aquitards except in the central area of Mourquong within the Blanchetown Clay. Porosity within the Blanchetown increases laterally towards and beyond the lake margin, in an apparent association with a thinner sandier sequence which is contained within thin, relatively impermeable clays.

Porosity is predominantly the interparticle type in sorted sands. Less abundant porosity in the sequence comprises minor intercrystalline porosity in the carbonates, and some fenestral porosity in bioturbated horizons.

Porosity distribution in the Mourquong sequence is presented in Figures Figures **5.12** to **5.14**. Details of porosity type and distribution is shown in the lithological logs of Appendix I of Radke (1992b).

5.3.4.2 Parilla Sand

Porosity is generally good, with uniform high interparticle porosity, but decreases gradually up to the Blanchetown contact. This reduction is a direct result of mud from the Blanchetown Clay.

5.3.4.3 Blanchetown Clay

This unit has extremely variable interparticle porosity, corresponding to the presence of thin interbedded sands, especially in the lower transitional interval with the Parilla Sand, as well as to the west beyond the lake margin where sands, sand interbeds, and muddy sands lie between less permeable Blanchetown muds.

Carbonate horizons, and the very pyritic laminae are both relatively porous, with intercrystalline porosity predominant.

5.3.4.4 Woorinen Formation

Medium interparticle porosity in the slightly clayey sands, is reduced within the calcrete profiles, corresponding to variable occlusion by micritic calcite cement. Fenestral and bioturbation porosity which is more erratic in distribution, becomes relatively abundant in these intervals.

5.3.4.5 Yamba Formation

Interparticle porosity has a predominantly stratiform distribution in thin flaser-like interbeds of lake muds and relatively porous clastic gypsum sands. Extensive quartz-dominant aeolian sand stringers and sheets, forming two intervals within this formation, are even higher in interparticle porosity.

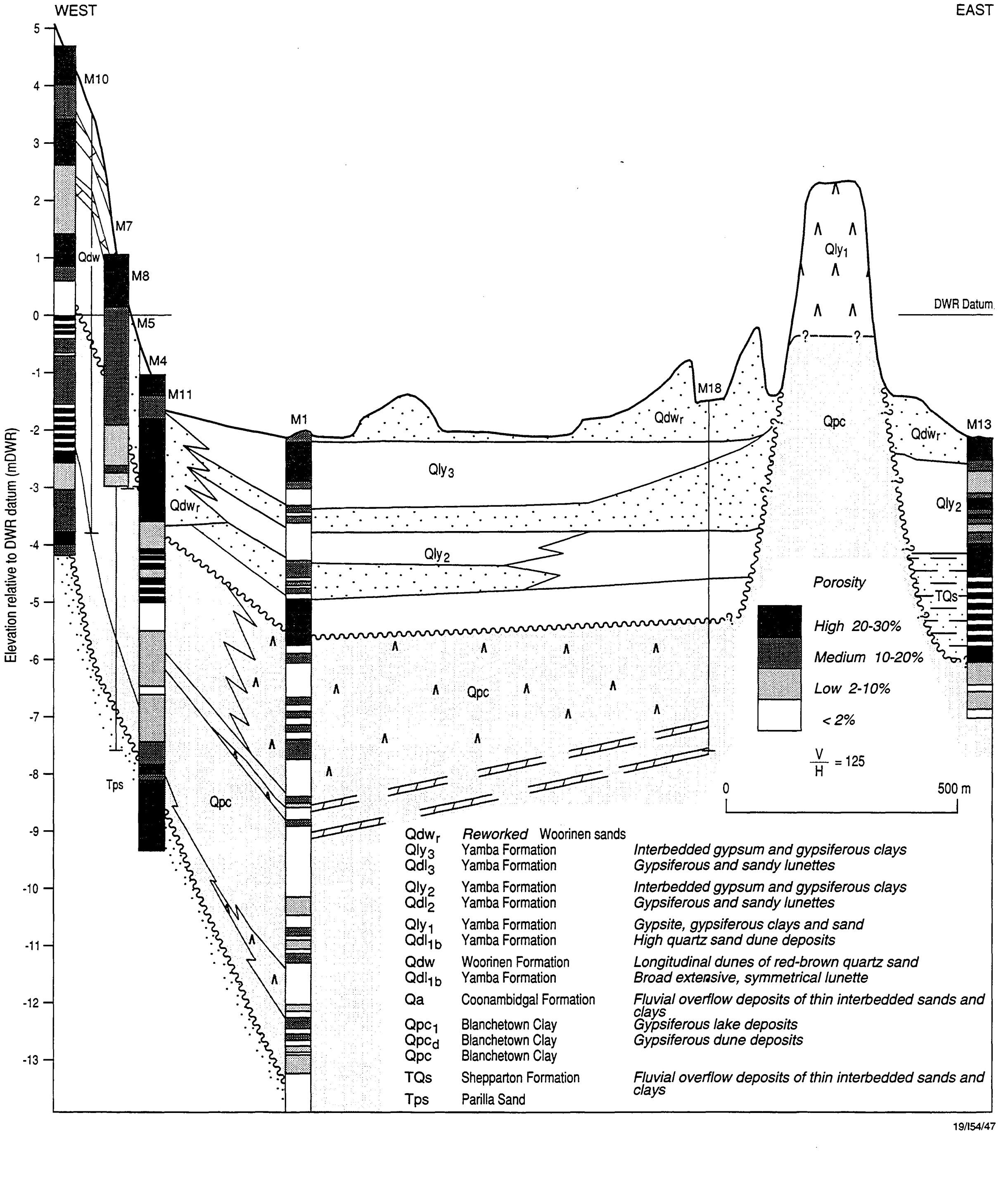

Fig. 5.12 Porosity of the Mourquong Disposal Basin; E-W section

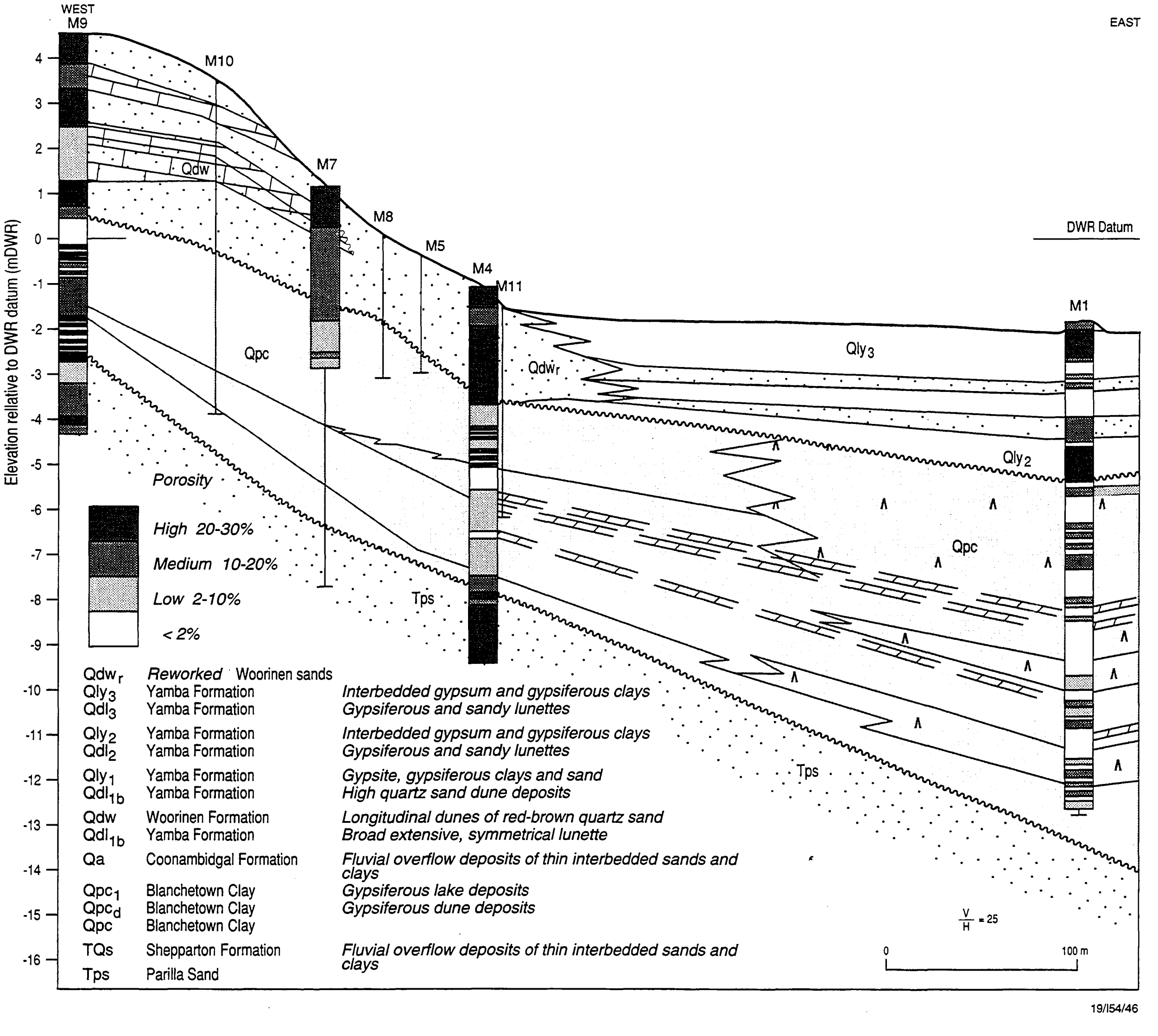

Fig. 5.13 Porosity of the Mourquong Disposal Basin; western section

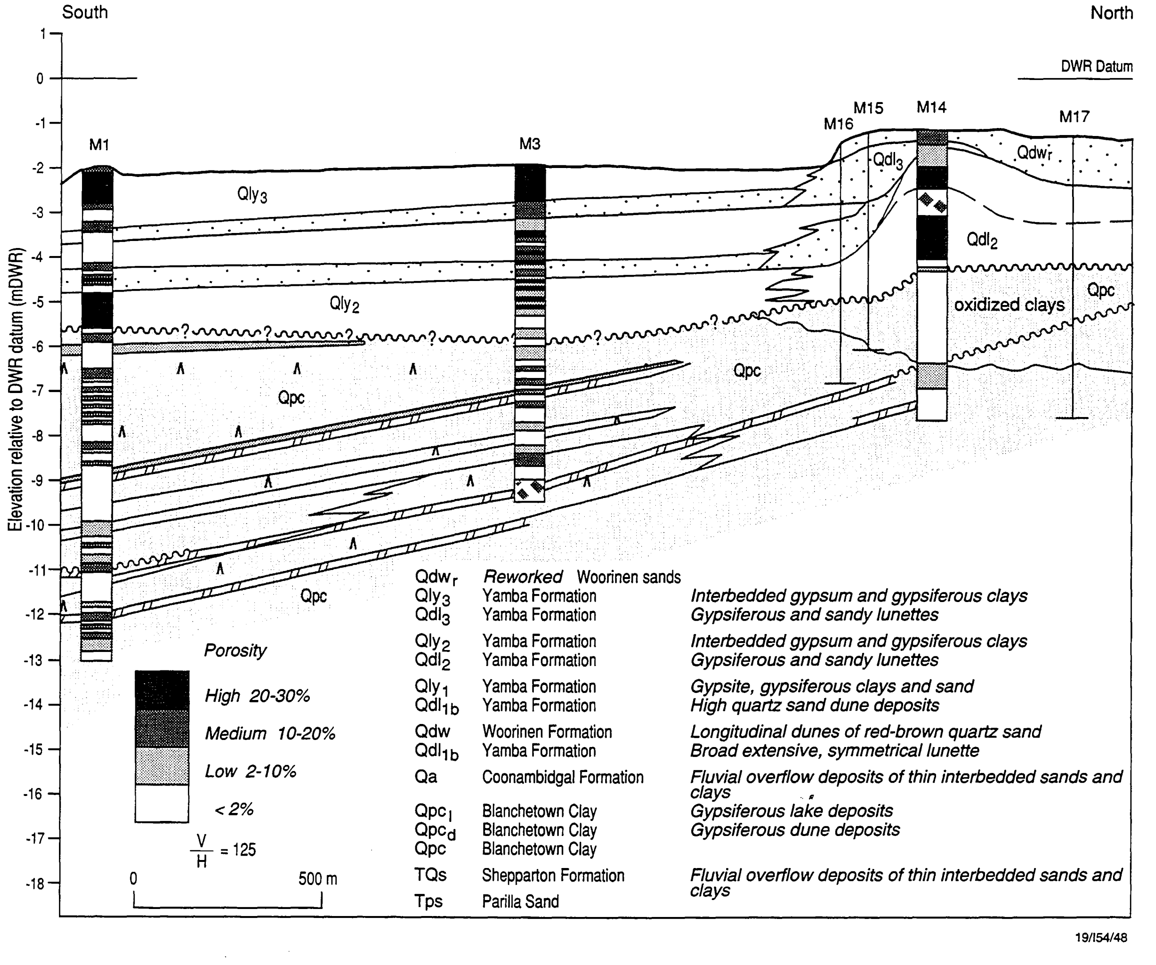

Fig. 5.14 Porosity of the Mourquong Disposal Basin; N-S section

5.3.5 Regional Structure

The Mourquong Discharge Complex is a topographic depression overlying the Koorlong Trough which has a western faulted margin along the Danyo Fault, separating it from the Merbein Ridge immediately to the west (Rural Water Commission, 1991). The location of this fault is placed further east of the active lake under the Mourquong Swamp by Scott et al.(1991) although their stratigraphic cross-section enigmatically contradicts this position. Dislocation on the Danyo fault is only below the Tertiary sequence and subsidence in the trough is implied throughout the Tertiary (Rural Water Commission, 1991). The present physiographic features of Mourquong are also an expression of this subsidence in the Koorlong Trough. More detailed geophysical delineation of the fault would be desirable to clarify this issue.

Thicknesses of both the Blanchetown Clay and Yamba Formation confirm subsidence in the limited area investigated. Airphoto and TM interpretation indicates the extent of the complex is a semicircular depression within the Koorlong Trough (Figures **5.2** and **5.6**).

5.3.6 History of Mourquong as a Discharge Complex

The present-day physiography of the Mourquong Discharge Complex reflects differential subsidence of the Tertiary sequence, controlled by pre-Tertiary structure. The discharge complex is a depression which overlies part of the western side of the Koorlong Trough and has existed throughout Blanchetown Clay and Yamba deposition, with the depocentre located approximately 1 km further east of M13.

Blanchetown deposition was initially and predominantly under lower salinities with intermixture of muds with sand derived from surrounding exposed Parilla Sand. Intermittent dolomite precipitation occurred in this earlier period of generally lower salinities. Three phases of higher salinities contributed minor gypsum to the lake muds. The last phase produced the thickest and uppermost gypsiferous facies.

These protracted phases of higher salinity fluctuations were apparently restricted to the central depocentre.

Additional introduction of sands from the west occurred intermittently on the western margin and probably relates to fluvial events (Shepparton Formation) on the higher exposed terrain marginal to Lake Bungunnia. With the demise of this lake, conditions became more saline and extensive areas of gypsum accumulation characterize the upper Blanchetown Clay (Brown and Stephenson, 1991). Probable remnants of this event and related deflation and gypsite dune accretion occur several kilometres east of the Mourquong discharge complex.

At some stage, the Mourquong depression was invaded to form part of the Murray floodplain. Significant erosion occurred with channel erosion of the Blanchetown Clay down to 6 - 8metres depth. These channels were later infilled or partially filled with overbank deposits (TQs - Shepparton Formation).

Probably with increasing aridity but with a lag in groundwater level, surface evaporation created salt impregnation of the lacustrine sediments and substantial deflation of the area commenced, creating a large symmetrically arcuate sequence of lunettes on the eastern margin and a semicircular deflated surface some 7 to 8 km across (Qdl_{1a}). This may have developed at the onset of the major arid period when the Woorinen sands became established. Longitudinal dunes (Qdw) still cover the western slope down into the Mourquong depression and the northern part of this initial series of lunettes. This suggests that a groundwater discharge lake may have existed in the southern half, preventing normal dune development in the southern area.

Following cessation of Woorinen dune formation, another significant deflation event modified the southern major lunette and accreted additional aeolian sediment on the internal side of it (Qdl_{1b}). The sediment was probably reworked from less regular Woorinen features that covered the discharge area. It appears that predominantly authigenic gypsiferous deposits (Qly_1) accumulated within the deflation feature at this time. An alternative explanation is that this gypsum accumulated during the termination of Blanchetown Clay deposition, and acted as a resistant capping prior to alluvial erosion and Shepparton deposition.

In the next major deflation event, this gypsiferous pavement was eroded in a random and unpredictable manner. Erosion was most severe on the western side of the complex where up to 7 metres of relief was created. Lunettes (Qdl_2) accreted against the western scarps of this irregularly-incised pavement. With this irregularity, the lunette patterns were comparably complex.

Another significant lacustrine phase deposited alternating laminae of clays and gypsum, probably seasonally, to produce gypsum deposits locally (Qly_2). These lake deposits mark a lowered lake surface across much of the eastern side of the complex.

A further deflation event eroded the western side of the basin down another 1.5 metres approximately. This event apparently extended into a very arid period and Woorinen sands were remobilized and deposited a thin sand sheet across the lake floor, possibly as the conditions changed away from the aridity. Irregular low relief sunes cover parts of the terrain in the dissected east of the basin. Gypsiferous aeolian sediments (Qdl_3) accumulated locally against the existing lake.

In these latter accumulations, the seed gypsum-rich sediment may be accumulating by aeolian processes seasonally, alternatively with the seasons of precipitation, to produce near-stratiform deposits but with a palimpsest low ridgelining of former lake margins.

Deposition of alternating clays and gypsum laminae (Qly3) continues within the lake.

5.3.7 Comparison of Mourquong and Nulla Discharge Complexes

Both Mourquong and Nulla Discharge Complexes have comparable lake deposits in a continuum through Blanchetown Clay to recent deposits. Radke (1992a) presented three stratigraphic models for the Nulla sequence and favoured the absence of Blanchetown Clay below Nulla Spring Lake. Following this study of the Mourquong sequence, and the transitions within the Blanchetown Clay away from the lake, his third model (Radke, 1992a, fig.18b) is now seen as a more viable model.

The major difference between the discharge complexes is in the structural and tectonic setting. At Mourquong, the subsidence and resultant lake deposition has its depocentre centrally or possibly to the eastern side of the complex. At Nulla, initially deposition was within a complex terrain resulting from differential erosion within a former Parilla dunefield. In the southwestern margin, around Nulla Spring Lake, there is greater lateral differentiation of lacustrine to the west and aeolian facies to the east.

Given the asymmetry of both complexes resulting from wind transport and therefore lunette accumulation predominantly on the eastern side, then we see the significant difference in the sequence facies geometry arising from different tectonism. At Mourquong, deflation of aeolian sands and clays on the western margin causes admixture with authigenic lake gypsum accumulating centrally as lake deposits. Lunette deposits accumulate to the east and then prograde westwards. However, with subsequent reflooding of the lake, and subsidence to the east, lacustrine deposits accumulate over the entire area, including between former lunette deposits and the overall spatial facies distribution is highly entropic over the whole area.

In contrast, Nulla Spring Lake has its depocentre of accumulation on the western margin. Lunette deposits are always on the raised eastern side and are subject to more deflation than at Morquong. At Nulla, successive deflation and flooding events tend to be more restricted to the western margin and at lower levels. This pattern may also indicate either lower gypsum precipitation rates, or more effective deflation of sediment out of the complex.

Both discharge complexes have comparable major deflation and lacustrine events. Evidence exists in both complexes for the initial major deflation to have occurred pre-Woorinen, with two subsequent deflation events. This degree of comparability is strongly indicative of predominantly climatic controls on their evolution.

5.3.8 Summary and Conclusions

1. The Mourquong Discharge Complex occurs on the western margin of the Koorlong Trough, adjacent to the pre-Tertiary Danyo Fault. The discharge complex has been the subsiding and consequently has been a depocentre since at least the Pleistocene. Regional patterns suggest gentle subsidence may have been continuous throughout the Tertiary.

2. The AGSO drilling has defined the western margin and north-south variations within the complex. However the eastern area has a possibly significant and thicker lacustrine sequence which remains uninvestigated.

3. The observed sequence is consistent with that of Scott et al.(1991); Parilla Sand with significant lateral relief, over-draping of Blanchetown Clay, and overlying saline lacustrine deposits of the Yanba Formation. A small erosional bench has been incised into the Blanchetown Clay on the western margin, but did not significantly penetrate the formation. Although there is no window into the Parilla sand, lateral facies and porosity variations in the Blanchetown Clay, sandier and more permeable to the west, would allow lateral fluid migration.

4. Aside from the highly porous Parilla Sand and Woorinen Formation, the lacustrine Yamba Formation has highly porous sand horizons, especially basally and in the upper section. Blanchetown clay has modest but isolated sandy porous intervals under the lake. However, laterally to the west away from the lake margin, porosity increases in the Blanchetown Clay with increasingly mixed and interbedded sands in the unit. The dominant porosity is interparticle porosity in sands.

5. Mourquong evolved into a saline evaporative basin gradually. During Blanchetown deposition, the central facies was intermittent and moderately gypseous. During and/or following Woorinen development, salinities were much higher, with predominant primary gypsum deposition in seasonal? or recurring events (Yamba Formation). Gypseous lunette remnants in the central-eastern part of the complex indicate several phases of significant deflation which is also evident from extensive thin sheets of quartz dune sand (Woorinen sand derivative) and thin gypseous hardpans within the Yamba Formation.

6. Because of the continuous subsidence, greater in the central and possibly also in the eastern leeward area, a less interrupted depositional sequence is preserved with a generally stratiform geometry. The surface distribution of lunettes and lake deposits from overflooding is correspondingly complex (see Figure **5.2**).

7. In contrast, Nulla Discharge Complex has had little or no subsidence and is located among remnant islands of Blanchetown Clay. Locally at Nulla Spring Lake, the thickest sequence is on the western side and facies are laterally differentiated;

lacustrine deposits predominate on the western side, and lunette deposits with interspersed erosional events predominate to the east. Major deflation events have sequentially incised the lake level deeper on the western edge of the complex.

8. In summary, the Mourquong Discharge Complex, has had greater subsidence and consequent lower differentiation of facies, and minimal loss from deflation in comparison to Nulla.

5.4 Surface Water Hydrodynamics and Hydrochemistry

5.4.1 Disposal Area Topography

The usually flooded part of the disposal basin (Figure **5.15**) is a cresent shaped, north-south orientated area located in the western part of the Mourquong Discharge Complex but there are lower areas to the east, nearer the centre of the complex. These lower areas (e.g. -2.14 mDWR at M13) are partly isolated from the main area of the disposal basin (e.g. -1.99 mDWR at M1) by a raised gypsite terrace (Figures **5.2** and **5.7**). Northwards of the centre of the basin, deflation has removed most of this terrace, leaving only a low barrier ($\leq$ -1.4 mDWR) to flooding.

The area of the discharge complex at the northern margin of the disposal basin contains lacustrine sediments overlain by reworked Woorinen Sand (Figures **5.2** and **5.9**). This area is topographically only slightly higher (e.g. -1.42 mDWR) than the nearby margin of the flooded area (e.g. -1.51 at M16). There is a possible topographic barrier (e.g. -1.13 mDWR) at this northern margin but it is probably not continuous and is breached by, for example, vehicle tracks.

5.4.2 Surface Water Flow

The disposal water discharges from an inlet pipe at the southern extremity of the disposal basin (Fig. **5.15**) and flows north, initially through relatively well-defined channels. As the water approaches the middle of the disposal basin, flow is directed towards the western side of the flooded area where further movement eastwards is blocked by the gypsite terrace and lower dunes of reworked Woorinen Sands which have accumulated on its western flank (Figure **5.10**). From the western side, the disposal water spreads eastwards to form the broadest part of the disposal basin. It then funnels northwards along the western side of the discharge complex.

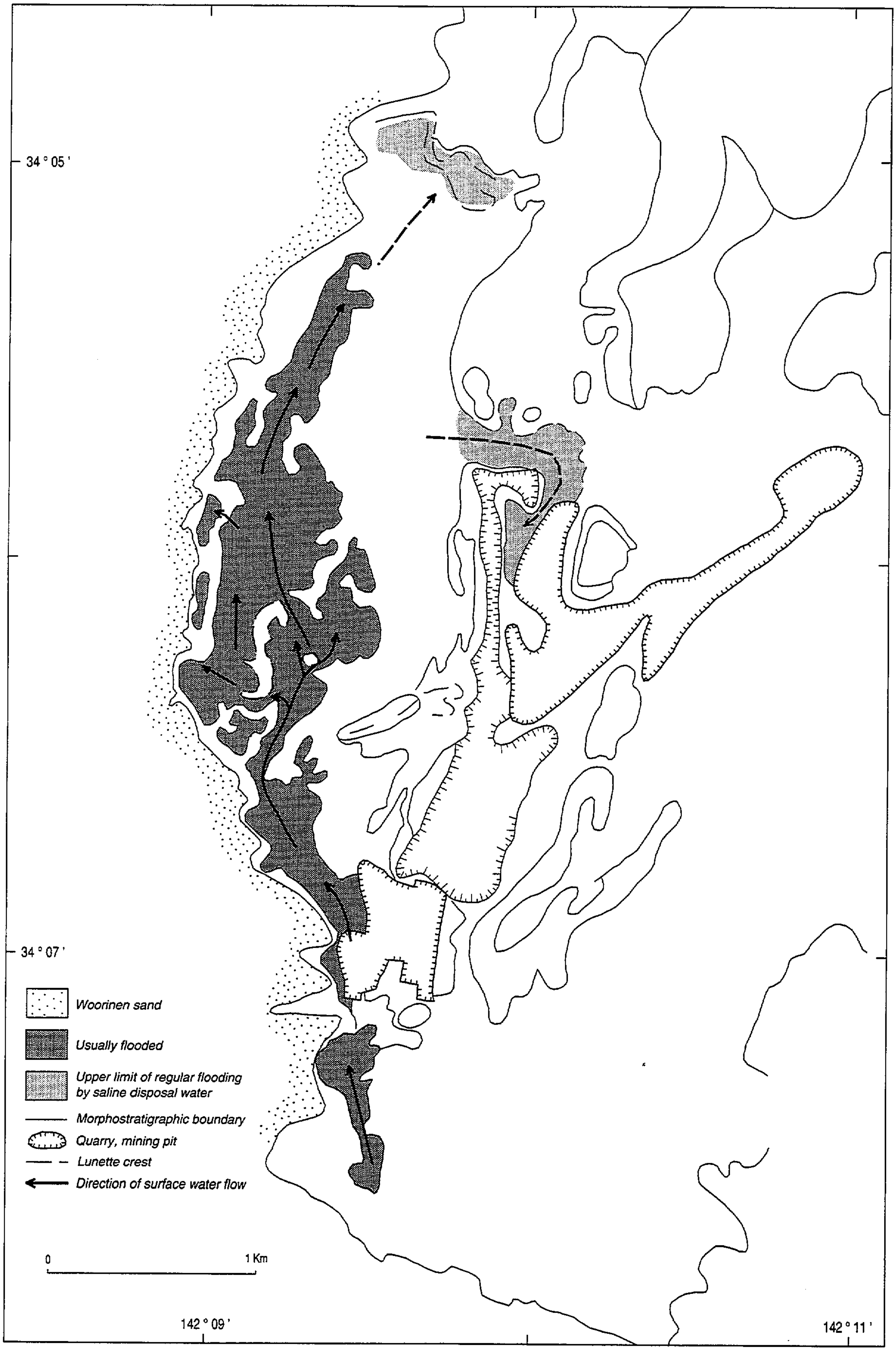

Fig. 5.15. Example of the extent of surface water flooding under low basin pool operating conditions (low discharge/high evaporation rates) and an indication of the upper limit of flooding under occasional very high operating conditions. Likely flow directions are also shown.

During occasional very high basin pool operating conditions the disposal water crosses the deflated area in the gypsite terrace and floods the topographically lower areas to the east. This floodwater is trapped when the operating levels drop, and evaporates to dryness leaving a surficial crust of salt on the lower areas behind the gypsite terrace.

5.4.3 Basin Pool Operating Water Level and Extent of Flooding

Information on the water level in the disposal basin is limited to observations made during a period of low basin operating levels (i.e. low discharge/high evaporation) in summer (Feb/March 1993) and during a period of moderately high operating levels in late winter (August 1992). The available data are in Table **5.1**.

Table 5.1. *Surface Water Levels and Salinity, Mourquong Disposal Basin*

Operating pool level	*Location*	*Season*	*Water Level (mDWR)*	*Salinity (mg/L)*
Low	Near M1	Summer	-1.94	296,000
	M3	Summer	-1.88	
Moderately high	M1	Winter	-1.75	96,000
	Western shore	Winter	-1.61	91,500

The difference in the operating water level between the summer and winter observations is not large (up to 0.33 m, Table **5.1**). However, the disposal basin is very broad and shallow and this difference is sufficient to cause a large change in the area of the disposal basin and in the salinity of the surface water. The observed late summer water levels were sufficiently low for the flooded areas in the western of the central area and to the north to break up into ponds of 0.1 to 1 km^2 in area (Fig. **5.15**).

The highest surface water level observed appears to be well short of that which attained during regular high operating conditions. Because this level defines the limit of potential vertically downwards movement of disposal water into the underlying sediment, estimates of its elevation have been made. These estimates are based on residual effects such as the presence of surficial salt and the upper limit of a zone of dead grass at the western margin (Table **5.2**).

The best indicator of the regular high operating water level is the elevations of sites M16, on the northern margin, and M18 on the eastern margin which, as indicated by the extent of devegetation, are close to the limit of the obviously regularly flooded area. Their elevations are similar (-1.51 and -1.46 mDWR, respectively), which suggests a 'best guess' for the upper limit of regular flooding as -1.5 mDWR. Assuming the lower limit of regular low pool operating levels is about -1.9 mDWR, the range of pool operating levels in the disposal basin is about 0.5 m.

Table 5.2. *Indicators of Regular High Operating Water Levels, Mourquong Disposal Basin*

Location	*Site*	*Ground level (mDWR)*	*Salinization*
Northern margin (N-S transect)	M17	-1.37	No flooding
	M14	-1.13	?
	M15	-1.25	transition zone
	M16	-1.51	'just on lake'
Eastern margin (eastern transect)	M18	-1.46	transition zone
	M13	-2.14	overflow flooding
Western margin	MT-1	-0.75	limit of dead grass

The upper value for this range of operating levels is not the limit of the influence of the disposal waters on the adjacent surface sediments. The basin boundary is diffuse, probably because of a continuously decreasing frequency of flooding at the higher operating levels, but also because of the effects of wave action and salt spray. These effects would account for the presence of the dead grass at -0.75 mDWR, which is considerably higher than the predicted high pool operating levels.

5.4.4 Salinity of Surface Water

The salinity of the surface water in the basin ranges widely (34,000 to >350,000 mg/L.), depending on pool operating conditions (Table **5.1**) and distance from the disposal water inlet (Figure **5.16**).

Under low pool operating conditions in summer, the salinity in the disposal area increased progressively with distance northwards, from 34,000 mg/L in the inlet pipe

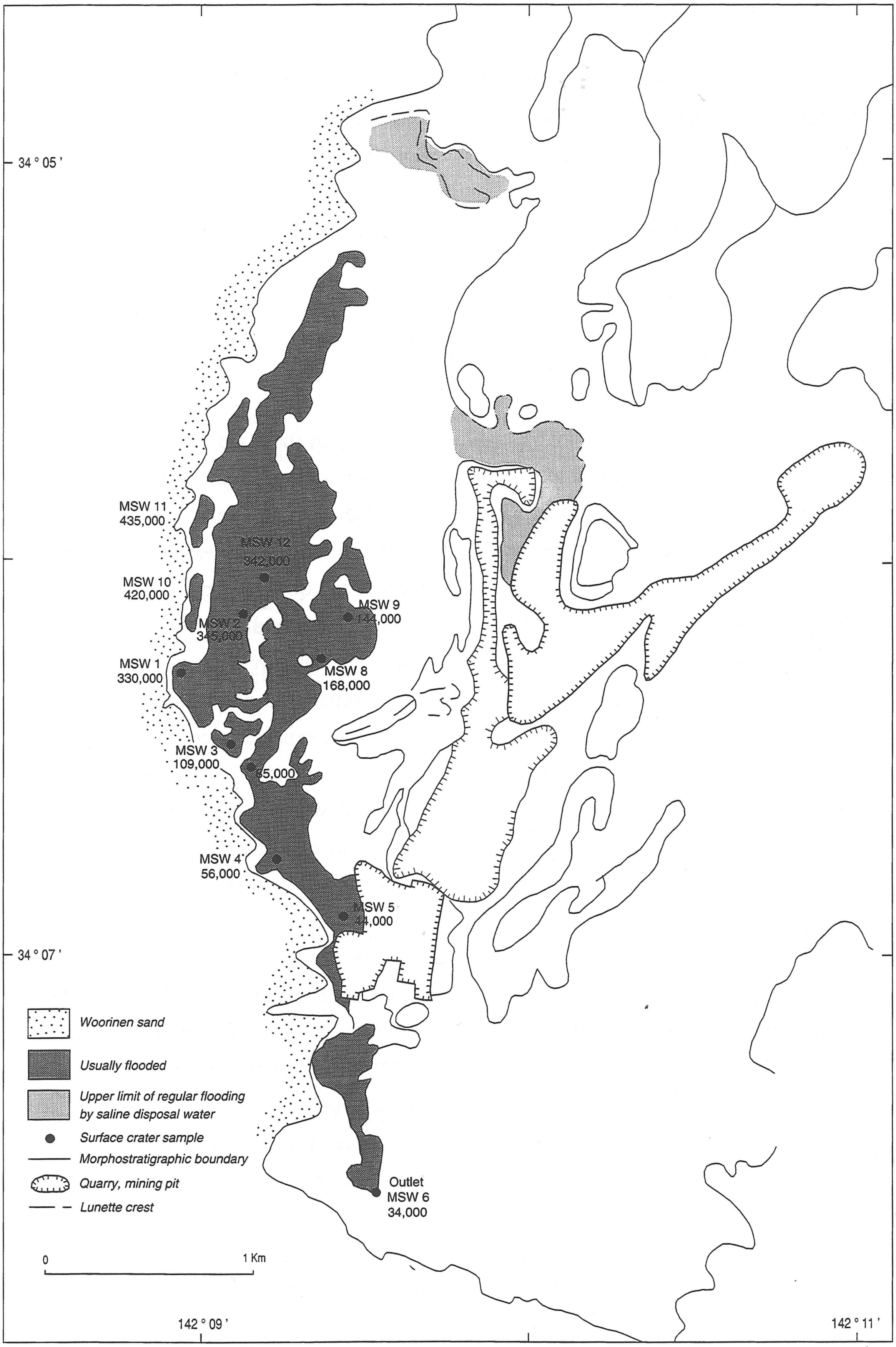

Fig. 5.16 Surface water salinity in the disposal basin in early autum (March 1993). Salinity increases with distance away from the point of discharge of disposal water. Winter salinity is much lower.

to considerably more than 350,000mg/L in isolated, almost dry, evaporite-rich ponds on the western side of the disposal area (Figure **5.16**).

Under high pool operating conditions in winter, the salinity in the disposal basin was much lower. For example, near M1 the winter value was about 90,000 mg/L (Table **5.1**) which is less than one-third the comparable summer value of about 300,000 mg/L. The winter salinity is considerably below that for halite saturation, which implies that almost all of the halite and more soluble salts precipitated in the disposal area during the previous summer were redissolved as the pool operating levels increased.

5.4.5 Hydrochemistry of Surface Water

The disposal water is seawater-like in salinity but there are differences in major ion composition which could lead to the precipitation of a different suite of evaporite minerals. Further, the changes in salinity which the disposal water undergoes in the evaporation basin are cyclical and occur during two phases. (1) Evaporative formation of brine and precipitation of salts (leaving bitterns) as conditions change from high to low pool operating conditions. (2) Re-solution of salts and dilution of the residual bitterns by new disposal water as pool operating water levels return to high levels.

The first phase could result in progressive separation of evaporite minerals as they precipitate along the disposal water flow path. This separation could be maintained at high pool levels if mixing was poor during the dilution and re-solution phase. Potentially, a combination of a disposal water source which is different in major ion composition from that of seawater with effective mineral separation processes in the basin could produce an unusual suite of evaporite minerals, perhaps with commercial significance.

To test this hypothesis (a) the chemical composition of the disposal water and its predicted evaporative products were compared with seawater and its predicted evaporation products, and (b) the disposal basin water samples from the locations shown in Figure **5.16** were analysed to assess if they represented a series:

i) which has evolved solely by evaporation of the inlet water, or

ii) which has been modified by re-solution of precipitated salts, or

iii) which has resulted from mixing of inlet water and bitterns.

Analytical data for Ca, Mg, Na, K, Cl and SO_4 in mg/L (data are in the Appendices) were converted to molal (Table **5.3**) using an estimated density. Subsequent calculation of equilibrium activities, solubilities, and densities using the Pitzer formulations in the Chemix module of the CSIRO Thermochemistry System

(Turnbull and Wadsley, 1988; Chambers et al., 1992) showed good agreement for the density values (Table **5.3**).

The predicted Na, Mg, SO_4, and Cl molal composition of brines which would evolve by equilibrium evaporation at 25°C of the inlet water (MSW 6) and two other relatively low salinity samples (MWS 3 and 5) is compared, graphically to the measured composition of the disposal basin brines in Figure **5.17**. At high salinity there appears to be some deviation between the predicted concentrations for the evaporated waters and the compositions of the highly saline samples, but the differences are close to those expected from analytical accuracies.

The evaporation pathway of the Mourquong Disposal Basin inlet water is compared to that for seawater in Figure **5.18**. The extent of evaporation is represented as the decrease of water concentration. The ionic strength at some water concentrations is shown, but ionic strength is not a simple mathematical function of water concentration. In the equilibrium evaporative evolution of seawater, gypsum ($CaSO_4.2H_2O$) precipitates at an ionic strength of about 2.6 molal and is replaced by anhydrite ($CaSO_4$) just prior to halite (NaCl) saturation which occurs at an ionic strength of about 7.3 molal. Glauberite ($CaNa_2(SO_4)_2$) forms subsequently (ionic strength of about 7.6 molal) at the expense of anhydrite through reaction with the brine.

$$CaSO_4 + 2Na^+ + SO_4^{2-} = CaNa_2(SO_4)_2$$

This reaction is partly reversed, but glauberite and anhydrite both react with the brine to form polyhalite at about the same time as the magnesium sulphates (Epsomite, $MgSO_4 \cdot 7H_2O$; Hexahydrite, $MgSO_4 \cdot 6H_2O$; Kieserite $MgSO_4 \cdot H_2O$) begin to precipitate sequentially as evaporation proceeds.

$$CaSO_4 + CaNa_2(SO_4)_2 + 2K^+ + SO_4^{2-} + Mg^{2+} + 2H_2O$$
$$= K_2MgCa_2(SO_4)_4 \cdot 2H_2O + 2Na^+$$

Finally, polyhalite reacts with the brine re-forming anhydrite and producing carnallite.

$$K_2MgCa_2(SO_4)_4 \cdot 2H_2O + 4H_2O + 3Cl^-$$
$$= 2CaSO_4 + KMgCl_3 \cdot 6H_2O + 2SO_4^{2-} + K^+$$

The chemistry of the Mourquong Disposal Basin inlet water is sufficiently different (Table **5.4**) from seawater to allow glauberite to form during equilibrium evaporation, at an ionic strength of about 7.4 molal, just prior to halite saturation (ionic strength of about 7.5 molal).

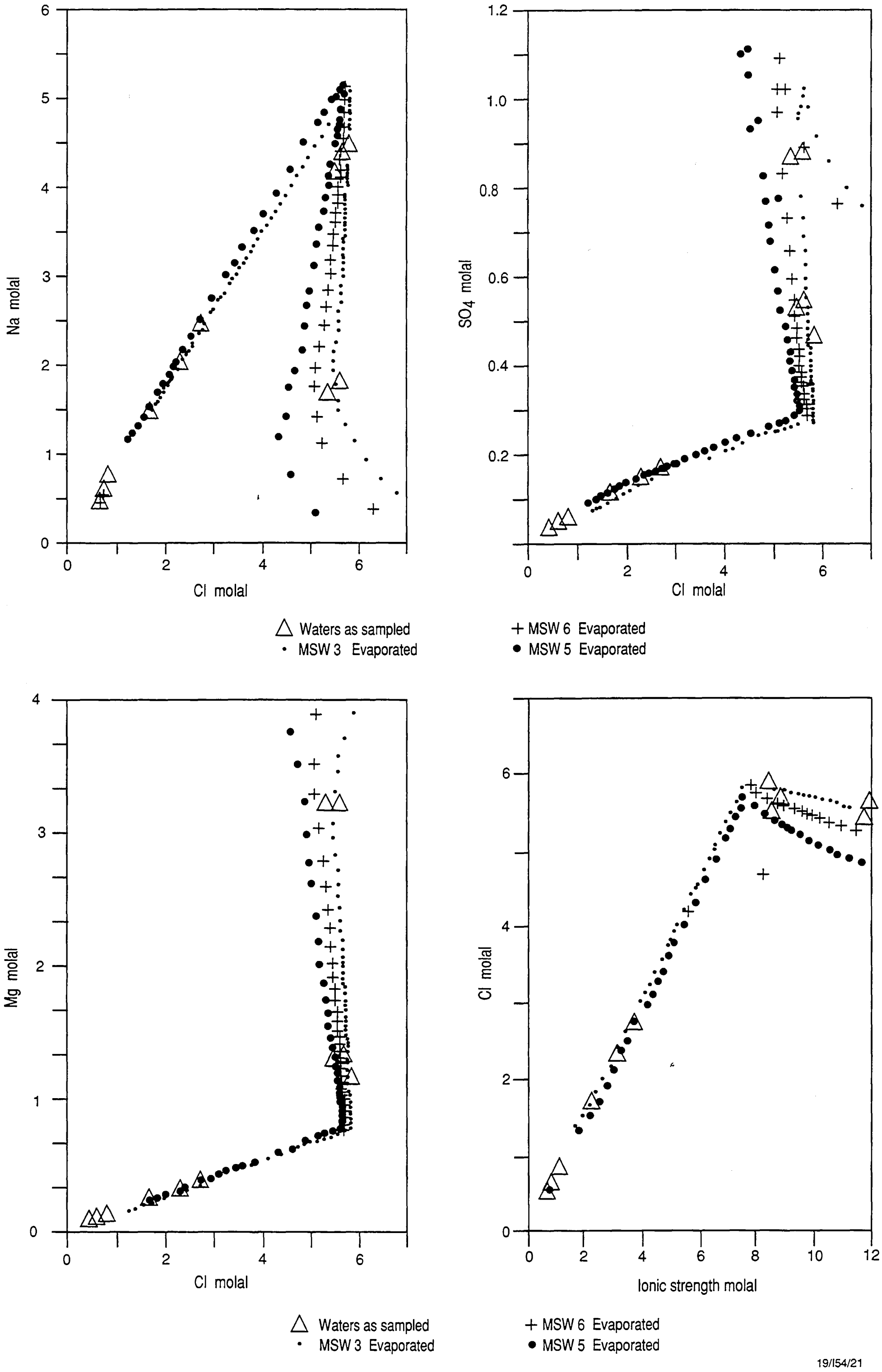

Fig. 5.17 Comparison of the ionic composition of Mourquong Disposal Basin surface water with the compositions expected from equilibrium evaporation (at 25 °C) of the inlet water (MSW 6) and two comparatively low-salinity samples (MSW 3 and 5).

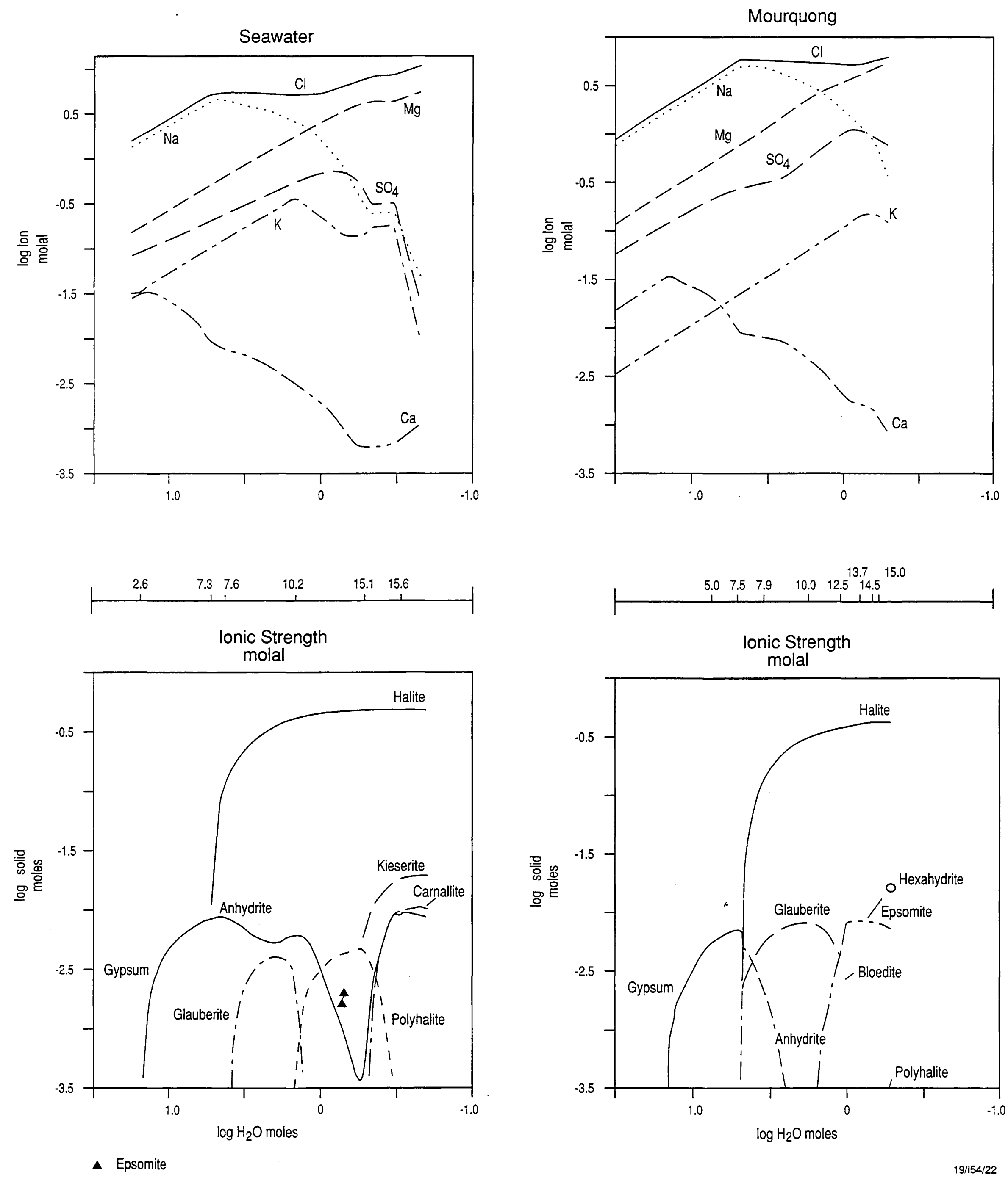

Fig. 5.18 Comparison of equilibium evaporation of seawater and Mourquong Disposal Basin inlet water. For 1kg of each water, the graphs show the changes in the molality of major solutes and the solids precipitated in equilibrium as H_2O is removed by evaporation at 25°C.

Table 5.3 *Estimated and Calculated Density, and Molal Concentrations of Surface Water, Mourquong Disposal Basin*

	Estimated density (g/CC)	*Computed density (g/CC)*	*Na molal*	*K molal*	*Mg molal*	*Ca molal*	*HCO3 molal*	*Cl molal*	*SO4 molal*
MSW 1	1.245	1.230	4.608	0.0290	1.132	0.0039	0.0151	6.021	0.460
MSW 2	1.235	1.231	4.159	0.0317	1.278	0.0028	0.0169	5.521	0.524
MSW 3	1.072	1.074	1.445	0.0000	0.219	0.0284	0.0033	1.668	0.107
MSW 4	1.036	1.038	0.753	0.0037	0.112	0.0150	0.0021	0.833	0.054
MSW 5	1.026	1.028	0.569	0.0029	0.085	0.0110	0.0032	0.620	0.041
MSW 6	1.020	1.022	0.439	0.0019	0.065	0.0105	0.0045	0.493	0.032
MSW 8	1.116	1.116	2.423	0.0130	0.358	0.0260	0.0032	2.723	0.162
MSW 9	1.099	1.099	2.013	0.0113	0.298	0.0353	0.0030	2.298	0.147
MSW 10	1.247	1.247	1.666	0.0922	3.210	0.0017	0.0477	5.395	0.865
MSW 11	1.253	1.253	1.807	0.0921	3.108	0.0017	0.0467	5.631	0.870
MSW 12	1.243	1.243	4.388	0.0312	1.305	0.0024	0.0168	5.699	0.540

Gypsum precipitation occurs at approximately the same ionic strength as in seawater. With further evaporation glauberite completely replaces anhydrite and then reacts with the brine to re-precipitate anhydrite and produce bloedite ($MgNa_2(SO_4)_2 \cdot 4H_2O$).

$$CaNa_2(SO_4)_2 + Mg^{2+} + SO_4^{2-} + 4H_2O = MgNa_2(SO_4)_2 \cdot 4H_2O + CaSO_4$$

Bloedite is lost in favour of epsomite

$$MgNa_2(SO_4)_2 \cdot 4H_2O + Ca^{2+} + 3H_2O = Mg(SO_4) \cdot 7H_2O + CaSO_4 + 2Na^+$$

and a further reaction produces polyhalite, but at a much higher ionic strength (≈ 14.5 m) than for seawater (≈ 10.2 m).

$$Mg(SO_4) \cdot 7H_2O + 2CaSO_4 + 2K^+ + SO_4^{2-} = K_2MgCa_2(SO_4)_4 \cdot 2H_2O + 5H_2O$$

Table 5.4. *Comparison of Mourquong Inlet Water and Seawater*

	MSW6	Seawater
Na	0.439	0.468
K	0.0019	0.0102
Ca	0.011	0.010
Mg	0.065	0.053
HCO3	0.0045	0.0023
Cl	0.493	0.546
SO4	0.032	0.028

The differences between the evaporation paths of the Mourquong disposal water and seawater at moderate ionic strengths can be seen in detail in the plots of predicted SO_4^{2-} versus Cl^- concentrations (Figure **5.19**).

Modification of the Mourquong Disposal Basin inlet water by re-solution would most likely involve the salts described above, plus halite. However, modelling the equilibrium evaporation of 1 kg of the disposal water (MSW6) with additional solid halite (0.5 mole) and glauberite (0.05 mole) shows an evolution of SO_4^{2-} in relation to Cl^- (Figure **5.20**) which is quite distinct from that of the disposal basin inlet water. Similarly, evaporation of mixtures of inlet water and bitterns causes considerably greater deviations in the evolution of the ionic concentrations than are seen in the suite of sampled waters (Figure **5.20**).

The geochemical calculations discussed above indicate that the major ion composition of the suite of Mourquong Disposal Basin surface waters is that expected to evolve solely by evaporation of the inlet water. That is, any spatial separation of evaporite minerals produced during low pool operating conditions is almost completely removed by the return to high operating conditions. There are differences between the evaporation path of the disposal water and seawater which could conceivably be

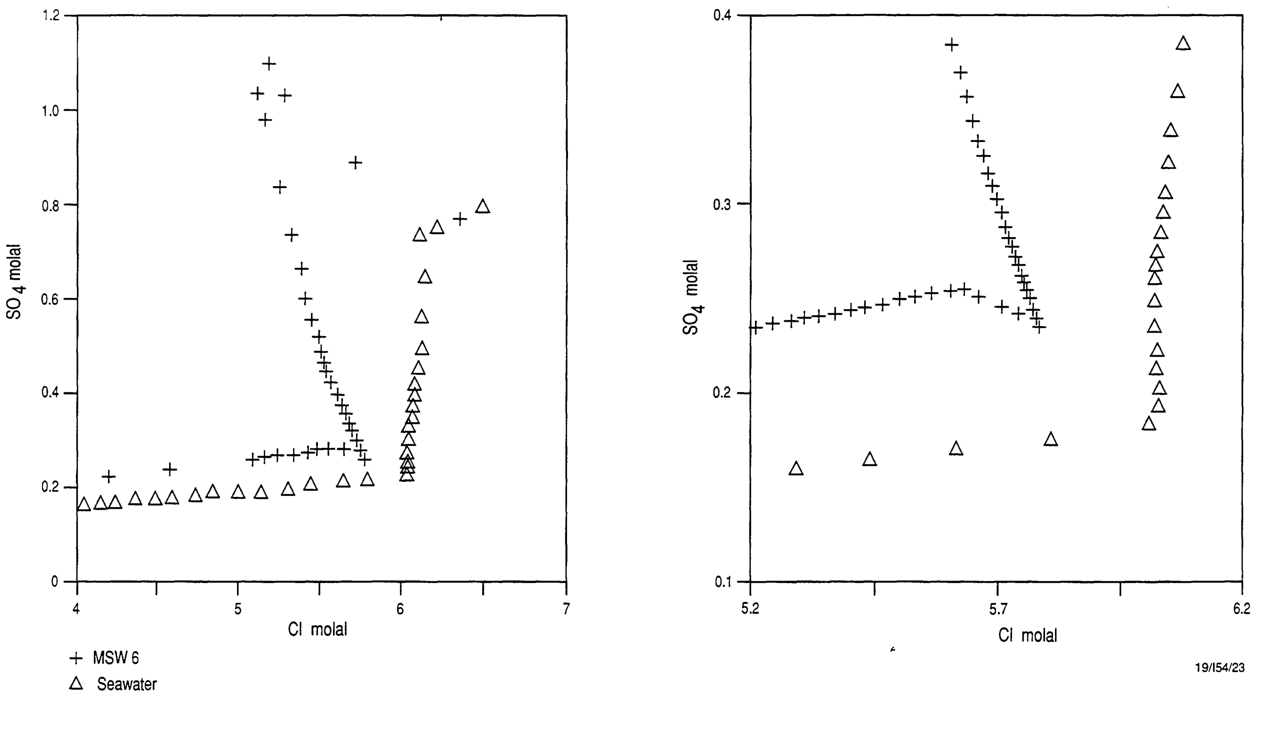

Fig. 5.19 Relative changes in sulphate and chloride concentrations for seawater and the Mourquong Disposal Basin inlet water (MSW6) during equilibrium evaporation at 25°C. The enlargement shows the start of precipitation of glauberite and halite.

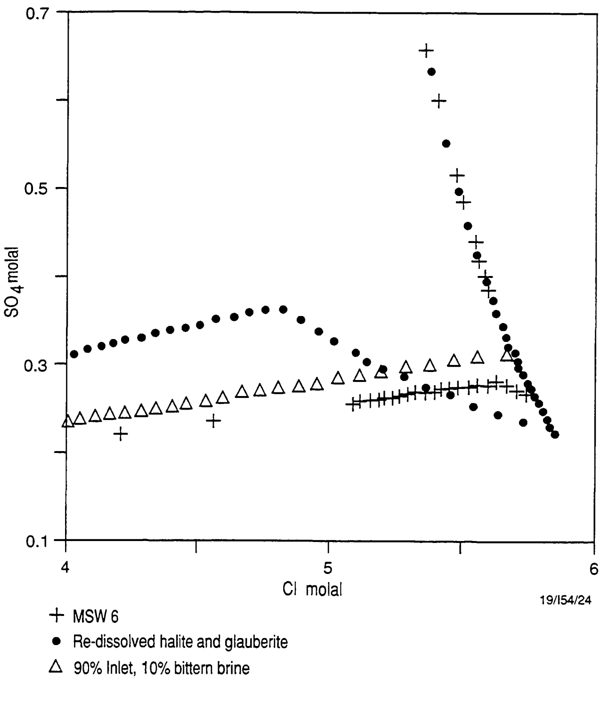

Fig. 5.20 Relative changes in sulphate and chloride concentrations during equilibrium evaporation at 25°C for Mourquong Disposal Basin inlet water (MSW6), inlet water containing redissolved halite and glauberite, and inlet water mixed with a bittern formed by evaporation of the inlet water.

exploited to produce different proportions of evaporite minerals. However, the differences are mainly in the transient minerals and the equilibrium mineral assemblage which would be precipitated if the disposal water was evaporated to dryness is not greatly different from that of seawater.

The close chemical evolutionary relationship between the composition of inlet water and that the disposal basin brines indicates that selective removal by aeolian deflation of some of the more soluble evaporite minerals from the surface water/evaporite system has not occurred to a significant extent. This conclusion is supported by Cl/Br ratios of the surface water which change relatively little (400 to 500) over the range of Cl concentrations below halite saturation. The opportunity for loss of salt by deflation is limited by the short time that the disposal basin has been in operation and by the maintenance of some flooding during summer. This regime may not be as favourable to drying and deflation of salt and sediment from the margins as occurs in the natural lakes at Nulla and Scotia

5.5 Groundwater Salinity

Data on groundwater salinity are presented as vertical profiles of salinity against depth (Figures **5.21** to **5.25**) and on sections showing iso-salinity contours (Figures **5.26** to **5.28**).

There is a progressive change in the shape of the salinity profiles along the western and N-S transects from sites within the flooded area, where the presence of disposal water is clearly evident in the upper part of the profile, through a transition zone at the basin margin, to sites beyond the disposal basin margin, which appear to be unaffected and representative of natural conditions in the discharge complex. The eastern transect extends only as far as marginal, disposal water-affected sites.

5.5.1 Salinity Beneath the Disposal Basin

Groundwater beneath the disposal basin was sampled at two sites (M1 and M3) on the N-S transect (Figure **5.2**) and a more southerly site (M2) about midway between M1 and the inlet pipe. Salinity against depth profiles at sites M1 and M3 (Figure **5.2**) show clearly the presence of disposal water saturating the upper 2.5 m of the sediment. This salinity data, and that for M2, show that the salinity of the disposal water-affected groundwater, like that of the surface water, increases northwards away from the inlet pipe (M2, 100,000; M1, 250,000; M3, 300,000 mg/L).

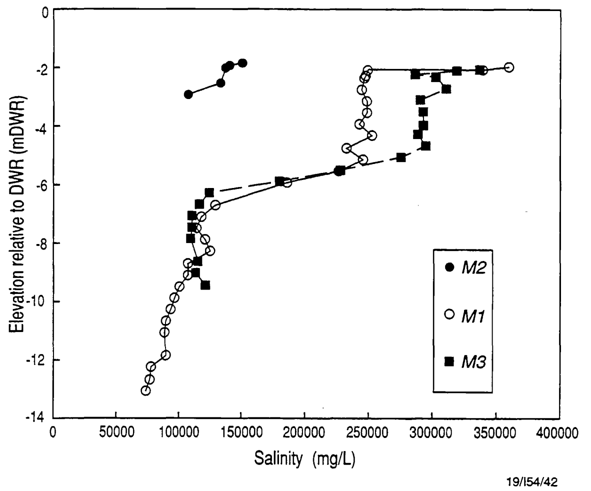

Fig. 5.21 Groundwater salinity beneath the normally flooded area of the disposal basin, showing disposal water overlying a transition zone and the natural groundwaters.

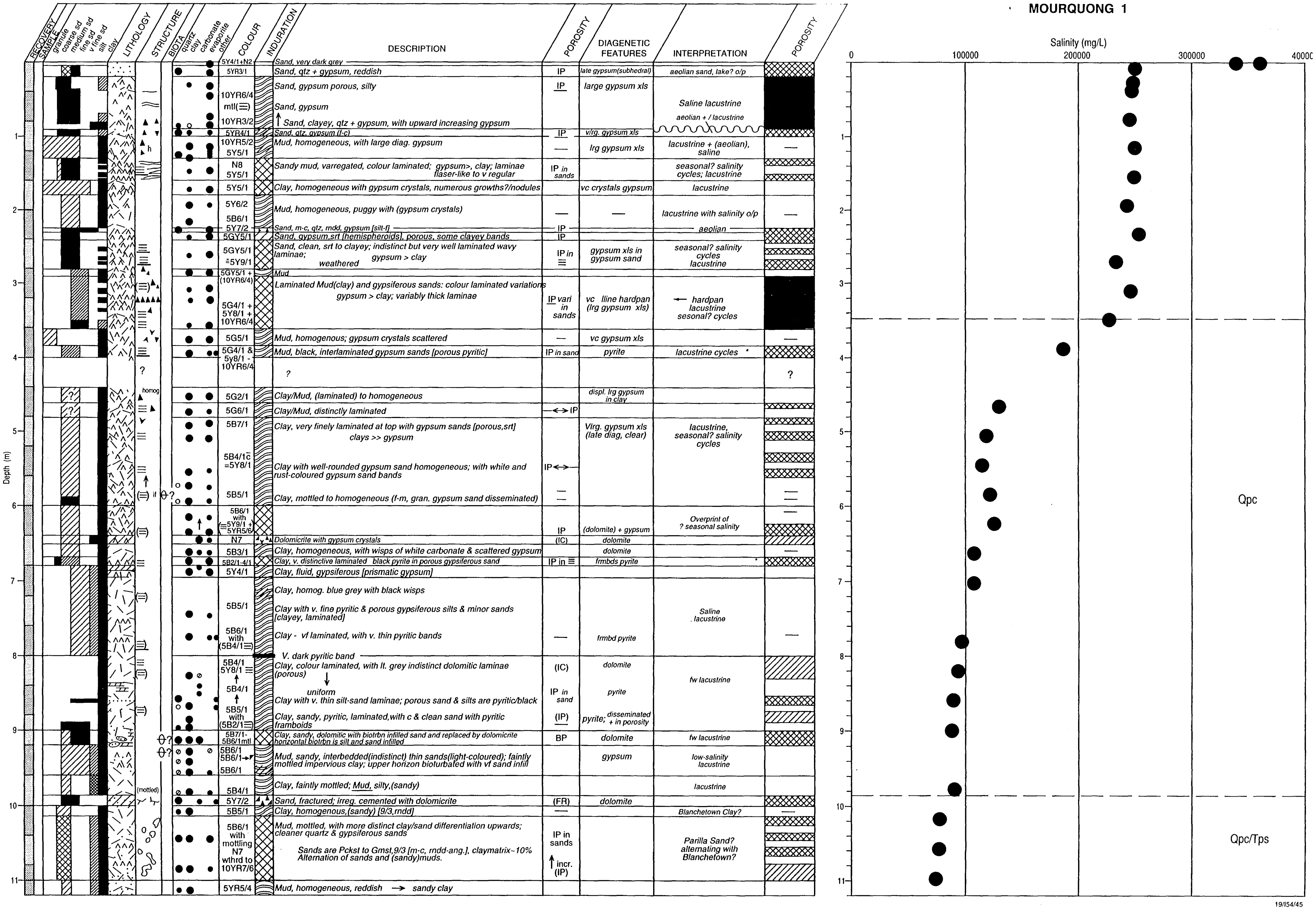

Fig. 5.22 Groundwater salinity at site M1 and its relationship to sediment lithology

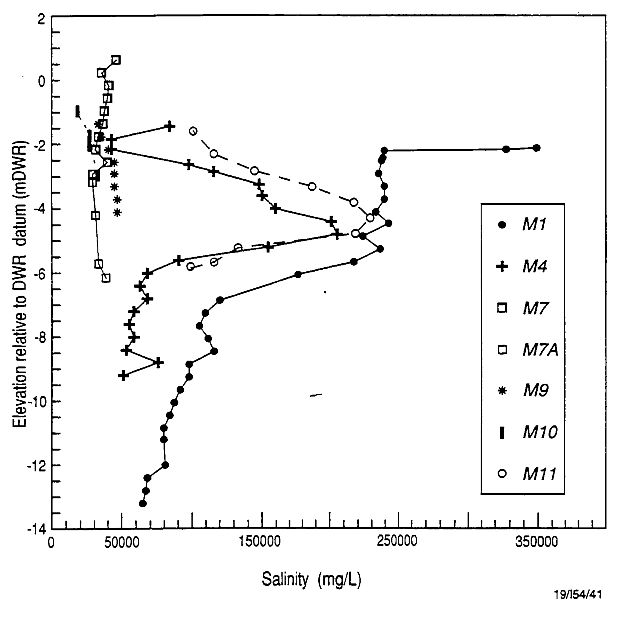

Fig. 5.23 Changes in groundwater salinity along the western transect showing the progressive change from disposal water-affected to natural conditions. Locations of the drill sites are in Figure **5.4.**

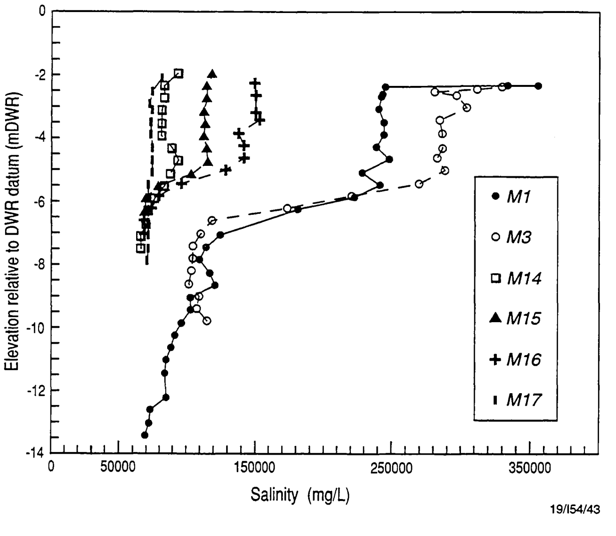

Fig. 5.24 Changes in groundwater salinity along the N-S transect showing the progressive change from disposal water-affected to natural conditions. Locations of the drill sites are in Figure **5.5.**

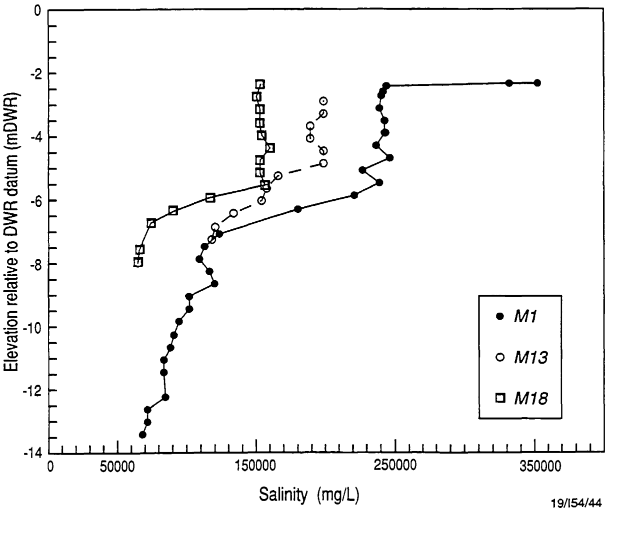

Fig. 5.25 Changes in groundwater salinity along the eastern transect. The profile at M13 shows the effects of occasional disposal water flooding, followed by ponding and subsequent evaporation to dryness. Locations of the drill sites are in Figure **5.3.**

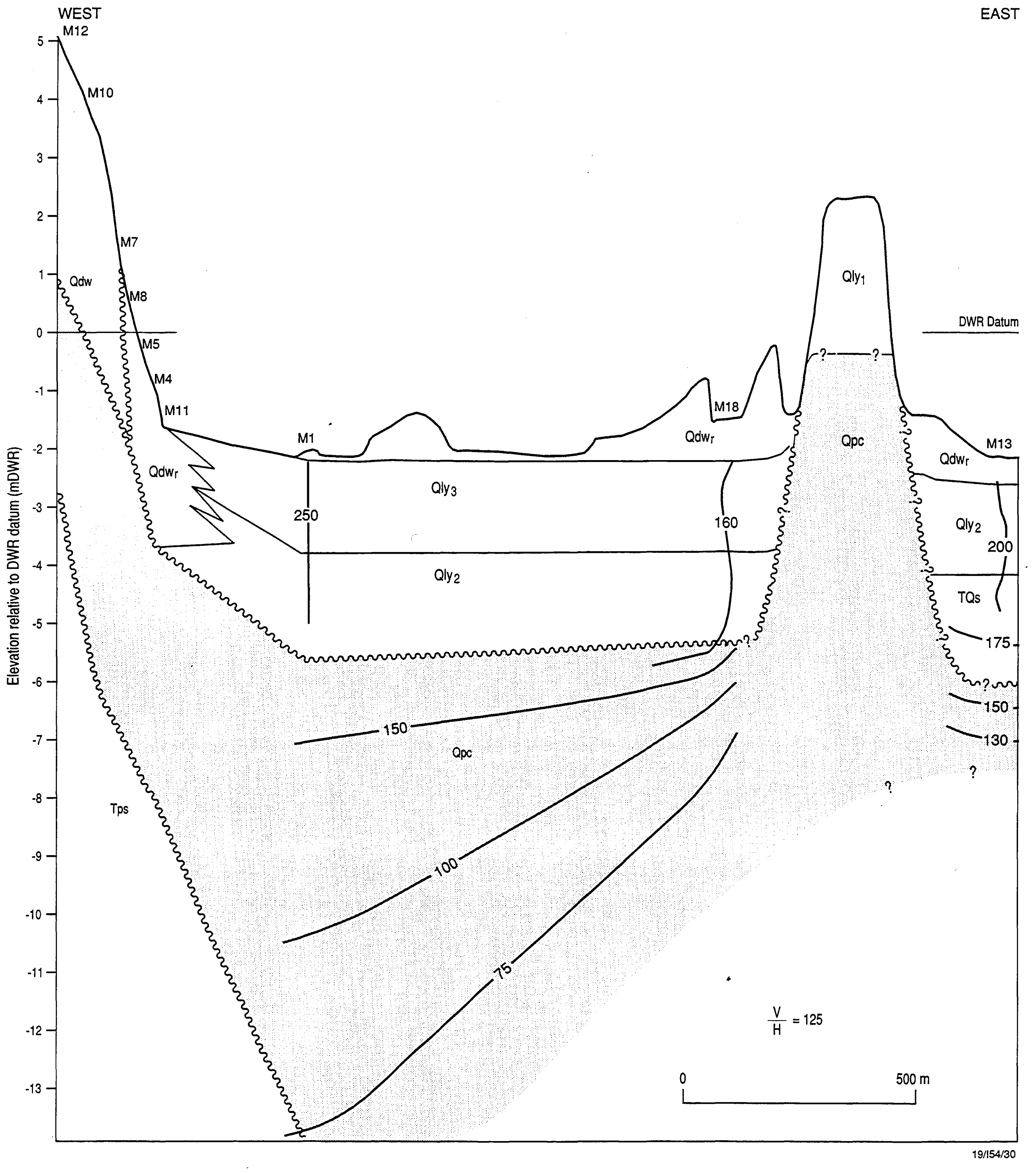

Fig. 5.26 Iso-salinity contours for the E-W section showing the natural groundwater and superimposed disposal waters.

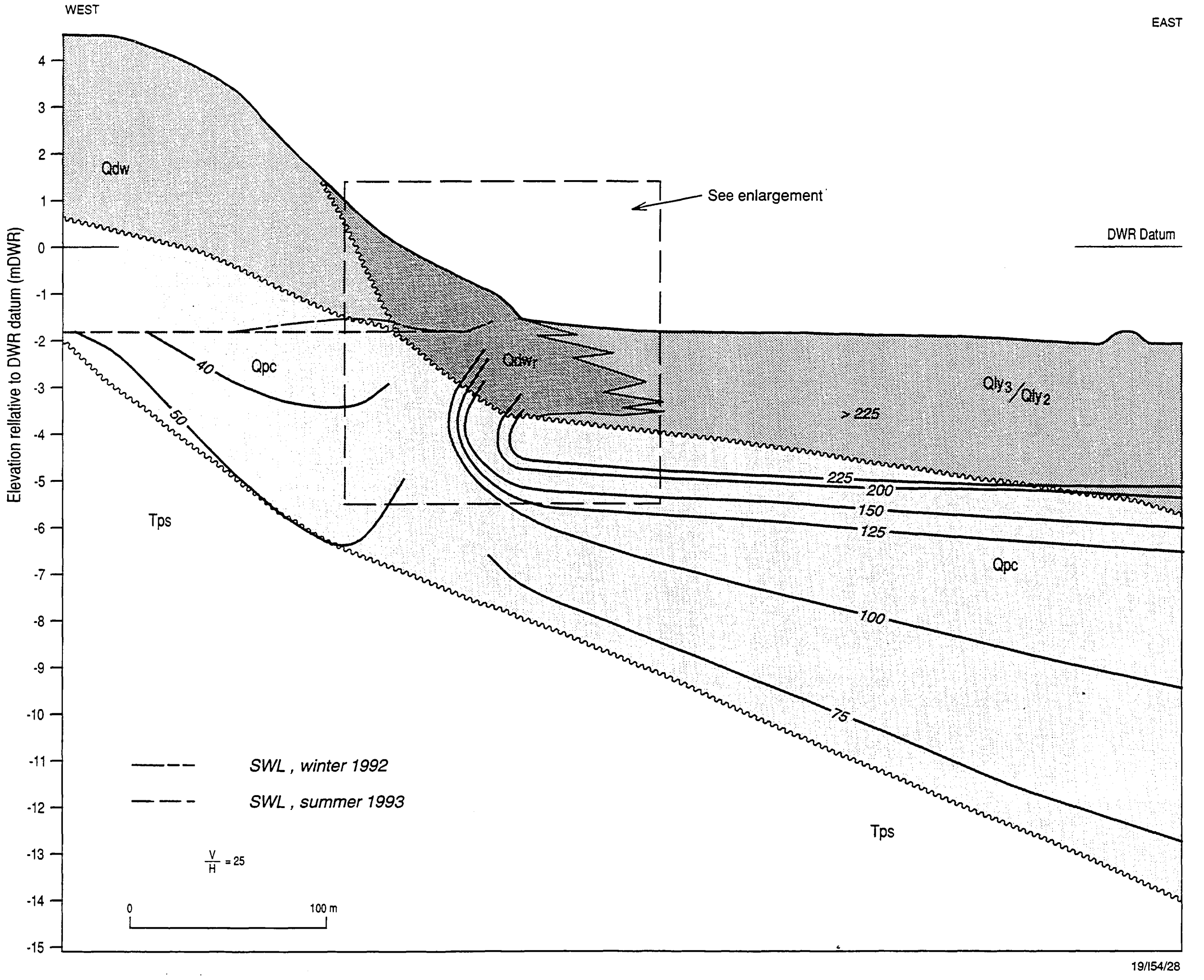

Fig. 5.27 Iso-salinity contours for the western section showing the effect of the disposal water on the natural groundwater at the base of the Woorinen Formation dune.

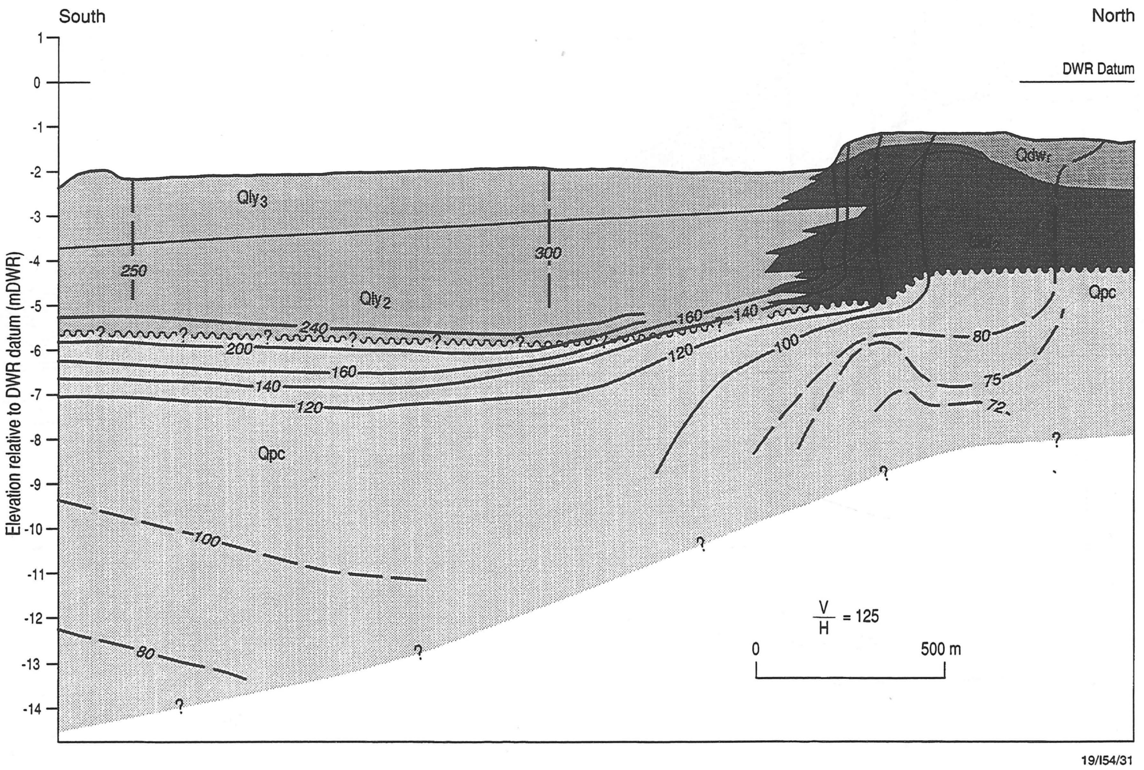

Fig. 5.28 Iso-salinity contours for the N-S section the effect of the disposal water on the natural groundwater of the northern area of the discharge complex.

The most detailed salinity against depth information is available from site Ml (Figure **5.22**). The top two samples from this site have high salinity because they are evaporation-affected. The remainder of the profile consists of three parts.

(1) *The upper 3.2 m over which the salinity is almost constant at about 250,000 mg/L.* This zone probably contains almost pure disposal water which has moved downwards from the surface. The salinity of the surface water near this site ranged from 96,000 to 296,000 mg/L (Table **5.1**) and the salinity of the infiltrating water is towards the high end of this range, which suggests that the sediment "sees" some form of time-weighted average of the surface values. If this hypothesis is correct, then high salinity of the infiltrating disposal water, and the significant change in salinity of the infiltrated water with distance from the inlet, indicate that the disposal basin operates with a bias towards relatively low pool operating conditions.

The salinity is remarkably constant within the upper zone which suggests that the disposal water has effectively displaced the natural porewater from the clay layers as well as the sand layers in the Yamba Formation sediments.

(2) *A transition zone of 1.8 m over which the salinity sharply decreases from 250,000 to about 120,000 mg/L.* The top 0.2 m of this transition zone is in the Yamba Formation but the remainder is in the Blanchetown Clay. Calculations (by I. W. White) involving the length of time that the disposal basin has been in operation (13 years), the difference in salinity between the top and bottom of the transition zone, and the breadth of the transition zone, indicate that the disposal water is still moving downwards by advection, although it has reached the upper part of the Blanchetown Clay.

(3) A lower zone of natural groundwater which extends through the remainder of the Blanchetown Clay into the underlying sandy clay at the top of the Parilla Sand. Salinity in this zone decreases linearly with depth. The linear profile reflects a previous natural groundwater regime within the discharge complex in which salt from a brine in the Yamba Formation was diffusing downwards through the Blanchetown Clay to the Parilla Sand aquifer. There are minor perturbations to slightly higher salinity in this zone, the base of which correlates with the presence of some of the thin bands of carbonate in the Blanchetown Clay (Figure **5.22**). Presumably the carbonate layers are relatively premeable and act as conduits for the flow of groundwater through the clay.

5.5.2 Salinity at the Disposal Basin Margin

Changes in salinity with distance away from the disposal basin are most evident at the western margin, and are clearly displayed by the salinity-depth profiles at individual sites (Figure **5.23**) and by iso-salinity contours on the stratigraphic section (Figure **5.27**). At a site (M11) immediately landwards of the usual high operating level, the presence of laterally-moving disposal water, but little downwards-moving surface floodwater, is evident in the form of a pronounced salinity peak at about 3 m below GL whose maximum salinity is similar to that of the disposal water at M1. The magnitude of this peak decreases with increasing distance landward and it eventually receeds into the background of the natural groundwater beneath the Woorinen Formation dune.

A similar pattern is evident at the northern margin (Figures **5.24** and **5.28**), but it is modified by the lower topographic gradient in this area. This lower gradient has produced a marginal environment in which the zone between the low and high pool operating levels is much broader than at the western margin. The sites closest to the disposal basin (M16 and M15) are influenced by downwards-moving disposal water but the average salinity of the floodwater at these sites is considerably lower than that at the nearest site (M3) in the normally flooded area (M3, 300,000 mg/L; M16, 140,000 mg/L; M15, 110,000 mg/L). Presumably, this correlation of lower floodwater salinity with increasing distance from the disposal basin reflects a decreasing frequency of flooding and a corresponding decreasing salinity of the floodwaters as pool operating conditions become higher. Lateral flow of disposal water at the northern margin is evident in an attenuated form, perhaps at M16, but more definitely further away from the disposal basin at M14.

At the two sites on the eastern margin (Figures **5.25** and **5.26**) the effects of surface flooding rather than lateral flow dominate the salinity profiles. The average salinity of the surface floodwaters at the most easterly site (M13) is higher than that at the margin of the main basin (M18) because, as mentioned previously, the disposal water floodwaters are trapped east of the gypsite terrace and evaporate to dryness.

A significant feature of the salinity-depth profiles at sites on both the western and N-S transects is almost constant elevation (-4.5 mDWR) of the salinity peak due to lateral flow (Figures **5.23** and **5.24**). This elevation corresponds fairly well with the base of the disposal water-saturated upper zone at sites in the disposal basin and on the eastern margin. The Yamba Formation-Blanchetown Clay boundary is close to this elevation only at M1, and elsewhere the disposal waters have entered the Blanchetown Clay, both laterally and vertically. This implies that the upper sediments of the Blanchetown Clay have not yet noticably influenced the progress of the disposal water.

5.6 Hydrodynamics

5.6.1 Hydraulic Head

The lateral and vertical hydraulic gradients in the Mourquong Disposal Complex have been determined separately using freshwater and environmental water heads, respectively. The concepts are those developed by Lusczynski (1961), as detailed in the Appendix.

5.6.1.1 Lateral (freshwater) Hydraulic Head

The lateral hydraulic heads in the Mourquong Disposal Complex have been determined from piezometers set close to an elevation of -2.2 mDWR on the western and N-S transects (Figures **5.4** and **5.5**). Groundwater pressure (P_{actual}) data from these piezometers was normalised to a constant elevation of -2.2m DWR and then converted to freshwater heads. This elevation was chosen because it crosses the zone of disposal water-saturated sediments beneath the disposal basin.

The freshwater heads at -2.2 mDWR across the western transect during high (winter) and low (summer) basin pool operating conditions are shown in Figure **5.29**. In summer, the freshwater heads decrease from the Woorinen Formation dune towards the basin margin and reach a minimum before increasing towards the centre of the disposal basin. i.e. the potential is for regional water to flow towards the disposal basin and for disposal groundwater to flow out of the disposal basin landwards towards this area of minimum freshwater head.

In winter, the hydrodynamics near the base of the dune are complicated by the presence of a transient perched water table at shallow depths. The salinity data indicate that this part of the dune is not a site of recharge, which indicates that the perched water eventually flows into the disposal basin or is removed by evaporation in summer.

Under low pool operating conditions, the head in the disposal basin is equal to that of the regional groundwater in the dune at about 150 m from the disposal basin margin (site M10). Under higher conditions, the head in the disposal basin is about 0.2m higher than the regional head at the landward limit of the transect, which is about 300 m from the disposal basin.

The freshwater heads at the northern margin decrease from the disposal basin towards the northern area of the discharge complex (Figure **5.30**). Whether or not they subsequently rise in the regional groundwater system beyond the discharge complex has not been determined. The difference in freshwater head between the disposal basin and the discharge complex at the northern margin is about 1.0 m, which is about double that at the western margin. i.e. the driving force for lateral groundwater flow out of the disposal basin into the remainder of the discharge complex is twice as strong as that driving it out of the discharge complex towards the regional groundwater system in the west.

5.6.1.2 Vertical (environmental water) Hydraulic Head

Environmental water heads and vertical hydraulic gradients (Table **5.5**) were calculated for the nests of piezometers on the western and northern transects (additional data are in the Appendix). The vertical hydraulic gradients are presented in Figures **5.31** and **5.32**.

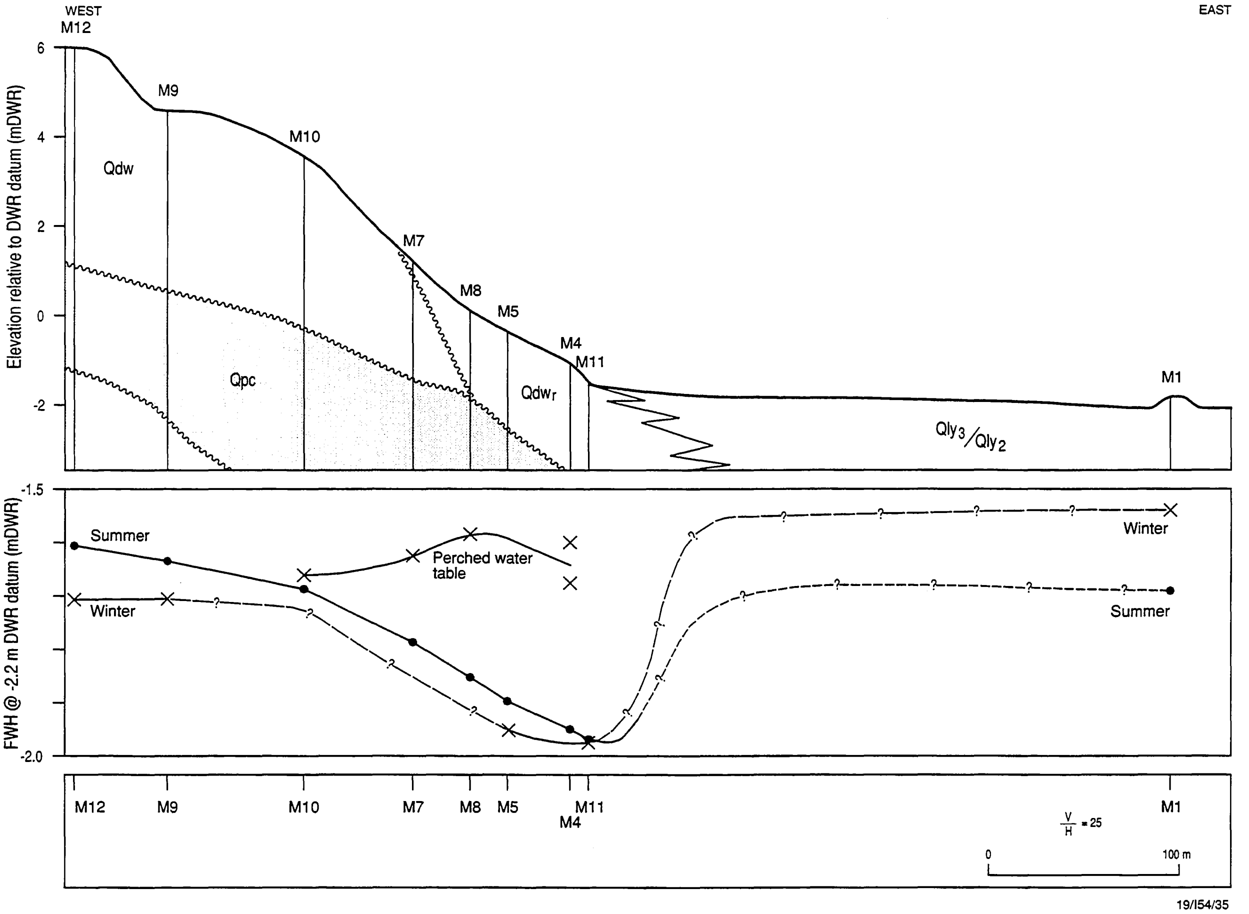

Fig. 5.29 Lateral (freshwater) hydraulic heads at -2.2 mDWR elevation for the western section. Note the minimum at the disposal basin margin under low pool operating conditions in summer and the perched water table under high pool operating conditions in winter.

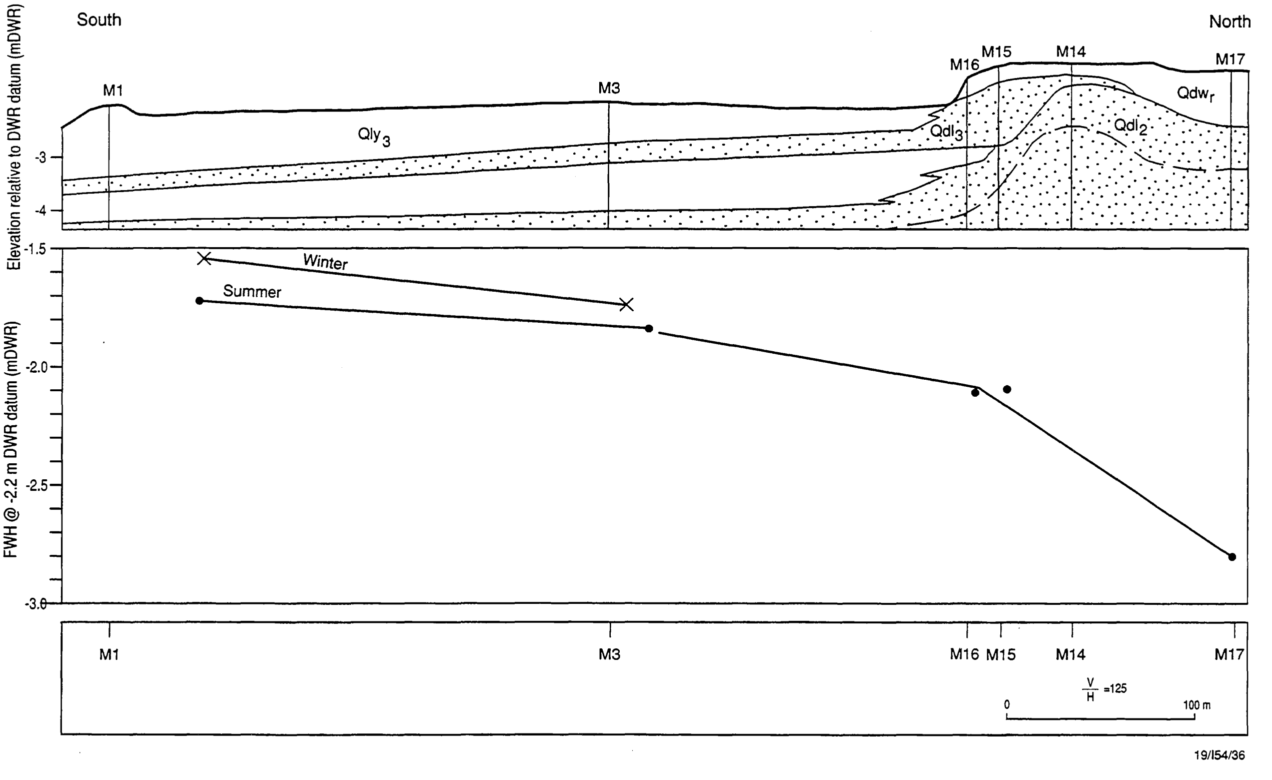

Fig. 5.30 Lateral (freshwater) hydraulic heads at -2.2 mDWR elevation for the N-S section. Measurements were made during low pool operating conditions in summer and high pool operating conditions in winter.

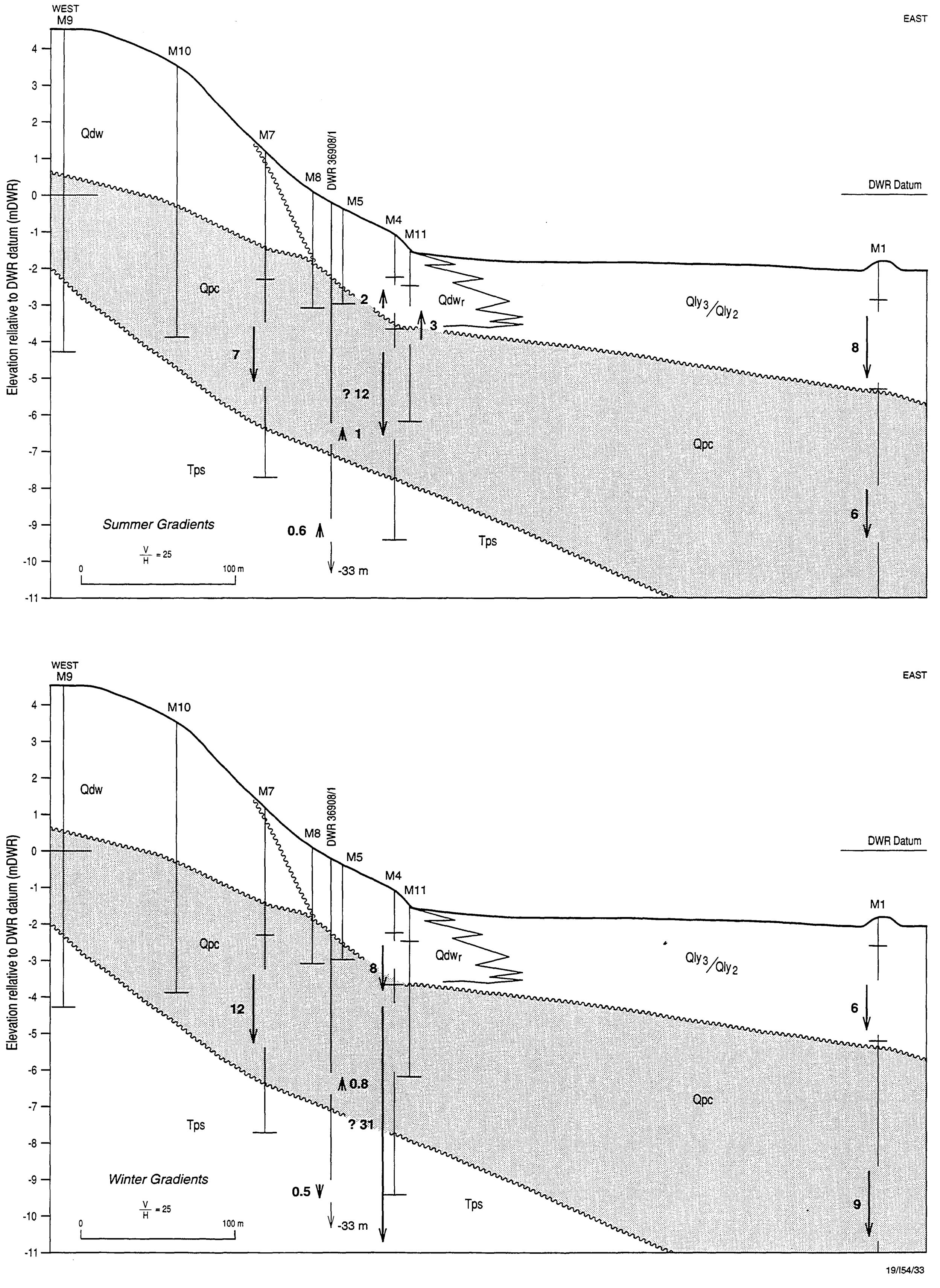

Fig. 5.31 Vertical (environmental water) hydraulic gradients at sites on the western transect during low pool operating conditions in summer and high pool operating conditions in winter.

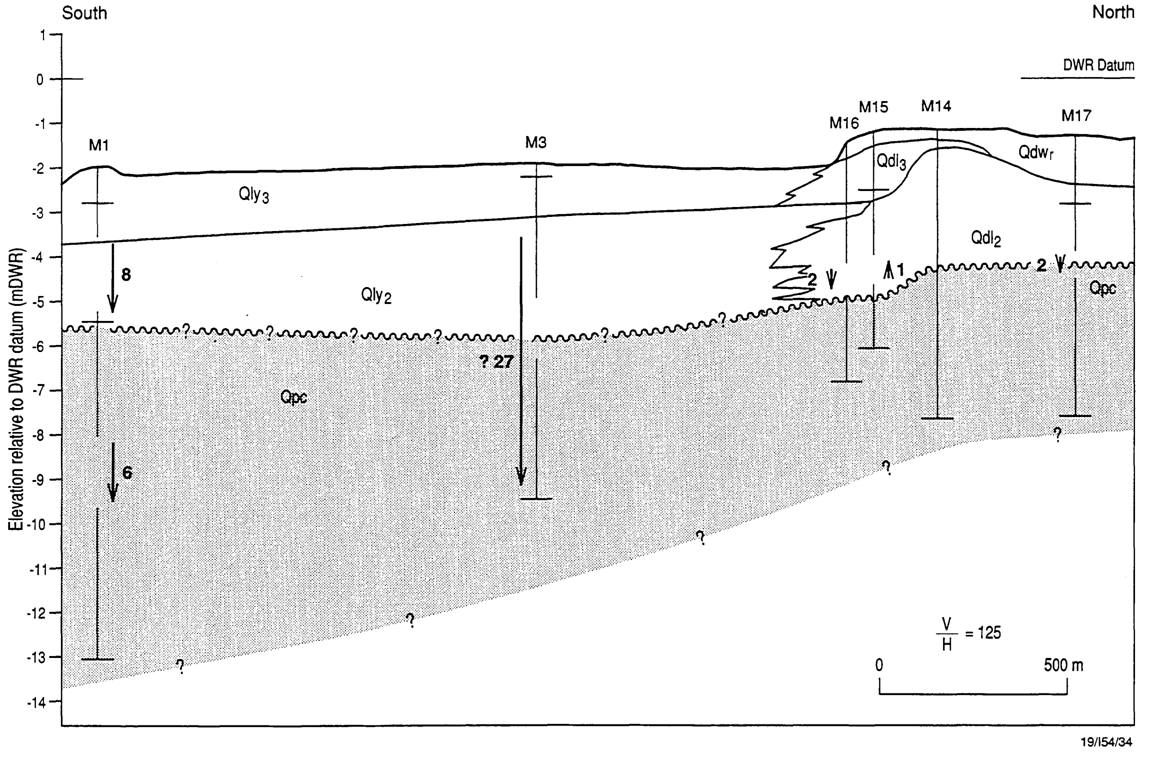

Fig. 5.32 Vertical (environmental water) hydraulic gradients at sites on the N-S transect during low pool operating conditions in summer.

Table 5.5. *Vertical Hydraulic Gradients on the Western and Northern Transects, Mourquong Disposal Basin*

Site	*Conditions*	*Piezometers*	*Depth(mDWR)*	*Stratigraphic Units*	*V. Gradient* (m/100m)
M7	summer	M7 to M7A	-1.9 to -7.1	Qpc to Tps	7 down
	winter				12 down
M8	summer	M8 to DWR	-2.15 to -33	Qpc to Tps	0.6 up
	winter				0.5 down
M5	summer	M5 to DWR	-2.15 to -33	Qdwr to Tps	1 up
	winter				0.8 up
M4	summer	M4A to M4	-2.25 to -3.3	Qdrw to Qdwr	2 up
	winter				8 down
M4	summer	M4 to M4B	-3.3 to -8.7	Qdwr to Tps	?12 down
	winter				?31 down
M11	summer	M11A to M11	-2.3 to -6.0	Qdwr to Qpc	3 up
M1	summer	M1B to M1A	-2.7 to -5.3	Qly3 to Qly2	8 down
	winter				6 down
	summer	M1A to M1	-5.3 to -13	Qly2 to Qpc/Tps	6 down
	winter				9 down
	est. high level	M1B to M1	-2.7 to -13	Qly3 to Qpc/Tps	10 down
M3	summer	M3A to M3	-2 to -9	Qly3 to Qpc	?27 down
M16	summer	M16A to M16B	-3.1 to -6.3	Qdl3 to Qpc	2 down
M15	summer	M15A to M15B	-2.8 to -5.2	Qdl3 to Qdl2	1up
M17	summer	M17A to M17	-2.9 to -7.1	Qdl2/Qpc	2 down

Qpc: Blanchetown Clay

Tpc: Parilla Sand

Qdwr: reworked Woorinen Formation sands

Qly2 & 3, Qdl3: Yamba Formation.

Uncertainty of the vertical gradients is based on a SWL/salinity measurement error equivalent to 0.01m for each piezometer. The resultant gradient error depends on the distance between the piezometers and ranges from ±2m/100m for M4A/4 to ±0.0 2m/100m for M8/DWR

The vertical gradients in the centre of the disposal basin are best represented by those at M1 (Fig. **5.31**), because one of the piezometers at M3 may not have come to equilibrium. Gradients at this location were measure between the two units of the Yamba Formation and between the Yamba Formation and the Blanchetown Clay/Parilla Sand interface. The gradients were directed downwards in both summer and winter, and range from 6 to 9m/100m. Presumably, the average downwards hydraulic gradient which has operated at M1 since the disposal basin was established is intermediate between these values, and is estimated to 7.5m/100m for the vertical hydraulic gradient from the surface to the Blanchetown Clay/ Parilla Sand interface.

In the marginal areas of the disposal basin and adjacent pristine environments the vertical hydraulic gradients are influenced by: (1) the groundwater in the regional Parilla Sand; (2) local recharge by rainfall/runoff: and (3) the disposal water. On the western transect (Figure **5.31**) there are data on the vertical gradients between the shallow units (Woorinen Formation, reworked Woorinen Formation, Blanchetown Clay) at one pristine site (M7), and two sites where saline disposal water is present (M4 and M11). Gradients associated with the deeper part of the Parilla Sand aquifer have been obtained by combining data from the DWR piezometer (which is set at at -33 mDWR) with that from nearby shallow piezometers at M5 and M8. The situation on this margin is further complicated by the fact that all of these sites are within the area where a perched water table forms in winter. As a result, there are significant seasonal changes in the magnitude and/or the direction of the vertical gradients.

Near the the margin of the disposal basin/discharge complex (sites M5 or M8 and DWR 36908/1) the gradient from the middle of the Parilla Sand aquifer is slightly upwards (0.6 to 1m/100m), except in winter at M8 where local recharge reverses the gradient. The upwards gradient is consistent with inflow of regional groundwaters to the discharge complex at the margins, as predicted by the hydrodynamic models and observed at Nulla Spring Lake.

The influence of local recharge to the regional groundwater system beneath the Woorinen Formation dune is evident at M7. The gradient from near the top of the water table in the Blanchetown Clay to the top of the Parilla Sand is strongly downwards, particularly in the winter (7 m/100m in summer compared to 12 m/100 m in winter). This downwards gradient is consistent with the salinity data for M7 (Figure **5.23**) which show the presence of lower-salinity water near the top of the water table.

The data for the disposal water-affected marginal site M11 indicate an upward gradient of 3 m/100 m from the Blanchetown Clay to the overlying reworked Woorinen Formation sands. The gradient is not large (about one-tenth those at Nulla Spring Lake) which indicates that, at the basin margin, the Blanchetown Clay has, at most, a small confining effect on the Parilla Sand groundwater.

The hydrodynamic situation at the northern margin is less complex (Figure **5.32**) Data for the N-S transect is available only for summer and, as discussed above, that for M3 is suspect. The remaining data indicate that vertical gradients at the disposal basin margin are small, ranging from 1 to 2m/100m. At the edge of the disposal area (M16), the gradient between the Yambah Formation (Qdl_2 & $_3$) and the underlying Blanchetown Clay is slightly downwards (2m/100m) and is comparable to that in the unaffected area to the north (M17). i.e. in summer at least, the vertically downwards hydraulic gradients near the disposal basin margin are far smaller than those near the centre.

Vertical gradients in the pristine area of the discharge complex at the northern margin are small. The gradients between the Yamba Formation and the Blanchetown Clay at the landward end of the N-S transect (M15 and M17) could be seasonal and reflect normal hydrodynamic processes (such as evaporation/recharge) in the discharge complex. The salinity-depth profile at M17 (Figure **5.24**) shows that the salinity is almost constant over all but the top 0.5 m of the profile and that this salinity is similar that at the top of the Parilla Sand aquifer beneath the disposal basin. This suggests that evaporation-induced upwards movement of underlying regional groundwater is the dominant process in this part of the discharge complex. In this respect, the hydrodynamics at the northern area of the Mourquong Discharge Complex are similar to those of the fossil lake (gypsum hardpan) surface to the east of Nulla Spring Lake.

5.6.2 Porosity

The porosity of the lithostratigraphic units intersected by the western transect at Mourquong, as presented in Figure **5.13**, has been generalised as a guide to the distribution of permeability at the western margin of the discharge complex. This generalised data is presented in Figure **5.33**.

The distinctive features of this approximate permeability distribution and their likely hydrodynamic influence are as follows.

(1) The presence of low-permeability calcrete layers in the Woorinen Formation dune would direct rainfall recharge the lower part of the dune and the adjacent reworked Woorinen Formation sands.

(2) The occurrance of a sandy, high permeability area of sediment in the Blanchetown Clay near the discharge complex margin. This area could be a conduit *via* which regional Parilla Sand groundwater moves through the Blanchetown Clay and into the discharge complex.

(3) The generally high permeability of the Yamba Formation/reworked Woorinen Formation sand sediments which overlie the Blanchetown Clay could allow relatively rapid lateral flow of disposal water throughout the discharge complex.

(4) The presence beneath the centre of the disposal basin of more than 8m of low permeability Blanchetown Clay. Assuming that fracture flow is not significant, this thickness of clay should be more than adequate to slow the advective downwards

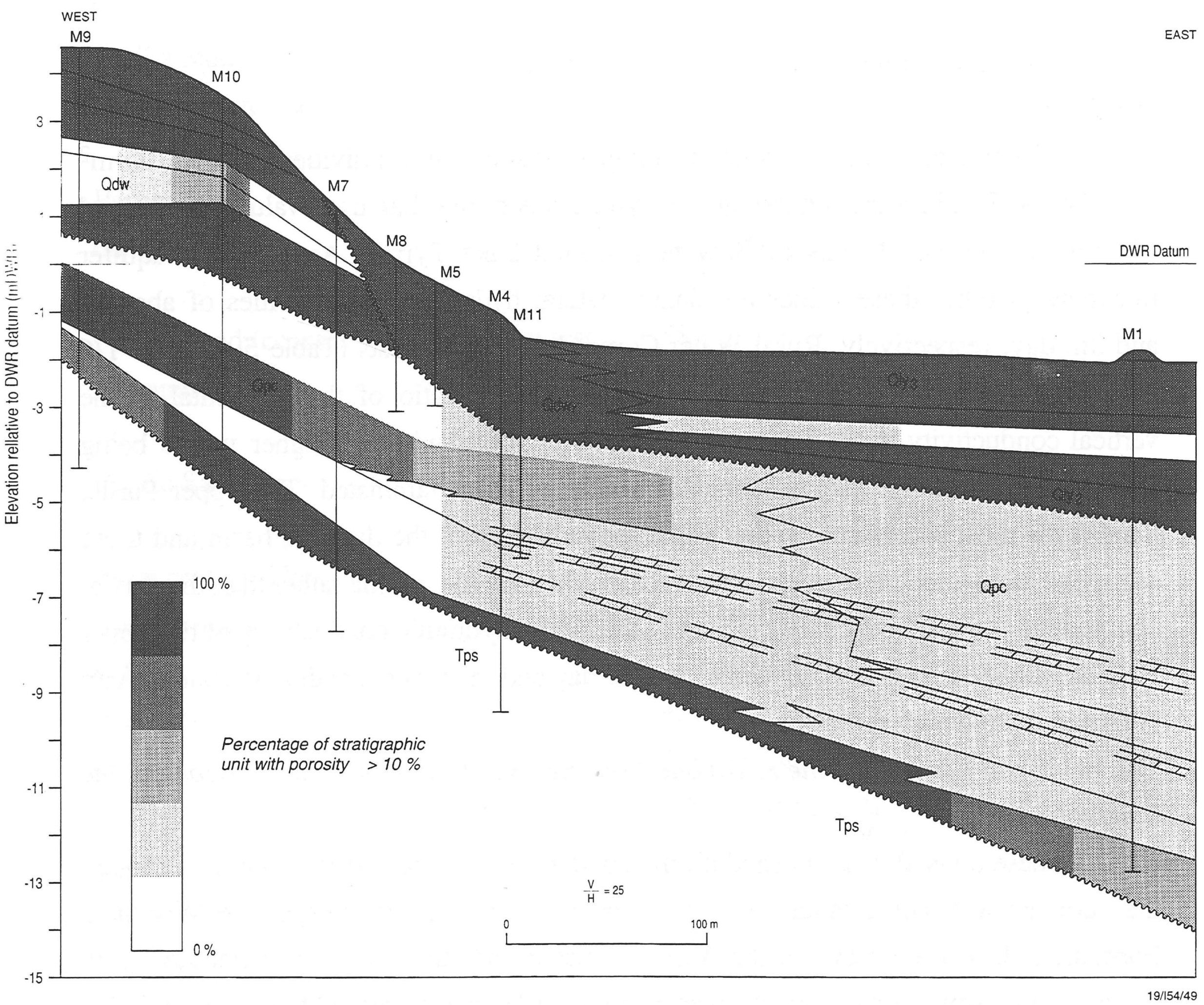

Fig. 5.33 Generalised distribution of porosity along the western transect. The higher porosity area in the Blanchetown Clay at the discharge complex margin allows regional Parilla Sand groundwater access to the Yamba Formation sediments in the discharge complex.

movement of disposal water to the stage where diffusion of salt is the rate-determining process.

5.6.3 Hydraulic Conductivity

Estimates of the hydraulic conductivity of the Mourquong sediments have been made in two ways. (1) From literature values for the same lithostratigrapic units from elsewhere in the Murray Basin. (2) By calculation based on the the distance that the disposal water has flowed, the observed hydraulic gradients, and the length of time that the disposal basin has been in operation,

5.6.3.1 Literature values

Parilla Sand

Macumber (1991) has quoted a range of lateral transmissivities of 50 to 700 m^2 /day for the Parilla Sand aquifer in the Tyrrell Basin, and has used values of 70 and 170 m^2 /day in calculations of flow nets around Lake Tyrrell. Assuming an aquifer thickness of 60m, these values translate to lateral hydraulic conductivities of about 1 and 3m/day. respectively. Rural Water Commission pump tests (Table **5.6**) give 1.6 m/day. J.Kellett (pers.comm.) has estimated that the ratio of the horizontal to the vertical conductivity in the Parilla Sand is 100 to 1000, with the higher values being associated with the fluvial components, which are more laminated. The upper Parilla Sand is the most pertinent to saline water movement from the disposal basin and these sediments tend to be more permeable, because they are the marine rather than the fluvial component of the sequence. Accordingly, the lateral hydraulic conductivity of the upper Parilla Sand sediments is estimated to be 3 m/day and the vertical hydraulic conductivity is estimated to be 0.03 m/day.

The Woorinen Formation, the reworked Woorinen Sands, and the sand horizons in the Yamba Formation

These units all contain sand ultimately derived from the Parilla Sand. Although they contain alternating layers of lower permeability (e.g calcretes in the Woorinen Formation; lacustrine clays in the Yamba Formation), and higher permeability (e.g. sand-sized gypsum in the Yamba Formation) the effective permeability is probably that of the sands. On this basis, the estimated hydraulic conductivity for the Yamba Formation sediments is the same as that for the Parilla Sand - i.e. the lateral hydraulic conductivity is 3m/day and the vertical hydraulic conductivity is $3*10^{-2}$ m/day.

Table 5.6. *Hydraulic Conductivity of Murray Basin Aquifers and Aquitards*

Stratigraphic Unit	*Method*	*Hydraulic Cond. (m/day)*	*Reference*
Parilla Sand/Alluvial Channel Sands	Pump test	4.4 (combined)	Thorne *et al.* (1990)
Parilla Sand	Pump test	4.0	"
Blanchetown Clay		$3.5*10^{-2}$(vertical)	
Parilla Sand	Pump test	5.4	"
Channel Sands		26 (average)	
Parilla Sand (coarse)	Pump test	58-70	"
Channel Sands	27		
Parilla Sand	Pump test	1.6	"
Blanchetown Clay:			
clayey silt	Lab. test	$8.6*10^{-4}$(vertical)	"
silt		$1.7*10^{-3}$(vertical)	
silty clay		$4.3*10^{-4}$(vertical)	
clay		$3.5*10^{-4}$(vertical)	
clay		$1.7*10^{-4}$(vertical)	

Blanchetown Clay

The lateral hydraulic conductivity of the Blanchetown Clay may be about $1*10^{-4}$ m/day if the sand content is low and, for very low permeability sediments of this type, the lateral and vertical hydraulic conductivities are probably about equal (J.Kellett, pers.comm.). Accordingly, the lateral and vertical hydraulic conductivities of the Blanchetown Clay underlying the central part of the Mourquong Disposal Basin could be as low as $1*10^{-4}$ m/day. For comparison, the Geera Clay, which is probably less permeable than the Blanchetown Clay, has been assigned a vertical hydraulic conductivity of $1.75*10^{-3}$ m/day by Lawrence (1975), as quoted by Macumber (1991).

The vertical hydraulic conductivity of the Blanchetown Clay has been measured by Thorne et al. (1990) both from pump tests and laboratory measurements of hydraulic conductivity (Table **5.6**). Laboratory analyses gave values ranging from $1.7*10^{-3}$ m/day for a silt, to $1.7*10^{-4}$ m/day for a dense, highly plastic clay. Vertical hydraulic conductivity determined by two pumping tests in the field was significantly higher at $3.5*10^{-2}$ m/day. The latter value is close to a value of $2*10^{-2}$ m/day obtained in this investigation for a slug test of piezometer M8, which is set in the upper, sandy parts of the Blanchetown Clay beneath the Woorinen Formation dune on the western margin.

5.6.3.2 Calculated Values

Vertical hydraulic conductivities for the Yamba Formation at site M1, calculated from the distance the disposal water has moved, the measured hydraulic gradients, and the time for which the disposal basin has been in operation, are shown in Table **5.7**.

There are two main scenarios to be considered in interpreting the Mourquong vertical salinity profiles: (1) the disposal water has rapidly infiltrated the Yamba Formation sediments and has then slowed considerably upon reaching the Blanchetown Clay; or (2) the disposal water has not yet been significantly impeded by the lower permeability sediments and has moved downwards at a rate which has been relatively constant over the period during which the evaporation basin has been operating. The following indications from the vertical salinity profiles suggest that the latter is more likely to be correct.

Table 5.7. *Calculated Hydraulic Conductivity for the Yamba Formation at M1*

Time (Years)	*Distance (meters)*	*Velocity (m/day)*	*Vertical hydraulic gradient (m/100m)*	*Vertical hydraulic conductivity(m/day)*
1	4	0.011	7.5	1.5*10^-1
2	4	0.0055	7.5	7.3*10^-2
5	4	0.0022	7.5	2.9*10^-2
13	4	0.00084	7.5	1.1*10^-2

The start of the salinity transition zone occurs at almost constant elevation. i.e., the depth to which the disposal water has penetrated is almost constant. In particular, the depth is similar in M1 and M3, although the start of the transition zone at M1 is close to the Yamba - Blanchetown interface and significantly above it at M3. This suggests that the position of the Yamba-Blanchetown interface is not yet a major determinant of the depth to which the disposal water has penetrated. If this is correct, then water is still moving downwards by advection, and the effective vertical velocity (based on M1 and taking the salinity midpoint of the transition zone as the depth to which the saline disposal water has penetrated) is 4m in 13years or $8.4*10^{-4}$ m/day. For an average vertical hydraulic gradient of 7.5 m/100m, this corresponds to a vertical hydraulic conductivity of $1.1*10^{-2}$ m/day, This calculated vertical hydraulic conductivity is about 100 to 1000 that of the estimated horizontal hydraulic conductivity of the Yamba Formation Sands. This ratio is consistent with the strongly laminated sand-clay structure of the Yamba Formation.

5.7 Discussion

5.7.1 Natural Groundwater Salinity and Hydrodynamics

The natural, pre-flooding groundwater salinity in the part of the discharge complex now used as a disposal basin has been determined from the data on the surrounding pristine areas and has been inferred from information on the natural groundwater discharge complexes at Scotia and Nulla. The natural iso-salinity contours along the western transect derived by this procedure are shown in Figure **5.34** and the hydrodynamics in Figure **5.35**.

The following are the major features of the salinity distribution (Figure **5.34**).

(1) The presence of a saline brine (about 120,000 mg/L) in the deeper parts of the Parilla Sand aquifer. There is a salinity minimum between this brine and brine in the overlying Blanchetown Clay/Yamba Formation, at least in the western area of the discharge complex. In this respect, the western area of the Mourquong Discharge Complex and Nulla Spring Lake are similar.

(2) In the topographically lower areas of the discharge complex, linearly decreasing salinity from the top of the Blanchetown Clay to the top of the underlying Parilla Sand. Extrapolation of the salinity profile at M1 from the Blanchetown Clay to the overlying Yamba Formation indicates an original salinity of about 120,000 to 150,000 mg/L in the Yamba Formation. The underlying salinity at the top of the Parilla Sand is about 70,000 mg/L, which is similar to that beneath Nulla Spring Lake.

(3) There are areas at the margin of the discharge complex between the bordering Woorinen Formation dunes and the areas where brine accumulates in the Yamba Formation where the salinity changes little with depth and the salinity near the surface is

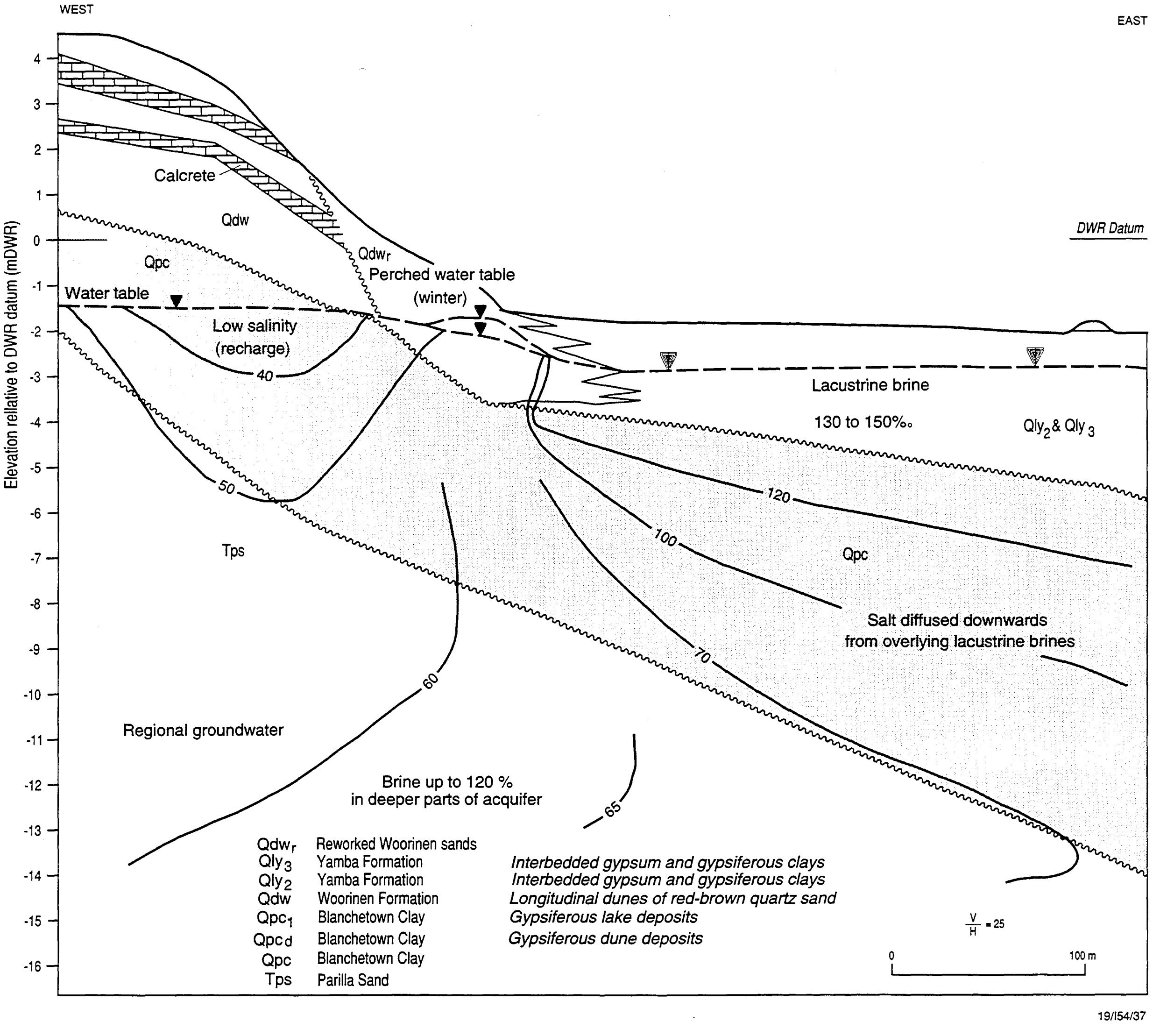

Fig. 5.34 Inferred salinity distribution at the western area of the discharge complex before flooding.

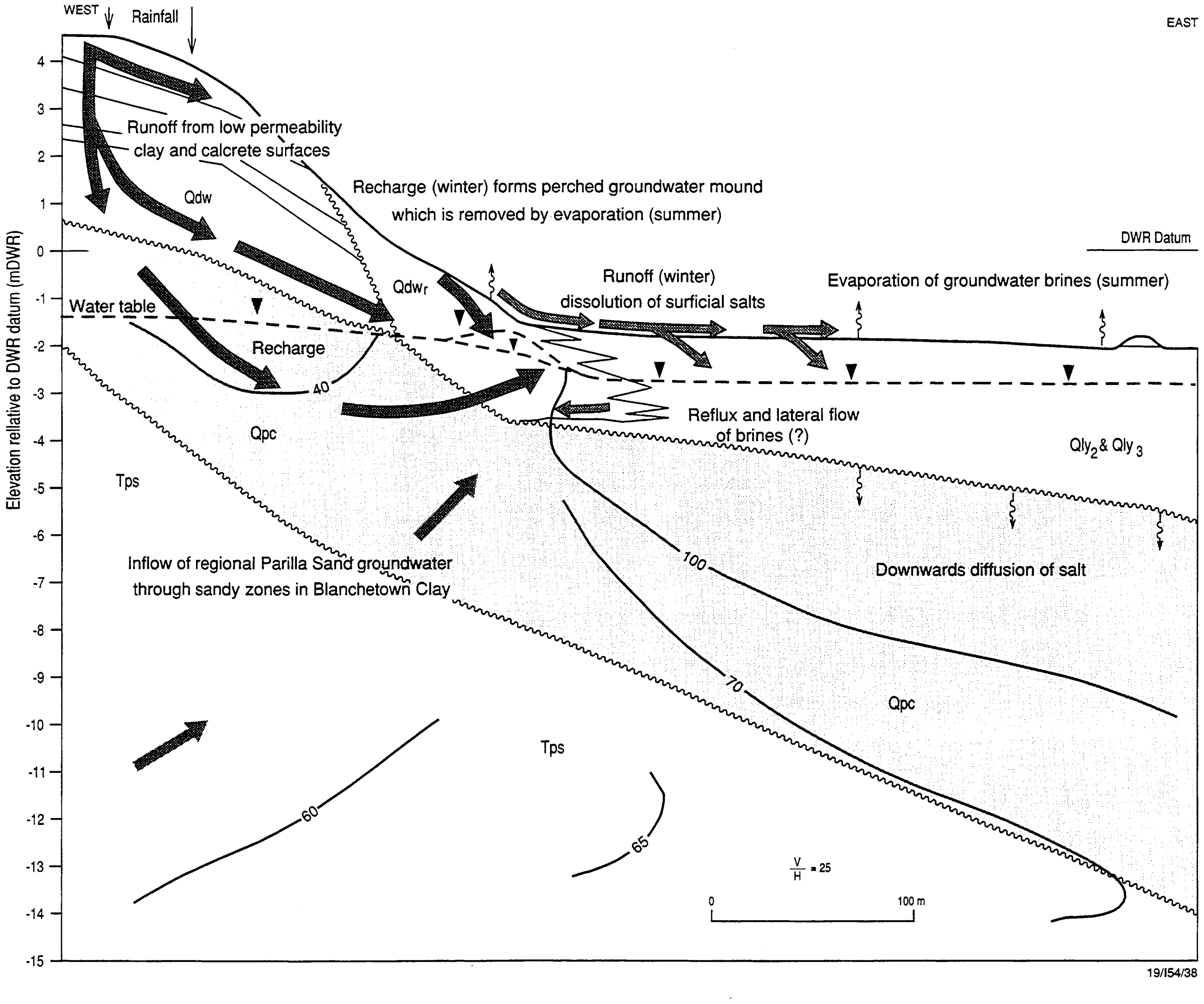

Fig. 5.35 Inferred hydrodynamics of the western area of the discharge complex before flooding.

close to that at the top of the underlying Parilla Sand aquifer. These areas are broad to the north, narrow to the west.

(4) Beneath the western side of the Woorinen Formation dune there is an area of shallow, relatively low salinity regional groundwater beneath which the salinity increases downwards to that of the regional groundwater and then to that of the underlying brine.

The following are the major hydrodynamic processes (Figure **5.35**) which have been inferred from the salinity distribution.

(1) *Recharge by rainfall of the regional groundwater system beneath the large Woorenin dune at the western margin.* Recharge appears to have its maximum influence beneath an area centred on the lower third of the western face of the dune. This area is probably the most favourable for recharge because lateral and downwards flow of recharge water over lower permeability surfaces (e.g. calcretes) in the upperpart of the dune would be directed to this location. Also, the depth to watertable may be shallow enough for recharge but deep enough to protect the recharge water from evaporation before it reaches the groundwater table.

(2) *Development of transient, "perched" water tables in the reworked Woorinen Sands near the base of the Woorinen Formation dune.* Rainfall/runoff recharge produces measurable increases in groundwater pressures in winter but there is no significant effect on the salinity of the underlying groundwater. The recharge water may flow laterally towards the disposal basin and/or, because the water table is near the surface the recharge water could be removed by evaporation during summer.

(3) *Flow of Parilla Sand regional groundwater towards the margin of the discharge complex.* This regional water entrains some recharge water from beneath the Woorinen Dune and some underlying brine from the deeper part of the Parilla Sand. Access to the discharge complex is through sandy areas in the Blanchetown Clay

(4) *Development of a groundwater brine in the permeable Yamba Formation sediments in the lower areas of the discharge complex.* The following seasonal processes are involved: (a) during summer, evaporation of the incoming regional Parilla Sand groundwater at the (broader) margins of the groundwater discharge zone to forn surface efflorescences of evaporite minerals; (b) during winter, dissolution of these efflorescences by rainfall/runoff and flow of the saline water to the topographically lower areas of the discharge complex; and (c) during summer, evaporation of the saline water to produce a highly saline brine in the Yamba Formation sediments.

(5) *Downwards diffusion of salt from the brine pool in the Yamba Formation, through the Blanchetown Clay, towards the underlying lower salinity regional groundwater.*

5.7.2 Disposal Basin Hydrodynamics

The disposal waters have been superimposed on the natural groundwater regime of the discharge complex, and most of the hydrodynamic processes are readily understood as a combination of the two regimes.

The most important effect of the disposal water is the (perhaps temporary) change from downwards diffusion to downwards advection of water/salt in the centre of the disposal basin. At the margin of the disposal basin, two processes occur : (1) vertically downwards movement of disposal surface floodwater becomes progressively less important with distance from the regularly flooded area of the basin; and (2) lateral outwards flow of brine occurs from near the base of the disposal water-saturated sediments beneath the basin.

Perhaps the most unexpected observation was the minor influence that the stratigraphy boundaries has had on the distribution of the disposal water beneath the basin. The Blanchetown Clay is a potential barrier to disposal water leaving the discharge complex but the effect of sandy zones in the clay remains to be seen. If these zones are fluvial deposits of the Shepparton Formation , then they could be widespread in the discharge complex, and other margins may also contain conduits by which disposal water could leave the discharge complex.

The limit to which disposal water could flow laterally from the basin is the contour where the hydrodynamic (freshwater) head in the surrounding regional groundwater is equal to that in the disposal basin (the hydrodynamic equipotential contour). This limit could be within 500 m of the discharge complex on the western side, but elsewhere its position is unknown. Of particular importance is its position on the southern (Murray River) side of the complex. Hydraulic heads in the disposal basin may be highest in this area, and if there are permeable river channel sands (Shepparton Fm.) in this area the existance of a hydrodynamic barrier between the disposal basin and the river may be necessary for effective containment of the disposal water.

Vertical advective movement of the disposal water into the Blanchetown Clay appears to be occurring. It remains to be seen whether the lower units of the Blanchetown Clay will eventually slow vertical movement to the extent that diffusion will become rate-determining.

5.8 Conclusions

1. The Mourquong Disposal Basin is underlain by and, at the western margin, is enclosed by the Blanchetown Clay which ranges in thickness from at least 8m near the centre to about 4m at the western side. This unit is composed mainly of fine-grained

clays with an inferred very low vertical and, generally, horizontal permeability to porous flow. However, there is a relatively high permeability zone of interbedded sands and clays at the western margin which is a potental site for lateral movement of groundwaters.

2. In the disposal site the Blanchetown Clay is overlain by 3 to 4m of much higher permeability lacustrine sediments comprising gypseous sands and clays. At the western, eastern and northern margins of the disposal site the lacustrine sediments are overlain by reworked aeolian dune sands derived from the Woorinen Formation. At the western margin the area of reworked sands is narrow (about150m) and the lacustrine sequence grades relatively sharply into a large Woorinen sand dune. At the northern margin the surficial reworked sands extend at least 300m into the discharge complex, overlying and partly infilling an area of older lacustrine sediments to the north of the disposal site.

3. There is evidence on the eastern margin of high permeability interbedded sand and clay fluvial overflow deposits of the Shepparton Formation. The disharge complex is a large circular structure, which indicates that there has been a surface water dominated phase at some time during its evolution. The extent of these flood deposits is unknown, but they could be a major control on lateral groundwater movement within the discharge complex. If these deposits extended outside the discharge zone and formed a connection with the nearby Murray River floodplain sediments through (hypothetical) fossil connecting channels, then they could provide a conduit through which disposal water could flow back towards the river.

4. Lateral groundwater pressure heads have been measured at shallow depths at the western margin. In summer, there is a pronounced minimum between the pressure head in the flooded area and the regional groundwater pressure beneath the adjoining Woorinen Formation dune, indicating the potential for groundwater flow is towards this minimum from both directions. When the summer surface water levels in the flooded area are low, the regional groundwater pressure in the dune is equal to that in the disposal area at a distance of about 150m westwards of the flooded area. In the winter, the pressure in the disposal area is greater than the maximum value measured in the dune and the contour of equal pressure is greater than 300m from the disposal area margin.

5. Lateral groundwater pressure heads at the northern and eastern margins of the disposal are are directed away from the flooded area in both summer and winter, suggesting a potential for groundwater to move out of the disposal area into the adjacent areas of the discharge complex. The position of the equipotential contour for these sides of the disposal area have not been determined but to the north, at least, the contour is probably off the discharge complex and in the adjacent Woorinen Formation. dunefield.

6. FUTURE WORK

The Mourquong Discharge Complex is an example of a class of groundwater discharge complex which at some stage(s) of their geological evolution have been strongly influenced by surface water-dominated phases involving input from adjacent major rivers such as the Murray and the Darling. It is this enhanced fluvial influence which distinguishes these discharge complexes from others, such as the Nulla Discharge Complex, in which the the wetter phases of lacustrine evolution have resulted in a more locally-sourced and less influential surface water regime. Because of this enhanced fluvial influence, these areas have been termed "fluvio-discharge complexes".

The most obvious characteristics of the fluvio-discharge complexes are their relatively large size, their well-defined sub-circular shape, and their proximity to major rivers. Some of these complexes contain wetlands (e.g. Gol Gol swamp), others are occasionally flooded during high river levels and are used for storage of fresh water (e.g. Lake Victoria) and others are completely isolated from river floodwater and are used for agricultural purposes (e.g. Lake Tandou and Lake Popildah) or evaporation basins. A variety of problems have been noted. They include: salinisation of the wetlands; possible environmental damage caused by surface water transfer of salt between the fluvio-discharge complex and the river (e.g. Fletchers Lake); salinisation of land surrounding large freshwater storage sites. The effects of agricultural and evaporation basin usage are not well known.

The Mourquong investigation has shown that the enhanced fluvial activity has introduced an additional dimension of geological complexity in the form of fluvial-deposited lithostratigraphic units. The nature and extent of these fluvial units has been only partly defined by the present investigation but there seems little doubt that they have had a strong influence on the natural hydrodynamics of the complex and they are potentially a major determinant of the direction, rate and extent to which irrigation water or saline disposal water could move into surrounding areas.

It is therefore proposed that the investigations of the Mourquong Fluvio-discharge Complex and Disposal Basin be extended to include the following aspects.

(1) A more comprehensive lithostratigraphic survey of the fluvio-discharge complex and the adjacent area to the south, between the complex and the Murray River. This survey will attempt to confirm the presence of significant fluvial sediments in the complex and determine their origin, extent and porosity. Data from the area to the south

will determine whether the fluvial sediments are continuous from the complex to the river.

(2) Determination of hydraulic gradients and extent to which disposal water has moved southwards from the disposal basin towards the river. This area is one of the more sensitive of the surrounding areas and it is potentially most at risk because the hydraulic gradient away from the discharge complex higher in this area than elsewhere. The area was not investigated previously because of potential drilling problems involving very soft wet sediments and the likelyhood that the smaller salinity contrast between the disposal and natural groundwater would make distinguishing between them more difficult.

(3) Supplementary investigations of the northern, western and perhaps the eastern areas to define to zone where the hydraulic head in the disposal basin and the surrounding regional are equal, which should indicate the limit to which the disposal water could flow laterally.

(4) Development of a groundwater flow model which can be calibrated with the measured data on hydraulic gradients, current extent of groundwater movement and estimated hydraulic conductivity, and used to predict rates of groundwater flow from the disposal basin.

7. APPENDIX

7.1 Methods

7.1.1 Drilling Techniques and Sediment Storage

The following procedures were designed to sample lacustrine clays and sandy clays in playas and salt lakes. The drilling equipment was readily dismantled and transported between sites with vehicle access to the lake shore, and then either hand carried or ferried by hovercraft. Lake surface conditions which ranged from dry, through muddy, to surface water less than 0.5 m deep have been successfully drilled. Existing techniques would have to be modified to cope with greater water depths.

The drilling method employed is a variation of the penetrometer technique in which steel tubes (5 cm diameter; 0.5 m long) are hammered into the sediments to 0.4 m depth using a drop hammer. The hammer is operated by a motorised hoist and mounted on an aluminium tripod derrick. The tripod accomodates lifting tools in 3m sections.

In lakes where surface conditions were wet or muddy a 20 cm diameter PVC tube was used to protect the drill-hole from influx of surface water. A steel tube was then hammered into the lake sediments, the uppermost wet, unconsolidated sediment removed, and the core tube extracted. A lightweight portable auger was then used to enlarge the core hole to 10 cm diameter The next steel tube attached to a drill rod was inserted and hammered down a further 0.4 m. This alternating hammering and augering procedure was repeated to the limits of the ability of the equipment to retrieve the cores, or until changes in the nature of the sediment made the technique inappropriate.

Holes up to 11 m and typically 6 m deep were cored by this method. The degree of sucess is a function of the clay content of the sediments. In the Murray Basin, the Blanchetown Clay and younger lacustrine clays were readily cored, and there was some sucess with the clayey sands which occur at the transition from the top of the Parilla Sand to the lacustrine clays. Water-saturated aeolian-derived sands, such as those which occur interspersed with lacustrine sediments above the Blanchetown in the

Mourquong evaporation basin, rapidly refilled the core-hole. These sand layers could not be cored unless they were less than about 0.5m thick.

Cores were sealed and transported in the steel core tubes. Prolonged storage in these tubes caused significant damage to the sediments and later cores were dealt with by the following procedures. Clay sediments were extruded either on site or in the laboratory using a specially designed hydraulic extruder. Cores containing sandy sediments could not be extruded and the tubes were cut lengthwise. The cores were extruded onto lengthwise-cut 8 cm PVC tubing and split. Each section was then sealed into an evacuated plastic sleeve to provide medium-term preservation against dehydration.

7.1.2 Porewater Extraction and Analyses

To minimise the possibility of contamination by 'float', sediment samples for porewater analyses were obtained from the bottom 0.1m of each 0.5m tube. Salinity was determined by optical refractometry using a portion of small volume of porewater (typically ≤ 1 ml total) extracted from the sediments using a Manheim press or, occasionally for sandy sediments, by centrifugation.

Surface water samples were filtered through a disposable 0.45μ filter, and an aliquot (usually 10 ml) pipetted into a separate container for determination of alkalinity. A portion of the sample for determination of cations was preserved by addition of a small quantity of concentrated nitric acid.

Analyses of cations was by ICP and analysis of anions was by ion chromatography.

7.1.3 Installation of Piezometers

Piezometers used for water sampling and the determination of standing water levels in shallow holes were 8 cm - diameter PVC tubing, slotted over 1m in length. Where possible, the piezometers were cemented into place. This type of piezometer was effective when installed in the clayey sands at the Parilla Sand - Blanchetown Clay transition zone, or in the shallow, bedded clays and sands typical of the Yamba Formation at Mourquong.

7.1.4 Piezometer Measurements

The standing water level and then a two or three point salinity profile down the water column in the piezometer was usually measured and averaged if necessary. The density of the water in the piezometers was calculated from the salinity assuming a temperature of 20°C.

Response of piezometers set in the Blanchetown Clay can be very slow so a measurements at different times were made for each piezometer till the water level reached a constant or fluctuating level. This situation ,which is an indiction that the water in the piezometer had reached its equilibrium level, had not been reached for some piezometers at the time of preparation of this report (see below).

7.1.5 Calculation of Hydraulic Heads

Lateral and vertical hydraulic heads and gradients were determined separately using the concepts (Figure **7.1**) developed by Lusczynski (1961) and Lusczynski and Swarenski (1966). This concept implies that lateral gradients can be determined from freshwater heads in piezometers screened to the same depth relative to a datum, and that vertical gradients can be obtained from environmental water heads measured along a vertical.

Application of the Lusczynski and Swarenski (1966) concepts to the hydrodynamics of groundwater discharge complexes has been described by Macumber (1991). The lateral heads are freshwater heads, calculated from the equation:

$$\rho_f H_{if} = \rho_i H_{ip} - Z_i(\rho_i - \rho_f)$$

The vertical heads are environmental water heads, calculated from the equation:

$$\rho_f H_{in} = \rho_i H_{ip} - Z_i(\rho_i - \rho_a) - Z_r(\rho_a - \rho_f)$$

H_{if} is the freshwater head at the point 'i' in groundwater of variable density
H_{ip} is the pointwater head at 'i'
Z_i is the elevation of 'i', with measurements being positive upwards
ρ_i is the density of water at point 'i'
ρ_f is the density of fresh water
ρ_a is the average density of water between elevations Z_r and 'i'
H_{in} is the environmental water head at 'i'
Z_r is the elevation of the reference point from which the average density of water to 'i' is determined, and above which the water is fresh

In the calculations of H_{in}, for Scotia, Nulla and Mourquong, Z_r was taken as equal to the top of the zone of saturation. Because this measurement was was not known at most locations, the SWL in the topmost piezometer was used instead. The value for the freshwater density was taken as 1.00 g/cm^3. Macumber (1991) has pointed out that, for the Lake Tyrrell brines, a change of the freshwater density from1.03 to 1.00 g/cm^3 made less than 4 cm difference to the value of H_{in}.

The lateral and vertical velocities were calculated from the equations:

$$v_x = -K_x [\partial H_{if}/\partial x]$$
$$v_z = -Kz[\partial H_{in}/\partial z]$$

For this investigation, the horizontal gradients were determined from piezometers set as close as possible to a constant elevation, and the vertical gradients from nests of piezometers at different depths at the same location. Under field conditions, installation of the piezometers to constant depth was not always feasible and

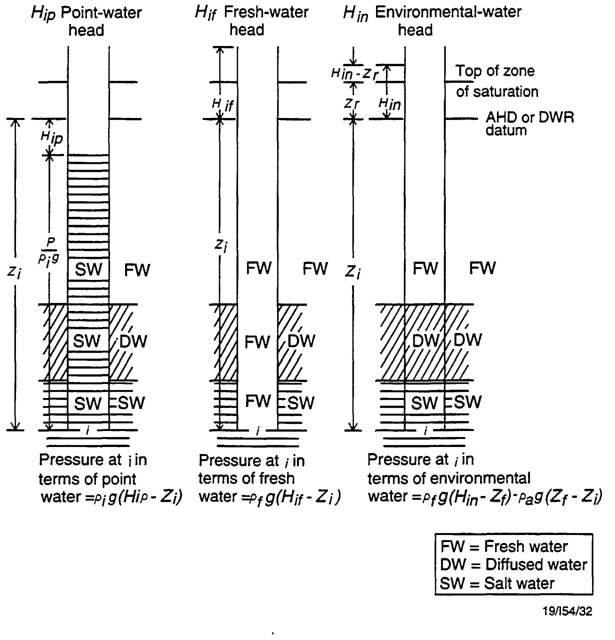

Fig 7.1 Hydraulic heads in groundwater of variable density.

the freshwater head at the designated depth was approximated by interpolation or extrapolation assuming a linear change in pressure with depth between piezometers. Interpolations and extrapolations were made using measurements of the actual groundwater pressure (P_{actual}) in piezometer nests. Care was taken to use piezometers in the same aquifer (e.g. the Parilla Sand) or the same aquitard (e.g. the Blanchetown Clay) to determine the vertical pressure gradients. These interpolated or extrapolated pressures were then converted to freshwater heads. For locations where only one piezometer had been installed, it was assumed that $P_{actual} = 0$ at a depth equal to the SWL in the piezometer, and the interpolations and extrapolations made on this basis.

The errors in the Mourquong vertical gradients depend on the accuracy of the SWL/salinity measurements on each piezometer and the vertical distance between the piezometers. Values of H_{in} are probably accurate to ±0.01m, which translates to an error of ±0.02m/30.85m or 0.06m/100m for the piezometers set furthest apart (M8 and DWR 36908/1), but ±0.02m/1.05m or 2m/100m for the closest set piezometers (M4 and 4A). Consequently, gradients > 0.5m/100m obtained for the latter combination of piezometers are well within the measurement errors, but a value of 2m/100m obtained for M4/4A is not.

There is evidence that the piezometers at site M3 had not reached equilibrium when the latest measurements were taken. Significant increases in the water level between successive measurements were still occurring (e.g. an increase from -4.35 to -3.28mDWR over a 4 month period) and the calculated downwards hydraulic gradient (27 m/100m) appears artificially high. Questionable vertical gradients, both upwards and downwards (12 and 31 m/100 m) are also evident at site M4. The M3 and M4 values have been labelled with a question mark in Table **5.5** and Figures **5.31** and **5.32**.

7.1.6 Logging

7.1.6.1 Core preparation

Core was stored under dark coldroom conditions in air-evacuated sealed plastic tubes. Where possible core was extruded from the steel core tubes using a hydraulic press, into PVC half tubes and cut with a putty knife. If the sediment was predominantly sand, or the core old and the internal steel partly corroded, the core tube and sediment was cut with a power jigsaw and the core manually transferred to PVC half tubes. The homogenized cut surface was cleaned by a variety of methods dependant on the sediment type, stiffness, induration, or desiccation; cutting or scraping with a putty knife, or brushing with a soft bristle brush.

7.1.6.2 Documentation

Where possible core was photographed immediately in colour. Methodical observation of the sediment, observation of sedimentary structures, and measurement of clastic sediment particle size used a Wild M5 field stereomicroscope with calibrated graticule. Particle-size assessment usually involved disaggregation of a small fraction in a watch glass using distilled water and dilute HCl where necessary. The mineralogical composition was assessed visually at this stage. Where clay composition or an unidentified component required identification, X-ray diffraction samples were taken. Colour assessment was always made of wet surfaces, by comparison with colour tiles of the Rock Color Chart, and recorded using the Munsell system.

Information was recorded on graphic log and notations as described by Radke (1992). Porosity type and qualitative abundance was assessed visually.

The scale of logging was generally at 1:2 for Nulla and Scotia fully cored holes, and at 1:25 for the Mourquong material.

In the deeper, 60 metre stratigraphic holes, coring was only undertaken in the uppermost 5 metres, and cuttings taken in each subsequent metre to the bottom of the hole. These holes were logged at 1:200 scale.

7.1.6.3 Logging Reduction

With the detailed logging at 1:2, it was necessary to reduce these logs for generalisations to be made on the lithostratigraphy. The condensing process was based on a 25 cm interval in which all information was reduced to one statement per category and recorded at 1:33. Lithologies in this reduction were recorded in histogram format, and the reliability of each increment qualified by a core-recovery assessment.

7.1.7 Core Sampling

Where minerals could not be identified, XRD samples were taken, either as a segment of core for clays and fine-grained carbonates, or individual particles hand-picked in the case of trace components.

Petrographic samples were taken of characteristic sediments, or unusual structures.

7.1.9 Imagery interpretation

7.1.9.1 TM interpretation

A regional assessment of geomorphological features, specifically other discharge zones, their lunette fields, and Parilla strandlines, as well as any structural elements, were interpreted from Thematic Mapper Imagery. Several manipulations of the rectified raw data were undertaken by Phil Bierwirth to remove instrument and atmospheric artifacts from the data. Principal components analysis and unmixing techniques were applied to attempt to delineate the geomorphological, structural, as well as mineral components of the discharge complex sediments.

These techniques were applied in conjunction with and using recent geological mapping of the Anabranch sheet by Rae (unpublished) as a control.

7.1.9.2 Airphoto Interpretation

Photogeological interpretation of Nulla, Scotia, and Mourquong Discharge Complexes was based on detailed air photo interpretation. Imagery used was black and white 1:27 200 scale photography flown on the 29/9/89 by the Australian Survey and Land Information Group. Morphostratigraphic interpretation and elucidation of processes at Nulla and Scotia were aided by detailed contouring of topography, based on spot height data by AUSLIG.

7.2 Hydrochemical Data

Data on surface water chemistry and groundwater salinity are presented in Tables MA-1 and MA-2.

Table MA.1. Mourquong Disposal Basin Surface Water Chemistry, Febuary 1992

Concentrations are in mg/L

Site	Lab Ref.	Salinity	pH	Alkalinity (meq/L)	Al	Fe	Mn	Cu	Zn	Si	B
MSW 1	920055	330000	7.43	13.5	<0.01	0.12	1.7	<0.005	<0.005	2.2	12
MSW 2	920056	345000	7.38	15.2	<0.01	0.14	1.6	<0.005	0.01	1.2	14
MSW 3	920057	109000	7.11	3.175	<0.01	0.14	0.01	0.05	<0.005	1.8	4.3
MSW 4	920058	56000	7.9	2.075	<0.01	0.15	0.01	0.05	<0.005	1.6	2.7
MSW 5	920059	44000	7.43	3.175	<0.01	0.16	0.01	0.05	<0.005	4.1	2.2
MSW 6	920060	34000	6.96	4.45	<0.01	0.14	1.1	<0.005	0.01	8.4	1.7
MSW 8	920061	168000	8.21	3.075	<0.01	0.14	0.04	0.06	0.01	0.48	5.4
MSW 9	920062	144000	7.64	2.875	<0.01	0.12	0.01	0.05	<0.005	1.3	5.1
MSW 10	920063	420000	6.89	42.5	<0.01	0.52	22	0.08	0.07	1.8	54
MSW 11	920064	435000	7.01	41.5	<0.01	0.25	22	<0.005	<0.005	0.88	36
MSW 12	920065	342000	7.42	15.05	<0.01	0.32	1.7	<0.01	0.02	1	14

Site	Lab Ref.	Sr	Li	Ca	Mg	Na	K	Ba	Br	Cl	SO4
MSW 1	920055	11	8.3	139	24600	94700	1010	<0.005	575	191000	39500
MSW 2	920056	10	8.7	99.3	27900	85900	1110	<0.005	736	176000	45200
MSW 3	920057	20	1.1	1100	5140	32100		0.08	128	57200	9930
MSW 4	920058	12	0.4	591	2670	17000	140	0.05	58.4	29000	5130
MSW 5	920059	9.63	0.27	435	2040	12900	110	0.04	35.8	21700	3840
MSW 6	920060	8.7	0.19	416	1570	9970	72	0.02	36.6	17300	3040
MSW 8	920061	25	1.8	988	8260	52800	480	0.07	217	91600	14700
MSW 9	920062	25.6	1.5	1350	6910	44200	420	0.08	184	77900	13500
MSW 10	920063	5.5	11	<60	69700	34200	3210	<0.005	2090	171000	74100
MSW 11	920064	4.3	11	<60	67300	37000	3200	<0.005	2180	178000	74400
MSW 12	920065	11	6.5	85.9	28400	90300	1090	<0.01	757	181000	46400

Table MA.2 Salinity of Mourquong Groundwater

Site	Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site MI			
	0	-1.991	361500
	0-0.02	-2.001	340000
	0.05-0.10	-2.066	251000
	0.25-0.30	-2.266	249000
	0.35-0.40	-2.366	248000
	0.75-0.8	-2.766	246000
	1.15-1.20	-3.166	250000
	1.55-1.60	-3.566	250000
	1.95-2.00	-3.966	244000
	2.35-2.40	-4.366	254000
	2.75-2.80	-4.766	234000
	3.15-3.20	-5.166	247000
	3.55-3.60	-5.566	228000
	3.95-4.00	-5.966	187000
	4.75-4.80	-6.766	130000
	5.15-5.2	-7.166	119000
	5.55-5.6	-7.566	115000
	5.95-6.0	-7.966	122000
	6.35-6.4	-8.366	126000
	6.75-6.80	-8.766	108000
	7.15-7.2	-9.166	108000
	7.55-7.60	-9.566	101000
	7.95-8.0	-9.966	97000
	8.35-8.40	-10.366	94000
	8.75-8.8	-10.766	90000
	9.15-9.20	-11.166	89000
	9.95-10.0		
	9.95-10.0	-11.966	90500
	10.35-10.4	-12.366	78000
	10.75-10.8	-12.766	77000
	11.15-11.2	-13.166	74000

Site	Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M2			
	0.05-0.10	-1.825	155000
	0.15-0.20	-1.925	145000
	0.25-0.3	-2.025	142000
	0.34-0.4	-2.125	142000
	0.75-0.8	-2.525	138000
	1.15-1.20	-2.925	112000
	1.95-2.0 ?	-3.725	112000
	2.35-2.4 ?	-4.125	112000
	2.75-2.8 ?	-4.525	112000
	3.15-3.2 ?	-4.925	112000
	3.55-3.6 ?	-5.325	112000
Site M5			
	1.5-2.0	-2.18	58000

Site	Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M7 & 7A (3.55 to 8.0)			
	0.35-0.4	0.745	55000
	0.75-0.8	0.345	44000
	1.15-1.2	-0.055	50000
	1.55-1.6	-0.455	48000
	1.95-2.00	-0.855	46000
	2.35-2.40	-1.255	45000
	2.75-2.8	-1.655	42000
	3.15-3.2	-2.055	40000
	3.55-3.6	-2.455	48000
	3.95-4.0	-2.825	38000
	4.0-4.5	-3.1	
	4.5-5.0	-3.6	40000
	5.0-5.5	-4.1	
	5.5-6.0	-4.6	42000
	6.5-7.0	-5.625	47000
	7.0-7.5	-6.1	
	7.5-8.0	-6.6	50000
Site M8			
	2.00-2.5	-2.175	38000

Site	Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M9			
	5.95-6.0	-1.335	42000
	6.35-6.4	-1.735	44000
	6.75-6.8	-2.135	50000
	7.15-7.2	-2.535	54000
	7.55-7.6	-2.935	54000
	7.95-8.0	-3.335	54000
	8.35-8.4	-3.735	56000
	8.75-8.8	-4.135	56000
	0-0.05	-1.625	112000
	0.5-1.0	-2.35	127000
	1.0-1.5	-2.85	156000
	1.5-2.0	-3.35	198000
	2.0-2.5	-3.85	228000
	2.5-3.0	-4.35	240000
	3.0-3.5	-4.85	230000
	3.4-4.0	-5.3	144000
	4.0-4.3	-5.75	126000
	4.0-4.5	-5.85	109000

Site	Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M15			
	0.35-0.40	-1.655	126000
	0.75-0.80	-2.055	122000
	1.15-1.20	-2.455	122000
	1.55-1.60	-2.855	120000
	1.95-2.00	-3.255	121000
	2.35-2.40	-3.655	120000
	2.75-2.80	-4.055	121500
	3.15-3.20	-4.455	123000
	3.55-3.60	-4.855	110500
	3.95-4.00	-5.255	86000
	4.35-4.40	-5.655	76000
	4.75-4.80	-6.055	75000

Site	Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M16			
	0.35-0.40	-1.915	156000
	0.75-0.80	-2.315	157000
	1.32-1.37	-2.885	157000
	1.55-1.60	-3.115	160000
	1.95-2.00	-3.515	145000
	2.35-2.40	-3.915	149000
	2.75-2.80	-4.315	149000
	3.15-3.20	-4.715	135000
	3.55-3.60	-5.115	103000
	3.95-4.00	-5.515	86000
	4.35-4.40	-5.915	80000
	4.75-4.80	-6.315	75000
	5.15-5.20	-6.715	75000

Table MA.2 (cont.) Salinity of Mourquong Groundwater

Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M3		
0.10-0.11	-2.045	340000
0.15-0.2	-2.115	322000
0.25-0.3	-2.215	290000
0.35-0.4	-2.315	306000
0.75-0.8	-2.715	314000
1.15-1.20	-3.115	294000
1.55-1.6	-3.515	296000
2.0-2.05	-4.015	296000
2.35-2.4	-4.315	292000
2.75-2.8	-4.715	298000
3.15-3.2	-5.115	279000
3.55-3.60	-5.515	230000
3.95-4.0	-5.915	182000
4.35-4.40	-6.315	127000
4.75-4.8	-6.715	119000
5.15-5.20	-7.115	113000
5.55-5.60	-7.515	113000
5.95-6.0	-7.915	112000
6.35-6.4	-8.315	110000
6.75-6.8	-8.715	118000
7.15-7.2	-9.115	116000
7.55-7.6	-9.515	124000

Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M4 &4B (4.55 to 8.2 m)		
0.35-0.4	-1.405	94000
0.75-0.8	-1.805	52000
1.00-1.20	-2.13	52000
1.55-1.60	-2.605	108000
1.75-1.80	-2.805	126000
2.15-2.20	-3.205	158000
2.55-2.60	-3.605	160000
2.95-3.0	-4.005	170000
3.35-3.4	-4.405	212000
3.75-3.8	-4.805	216000
4.15-4.2	-5.205	164000
4.55-4.60	-5.605	100000
4.95-5.00	-6.005	78000
5.35-5.40	-6.405	72000
5.75-5.8	-6.805	78000
6.15-6.20	-7.205	68000
6.55-6.60	-7.605	65000
6.95-7.0	-8.005	68000
7.35-7.4	-8.405	62000
7.75-7.80	-8.805	85000
8.15-8.2	-9.205	60000

Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M10		
4.35-4.55	-0.91	24000
5.10-5.30	-1.66	32000
5.45-5.60	-1.98	32000
6.35-6.55	-2.91	39000
Site M12		
8.05-9.05	-2.25	44000
Site M13		
0.4	-2.54	210000
0.8	-2.94	210000
1.2	-3.34	200000
1.6	-3.74	200000
2.0 some lost?	-4.14	210000
2.4 some lost?	-4.54	210000
2.8	-4.94	176000
3.2	-5.34	168000
3.6	-5.74	164000
4	-6.14	144000
4.4	-6.54	130000
4.8	-6.94	128000

Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M14		
0.4	-1.6	100000
0.8	-2	90000
1.2	-2.4	90000
1.6	-2.8	88000
2	-3.2	88000
2.4	-3.6	88000
2.8	-4	96000
3.2	-4.4	100000
3.6	-4.8	95000
4	-5.2	90000
4.4	-5.6	82000
4.8	-6	78000
5.2	-6.4	76000
5.6	-6.8	72000
6	-7.2	72000

Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M17		
0.35-0.40	-1.785	85000
0.75-0.80	-2.185	77500
1.15-1.20	-2.585	76000
1.35-1.40	-2.785	77500
1.75-1.80	-3.185	76500
2.15-2.20	-3.585	76500
2.55-2.60	-3.985	77500
2.95-3.00	-4.385	77500
3.35-3.40	-4.785	77500
3.75-3.80	-5.185	75000
4.15-4.20	-5.585	75000
4.55-4.60	-5.985	75000
4.95-5.00	-6.385	75000
5.35-5.40	-6.785	75000
5.75-5.80	-7.185	75000
6.15-6.20	-7.585	74000

Depth below GL (m)	Elevation (mDWR)	Salinity (mg/L)
Site M18		
0.35-0.40	-2.045	160000
0.75-0.80	-2.445	158000
1.15-1.20	-2.845	160000
1.55-1.60	-3.245	160000
1.95-2.00	-3.645	161000
2.35-2.40	-4.045	167000
2.75-2.80	-4.445	160000
3.15-3.20	-4.845	160000
3.55-3.60	-5.245	163000
3.95-4.00	-5.645	124000
4.35-4.40	-6.045	97000
4.75-4.80	-6.445	80500
5.15-5.20	-6.845	
5.55-5.60	-7.245	72000
5.95-6.00	-7.645	71000

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