

# Case History No. 9.1. Latrobe Valley, Victoria, Australia, by C. S. Gloe, State Electricity Commission of Victoria, Victoria, Australia

## 9.1.1 INTRODUCTION

The Gippsland Basin covers an area of some 40,000 km<sup>2</sup>. Four-fifths of this area is located off-shore and the remaining fifth in the Gippsland Region of south-eastern Victoria. The offshore area contains a number of oil and gas fields, while the on-shore portion includes an area of some 800 km<sup>2</sup> known as the Latrobe Valley Depression where major deposits of brown coal occur beneath a thin cover of overburden.

The excavation of brown coal for the generation of electricity and production of briquettes commenced in the Latrobe Valley some 50 years ago. The coal is won from open cuts, the development of which has been accompanied by significant vertical and horizontal movements, both within the excavation as well as in surrounding areas. To enable the coal from the second major open cut to be excavated under safe operating conditions, it has been necessary to reduce the artesian pressures of underlying aquifers. The resulting increased effective stresses have induced consolidation of strata and cause subsidence which is now regional in extent.

## 9.1.2 GEOLOGY

The Gippsland Basin developed in the off-shore area in Upper Cretaceous times with the deposition of lacustrine and fluvial sands and clays and a number of brown coal seams. The basin gradually developed westwards and lithologically similar sediments were deposited in the onshore area in Lower Tertiary times (Figure 9.1.1).

Within the Latrobe Valley Depression some 700 m of Tertiary sediments named the Latrobe Valley Coal Measures, and including some volcanics towards the base, were deposited mainly on Lower Cretaceous arkoses and shales. The coal measures include three groups of major coal seams, separated and underlain by clays and sands (Gloe, 1975).

In late Tertiary times the coal measures were tilted, folded and faulted. Extensive erosion followed, virtually to the stage of peneplanation. Subsequently, a thin cover of clays, silts and sands was deposited on the eroded surface. As a result of the peneplanation, considerable thicknesses of sediments were removed from uplifted blocks. In the areas of the Yallourn and Morwell open cuts, the two major open cuts in the Latrobe Valley, up to 150 m and 300 m respectively of clays, sands and brown coals were removed (Figure 9.1.2).

In the Yallourn open cut the Yallourn seam averages 60 m in thickness and underlies 10 to 15 m of younger overburden. Beneath the Yallourn seam are some 120 to 150 m of sands and clays overlying a further thick coal seam.

The Morwell 1 (M1) seam being excavated in the Morwell open cut ranges from about 90 to 135 m in thickness beneath 12 to 15 m of overburden. Underlying the coal seam are 15 to 23 m of sands and clays followed by the Morwell 2 (M2) coal seam which is up to 50 m thick in this area. A further sequence of clays and sands, including an almost completely weathered layer of basalt and a thick basal silty gravel, totalling some 140 m in thickness, underlies the M2 seam.

## 9.1.3 HYDROLOGY

Unconfined ground waters are present over most of the area, but quantities are mainly small. The water occurs in the overburden sands as well as in the joint system of the uppermost coal seam.

Confined waters are found in the sands underlying coal seams, and in some fresh basalt flows. Prior to the development of the Morwell open cut, water struck in bores in low-lying areas flowed at the surface, sometimes under considerable head (Gloe, 1967).

In the area of the Morwell open cut some 8 to 9 m of medium to coarse grained, poorly sorted and highly permeable sands, known as the M1 aquifer, occur beneath the M1 seam. The sands are irregular and typical sheet deposits (Barton, 1971). Along the northern edge of the open cut the original piezometric level stood at +60 AHD, a height some 150 m above the level of the aquifer in that area.

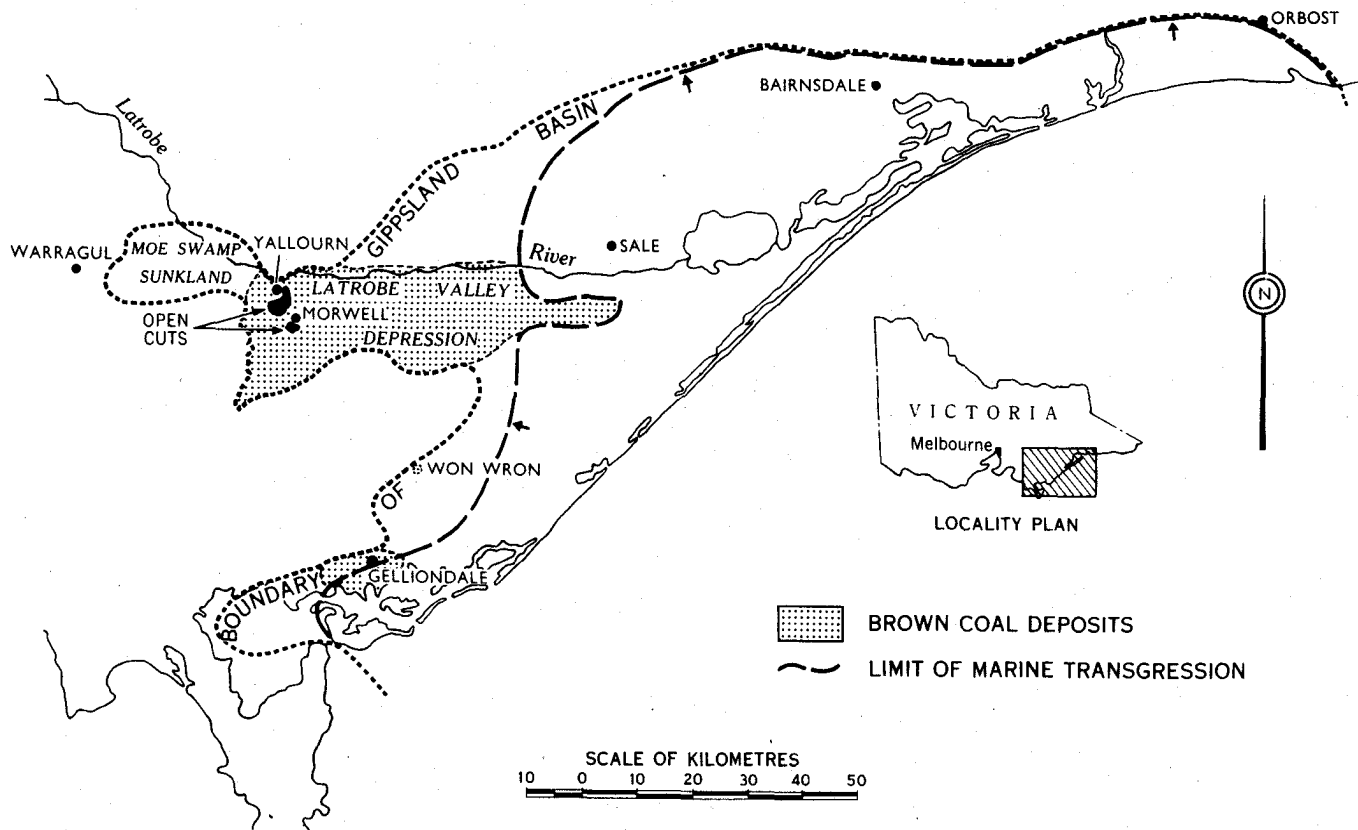


Figure 9.1.1 Gippsland Basin.

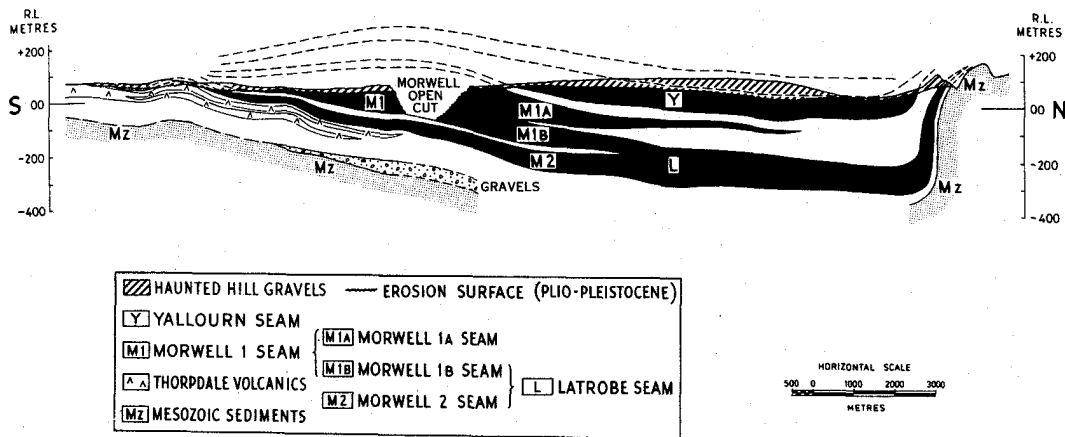


Figure 9.1.2 Reconstruction of pre-erosional stratigraphy

The M2 aquifer consists of several irregular sand beds occurring between 3 and 50 m below the M2 seam. There is evidence of vertical leakage between the M1 and M2 aquifers--partly due to numerous boreholes, partly to the fracturing which accompanied heaving of the floor of the open cut as new levels were established, but also naturally as part of a leaky aquifer system.

In the Yallourn open cut the weight of the clays underlying the Yallourn seam is sufficient to withstand the hydrostatic pressure of the artesian waters present in that area. However, at Morwell it had been calculated that the weight of coal and clay would be unable to withstand the artesian pressures once a working level had been established to an area 300 m across at a depth of some 65 m below the original surface. As this still left some 50 m of coal above the base of the seam, it was clear that the M1 aquifer pressures would need to be progressively reduced as the open cut was developed in depth (Gloe, 1967).

The main program of pressure reduction, frequently called dewatering, commenced in 1960 as the first coal cut was excavated. Initially, free-flow bores were used, new bores being established as new levels were opened up. By 1967 it was found necessary to construct pumping bores in the M1 aquifer. Subsequent investigations established that the pressures from the M2 aquifer, although already substantially reduced through leakage, would require further lowering to ensure safe operating conditions. This reduction was achieved initially through free-flow bores and subsequently using pumping bores with yields of up to 160 l/s.

The maximum rate of pumping from the M2 aquifers was 1160 l/s at which time the total pumping rate was 1320 l/s. Piezometric levels were lowered to safe operational levels and have been maintained for two years with yields of 925 l/s from M2 aquifer and 130 l/s from M1 aquifer. Total artesian water pumped from Morwell open cut to June 1977 was  $250,000 \times 10^6$  l.

Contours of the M1 aquifer piezometric surface as at July 1977 are shown in Figure 9.1.3. The M2 aquifer levels have a generally similar pattern. The original levels were of a gently sloping surface with values of +60 AHD at Morwell open cut and rising to +65 AHD in the west.

Investigations of recharge and intake areas have included carbon dating of water samples. The youngest water from near the western edge of the basin was 2200 years old, while the water pumped from the Morwell open cut gave values of 23 500 years for the M1 and 13 800 years for the M2 aquifer waters. These ages conform with the concept of a multi-aquifer and aquitard, or leaky aquifer system, with a large volume of water in storage, but in which the upper aquifers at least are not replenished by rapid infiltration of rainwater in intake areas. It is considered that much of the water pumped from the M1 aquifer has been derived through leakage from lower aquifers and from compaction of aquitards.

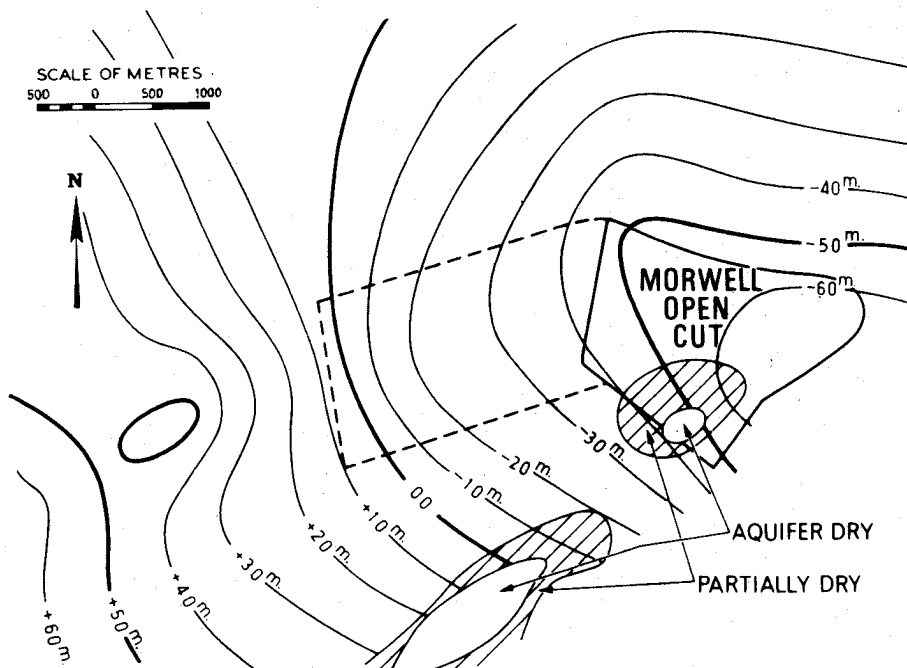


Figure 9.1.3 Piezometric surface of Morwell 1 aquifer.

#### 9.1.4 MECHANICAL PROPERTIES OF BROWN COAL AND ASSOCIATED STRATA

##### 9.1.4.1 Brown coal

Properties of brown coal have been described by Gloe, James and McKenzie (1973). Brown coal was shown to be a highly preconsolidated organic material with a low bulk density ( $1.13 \text{ g/cm}^3$ ) and very high moisture content (up to 200 per cent as expressed on an engineering basis).

Average values of preconsolidation pressures assigned to M1 and M2 coals in the vicinity of the Morwell open cut based on estimates made using Casagrande's method were 2300 kPa and 2900 kPa respectively.

The coefficient of volume decrease (mv) depends both on the consolidation pressure and initial moisture content, but for purposes of calculating consolidation settlements where the consolidation pressure is less than 1300 kPa the following values of (mv) were assigned:

M1 coal-- $0.2 \text{ cm}^2/\text{kN}$  at top of seam to  $0.1 \text{ cm}^2/\text{kN}$  at base of seam;

M2 coal-- $0.1 \text{ cm}^2/\text{kN}$ .

##### 9.1.4.2 M1 aquiclude

Beneath the M1 seam there is a 3 to 13 m layer of stiff grey preconsolidated silty clay. The clay is composed of kaolinite and a-quartz with a plasticity index around 20 to 25 per cent and a liquid limit of about 60 per cent.

Average properties for the clay are

Clay fraction, 44 per cent

Bulk density,  $1.8 \text{ g/cm}^3$

Compression index ( $C_c$ ), 0.5

Coefficient of volume decrease (mv),  $0.2 \text{ cm}^2/\text{kN}$

Consolidation pressures, 1300 kPa

##### 9.1.4.3 M1 and M2 aquifer sands

The gradation of the M1 sand is highly variable ranging from coarse sand with fine gravel and fine sand to silty fine sand. The sand is dense to very dense and relatively incompressible. In the area of the open cut the M2 sands are generally thicker and hence have a higher transmissibility than those of the M1 aquifer. In other respects the sands are similar.

##### 9.1.4.4 M2 aquicludes and aquitards

The M2 aquicludes and aquitards range from clays to silts with properties generally similar to those of the M1 aquiclude.

#### 9.1.5 EXTENT OF MOVEMENTS

Surface movements, both inside and outside the Yallourn and Morwell open cuts have occurred ever since excavation commenced. Regular surveys are carried out to determine the amounts of these movements.

The movements at Morwell open cut exceed those at Yallourn open cut, mainly because of the dewatering operations and greater depth of the open cut. The surveys at Morwell which were initiated prior to the commencement of open cut operations are based on a datum line remote from the open cut with survey beacons around the open cut being located by triangulation. The beacons form the control for precise traverses of pin lines established in and around the open cut.

By 1977 when the open cut had reached its full depth and was being developed to the west, horizontal movements had reached as much as 2.25 m and vertical movement 1.68 m at the top of the northern and eastern batters. These movements decrease outwards from the edge of the open

cut.

Contours of horizontal movement in the Morwell area and of subsidence in the Yallourn-Morwell area are shown on Figures 9.1.4 and 9.1.5 respectively. The pattern of horizontal movement is roughly concentric about the floor of the open cut with the major movement occurring within 400 m of the edge of the open cut. The 20 cm contour is at present stationary and approximately 1000 m north and east of the open cut. On the other hand, subsidence is far more regional in extent--now affecting the whole of the Yallourn-Morwell area and extending eastwards into Loy Yang, some 20 km east of Morwell. By 1977 the 20 cm and 50 cm subsidence contours were located some 7.2 km and 4.5 km respectively north of the open cut with the 50 cm contour embracing an area of 47 km<sup>2</sup> and including much of Morwell township.

The C line of survey marks passes through the southern portion of Morwell township at right angles to the northern edge of the open cut. Horizontal movement and subsidence profiles along the C line are shown in Figure 9.1.6. By 1977 the total southerly displacement of a point adjacent to the open cut was 2.01 m, but at a distance of 400 m from the open cut was only 0.39 m. Similar patterns of movement are found on other pin lines extending outwards from the open cut. In the vicinity of the open cut subsidence commenced at a slower rate, and at one stage was little more than half that of horizontal movement. However, a steady rate of subsidence has been maintained while horizontal movements have decreased after deepening of the open cut ceased and development extended westwards. At 200 m from the northern edge of the open cut, vertical and horizontal movements are now roughly equal, while at 800 m vertical movements exceed horizontal by 0.95 m (Figure 9.1.6).

Evidence of subsidence such as protrusion of casing above ground surface is visible at Morwell. Figure 9.1.7 shows clamps on an observation bore casing set in the M1 aquifer now standing 1.0 m above the shallow surface casing on which they originally rested.

9.1.6 CAUSES OF MOVEMENT

Factors contributing to movement were discussed by Gloe, James and Barton (1971), Gloe (1976) and Hutchings, Fajdiga and Raisbeck (1977). Apart from the geometry of the cut and the

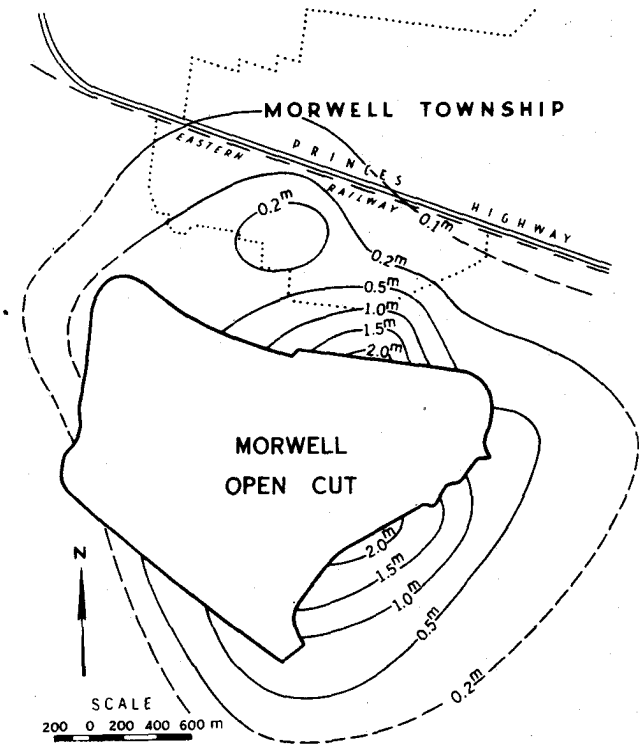


Figure 9.1.4 Horizontal movement adjacent to Morwell open cut

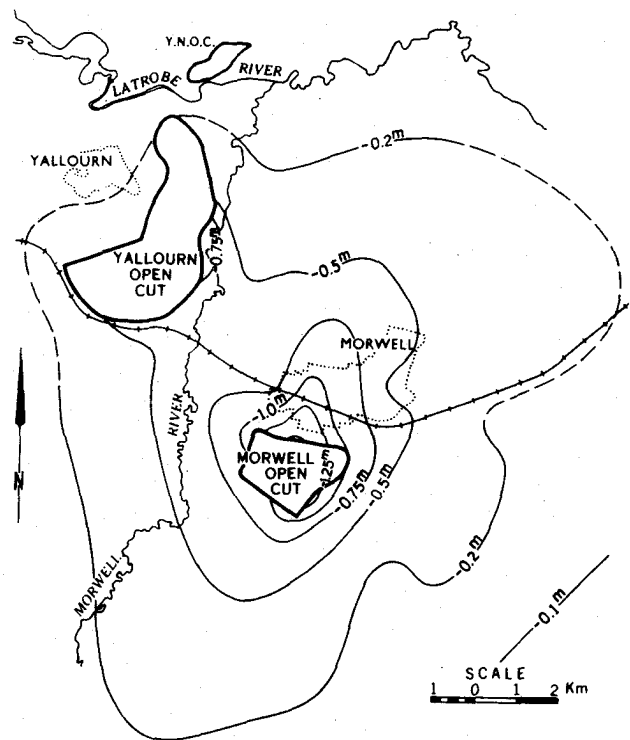


Figure 9.1.5 Regional subsidence in the Yallourn-Morwell area.

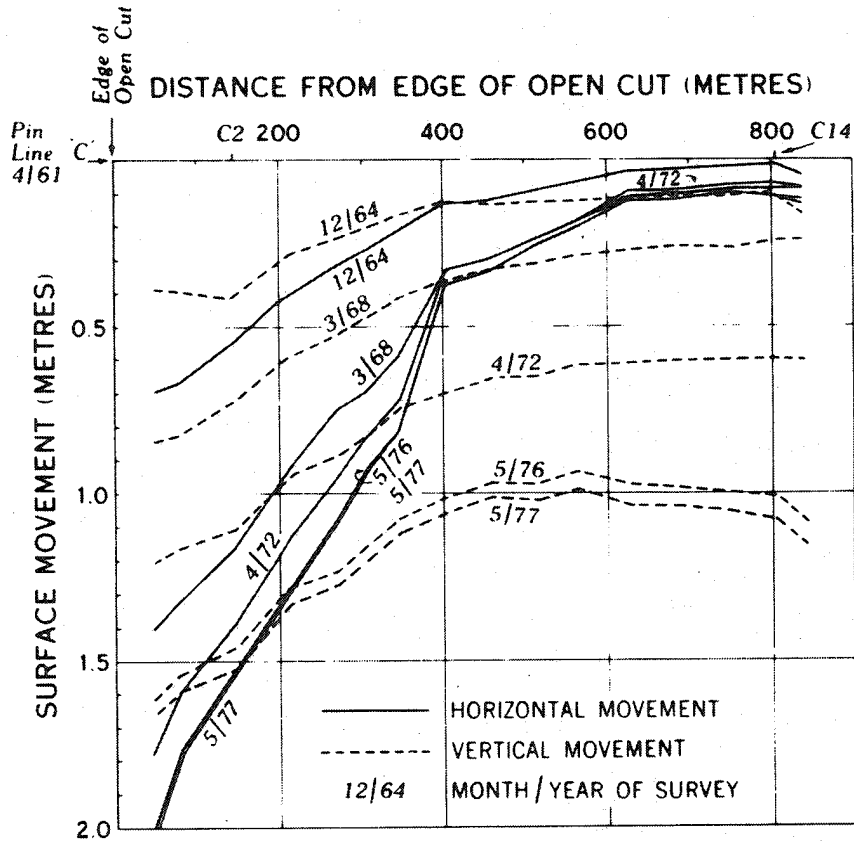


Figure 9.1.6 Horizontal movement and subsidence profiles on C line.

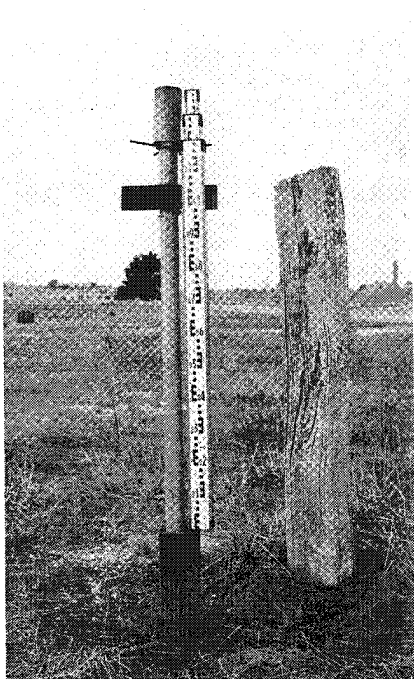


Figure 9.1.7 Protruding bore casing north of Morwell open cut.

geological structure, the significant factors influencing movements in the area around Morwell open cut are pressure relief and reduction in artesian and ground-water pressures.

As stated above, the major horizontal movements occur within a distance of some 400 m from the edge of the open cut and are considered to be due to pressure relief as well as to response to differential subsidence.

Subsidence near the open cut is influenced by pressure relief (inward and downward movement of batters), but regional subsidence is attributed mainly to consolidation of strata through increase of effective stresses resulting from the lowering of artesian water pressures. The lowering of the ground-water table by natural drainage through joints or horizontal bores drilled at toes of batters for lengths of up to 250 m also results in consolidation. However, such effects are not considered to extend beyond distances of 600 m from the open cut.

The relationships between subsidence, piezometric levels and flow rates are shown on Figure 9.1.8. Since 1960 the M1 and M2 aquifer pressure levels have been lowered by some 125 m and 120 m respectively in the area of the floor of the open cut. Dewatering of M2 aquifer was not commenced until 1970 and hence the 50 m reduction in piezometric level of this aquifer must have been achieved through upward leakage.

Although no significant horizontal movements have occurred at C14 (800 m north of open cut) this survey mark is subsiding at a rate similar to that at C2 (150 m north) where substantial horizontal movements have taken place. The regional character of subsidence is further illustrated by the steady lowering of Pin M158, located 5 km north of open cut, but where no horizontal movements have been recorded.

9.1.7 PREDICTED FUTURE MOVEMENTS

Future vertical movements in areas beyond the perimeter of the open cut have been estimated from consolidation theory on the assumption that drainage of batters and reduction of artesian pressures are the major factors contributing to subsidence. Fortunately the effective stresses resulting from the dewatering will be lower than preconsolidation pressures. Hence, future subsidence will occur as a result of consolidation on the recompression portion of the field consolidation curves.

With the full development of Morwell open cut, ultimate settlement values are predicted to reach approximately double those which have occurred to 1977 in the main Morwell township area. Values of up to 3 m are expected at the southern edge of the town and 1 m at the northern boundary. Present subsidence contours will increase towards the west and the 3 m contour will be located west of the Morwell River (about 3.5 km west of the present floor of the open cut).

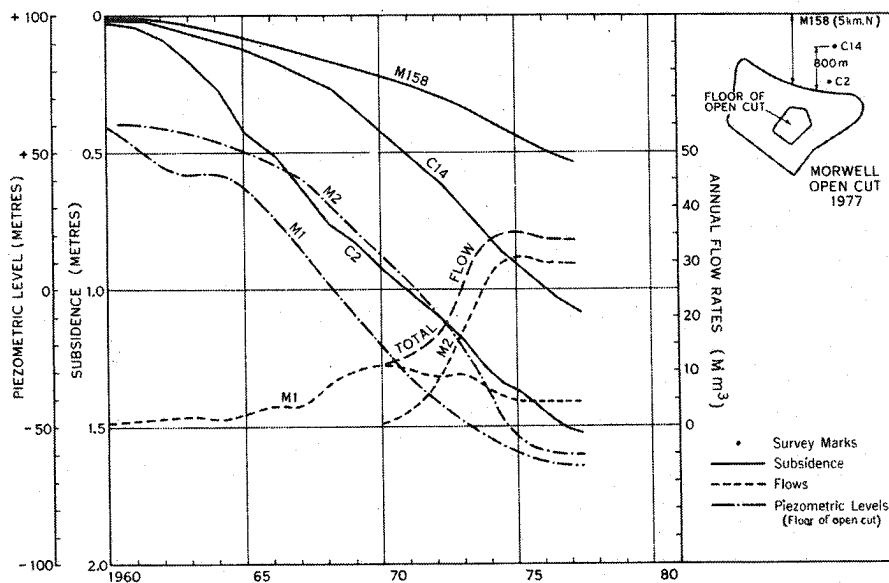


Figure 9.1.8 Relationship of piezometric levels and subsidence

Regional subsidence within the Latrobe Valley depression is likely to extend, both into the Moe Basin, a probable intake area, as well as to the east. The new major open cut at Loy Yang has a designed depth of 200 m and the required lowering of piezometric levels in this area is likely to result in even greater settlements than will occur at Morwell. Ultimately, the settlement "basins" at Morwell and Loy Yang are expected to coalesce.

#### 9.1.8 SIGNIFICANCE OF MOVEMENTS

Structural damage due to earth movements is related more to the degree of horizontal strain and differential subsidence than to absolute values of movements. The strain values are determined from precise surveys of survey pins generally 60 m apart and, therefore, abrupt discontinuities which may have developed could be masked. One such feature has been detected on the ground and can be traced from the open cut for some 200 m into the southern limits of the township.

##### 9.1.8.1 Effects on Morwell Township

Morwell township of 16 000 inhabitants extends to within 300 m of the northern edge of the open cut (Figure 9.1.5). Houses are mainly single storey and of timber or brick veneer construction with fibrous plaster lining. The commercial centre is located 1 km from the open cut and contains brick buildings of one or two stories. The recorded maximum value of north-south horizontal strain is less than 0.8 per cent. Strains are negligible over the northern portion of the township. Future strains in the southern township fringe are predicted to be about 0.5 per cent. Larger strains could occur in some localized areas and could affect houses and services.

Differential subsidence has rarely exceeded 0.3 per cent in Morwell township, and values are commonly less than 0.1 per cent over most of the area. With the predicted doubling of total subsidence in the township area, and the general differential subsidence values unlikely to exceed 0.3 per cent, it is concluded that differential subsidence will not significantly affect buildings and services within the township.

All relevant authorities in the township and district are fully aware of the history and amounts of movement occurring. Each receives copies of the annually revised earth movement survey data and the information is available to the public. A technical panel, consisting of two experienced geotechnical personnel from the State Electricity Commission, and a representative from the Commonwealth Scientific and Industrial Research Organization, Division of Applied Geomechanics, has been established to review claims for damage from owners of private property, and to assess whether the damage was due to open cut operations or to some other cause. A six-year period of surveillance has resulted in the detection of some minor cracking in concrete pavements and brickwork; however, to date no claims have been proved. It has also been shown that grades on drainage and sewage lines have not been significantly affected by earth movements.

##### 9.1.8.2 Effects on engineering structures

Important engineering structures associated with the mining operations and power generation are located within the open cut and beyond the perimeter. These structures include dredgers, conveyor systems, pipelines, power stations, storage bunkers, cooling towers and water storages. Risks of damage within the open cut are reduced by the designed geometry of the excavation, and by the design of equipment to minimize the effect of movements. Beyond the perimeter of the open cut, power stations and associated structures are generally located 500 to 700 m from the edge of the open cut where future ground strains are estimated to be within acceptable limits.

#### 9.1.9 CONCLUSIONS

Large vertical and horizontal movements have resulted from the development of deep and extensive open cuts in the brown coal deposits of the Latrobe valley.

Regional subsidence has been due to the reduction of artesian water pressures in aquifers underlying the coal seams, while horizontal movements are due mainly to pressure relief within the open cuts and are localized around each excavation.

Total, movements are expected to double as development of the Morwell open cut continues. Although the southern fringe of Morwell township could be affected by horizontal strain, serious problems are not anticipated. The regional subsidence is likely to be relatively uniform and the resulting low differential subsidence values should not affect buildings and services in Morwell township, nor major engineering structures outside the perimeter of the open cut.



Regular survey and surveillance programs will be continued in collaboration with the various authorities involved in the area, but no special measures to control or ameliorate subsidence are planned, other than to limit the reduction of artesian pressures to the minimum value consistent with safety of operations.

#### 9.1.10 ACKNOWLEDGEMENTS

The material in this case history is published with the permission of the State Electricity Commission of Victoria. The investigations described were carried out in collaboration with Golder Brawner and Associates Ltd of Vancouver.

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