1. INTRODUCTION

1.1 Nature and Scope of the Study

This study, dealing with groundwater systems in northern Victoria and their interactions with surface systems, grew out of an early involvement with the salinity problem in the Loddon Plain of northern Victoria. At that time, salting was generally assumed to be a post-irrigational problem, related essentially to the physical characteristics of the surficial sediments and the soils. However, the presence of a large number of nearby salt lakes, coupled with evidence of artesian conditions within the deeper aquifers, pointed to the possibility that while salinity was directly related to irrigation practice, there was a fundamental hydrological condition present that was also influencing the environmental response to irrigation.

Before any meaningful hypothesis could be proposed which linked the salinity problem, the salt lakes, and the underlying artesian aquifers, it was first necessary by means of a drilling program to establish the structural and stratigraphic framework for the drainage basin, and thereby determine the nature of the regional groundwater flow systems. The drilling program provided not only an understanding of the hydrogeology of the Loddon Basin (Macumber, 1978a) but also gave an insight into the Tertiary evolution of the Murray River drainage basin, of which the Loddon River is a tributary (Macumber, 1978b). Furthermore, since the Loddon Plain spans the boundary between the marine and fluvial parts of the Murray Basin, the program also provided data on the stratigraphic relationships between the marine and nonmarine sequences. While the relationship between the regional groundwater flow systems and the distribution of groundwater discharge zones was being established, a major hydrological event occurred in the 1973-75 period which revealed the delicately balanced hydrological equilibrium which existed between the groundwater systems and the surface water systems. This event was the sudden response of the deep piezometer network to sheet flooding of the Loddon Plain. At much the same time, it became clear that pressure levels had been continuously rising in the corresponding deeply buried regional aquifer in the neighbouring Campaspe Valley since before 1900, at a uniform rate. This permitted the prediction of the eventual establishment of a regional discharge zone in the Campaspe Valley which would greatly exacerbate the salinity problems already existing in the area. The 1973-75 rise in pressure levels in the Loddon Valley led to a 20 km upbasin migration of the hinge line between the regional groundwater recharge zone and the discharge zone. At Bears Lagoon, in the newly expanded discharge zone, a detailed study of the consequent discharge phenomena was undertaken.

Following the completion of the original study, new data from the Goulburn and Murray valley systems became available showing rising trends in the regional aquifers similar to those observed elsewhere on the plains (Macumber, 1984, 1985, 1986). Since this more recent work contains critical supporting evidence for hydrologic change on the Riverine Plain, data from it has been included in this report. In addition, a better conceptual understanding of the applicability of salinity control options was brought about by the division of the State into 15 salinity provinces and the development of the salinity management option trees - (SMOTS) (Macumber and Fitzpatrick, 1987). In order to tie the salinity work together, a subsection on salinity has been included in Chapter 4.

The second part of this study is devoted to the characteristics of groundwater flow in the Mallee region, in order to compare regional groundwater flow systems in non-marine sequences with those in the adjacent unconfined Parilla Sand aquifer of marine origin. In the aeolian Mallee landscape of northwestern Victoria, surface drainage is virtually absent, and downbasin flow is essentially via the groundwater systems, the uppermost of which is developed in the unconfined late Tertiary Parilla Sand aquifer. On passing downbasin, the water table gradually approaches the surface to become artesian in the northern Mallee, where ground-water outcrop is evidenced by the many saline lakes and gypsum flats scattered throughout the linear dunefields, and by the very large groundwater discharge complexes, the boinkas (Macumber 1980).

Salinity is also a major problem in parts of the northern Mallee where many previously grassed and treed depressions have suddenly gone saline, reflecting a gradual rise in the saline regional water table which has developed in the Parilla Sand. In this work, emphasis was again placed on the discharge areas; the chemistry of the salt lakes is shown to be determined by that of the regional groundwaters. Some unusual features of the groundwater flow system are highlighted, especially with respect to the hydrochemistry of the aquifers and the springs; for instance, the widespread occurrence of low pH groundwaters, the similarity of the regional groundwater with sea water, and the high salinities reached by groundwater brines.

The last part of this study deals with aspects of the hydraulics of the regional groundwaters and Tyrrell Basin groundwater brines; it provides an insight into brine formation in a continental setting, and the subsequent influence of the groundwater brines on both regional groundwater flow in the vicinity of salt lakes, and on lake–groundwater interactions.

1.2 Location and Physiography

The study area covers the western part of the Riverine Plain in Victoria extending westward across the aeolian landscape of the Mallee region of northwestern Victoria - an overall area of about 50,000 km^2 (Figure 1.1). Within the Riverine Plain, the greater part of the study was carried out on the Loddon River drainage basin, with some additional work on the Campaspe River drainage basin farther to the east. The Campaspe and Loddon rivers are the most westerly rivers which flow into the Murray River from the south. They rise in the southwestern extremity of the Great Dividing Range, which there forms a relatively low physiographic divide (less than 100 m above sea level) between the northflowing streams of the Murray Basin and the southflowing streams draining towards the Otway Basin.

Westwards of the Loddon River plain lies the Mallee region with its largely aeolian landscape. Streams which pass northward across the Mallee do not reach the Murray River but, instead, flow into terminal lake systems within the Mallee. The streams discussed in this report include the Avoca River which normally terminates at Lake Bael Bael and the Marshes;

The Avoca River distributaries, Lalbert Creek and Tyrrell Creek, which flow into Lake Timboram and Lake Tyrrell respectively; and the Wimmera River, which normally terminates at Lake Albacutya, but which occasionally continues northwards through the Wyperfeld lake system towards Wirrengren Plain (the final lake on the Wimmera River system, last filled in 1923). For the Mallee region, greatest attention has been paid to the regional groundwater discharge areas of the northern Mallee, including principally the Sunset Country of far northwestern Victoria, and the Tyrrell Basin. (It had previously been proposed that Lake Tyrrell should be used as an evaporating basin for saline water which could be pumped from irrigation districts on the Riverine Plain).

1.3 Climate

Climatic data was obtained from the Commonwealth Bureau of Meteorology and was collected by a number of recording stations scattered throughout the study area. Apart from the more southerly highland areas, the region is essentially semiarid; there is a tendency towards hot and dry summer months when the area comes under the influence of dry variable winds, which are associated with the high pressure (anticyclonic) belt. The rainfall period is in winter and is controlled by winter westerlies and the jet stream (Gentilli, 1971).

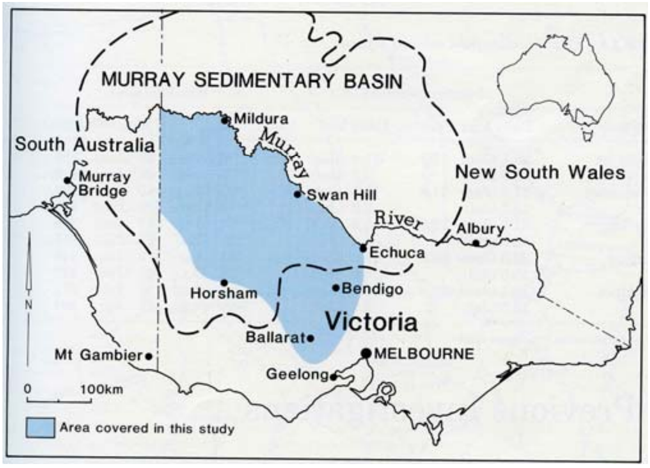

Figure 1.1 – Study area – northwestern Victoria

1.3.1 Rainfall

Rainfall is closely related to topography in the study area. The heaviest rainfall, which averages about 1060 mm per annum, occurs on the catchment divide, at the headwaters of the Loddon River, but decreases westward along the divide to about 700 mm in the catchment area of the Avoca River. On the Riverine Plain and in the Mallee annual rainfall is generally less than 500 mm, falling to about 250 mm in the far northwest of the Mallee. Northwards, across the Loddon Plain, rain varies from about 450 mm nearer the highlands to 370 mm near Kerang (Table 1.1).

Most of the rainfall occurs in winter, especially in the catchment area and on the Loddon River divide: the wettest month (June) has up to three times the rainfall of the driest (February). Within the Mallee seasonal contrast in the rainfall is not sharp, as shown by Ouyen and Sea Lake data: each having an annual rainfall of about 340 mm, a driest month of 20 mm (January), and a wettest month of 36 mm and 35 mm respectively (October).

1.3.2 Temperature

Like rainfall, temperature is closely related to physiography. The average maximum temperature is lowest (about 17°C to 18°C) in the southeastern highland region, but it rises to about 31°C to 32°C on the plains and in the Mallee (Table 1.1).

TABLE 1.1 - Climatic data from selected stations

	Mean temperature (°C)			Rainfall (mm)			
Station	**Daily Max.**	**Year**	**Daily Min.**	**Year**	**Max.**	**Min.**	**Annual**
Ballarat	25.5 (Jan) 9.9 (Jul)	17.3	11.4 (Jan) 3.2 (Jul)	7.3	*74 (Aug) **77 Aug)	38 (Jan) 32 (Jan)	719 719
Rochester	31.2 (Jan) 13.1 (Jul)	21.8	15.8 (Feb) 3.2 (Jul)	8.9	*47 (May) **47 (Jan)	20 (Jan) 30 (Dec)	460 470
Kerang	31.3 (Jan) 13.8 (Jul)	22.5	15.5 (Feb) 4.0 (Jul)	9.5	*34 (Aug) **38 (Oct)	12 (Jan) 21 (Jan)	365 367
Ouyen	32.5 (Jan) 15.0 (Jul)	23.5	15.6 (Jan) 4.2 (Jul)	9.6	*31 (Aug) **36 (Oct)	12 (Jan) 20 (Jan)	346 337
Mildura	32.1 (Jan) 15.3 (Jul)	23.6	16.9 (Jan) 4.3 (Jul)	10.3	*25 (Aug) **29 (Aug)	11 (Feb) 18 (Apr)	271 294

* = Median value, ** = Mean value

1.4 Previous Investigations

A number of reports on the geology and hydrogeology of northwestern Victoria have been written since systematic drilling for groundwater commenced late last century. A summary of this early work was included in a report by Gloe (1947), who comprehensively reviewed the bore hole data from the Mallee and Wimmera regions. An outline of the physiography of northwestern Victoria was provided by Hills (1939). Johns and Lawrence (1964) first discussed the geology and groundwater resources of the southeastern Riverine Plain in Victoria, while Lawrence (1966) gave a comprehensive account of the stratigraphy and structure of the Mallee. The relationship between salinization and geomorphic processes was first investigated by Macumber (1968), who later (Macumber, 1969) showed that the Parilla Sand extends eastward into the Loddon Plain and is marine. Lawrence (1975) carried out an integrated study of the hydrogeology of the southern Murray Basin.

During the course of the investigation, certain aspects of the work were published, especially those which were most relevant to the role of groundwater systems in salinization. Data from these papers are referred to throughout the text.

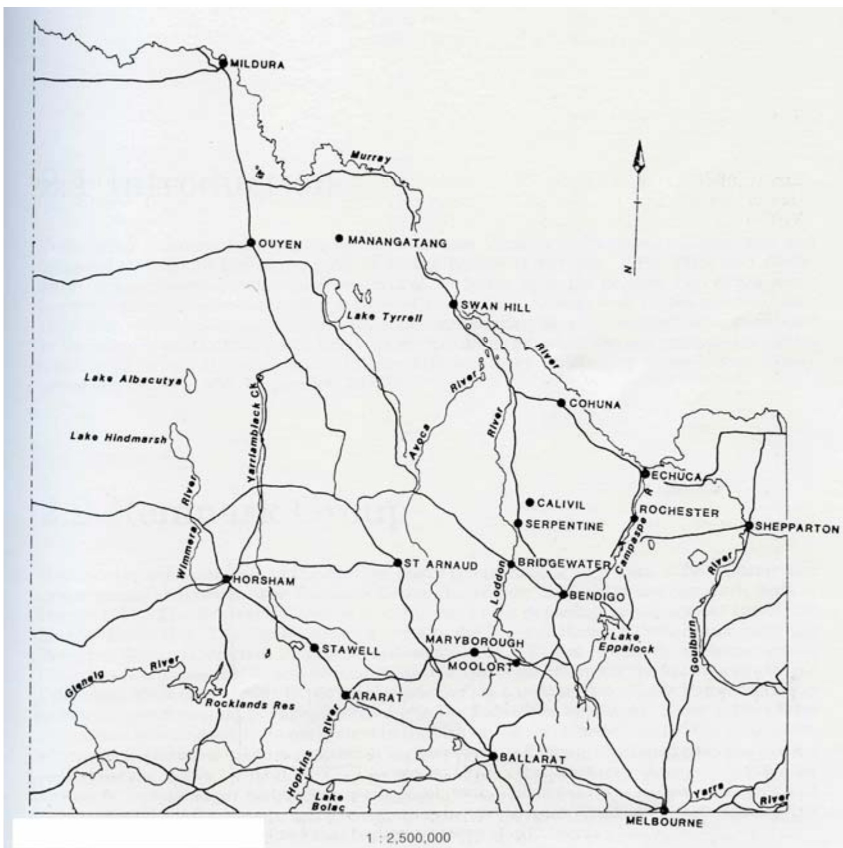

Figure 1.2 - Locality map of study area