

Plate 1 – The artificial entrance to the Gippsland Lakes (N Rosengren)

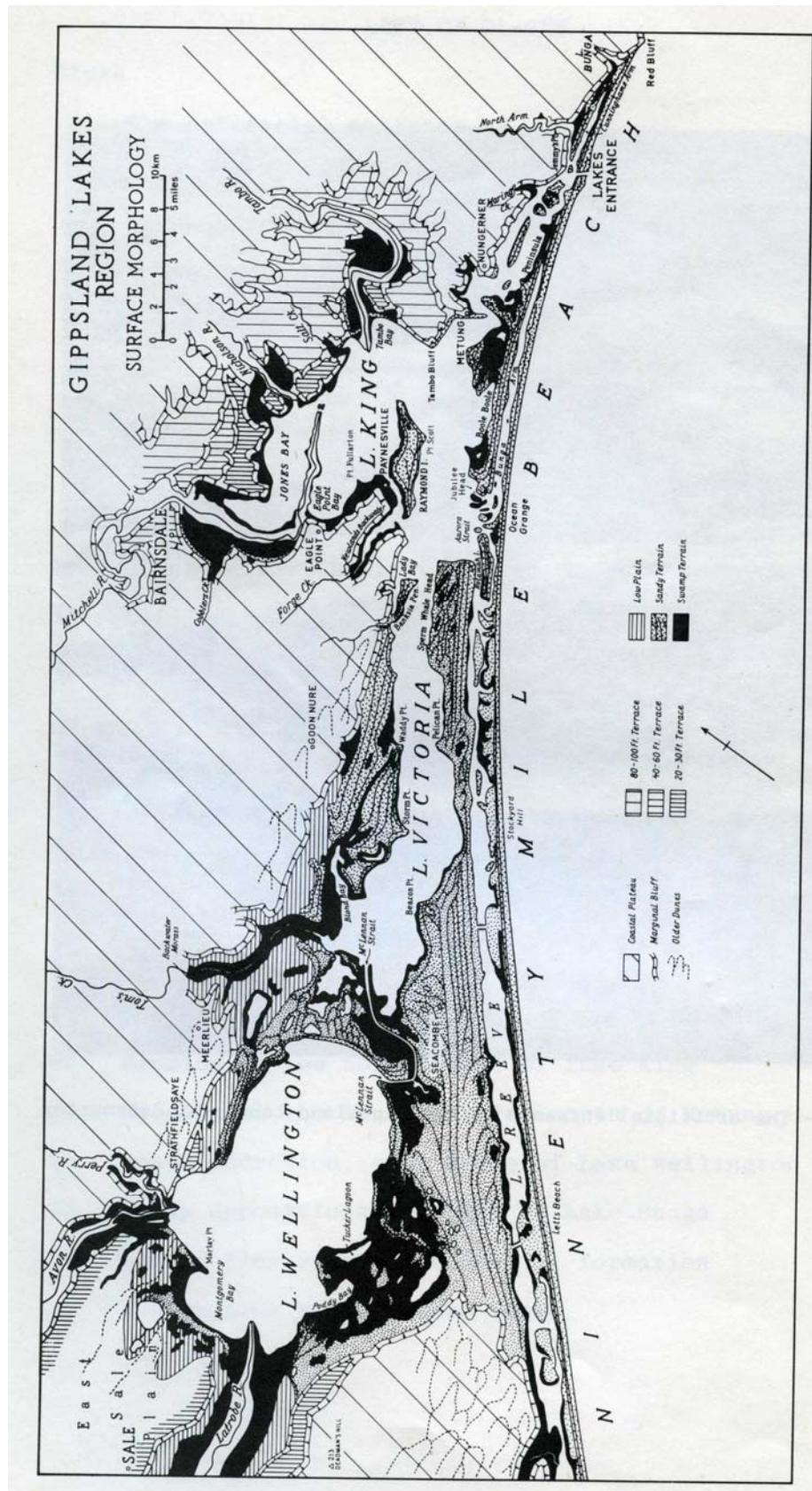


Figure 1 – Gippsland Lakes Region – Surface Morphology

THE LAKES AND THEIR ENVIRONMENT

The Gippsland Lakes (Figure 1) are a group of coastal lagoons in south-eastern Australia, separated from the sea by broad sandy barriers. They include Lake Wellington (138 sq. km; shoreline length 60 km), Lake Victoria (110 sq. km; shoreline length just over 100 km), Lake King (92 sq. km; shoreline length 160 km), and a number of smaller lagoons associated with extensive swamps on a low-lying depositional coastal plain. They are fed by five main river systems, the Latrobe and the Avon flowing into Lake Wellington, the Mitchell, Nicholson, and Tambo into Lake King; and together these drain a catchment of more than 20, 00sq. km, extending into the Eastern Highlands of Victoria (Figure 2). Much of the catchment above the 150 metre contour is still forested, but the lower country is mainly grazed or cultivated farmland, with some residual patches of bush and heathland. The river valleys are incised into a coastal plateau which borders the southern slopes of the Eastern Highlands, and ends in a marginal bluff overlooking the coastal plain and the Gippsland Lakes. The valley floors are low-lying and swampy, with natural levees bordering the river channels, and deltas protruding into the lakes. The coastal barriers are dune-covered, and bordered on the seaward side by the Ninety Mile Beach.

Coastal lagoons are area of shallow water that have been partly or wholly sealed off from the sea by the formation of depositional barriers. The term barrier indicates a sedimentary deposit built up above high tide level, and standing offshore, or across the mouths of coastal inlets or embayments, the term bar being restricted to similar features that are submerged by the sea for at least part of the normal tidal cycle (Bird 1976a). The Gippsland Lakes are therefore lagoons enclosed by depositional barriers, but it is convenient to follow local usage and refer to them as lakes. They are generally shallow (Figure 3), much of Lake Wellington being less than 4 metres in depth, and much of Lake King less than 6 metres. Lake Victoria occupies an elongated furrow up to 10 metres deep which extends eastwards across the southern part of Lake King, past Metung, and through Reeves Channel to Lakes Entrance. In McLennan Strait, which links Lake Wellington to Lake Victoria, the depth attains a maximum of 11 metres in the meander at Seacombe. The deepest point in the Gippsland Lakes is 15 metres, in the scour – hole eat of Shaving Point, at Metung.

The coastal barriers include an inner and an outer barrier between the lakes and the sea, and remnants of a prior barrier, so called because it was initiated before the inner and outer barriers developed to enclose the Gippsland Lakes in their present configuration. Each barrier is surmounted by dune topography, largely fixed in position by a cover of scrub, woodland, and heath vegetation. Each has a ground – pattern of dune ridges running parallel to the curved outline of the Ninety Mile Beach, but interrupted by blowouts and parabolic dunes. The crests of the dunes are generally less than 10 metres above mean sea level, but locally they are much higher, and some of the summits exceed 30 metres.

When Europeans first settled this area in the eighteen – forties, the Gippsland lakes were linked to the sea only by way of an intermittent and variable outlet through the eastern end of the barrier between Cunningham and Red Bluff (Figure 34.) Subsequently an artificial channel was cut through a narrow section of the outer barrier opposite Jemmys point to provide a navigable entrance to the lakes (Plate 1), and after this opened in 1889 the old natural outlet soon became sealed off permanently by sand deposition. Cunningham Arm, alongside the township of Lakes entrance, is the shrunken remnant of a former navigable channel that once led to the natural outlet; its eastern half has been filled in by the accumulation of lacustrine sediments, and overrun by dunes (Plates 2 and 3)

The climate of East Gippsland is mild and maritime. Meteorological records from Bairnsdale (Table 1), a station typical of the Gippsland Lakes region, show a range of mean temperature from 8.3°C in July to 19.6°C in February and a mean annual rainfall (1911 – 40) of 669 millimetres, evenly distributed through the year. East Sale has a mean annual rainfall of 602 mm, and Lakes Entrance 736 mm.

Rainfall is in fact more variable than the mean figures suggest (Figure 4), for long spells of dry weather occur from time to time, usually in late summer and autumn. Since 1885, the driest year at Bairnsdale was 1972 (362 mm) and the wettest 1949 (111 mm); the dry years 1938 – 48 (mean annual rainfall 875 mm) were followed by wet years 1949 – 56 (mean annual rainfall 875 mm). When this study was originally made rainfall was close to the 1911 – 40 average (1957, 662 mm; 1958, 691 mm; 1959, 693 mm), but nevertheless there were short dry spells in April 1958 and April – May 1959, and July 1957 was an exceptionally wet month (150 mm). Since 1960 there have been two unusually wet years, 1970 (1007 mm) and 1974 (1098 mm), and the exceptionally dry 1972 (362 mm).

Evaporation, estimated from records of mean monthly saturation deficits (Prescott 1931), total 996 millimetres for an average year, and is relatively high (more than 75 mm per month) from October to the end of March (Table 1, C). In 1949, a year of exceptionally high rainfall, tests carried out by the State Rivers and Water Supply Commission of Victoria showed an evaporation of about 900 mm over the lakes, and in a dry month evaporation probably exceeds 150 millimetres.

The prevailing winds are westerly. Figure 5 shows the wind regime at East Sale, which is typical of the East Gippsland coastal region. Easterly winds blow mainly during the summer months, but the regional wind resultant (268°) reflects the dominance of westerlies.

The hydrology of the Gippsland Lakes is influenced by local climate, the regime of the inflowing rivers, and the effects of the artificial entrance. Water is supplied to the lakes by rain and rivers and removed by evaporation; it passes in and out of the artificial entrance according to the relative levels of lake and sea.

It is possible to make a rough estimate of the quantities of water gained and lost from the Gippsland Lakes system. If the mean depth of Lake Wellington is 2 metres, that of Lake Victoria 4 metres, and Lake King 3 metres, the total volume of water in the Gippsland Lakes during calm, dry conditions is approximately 1000 million cubic metres. Mean annual rainfall over the 340 square kilometres of the lakes area (based on Bairnsdale rainfall records) is about 230 million cubic metres. Mean annual fluvial inflow (calculated from data compiled by the State Rivers and Water Supply Commission) is 3370 million cubic metres. There is thus a total of 3600 million cubic metres of fresh water annually to the Gippsland Lakes.

If a hydrological balance were to be maintained (i.e. if the salinity regime is to fluctuate around a sustained annual mean) this 3600 million cubic metres of fresh water would have to be dispersed each year, partly by evaporation and partly by a net outflow to the sea through artificial entrance. Evaporation is difficult to assess, because it varies with water depth and temperature and wind effects, but if the evaporation estimates from Bairnsdale and multiplied by the lake surface area a mean annual evaporation figure of 340 million cubic metres is obtained. Inflow and outflow of water through the artificial entrance are also difficult to measure: there is a strong inflow of sea water during high tides, especially when the lake level is low, but outflow during the ebb, strengthened when the lake level is high, substantially exceeds inflow. If the evaporation figure is approximately correct, mean annual outflow through the artificial entrance must exceed mean annual inflow by about 3260 million cubic metres: in other words, a water volume roughly equivalent to the mean annual fluvial input is discharged to the sea. As will be seen, there is evidence of an increase in the salinity of the Gippsland Lakes during the past 20 years, indicating that fresh water input has been exceeded by evaporation and discharge losses, permitting a net inflow of sea water during this period.

The hydrological regime is complicated by seasonal variations. Fluvial discharge reaches a maximum in late winter and early spring (Table 1, E), when runoff is augmented by the melting of snow in the Eastern Highlands: river flooding occurs most frequently at this time (Table 1, F). Rainfall means show little variation from month to month, but in winter evaporation is much reduced. Consequently, lake levels rise during the winter months, and outflow at the artificial entrance is strengthened by discharge of this additional water. During the summer the lake level fall, the minimum level being determined by sea level at the artificial entrance.

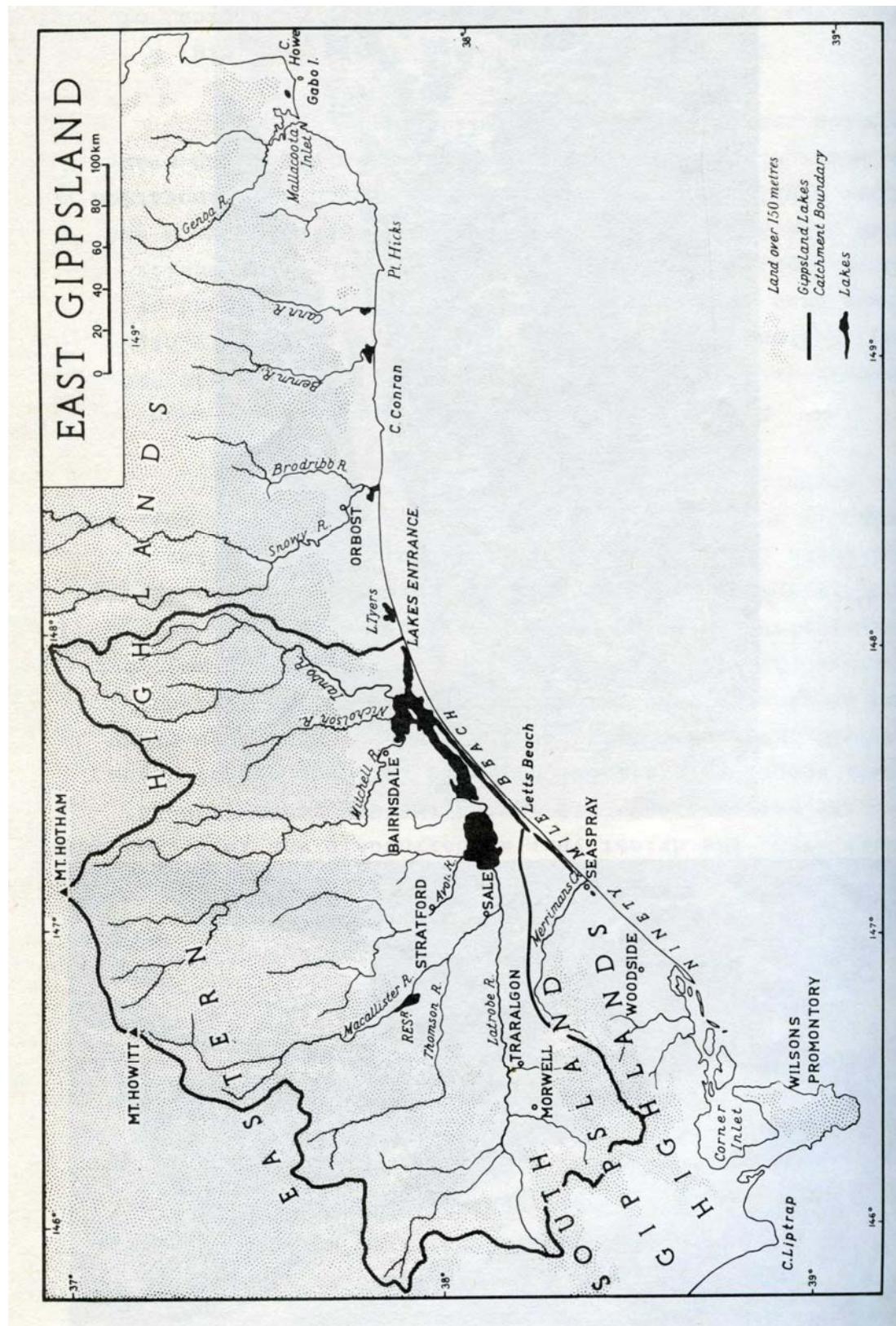


Figure 2 – East Gippsland



Plates 2 and 3 – Lakes Entrance and the Cunningham Arm (N Rosengren)

TABLE 1 METEOROLOGICAL AND HYDROLOGICAL DATA FOR BAIRNSDALE, VICTORIA

| JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | |
|--|------|------|------|------|-----|-----|-----|------|------|------|------|-------------------------|
| A – Mean Monthly Temperature (°C) | | | | | | | | | | | | |
| 18.2 | 19.6 | 16.7 | 14.1 | 11.3 | 8.8 | 8.3 | 9.6 | 11.7 | 13.6 | 15.6 | 17.3 | Mean 13.7 Range 11.2 |
| B – Mean Monthly Rainfall (1911 – 40) (millimetres) | | | | | | | | | | | | |
| 63 | 53 | 67 | 51 | 40 | 55 | 52 | 44 | 53 | 68 | 56 | 67 | Mean Total – 669mm |
| C – Estimated Evaporation (millimetres) | | | | | | | | | | | | |
| 147 | 115 | 94 | 58 | 43 | 31 | 30 | 48 | 67 | 100 | 118 | 145 | Mean Total – 996 mm |
| D – Mean Monthly Flow of Mitchell River (million cubic metres) | | | | | | | | | | | | |
| 37 | 22 | 25 | 25 | 42 | 99 | 111 | 123 | 154 | 117 | 54 | 38 | Mean Total – 847 |
| E – Mean Annual Fluvial Inflow (million cubic metres) | | | | | | | | | | | | |
| 150 | 94 | 112 | 125 | 204 | 336 | 403 | 469 | 516 | 461 | 294 | 205 | Mean Total – 3369 |
| F – Flood Incidence in East Gippsland 1991 – 53 | | | | | | | | | | | | |
| 4 | 5 | 1 | 6 | 6 | 10 | 15 | 10 | 8 | 11 | 3 | 4 | Total Recorded - 83 |

Sources: Temperature and rainfall data are based on figures supplied by the Commonwealth Bureau of Meteorology, Melbourne. Evaporation estimated from average monthly saturation deficits by Prescott's (1931) method. Monthly flow of Mitchell River from the State Rivers and Water Supply commission's River Gaugings (1971) and estimates of mean annual fluvial inflow based on estimates by Fryer (1971). Flood incidence from records published in the East Gippsland Region Resources survey 91954).

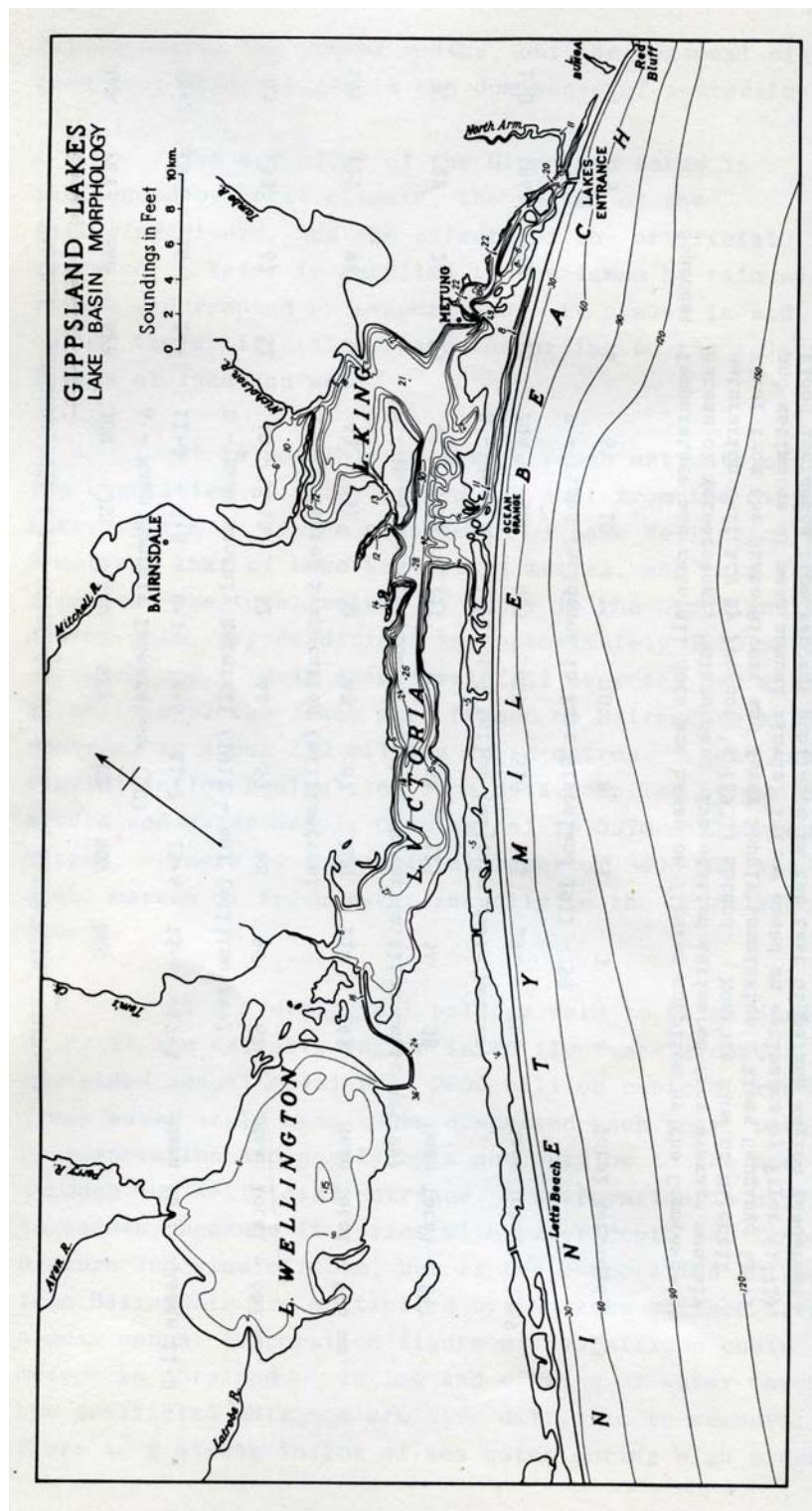


Figure 3 – Gippsland Lakes – Lake Basin Morphology

River flooding temporarily raises the level of the Gippsland Lakes by up to 2 metres, inundating extensive areas of the bordering lowlands. The severe flooding in June 1952 added about 900 million cubic metres of rain and river water to the lakes system during a period of three days. A rapid outflow developed through the artificial entrance, temporarily suppressing tidal fluctuations, and an unsuccessful attempt was made to cut a second outlet through a narrow part of the outer barrier east of Ocean Grange (*Bairnsdale Advertiser*, 26/6/52). More than a fortnight passed before the lakes were restored to their normal level.

At the end of January 1971 a heavy downpour in the area north-west of the Gippsland Lakes produced extensive flooding, especially around Lake Wellington. The effects of this flooding on the salinity, ecology and sedimentology of the Gippsland Lakes have been discussed by Bird (1972a).

Before the artificial entrance was cut river floods used to build up to the level of the lakes until water split out across a low-lying section of the outer barrier east of Cunningham, opening a natural outlet. In dry weather reduced river flow and high evaporation lowered the level of the lakes, and this outlet, no longer maintained by outflow, became sealed by sand deposition.

Spring tide range at Lakes entrance is about a metre, but tidal movements are not transmitted far into the lakes. At Metung (Figure 6) the tide range is only about 10 centimetres, and diurnal tides are barely perceptible farther west, in Lake Victoria and Lake Wellington. At Paynesville the tide gauge records irregular fluctuations, the slight diurnal tide being either masked or augmented by oscillations of lake level due to other causes, particularly wind stress and barometric pressure changes. In calm, dry weather the surface of the lakes stabilises close to mean sea level, and calm-weather lake level provides a useful approximate datum for the measurements of heights and depths around the lakes.

After heavy rain and river flooding raise the level of the lakes, water pours out to sea through the artificial entrance even when the tide is rising. Strong winds and variations in barometric pressure also modify lake levels, wind action moving water across the lakes to build up their level to leeward and lower it to windward by as much as 60 cm above and below calm-weather lake level. When the wind drops the calm-weather level is resorted after a succession of standing-wave level around the lake shores, and sharp alternations of current flow through McLennan Strait. These variations, and the currents that accompany them, are known locally as 'tides', but they are not related to the astronomically generated tidal cycles observed in adjacent ocean waves, although they mingle with these true tidal movements transmitted through the artificial entrance and into the eastern part of the Lake King.

Currents generated by the ebb and flow of tides through the artificial entrance attain velocities of up to 5 knots (2.2 m/sec) and similar⁵ velocities are generated by strong winds blowing over the lakes. River floods produce currents of up to 7 knots (3.0 m/sec) off river mouths, in narrow straits, and out through the artificial entrance, but these are short-lived. Considerable erosion may be accomplished, nevertheless, by such currents, several metres of land being scoured away from the shoreline of Lake Wellington near the mouth of the Avon by exceptional floods in 1952.

The lakes are oriented in such a way that the prevailing westerly winds blow up to a metre high, with lengths of up to 10 metres. The less frequent easterly winds also generate wave action across the lakes towards east-facing shore sectors.

These winds also produce waves in the sea area off the Ninety Mile Beach. The prevailing westerlies head offshore from the Gippsland Lakes sector, but winds between south-west and due east generate waves that move in towards the sandy ocean shoreline, and there are swells, originating in distant storms out in the Southern Ocean, which are transmitted through the sea area east of Tasmania to arrive from a southerly or south-easterly direction (Figure 14). Even in calm weather, these ocean swells persist as long, low waves approaching the beach. In stormy weather they are reinforced by southerly winds, or accompanied by other waves generated by winds from the south-west or the east. Ocean swell does not penetrate into the Gippsland Lakes, except in a very limited fashion, just inside the artificial entrance (Figure 16).

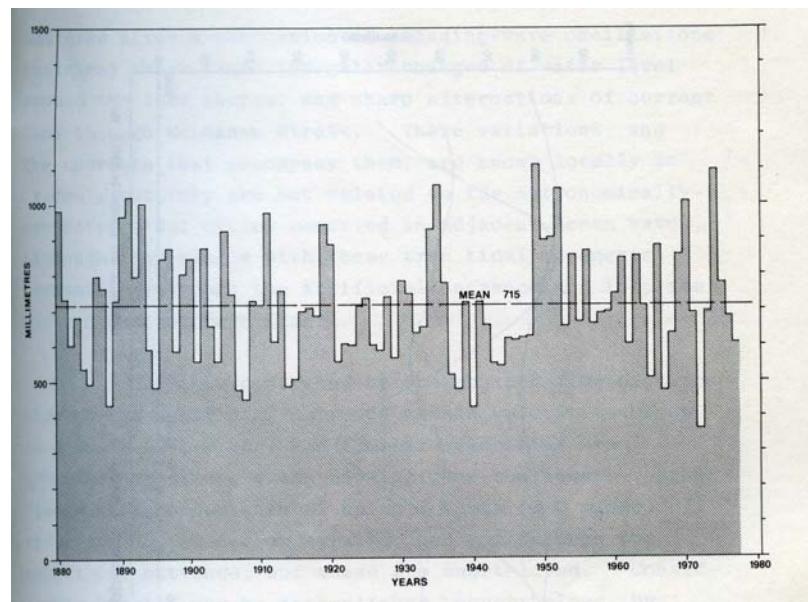


Figure 4 – Rainfall at Bairnsdale 1880 – 1977

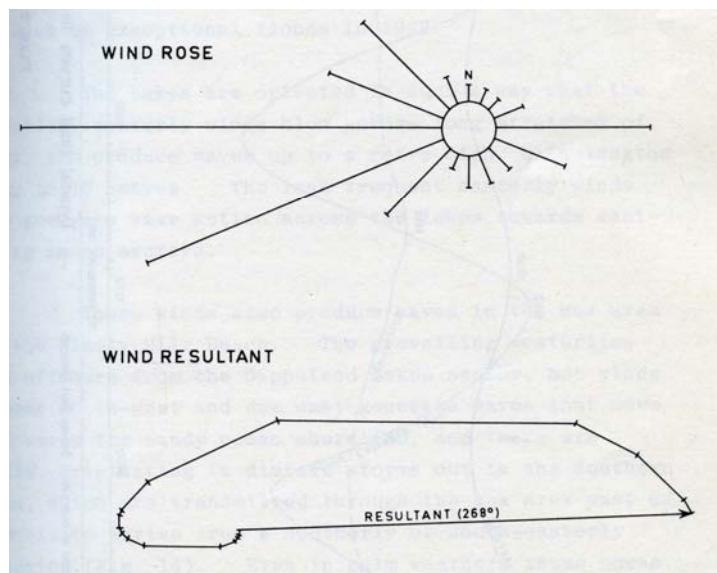


Figure 5

Salinity conditions in the Gippsland Lakes are largely determined by the meeting and mixing of fresh water from rain and rivers and salt water flowing in from the sea through the artificial entrance. Seepage of sea water through the barriers is limited by the buffering effect of fresh water held within the dunes, but occasionally sea water is swept over low-lying sections of the barrier during storms, notably near the eastern end of Bunga Arm, where washover fans are seen. Small quantities of marine salt are also carried into the lakes region by the wind in the form of 'cyclic salt' (Jennings 1955), derived from sea spray and brought down in rainfall. Chlorides have been detected in rainwater at Paynesville, and the East Gippsland rivers have a sodium chloride content in excess of that which could have been derived from erosion of catchment rocks (Anderson 1941). During 1957 – 59, measurements by the State Rivers and Water Supply Commission of Victoria indicated the presence of dissolved sodium chloride in each of the rivers draining into the Gippsland Lakes, the concentration reaching a maximum of 0.12‰ (parts per thousands) in the Mitchell River at Glenaladale at the end of the dry month of May 1959. Chlorides may also be derived from floodwater leaching of saline marshlands in the low-lying country and enclosed depressions south and west of Lake Wellington, where the salt is evidently an inheritance from earlier phases of marine inundation, perpetuated in the soils of poorly drained areas. However, most of the salinity in the lakes is derived from marine salts in the sea water invading at Lakes entrance. Measurements show that the typical pattern if estuarine (cf. Emery & Stevenson 1957), with a salinity gradient from fresh water at the river mouths to sea water outside the artificial entrance.

Salinity is here taken as the concentration of dissolved salts, calculated from measurements of the electrical conductivity of water samples from the lakes, corrected to a temperature of 20°C. Fresh water is defined as water with a salinity less than 0.5‰, brackish water between 0.5 and 20.0‰, and salt water between 20.0 and 35.0‰. Measurements by the State Rivers and Water Supply Commission, based on regular sampling at selected points across the Gippsland Lakes, have demonstrated a seasonal salinity regime. This is indicated by the graphs in figure 7, which show monthly variations in surface salinity at 11 points from east to west through the Gippsland Lakes during 1958, in relation to rainfall recorded at Bairnsdale in the preceding month. At each station, salinity rose during summer to an autumn maximum, and fell in the late winter to spring period. Comparison of the graphs in sequence shows the overall diminution in salinity from east to west across the lakes, from Lakes Entrance through to Lake Wellington.

Salinity at the surface is generally less than salinity at depth, particularly in calm weather, when a wedge of salt water spreads out across the lake floor, and is only gradually diluted by mixing with fresher surface water. However, surface salinity is a good indication of the extent to the ecology of sea water invasion wash year, and is also relevant to the ecology of shoreline and shallow water vegetation. The seasonal pattern of salinity in the Gippsland Lakes (Figure 8) is also shown by means of isohalines for quarterly observations at 19 points in the lakes during 1957 – 58. In summer and autumn, when evaporation is high and fresh water input from rain and rivers reduced, sea water invades the lakes, and salinity increase. At the end of summer Lake Wellington is brackish, with salinities up to 10V/oo, and the eastern part of the Lake King becomes virtually an arm of the sea, with salinity exceeding 30V/oo. The pattern is influenced by the fact that the bulk of the fresh water is of fluvial origin, delivered at the mouths of rivers: 60% from the Latrobe and 3% from the Avon into Lake Wellington; 25% from the Mitchell (much of it out through The Cut into Jones Bay), 1% from the Nicholson, and 7% from the Tambo into Lake King.

In winter, when evaporation is low, rainfall augmented by increasing river flow freshens the lakes, diluting and displacing the salt water, so that in spring they are relatively fresh. The greatest range of salinity during 1958 was measured at Hollands Landing, in McLennan Strait, with an April Maximum of 20.29V/oo and a November minimum of 0.83V/oo. There was no severe river flooding with this period, but during the major floods of June 1952 the lakes became temporarily fresh, even in the eastern part of Lake King.

The salinity of the lakes is an important factor in their plant and animal ecology, and also in modes of sedimentation. It is often observed that fine-grained sediment remains in cloudy suspension in the fresher parts of the lakes when the more brackish water is clear and green,

salt water having an electrolytic effect, coagulating and precipitating the fine-grained sediment. The boundary of clear and cloudy water is often visible on Lake Wellington, in McLennan Strait, or in the western part of Lake Victoria.

The present estuarine salinity regime depends on the existence of a permanent artificial entrance. Before this was cut the lakes were frequently sealed off from the sea, particularly in dry weather, when the natural outlet was closed by sand deposition, and it is unlikely that sea water spread as far into the lakes, or that salinity reached concentrations as high as those now attained. The lakes must have been fresh after the natural entrance was re-opened by escaping river floods. Sea water began to invade them as the floods abated, but the inflow was soon halted by sand deposition. It is therefore probable that salinity has increased in the Gippsland Lakes since the opening of the artificial entrance, and as will be seen, there are ecological and geomorphological changes which are attributable to salinity increase. Analysis of salinity measurements recorded by the State Rivers and Water Supply Commission over the period 1957 to 1976 shows marked fluctuations from year to year, with exceptionally low levels after periods of wet weather and river flooding, notably in February to April 1971 as a sequel to the late January floods (Bird 1972a). A trend towards continuing salinity increases is suggested by the fact that salinity levels measured in 1957 – 60 were generally below the 20 – year mean, whereas those measured in 1972 – 76 were generally above it.

The lakes have various types of shoreline. Some sections are fringed by reeds or rushes, other by beaches of sand, or sand and shingle. Some are advancing (prograding), others receding (retrograding), and others stationary (Figure 36). In the last few decades erosion has become widespread on the shores of Lake King and Lake Victoria, and there is evidence that shorelines which were previously prograded are now being cut back. Much of the land adjacent to the lakes is low-lying and swampy, subject to periodic flooding. There are tracts of Reedswamp (reed vegetation growing in shallow water), salt marsh (low herbaceous halophytic vegetation frequently submerged), and swamp scrub (dense shrub vegetation on land a few centimetres above calm-weather lake level, occasionally flooded). Mangroves are not present, although they occur on the shores of Corner Inlet, to the south-west. Tracts of featureless 'low plain' occur at a slightly higher level (1 – 2 metres above calm-weather lagoon level), and consist of deposits of sand and silt, inundated only occasionally by exceptionally high river floods.

The present work is concerned with the geomorphological evolution of the Gippsland Lakes, together with the barriers that enclose them and the low-lying country, including swamps and river deltas, bordering their shores. The marginal bluff forms a convenient landward boundary, interrupted at the mouths of the incised river valleys: the valley floors are considered in so far as they yield evidence relevant to the evolution of the lakes. The morphological map (Figure 1) was based on detailed field work, using air photographs supplied by the Royal Australian Air Force and the published 1:63, 360 Military Maps of the area, sheets 854 (Bairnsdale), 855 (Hartland), 836 (Sale), and 864 (Stockyard). Previous work included the account given by Gregory (1903), with an interpretation strongly influenced by his earlier studies of the Norfolk Broads in England (Gregory 1892; see also Lambert *et al.* 1960), descriptions by Hall (1914) and Hart (1922), and a brief reference by Hills (1940). Since *A Geomorphological Study of the Gippsland Lakes* was published in 1956 a number of other works have appeared, the most notable being Jenkin's (1968) substantial memoir on the geology and geomorphology of south –east Gippsland Lakes, and Hills' revised *Physiography of Victoria* (1975). The ministry for conservation has initiated a Gippsland Regional Environmental Study, and reports already issued include studies of the vegetation (Ladd *et al.* 1976; Ducker *et al.* 1977) and sedimentology (Davis *et al.* 1977) of the Gippsland Lakes area. Use has been made of these works in updating this geomorphological study.

The origin and development of the Gippsland Lakes are best introduced with an account of their geological setting.

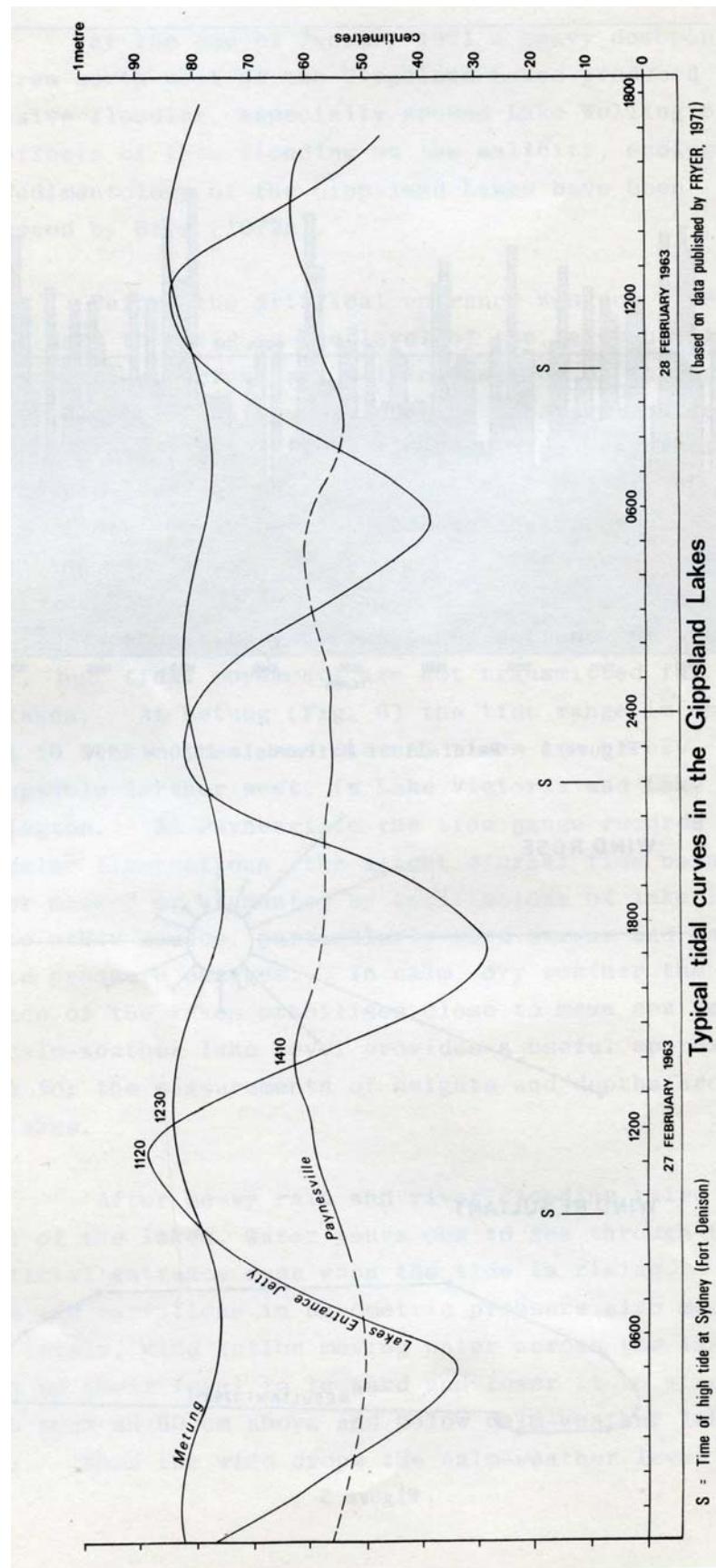


Figure 6 – Typical tidal curves in the Gippsland Lakes

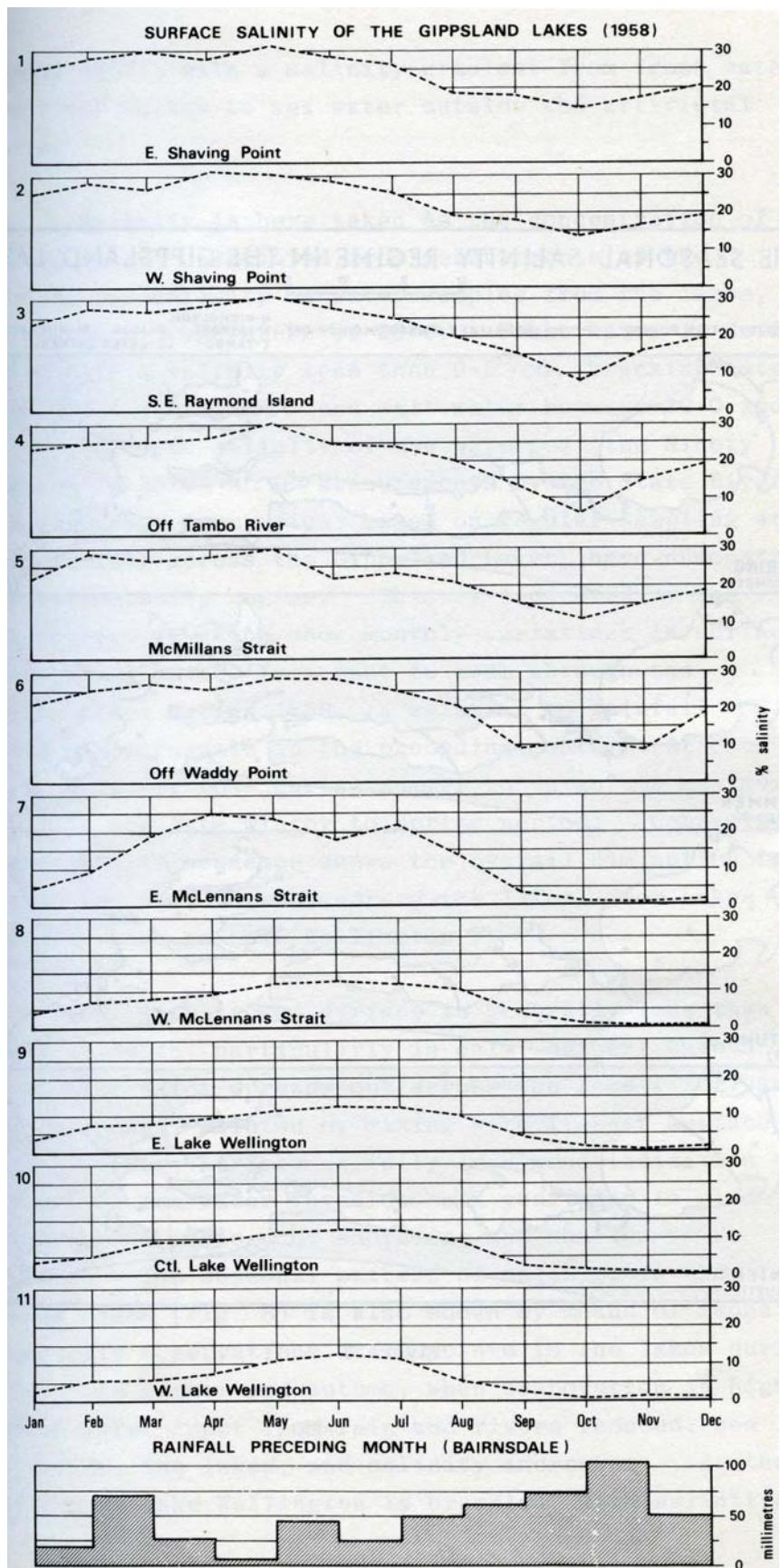


Figure 7 – Surface Salinity of the Gippsland Lakes (1958)

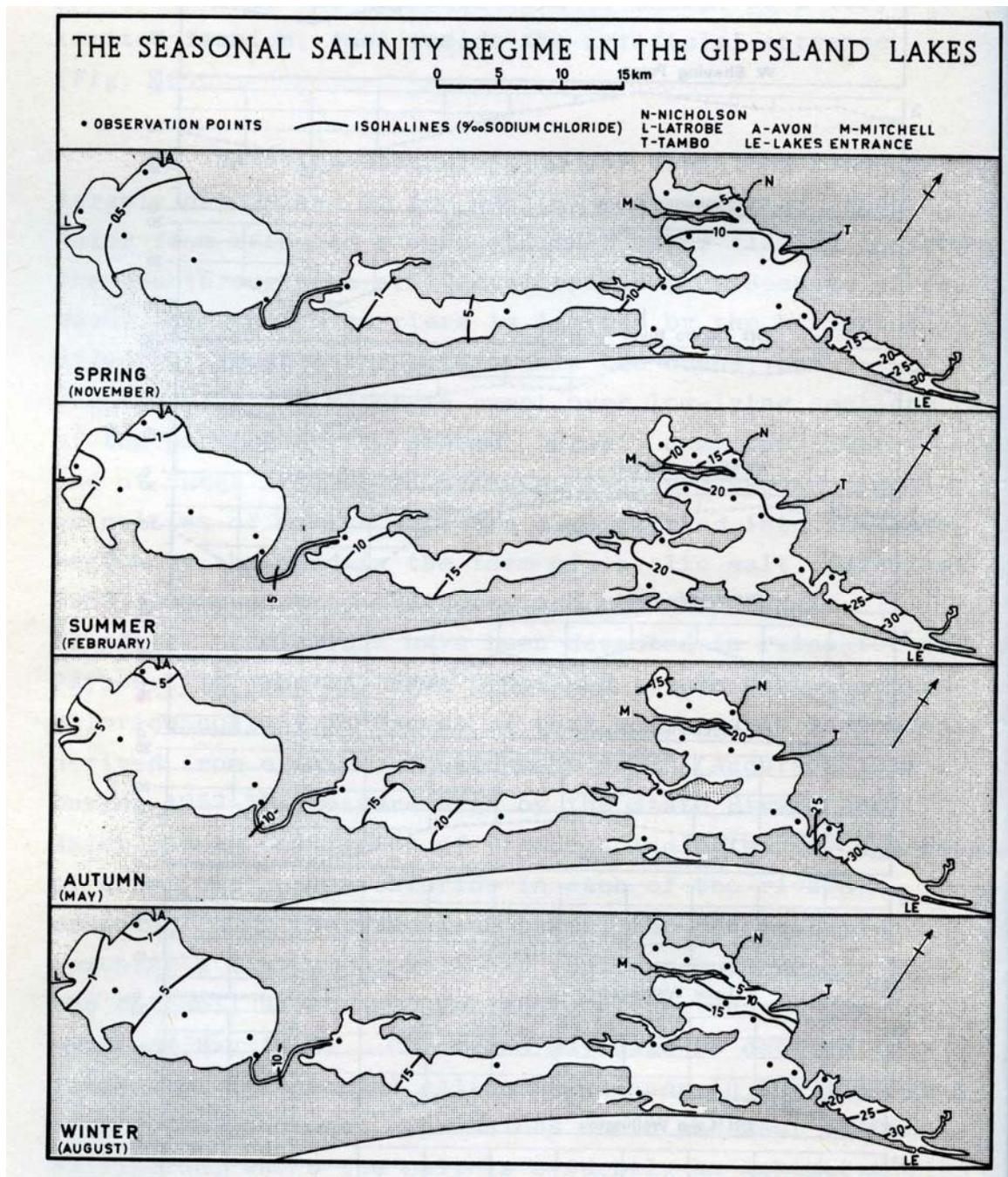


Figure 8 – The Seasonal Salinity regime in the Gippsland Lakes

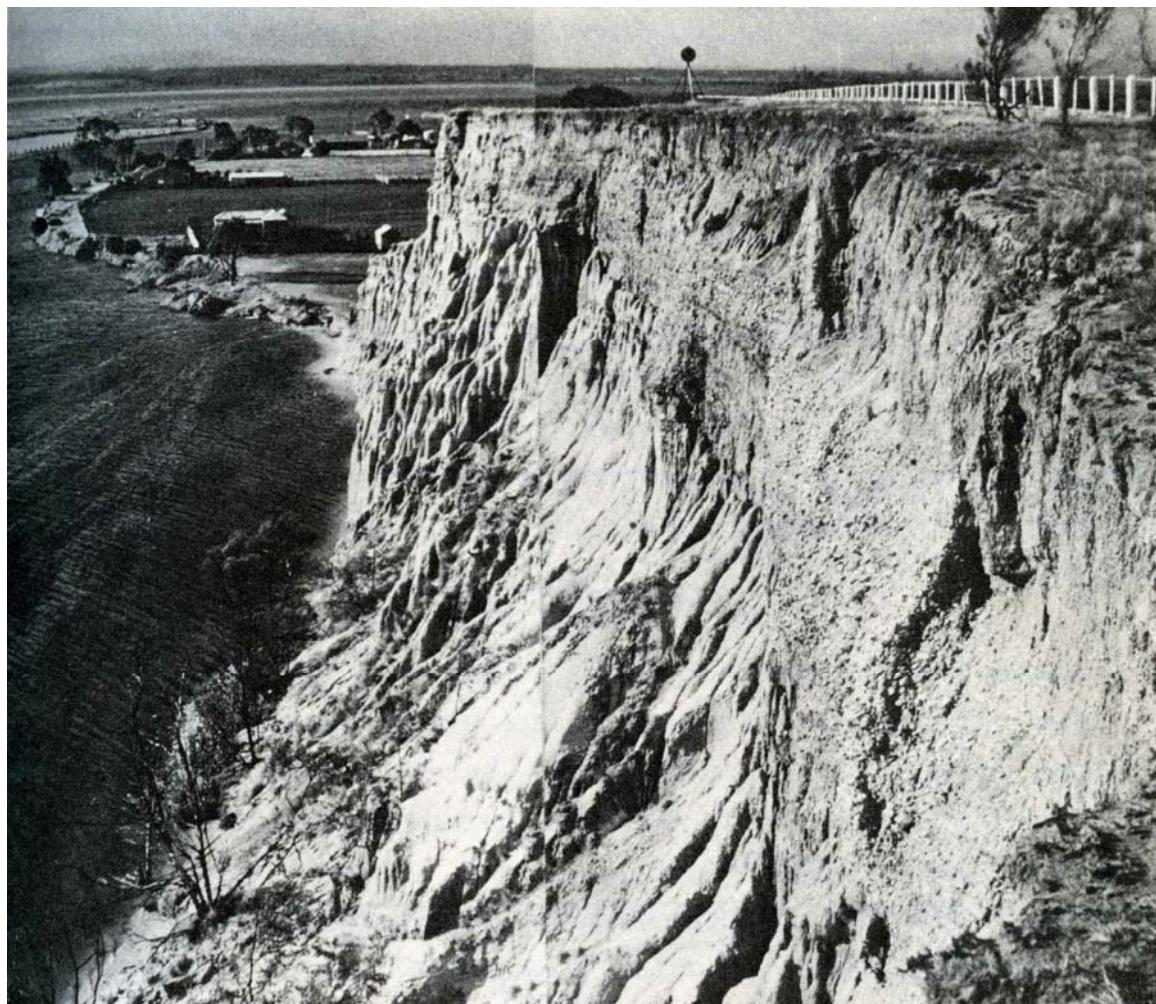


Plate 4 – Eagle Point Bluff (ECF Bird)

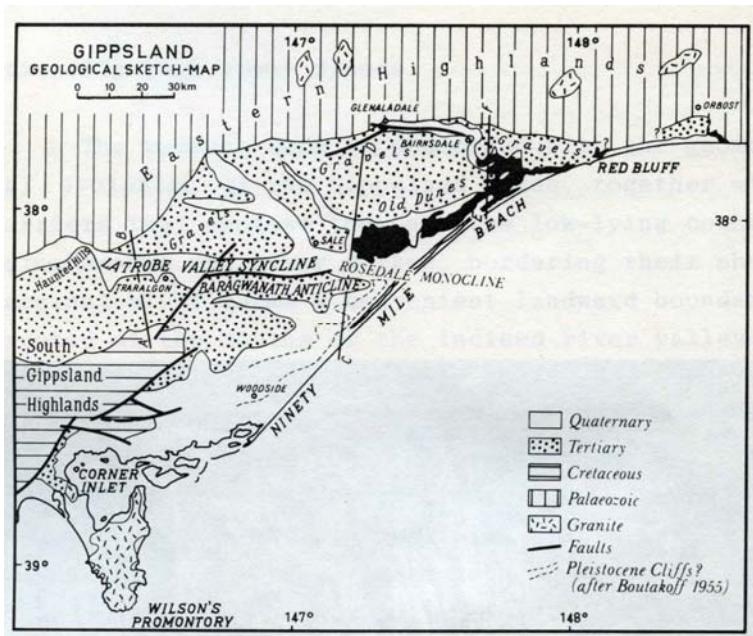


Figure 9 – Gippsland – Geological Sketch Map

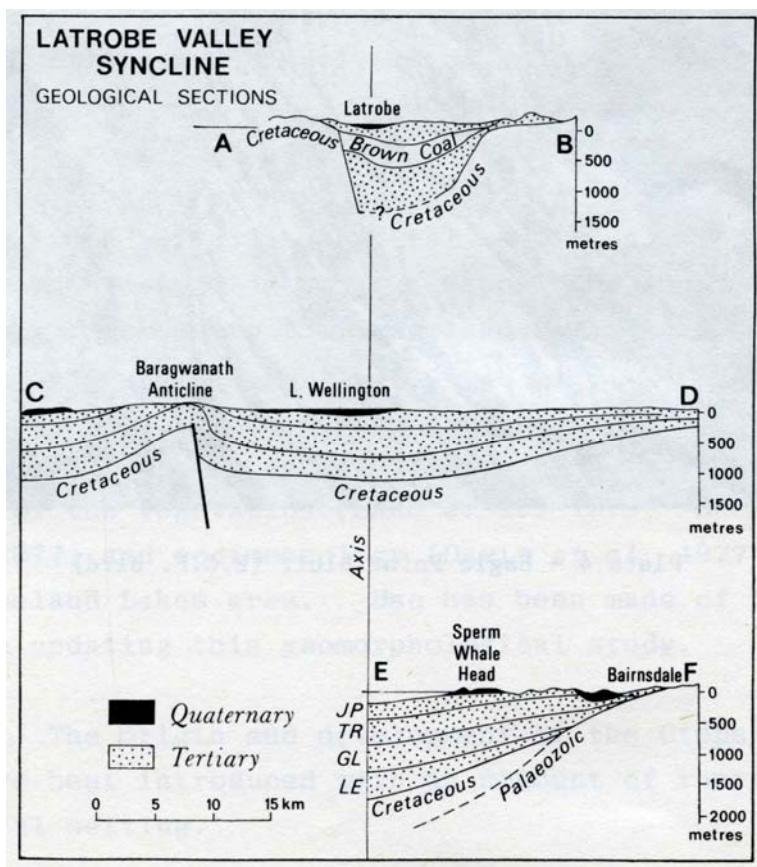


Figure 10 – Geological sections

| | |
|------------------------------------|-------------------------------|
| JP – Jemmies Point Formation | TR – Tambo River Formation |
| GL – Gippsland Limestone Formation | LE – Lakes Entrance Formation |