Falling Water Levels in the Latrobe Aquifer, Gippsland Basin: Determination of Cause and Recommendations for Future Work

by

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Summary

The Latrobe aquifer supports a number of water-related industries across the large region of South and Central Gippsland. Water levels in this aquifer have been falling across this region for a few decades, with associated impacts on irrigators and potentially on the wider community through land subsidence. There is current debate on the causes of these falling water levels. This report reviews current knowledge and publicly-available data in an attempt to determine the causes of these water table declines and the levels of uncertainty associated with those causes.

Mapped changes in aquifer pressures across the Gippsland Basin from the reconstructed virgin state of the aquifer prior to significant withdrawals of fluids reveal a complex pattern of pressure declines. This pattern reflects both the structural complexity of the Basin as well as the impacts of withdrawals by the mining, irrigation and offshore oil and gas industry. At the regional scale, offshore abstraction has a geographically variable impact on groundwater levels onshore. The extent of impact due to mine dewatering in the Latrobe Valley is also to some degree compartmentalised, but has apparently extended east of Sale. For specific districts such as the irrigation area around Yarram, regional studies such as this cannot accurately determine the proportion of impacts due to offshore or onshore abstraction, but there is no doubt that the former is a significant component of aquifer decline. Local abstraction for irrigation has an added effect that is superimposed upon these other regional influences on water levels.

A review of subsidence modelling and monitoring indicated no unambiguous history of subsidence except the well-documented subsidence around the mines of the Latrobe Valley. There is no compelling analysis that indicates a high risk of future subsidence, but there is certainly room for improvement in the forecasts based on better structural geological data and higher resolution monitoring.

Recommendations for further analyses that would better define the sustainability of local water supplies, the recovery of water levels and subsidence risk assessment and mitigation are: (1) a review and the re-publishment of a monitoring network, introduction of state-of-the-art telemetry and remote sensing technology; (2) regional 4D subsidence modelling for the Basin; (3) coupling the offshore and onshore reservoir and aquifer models; and (4) a decision support system to sustainably manage Gippsland’s groundwater resources while optimising petroleum resources production of the wider Gippsland Basin. These research and development investments are wholly justified given the critical importance of both resources as well as coal-mining to the people of Gippsland, to the socio-economics of Victoria and to Australia’s oil and gas self-sufficiency.
Understanding of Need

It is a matter of record that groundwater pressures within the Gippsland Basin of Victoria, in particular those associated with the Latrobe Aquifer, have fallen dramatically over the past decades. Associated with this pressure decline are impacts on water supplies as well as concerns regarding potential land subsidence. The cause of this decline is a matter of current debate, mostly revolving around the relative levels of influence due to coal mine dewatering, onshore abstraction for irrigation, and offshore abstraction associated with oil and gas field development. This report reviews current knowledge as well as original analyses of aquifer data toward a robust statement of likely causes of pressure declines and qualitatively their relative contributions. The uncertainties associated with these causes are highlighted. The report summarises the current and likely impacts of these pressure declines, chiefly supply restrictions to irrigators and land subsidence. It recommends a series of future actions that would greatly reduce the uncertainties regarding cause and impact. The report makes reference to, but does not reiterate or summarise, an extensive literature on the Gippsland Basin and associated hydrologic and hydrogeologic issues. A bibliography of this literature is appended.

What is the Gippsland Basin and the Latrobe Aquifer?

The Gippsland Basin in south eastern Victoria is a large sedimentary basin extending onshore and offshore in roughly equal proportions. The Basin extends south and east from the eastern highlands in the north and the South Gippsland Highlands (Strzelecki Ranges) to the west; the offshore limits are associated with basement highs at the limit of the continental shelf. The sediments are over 1000m thick onshore, extending to over 3000 m thick offshore. These sediments contain great amounts of coal, oil, gas and groundwater. The sediments themselves are composed of sequences of unconsolidated sands, clays, limestone and brown coal seams. There is a lengthy literature on the geology of the Basin, for these purposes best described by Hocking (1976) and Thompson and Walker (1982).

There are three main aquifer systems in the Gippsland Basin; the Latrobe Group Aquifer System is the deepest and most extensive. It is a continuous unit of many sand, gravel and basalt aquifers extending over most of the Gippsland Basin. It is the basal unit of the Basin and is the most productive, good quality aquifer onshore, and offshore contains massive hydrocarbon resources (Holdgate, 2003). In the Latrobe Valley, it is called the Traralgon Formation and consists of thick brown coal beds and coarse sands. The Latrobe Group outcrops around the northern and western margins of the Basin, adjacent to the highland bedrock; where it outcrops are the intake (recharge) zones for the aquifer. Groundwater flow prior to pumping was from these recharge areas in the north and west into the offshore. Further offshore, normal compaction and dewatering of sediments occurs due to sedimentary loading. This drives groundwater flow westwards from the farthest offshore parts of the aquifer system. These competing flow systems meet approximately in the middle of the offshore part of the basin, and from here flow southwards and most likely discharge by upward leakage to overlying formations or the seabed.

Overlying the Latrobe Group is the Latrobe Valley Group, best developed in the Latrobe Valley Depression and Seaspray Depression, where it reaches 400m and 200m in thickness, respectively. This unit comprises barrier sand sequences (Balook Formation) and marls, limestones and mudstones of the Gippsland Limestone and other units. The limestone serves as a major aquitard over the Latrobe Group, except in the western onshore part of the Basin; the hydraulic connection between the Latrobe
Group and the Latrobe Valley Group is variable; recharge to the latter is mainly by
leakage from overlying units. Groundwater extraction is mainly associated with local
mine dewatering in the Latrobe Valley.

The shallow aquifer systems consists of unconfined to semi-confined systems of sand,
clay and coal units on the onshore parts of the Basin, up to 150m thick. Recharge is by
direct rainfall.

Consideration of the Impacts of Falling Water Levels

The impacts of falling water levels in the Latrobe Aquifer include:

- The need to deepen or replace irrigation supply wells and increased pumping
costs from deeper water supply wells.
- Land subsidence, leading to coastal erosion, inundation, waterlogging and
onshore salinisation. Localised subsidence is measured and well documented
in the vicinity of the Latrobe Valley mining operations. The Gippsland coast is
considered to be particularly vulnerable to any subsidence, since the Gippsland
Lakes are only separated from the ocean by a narrow, low sand barrier.

Impacts on Irrigators

Hydrotechnology (1995) investigated the impact of declining water levels on irrigators,
and anticipated some 45% of bores investigated to likely fail within ten years, and
another 30% to fail within thirty years of that time. SKM (2001) produced a
comprehensive report on the impacts of the declining water levels on the irrigators at
Yarram, on behalf of the Department of Natural Resources and Environment. Impacts
noted included loss of artesian conditions, increased pumping durations and the need
to lower pumps in bores. Some 62 bores in the Latrobe Aquifer Group were identified
at risk, with an associated potential cost of $10M to redress. SKM (2003) revised this
estimate as between $3.8M to $5.3M (present value) over the next 30 years.

Subsidence Risk

Land subsidence in the immediate vicinity of the mining in the Latrobe Valley is well-
documented and up to 2.3m has been recorded; this subsidence is well-understood
and modelled (Evans 1983). However, there is no unambiguous empirical evidence of
subsidence along the coast.

SKM (1995) assessed the subsidence potential along the Gippsland Coast due to
subsurface fluid production. They concluded that the potential scale of subsidence is
significant and warranted detailed technical investigation. Based on current knowledge
and assumptions, they concluded it was reasonable to expect one to two metres of
subsidence to occur somewhere along the Gippsland coast after sufficient time has
elapsed. Importantly, the lack of significant subsidence to date was not considered
reassuring due to expected timelags in response to depressurisation.

SKM (1999) concluded that the preconsolidation stress has yet to be reached though
aquifer depressurisation, a conclusion supported by the lack of clear measured
subsidence to date. They also concluded that there was a 50:50 chance that this
critical threshold would be exceeded within 30 years and thus subsidence would
accelerate.
SKM (2001a, b) modelled subsidence at Yarram and West Golden Beach. For Yarram, they concluded that there was a 10% chance that subsidence will exceed 800 mm by cessation of oil and gas production in 2023. In both cases, some rebound was expected following cessation of extraction.

SKM (1999) reviewed subsidence worldwide and compared these experiences with the Gippsland Basin. Ten examples of subsidence due to fluid extraction with similarities to the Basin had subsidence of 0.3m to 9m. Three priority factors were highlighted as relevant to consideration of the rate and magnitude of subsidence: degree of consolidation of aquitards, thickness of compressible material, and pressure decline. The report also considered factors that might mitigate subsidence (extreme over consolidation, very low compressibility, bridging, and very slow time response). On balance, they concluded that based on the (limited) available evidence, there is a reasonable probability of significant subsidence occurring. This risk would be better understood with a better knowledge of the compaction properties of the sediments with depth.

Although not addressing the phenomenon of land subsidence, Lawson and Treloar (1995) assessed the vulnerability of the Gippsland Lakes to sea level rise, and identified significant natural areas at risk to a change of only 300 mm. SKM (1999) translated this work with respect to subsidence and concluded that between half and three quarters of the coastal dune width would be eroded within 50 years with 1m of subsidence, noting that any sea level rise due to climate change would be cumulative in terms of impact.

**Previous Analyses of Cause of Falling Water Levels**

Walker (1992) attributed the steady decline of onshore aquifer pressures mainly to offshore petroleum production, with bores in the upper and lower layers of the aquifer behaving similarly. Subsidence risk associated with this decline in pressures was identified, as was flow-on impacts to water supplies based on shallow, overlying aquifers (e.g., the Boisdale formation aquifer that is used for irrigation and town water supply at Sale).

SKM (1999e) calibrated a computer-based numerical groundwater model for the onshore portion of the Latrobe Aquifer, extending out toward the oil and gas fields. The results indicated that onshore groundwater extraction has only a small impact (a few percent) on the regional pressure decline. Simulation of the actual declining pressures necessitated the inference of a declining pressure boundary offshore to the east consistent with the likely effects of fluid extraction from the oil and gas fields.

The Gippsland Groundwater Issues Technical Working Group was formed in 1999 under the auspices of the Gippsland Groundwater Issues Steering Committee. The Terms of Reference for this working group were to investigate, review, assess and report on the situation, as well as to recommend remedies. The Technical Working Group produced a draft Executive Report to the Steering Committee in late 1999 that included a number of supplementary reports on water level declines and subsidence. That draft report reflected the consensus view of the Working Group but minority views were represented. However, the report has never been publicly released.
The Kinds of Data Used in this Report

Three fundamental kinds of data were used in this report, all publicly available. The first kind of data is the historical rates of abstraction from the Latrobe Aquifer across the region. The second kind of data is fluid (water) level or pressure in a great number of individual onshore and offshore wells. Some of this data consists of a water level at a single point in time (typically offshore data as described below). For other wells, data on water levels over time were available (typical of onshore data). The third kind of data used in interpretations relates to structural geology (e.g., mapped faults and aquifer thicknesses) and whatever has been inferred regarding aquifer recharge. In the sections that follow, this data (and its quality) is discussed in some detail.

History of Fluid Abstraction from the Latrobe Aquifer

The history of human activities significantly influencing pressures in the Latrobe Aquifer precedes the onset of large scale abstraction (circa 1969). However, these older activities (land use change, minor onshore irrigation development) are not thought to have significantly displaced the groundwater system from its long-term equilibrium position. For example, in 1969, total abstraction (chiefly coal mine dewatering) was about 10,000 ML per year; this is less than 10% of more recent levels of abstraction and a fraction of the average annual recharge as estimated by Brumley et al. (1981).

Since the late 1960s, fluids have been extracted from the Latrobe Aquifer system for a variety of purposes on a more significant scale. The extractions are mainly from four categories: 1) Coal mine dewatering in the Latrobe Valley; 2) Offshore oil and gas production; 3) Onshore water extraction for agricultural purposes; and 4) Onshore water extraction for industrial purposes. There have been various reports on fluid extraction history for the Latrobe Aquifer System and these are summarised in Figure 1, which shows that offshore oil and gas production makes up the majority of the total fluid extraction from the system but with a significant contribution to total extraction from mine dewatering. Onshore water extraction for agricultural and industrial uses are combined in this graph as they form only a small but increasing part of the total fluid extraction.

Dewatering associated with coal mine development commenced from the Latrobe Valley Group at Morwell Open Cut in 1960 and from the Latrobe Group in the same location in 1969. Since the early 1990s, additional dewatering at Loy Yang Open Cut has occurred. The history of this abstraction is well-documented (Evans 1983; GHD 2003). Over the past decade, about 20,000 to 30,000 ML per year has been extracted through mine dewatering, centred on Morwell.

Extraction of groundwater from the Latrobe Group for consumptive purposes (irrigation, centred on Yarram; industrial purposes such as the Longford Gas Plant) commenced in about 1970 and has increased in recent years (SKM 2004), typically on the order of 5,000 ML per year. Minor abstraction also occurs for local urban water supplies (some 3,500 ML per year).

Offshore abstraction of fluids from the Latrobe Group (mostly water but targeting oil and gas) commenced in a minor way in 1969 but rapidly scaled up to 40,000 ML per year by 1975 and peaked at 95,000 ML per year in 1995-2000 from seven major wellfields. Total fluid abstraction over time is shown in Fig 1.

Concerns over water level decline in the Latrobe aquifer have been addressed by a series of reports regarding cause, impacts and response.
The Formation Pressure Data Used in this Study

Water level and formation pressure data for this investigation were collected from several sources. As many data as possible were obtained given the time constraints of this investigation. Additional data exists both in the public domain and in confidential reports and datasets. Onshore data considered in this investigation came from published reports on the Latrobe Valley and the Yarram region. Hydrograph data in these areas are reported for 20 observation bores for various time periods for a particular screened interval in each well. In addition, there is a multitude of monitoring bores in the Latrobe Valley, but data from these could not all be accessed within the time constraints of the investigation. Instead, hydraulic head contours were used from previous reports (Report No Dd187, Oct 1983, R. Evans and Report #1000/8505/99 Geo-eng Pty Ltd. June 2000), which were based on the complete well suite over this area. These were supplemented with data from hydrographs for 7 monitoring bores in the region and reported in the Latrobe Valley groundwater annual report for 2002/2003. Contours used in the vicinity of the coal mines of the Latrobe Valley obtained from detailed studies were modified to fit with the observation bore data described above.

Offshore, the only public source of data is from Well Completion Reports (WCR) for oil and gas wells (normally for wells older than two years). Well completion reports from 80 wells were selected from the offshore area of the Gippsland Basin. The formation pressure values are comprised mainly from Drill Stem Test (DST), Production Test (PT) or Wireline Formation Test (WFT) type pressure measurements. Sixty-two of these wells contained pressure data and were entered in a relational pressure database and passed through a quality control procedure called PressureQC™ (Otto et al, 2000, Otto et al, 2001) to establish the degree of reliability for each data point (Tables 1 and 2). The remainder of the wells did not contain pressure or had incomplete data and were not used. The location of each well is shown in Figure 2.
Figure 2 Study area, well distribution and tectonic elements map.
Formation pressure data were converted to hydraulic head values (fluid potentials relative to mean sea level) assuming a constant formation water density. Using the Driving Force Ratio method (Otto et al. 2000) and (Bachu 1995) this assumption is valid for the regional Gippsland Basin.

A total of 1937 quality-controlled pressure data points have been entered into the database. More publicly available data exist for the Gippsland Basin. These can be added to the database at a later stage and used to help further constrain the preliminary interpretations in this report. In addition, individual operators of oil and gas fields have proprietary data on the historical pool pressures over time. This data can be requested later for a more detailed study. It would enhance the interpretation and reduce some of the geographic data gaps.

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<th>Number of data points</th>
<th>% of total</th>
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<tr>
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<td>6.7</td>
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<tr>
<td>WFT</td>
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<td>90.7</td>
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<tr>
<td>KICK</td>
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<td>0.05</td>
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</tbody>
</table>

Table 1 Statistics on pressure test data

Table 2 Statistics on the quality of pressure data

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<th>Class 2 (%)</th>
<th>Class 3 (%)</th>
<th>Class 4 (%)</th>
<th>Class 5 (%)</th>
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</table>

It should be noted that the scope of this investigation does not include a re-evaluation of the stratigraphic correlation and equivalency across the basin. Pressure data either from offshore testing or from onshore screened intervals were assumed to be accurately located in the defined stratigraphic interval. Confirming these stratigraphic allocations is required in future evaluations.
**Hydrostratigraphy and Basin Elements of the Latrobe Aquifer**

In order to define what parts of the Latrobe strata act as aquifer units that exhibit a degree of hydraulic communication, the pressure-elevation profile for each well with pressure data was examined. Given sufficient data to define a vertical pressure with depth profile, the degree of hydraulic communication can be estimated from a pressure gradient analysis. In this way, on a well-by-well basis the flow barriers are identified as locations where the pressure gradient with depth shows a break. If the hydraulic breaks from each well are consistent and can be correlated across the geographic area of interest then this defines the hydrostratigraphic geometry of the basin’s flow systems. For the Latrobe strata in the region of interest in this study, there is considerable variability in the hydraulic characteristics of the Latrobe strata across the basin reflecting the same degree of variability in the geological facies and lithology (Bodard et al. 1986). Offshore, there is however a relatively consistent hydraulic barrier between the Upper Latrobe strata (younger than Lower *M. diversus*) and the Lower Latrobe strata (older than the Lower *M. diversus*). In the central parts of the basin shales dominate the upper part of the Lower Latrobe and these form the hydraulic barrier between the two flow units. Toward the continental margins the coarse clastic content increases and the hydraulic barrier becomes less significant. For example, Figure 3 shows the pressure elevation plot for the Veilfin well, which is one of the few wells from the central part of the study area that has pressure data across a broad stratigraphic range.

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**Veilfin 1 Pressure Data**

![Veilfin 1 Pressure Data](image)

*Figure 3 Vertical pressure distribution in the Veilfin 1 well.*
In the upper Latrobe aquifer system the hydraulic head is showing signs of production induced draw down and is at –3m head while below the shales of the Lower *M. Diversus* to Lower *L. Balmei* the head is at 47m and then even lower in the *T. longus* it raises to 97m. This shows significant stratification of the flow system in the lower parts of the pressure-elevation plot with the shale zones acting as significant hydraulic barriers between aquifers. Toward the continental margin the vertical breaks in the pressure gradient tend to become less significant as the course clastic content of the upper part of the Lower Latrobe aquifer increases. For example, Figure 4 shows the pressure elevation plot for West Seahorse 1 with hydraulic head in the Upper Latrobe aquifer at 10m. This same pressure gradient representing 10m of head continues downward through the Lower *M. Diversus* and nearly to the *L. Balmei*. At this location, the entire sequence appears to be in hydraulic communication and acting as a single aquifer system. Figure 5 shows a generalised stratigraphic nomenclature for the Gippsland Basin based on previous published geological investigations.

![Figure 4 Vertical pressure distribution in the West Seahorse 1 well.](image-url)
Figure 5 shows the generalised hydrostratigraphy for the study area.
The major basin elements were shown on Figure 2. The western basin edge is indicated by a dashed orange line. The basin architecture is roughly symmetrical about an east-west axis. The Central Deep contains the bulk of the offshore hydrocarbon accumulations and is bounded to the north by the Rosedale Fault System and to the south by the Darriman Fault System. The onshore extension of the Rosedale Fault System forms an important boundary at the southern edge of the Latrobe Valley. There is some discrepancy in the literature as to the extent of faulting. Some publications interpret the fault system to either end at the top of the Strzelecki Group strata or partly into the lower Latrobe strata with upper Latrobe strata draping over the fault offset in an anticline. Other interpretations show the Rosedale Fault System to extend up to the top of the Latrobe Group strata or even to the surface. While some 2D-seismic show clear off-sets of the highly reflective coal measures zones and rollover related to late stage reactivation and minor inversion (e.g. Figure 6 shows the north-south seismic line GMPV97-01 which crosses the Rosedale fault system slightly west of the town of Sale), the data are not as definitive everywhere. More work needs to be conducted on the available 2D seismic to better define the significance of the fault offsets. The onshore extension of the Central Deep is termed the Seaspray Depression. Flanking the Central Deep/Seaspray Depression is the North and South Strzelecki Terraces. The North Strzelecki Terrace is bounded on the north by the Lake Wellington Fault System and the South Strzelecki Terrace is bounded on the south by the Foster Fault System. The Latrobe Valley is the inland extension of the North Strzelecki Terrace and the Yarram region is the onshore extension of the South Strzelecki Terrace. The boundary fault system (Darriman) between the Seaspray Depression and South Strzelecki Terrace is more poorly defined than the Rosedale Fault System with a more complicated geometry of smaller, discontinuous fault segments linked through relay zones. The onshore extension of the Darriman Fault system is unresolved and requires further investigation into its geometry. Finally, the Strzelecki Terraces are flanked by the Northern and Southern Platforms.

![Figure 6. North-south seismic line GMPV97-01 crossing the Rosedale Fault System.](image-url)
How these Data on the Latrobe Aquifer were Interpreted

These data can be used in various approaches to developing an understanding of the Latrobe Aquifer. The first of these is a direct consideration of the water level (pressure) changes over time, with particular reference to the onshore water levels. Such an analysis is presented in the following section, but sheds only limited insight into attribution of cause. A second approach is to try to construct an overall aquifer water balance (inflows and outflows) based on estimated recharge and our knowledge of the rates of fluid abstraction over time. This second approach assumes that the whole aquifer acts as a single bucket and that water level responses are independent of the location of abstraction. An attempt at this approach is presented below, but a key assumption here is that there is no significant compartmentalisation of the aquifer.

Finally, one can examine the emerging spatial patterns in onshore and offshore aquifer pressure levels in light of what is known about the structural geology across the region. This approach can reveal more about the issue of localisation vs. regionalisation of the effects of fluid abstraction and the rate at which these effects are propagated. The bulk of the results in this report are related to this latter approach.

Two World Views on Regional Groundwater Systems

View 1: Complexity

Large and deep sedimentary basins, like the Gippsland Basin, are made of complex sequences of materials deposited under varying geological and climatic conditions, resulting in quite heterogeneous and often discontinuous layers with widely varying hydraulic properties and continuity. Although there are recognisable layers, these consist of various materials and more significantly, have been subject to a long history of tectonic activity resulting in structural elements that may seal off one section from another to greater or lesser degrees. This compartmentalisation, together with the evolution of hydrocarbons and compressive forces arising from consolidation and settling of sediments, can create a complex spatial pattern of hydrodynamic pressures. Given this complexity and the transient conditions, it is not entirely possible to predict what will happen to the pressures at a regional scale if fluids are abstracted. Further, the resulting patterns following the stressing of the aquifer are not directly or easily attributable, at a given spot, to a given perturbation (withdrawal) at some distance, particularly across the great distances involved in the uses of the Latrobe Aquifer. In addition, the production of gas and oil reservoirs and associated water cuts have a different hydraulic behaviour and degrees of regional impacts due to their different physical properties and characteristics.

View Two: Simplicity

Despite the expected complexity of hydrogeological systems everywhere, there are emerging properties of groundwater systems (particularly confined groundwater systems) that make them to a large extent manageable and even predictable. As a rule, water level or pressure declines across a region are proportional to the volume abstracted, the distance from where that abstraction took place, and the time since the abstraction started or occurred. Structural features within the sediments, like faults, are rarely perfect in their function as barriers and thus only tend to slow down or distort the propagation of pressure declines due to abstraction. Thus, regional scale behaviour in watertable responses to withdrawals, particularly in confined aquifers like those of the Gippsland Basin, is to be expected.

The clash of these two world views is at the heart of the differing interpretations of cause and effect regarding the falling watertables in the Latrobe Aquifer.
Overview of Water Level Changes

Declines in aquifer pressures (falling onshore water levels) were observed by the early 1970s and was documented by Walker (1992), based on 15 deep monitoring bores spread over 140 km of coast. The oldest bore dates back to 1975. By typical water resources industry standards, all bores show a fairly consistent and uniform trend over this huge area, with onshore groundwater level declines of 0.25 to 1.2m/year (Figure 7) (average of 1.1m/year (SKM 1999g)). These trends have continued to date, with no indication of the aquifer reaching a new equilibrium. Part of the explanation of why the water level decline appears uniform is that within the study area, the coastline occurs roughly equidistance (roughly 50km) between two significant extractors of formation fluids: the coal mines onshore and the oil and gas production offshore. Coal mine extraction is historically about \( \frac{1}{3} \) that of hydrocarbon production (although this ratio is variable over time), however; the far field effects of extraction, in terms of a m/yr water level decline measure, is about 1.1m/yr. But this measure is not a particularly accurate one or an appropriate one for determining contribution of sources for the far field effects. It is more appropriate for typical water resource issues where extractors are impacting each other across much shorter distances and within much smaller aquifer volumes where the rate of water level decline covers a much larger range of values. For example, published reports on the same hydrograph data in this study area show calculated “average water level decline” to vary as much as 0.42m/yr for the same data from the same bore. Across a 30 year history this results in an uncertainty of over 12m. Similarly the range in decline rate (0.25 to 1.2m/yr) seems narrow, but across a 30 year history this correlates to a variation in the amount of decline between 7.5 and 36m (total decline). Understanding the basin architecture and relating that to the aquifer transmissivity allows for a geographic interpretation and better assessment of factors contributing to this variation.
Figure 7. Upper Latrobe Aquifer System average water level decline rates (m/yr) reported and calculated.
Estimating Inflows and Outflows for the Latrobe Aquifer

To get some handle of the likely volumes of recharge, discharge and abstraction associated with the Latrobe Group over the past decade, we present an approximate conceptual model.

Extraction estimates from the three major sources are reasonably well known (Figure 1) and total about 120,000ML/yr. Groundwater recharge is known with less confidence. We consider three recharge regions around the northern and western edges of the Basin; the first of these is the Yarram region with an estimated recharge volume of 20,000ML/yr, based on groundwater modelling work by SKM (1999). The Latrobe Valley recharge estimate of 30,000ML/yr is derived from modelling reported in Brumley et al. (1981) which indicated a total regional recharge to the Morwell Open Cut of about 13,000ML/yr, possibly rising to 35,000ML/yr with the development of the open cut over time. An estimate of the recharge from the northern part of the Basin, and along the northern part of the Baragwanath Anticline, was 15,000ML/yr (Walker and Mollica (1990). Recharge to the Latrobe Group in the eastern part of the Basin is probably small because the formations do not outcrop or subcrop to any great extent in this region; no calculation of recharge in the region has ever been published; a figure of 10,000ML/yr is a rough upper limit. Over the past decade, discharge to the continental shelf is assumed to be nil due to reversal of aquifer pressures due to extraction.

A certain amount of downward leakage into the Latrobe Group is assumed following commencement of extraction (originally, leakage would have been upward when regional aquifer pressures were well above sea level). An estimate of induced leakage of 20,000ML/yr is thus based on no quantitative data.

In summary, net inputs to the Latrobe Group may be of the order of 80,000ML/yr (assuming no discharge), with extraction totalling some 120,000ML/yr. This approximate water balance is consistent with the monitored water level declines, at least at a regional scale.

Characterising the Latrobe Aquifer Flow System and its Recent Dynamics

The hydrodynamics of the Gippsland Basin has had some attention in the literature both on and offshore. Onshore issues related to dewatering of coal mines and land surface subsidence due to offshore production have been the impetus for examining the hydrodynamics (Mudd et al. 1998, Brumley and Holdgate 1983, and Walker 1992). Lawrence (1992) has shown the Latrobe Group strata to form the most widespread aquifer system in the basin that recharges at outcrops onshore. This in turn drives flow within the Latrobe south and east with regional discharge in the offshore. Lawrence (1992) also shows the formation water salinity onshore to be fresh at about 1000mg/L passing through a freshwater/saltwater interface roughly 40km offshore.

Key to this investigation was characterising the evolution of the flow system from its virgin state (pre-production) to the present day. Impacts over time include onshore coal mine dewatering in the Latrobe Valley, onshore water extraction for agricultural and industrial use, and offshore hydrocarbon production. Based on data availability, four snapshots of the flow system through time have been derived and interpreted: the virgin flow system; the mid 1980’s; the mid 1990’s; and the present day. Onshore, there are few wells with available pressure data, but they are relatively evenly spaced across the study area and each well has a continuous pressure record through time. Offshore, there are many more wells available, but data is publicly available only for the pressure measure at the time of drilling for wells older than 2 years. In this case, the
offshore data distribution changes for each time map depending on which wells were drilled in that period of time. If the pressure history data were available for wells in producing fields (or field pressure over time) this would greatly enhance the flow system characterisation of the offshore part of the study area.

**Pre-Production Hydrodynamic System**

The virgin state of the aquifer system was characterised by examining the date at which a formation pressure was measured and the date at which various fields began production. Data which pre-date production, and certain data that post-date production but are located geographically far away from the site of production, were selected and used to characterise the virgin state of the flow system. Data are flagged on the maps either by a bright or dim yellow background. Hydraulic head values with a bright yellow background are used directly as control points for the contour map. Hydraulic head values with a dim yellow background are used indirectly to help constrain the contour distribution. For example if the contour map was for mid 1980's and a particular well had a hydraulic head value of 30m in 1989, the point cannot be used to directly constrain the contour distribution since the pressure could have dropped between the mid 1980's and 1989 when the pressure was measured, however, the point provides a minimum value for constraining the contours i.e. the head must have been at least 30m in the mid 1980's.

The distribution of virgin hydraulic head is shown in Figure 8. At each well the best available data is posted (relative to sea level). To assist in interpreting the hydraulic head distribution, the spud date (year) of each well is indicated and year each field began producing is indicated (e.g. Barracouta 69). Occasionally no well pressure data is known but the pre-production pool pressure is known. These values were also converted to hydraulic head and used to constrain the hydraulic head distribution. It was assumed that the pre-production pool pressure was valid at the time of the earliest well drilled for the field. In some cases there is a large time gap between field discovery and initiation of production. In these situations the quoted initial field pressure was not used as a control point at the later date (start of production), only at the discovery date. Field pressure history data could help define how long post discovery, the initial pool pressure could be used as a valid pressure constraint of the aquifer at each pool.

There appear to be several mechanisms driving fluid flow in the Latrobe aquifer system. High topography at the western end of the Latrobe Valley (North Strzelecki Terrace), and western end of the Seaspray Depression, where the aquifer recharges, results in a topography driven flow system with 80m of hydraulic head near the edge of the basin. From the western end of the Seaspray Depression, a ridge of high hydraulic head (>60m) extends eastwards to the coastline and as far offshore as the Dolphin Field with values over 50m. Onshore, north of the Rosedale fault system (North Strzelecki Terrace) the hydraulic gradient decreases eastward. There is not much data control in this part of the study area, other than within the mine area of the Latrobe Valley and a point from a well near Lake Wellington. In the onshore region of the South Strzelecki Terrace there is a southwards gradient from about 40m head near the basin margin to about 20m of head along the coastline.
Figure 8. Upper Latrobe Aquifer System virgin hydraulic head distribution.
The offshore region of the flow system is dominated by a trough of low hydraulic head (30m) that appears to serve as a drain to the Upper Latrobe aquifer system within the Central Deep. It is speculated that this trough is connected to the Darriman Fault System that forms the southern boundary of the central deep (Dickinson et al. 2001) and which may provide for discharge to the sea floor or to shallow strata near the seafloor. The study area would require more well data from south of the Darriman Fault System in order to confirm this speculation. The trough of low hydraulic head trends northwest past the western edge of the Barracouta Field toward West Seahorse 1, north between Barracouta and Whiting to the Wirrah Field and Northeast between the Snapper and Marlin fields approaching the Rosedale Fault System suggesting that this segment of the fault system may provide hydraulic communication between the North Strzelecki Terrace and the Central Deep. Hydraulic head increases towards the north-eastern edge of the Central Deep to about 80m north of the Snapper Field and in the vicinity of the Tuna Field. These are likely to be related to compaction induced dewatering of the basin as part of the normal process of sedimentation over geological time. The sections of the Rosedale Fault System that boarders the region of high hydraulic head are likely sealing and hydraulically separating the Latrobe aquifer in the Central Deep from then North Strzelecki Terrace.

In summary, the virgin state of the flow system is approximated as closely as possible from the earliest pressure data available from on and offshore. High values of hydraulic head of 80m occur due to recharge at the basin margins in the Latrobe Valley and Seaspray Depression and in the northeast parts of the study area offshore against the Rosedale fault system likely due to compaction induced dewatering of the sedimentary column. Both these flow systems converge into the trough of low hydraulic head in the central part of the Central Deep. Discharge is likely along the southern part of the Central Deep up the Darriman Fault System to either shallow aquifers or the seabed.

**Mid 1980’s Hydrodynamic System**

By the middle of the 1980’s dewatering of the coal mines in the Latrobe Valley and offshore oil and gas production in the Central Deep had already made a significant impact on the hydraulic head distribution within the Upper Latrobe Aquifer System. Figure 9 shows an estimate of the potentiometric surface for the mid 1980’s. Onshore, data was selected from 1986 because detailed work in the Latrobe Valley based on all available observation bores and modelling was previously mapped for 1986 and reported on in “Stage 2 mathematical modelling studies V2.” Report no Dd187. Oct. 1983. R. Evans). The modelled contours in this report were used to show the potentiometric surface in the immediate vicinity of the coal mines in the Latrobe Valley. The contours were modified here (Fig. 9) to incorporate the actual observation well bore data that was available. Offshore data from the mid 1980’s was used to define the potentiometric surface. Regions where the potentiometric surface is poorly constrained have dashed contour lines. There is no data on the Northern Platform and only limited onshore data from the Southern Platform. Three features dominate the potentiometric surface map for the mid 1980’s.

There is a depression down to about -50m of hydraulic head centred on the coal mines of the Latrobe Valley, but this depression is largely restricted to the North Strzelecki Terrace. Data on the south side of the Rosedale Fault System nearest to the coal mines shows almost no change in 1986 from the virgin hydraulic head distribution. However, on the northern side of the Rosedale Fault System, bore data as far east as observation bore Sale 13, show a water level decline. In this time frame the Rosedale Fault system (or the vertical impact of it on the Latrobe aquifer) appears to be acting as
a hydraulic barrier with permeability sufficiently low as to restrict aquifer pressure depletion from mine dewatering in the Latrobe Valley to the North Strzelecki Terrace.

There is high hydraulic head (>80m) on the western edge of the Gippsland Basin within the Seaspray Depression. This forms a ridge of high hydraulic head extending eastward to about the coastline. The ridge of high hydraulic head is very similar to that described above for the virgin state of the aquifer system but subdued in comparison. The hydraulic head values making up the western edge of the hydraulic head ridge are the same as virgin values, but moving eastward there is increasing divergence between the two hydraulic head maps. At the position of the coastline the hydraulic head ridge in 1986 is about 35m less than in its virgin state. On the South Strzelecki Terrace there appears to be much less contrast between the virgin and mid 1980's potentiometric surfaces. The only well with sufficient data to directly compare between virgin and 1986 conditions is Woranga 12 which had a water level that dropped by 5m.

Finally, there is an offshore depression down to about -50m of hydraulic head centred on the Fortescue/Halibut oil field. While there has also been production from various other fields in the Central Deep (e.g. Barracouta since 1969) the impact on aquifer pressure depletion is less due to production being mainly gas. In the offshore it is more difficult to compare the hydraulic head values in the mid 1980's with the virgin state because the data set has a different distribution for each time slice. However, it appears that pressure depletion in the Central Deep has propagated onshore into the Seaspray depression and is on the order of 20m of water level decline along the shoreline in the Central Deep. While the Rosedale Fault System on the northern edge of the Central Deep appears to act as a hydraulic barrier on the time discussed here, the Darriman Fault System appears to act only as a partial barrier, with water levels onshore South Strzelecki Terrace by only on the order of 5m by the mid 1980's. The difference in seal potential between the Rosedale and Darriman fault systems may be related to issues such as fault zone orientation relative to the regional stress field, the amount of displacement, the abundance of relay zones, or the juxtaposition and fault zone architecture. These would need to be examined in detail to define the seal potential of the various fault systems.
Figure 9. Upper Latrobe Aquifer System hydraulic head distribution in the mid 1980's.
In summary, by the mid 1980’s there are two significant regions of pressure depletion in the Upper Latrobe Aquifer System. One centred at the coal mines of the Latrobe Valley and one centred on the Fortescue/Halibut oil field in the Central Deep. The pressure depletion from the Coal Mine dewatering appears to be mostly contained to the North Strzelecki Terrace, but extends east to the Sale 13 observation bore. The pressure depletion from the offshore oil and gas filed production is largely concentrated in the Central Deep but appears to extend onshore to the eastern parts of the Seaspray Depression. While the Darriman Fault System offers some level of containment, pressure depletion of the Upper Latrobe Aquifer System appears to occur at a subdued rate on the South Strzelecki Terrace due to offshore oil and gas production in the Central Deep. This suggests that at the timescale in question, the Darriman Fault System allows for limited hydraulic communication.

**Mid 1990’s Hydrodynamic System**

By the middle of the 1990’s, the hydraulic head distribution for the Upper Latrobe Aquifer System largely had the same features as that described for the mid 1980’s but with the effects of pressure depletion being stronger with further water level declines (Figure 10). There are, however, several regions with subtle changes that highlight issues with regard to the complex interaction of extraction from coal mine dewatering in the Latrobe Valley, offshore oil and gas production and onshore aquifer extractions.

Within the fault boundaries of the North Strzelecki Terrace, the declining water levels continue with the water levels near Lake Wellington dropping another 5m between the mid 1980’s and the mid 1990’s. The Rosedale Fault System itself remains a strong hydraulic barrier onshore that separates the pressure depletion in the Latrobe Valley from much higher hydraulic head in the Seaspray Depression. On the North Strzelecki Terrace, by the mid 1990’s, there is a saddle in the potentiometric surface at the town site of Sale. From here (hydraulic head of about 20m) the potentiometric surface declines westwards towards the coal mines, but also declines eastwards towards the coastline. At the Seacombe 7 monitoring bore the water level dropped from 24m in 1986 to 14m in 1995. By the mid 1990’s, in addition to pressure depletion of the North Strzelecki Terrace by coal mine dewatering, there appears to be an additional impact in the North Strzelecki Terrace from offshore oil and gas production which contributes to declining water levels on the North Strzelecki Terrace across a weak section of the Rosedale Fault System.
Figure 10. Upper Latrobe Aquifer System hydraulic head distribution in the mid 1990's.
Within the Central Deep and Seaspray Depression the cone of depletion on the potentiometric surface in the offshore is more extensive in the mid 1990’s than in the mid 1980’s. The hydraulic head at the Fortescue/Halibut field changed from -45m in 1985 to -74m in 1994. The pressure depletion has further extended onshore to the Seaspray Depression, but the ridge of high hydraulic head is resilient and still prominent on the potentiometric surface map. This suggests that significant recharge is still occurring at the west end of the Seaspray Depression seemingly along the axis of the current day river drainage. It may be that pressure depletion in the upper Latrobe Aquifer has caused a steepened vertical gradient from the shallow aquifer system which needs to be investigated further. It may also be that the subcrop of the Latrobe Aquifer system in this region occurs over a large geographic area at relatively high elevation and that this geometry allows for significant recharge to the aquifer at this location. More work is needed to determine the process of recharge to the Upper Latrobe Aquifer System at the west end of the Seaspray Depression. The potentiometric surface map of the offshore part of the study area for the mid 1990’s suffers from a lack of data between the coastline and the Fortescue, Halibut and Marlin fields, however, data onshore show that water levels along the coastline at the western edge of the Central Deep have dropped to about 10m by this time. Pool pressure data from the various producing oil and gas fields from the mid 1990’s would greatly increase the confidence in the potentiometric surface.

There are no public offshore pressure data available for the offshore part of the South Strzelecki Terrace. Onshore data show that between the mid 1980’s and the mid 1990’s there has been a regional reduction in water levels of between 3 (Welshpool 31 observation bore) and 9m (Woodside 12 well) along the coastline suggesting a limited regional influence from offshore oil and gas production perhaps partly sheltered by the Darramin Fault System. The strength of the seal potential for the Darramin Fault System appear to be less than that for Rosedale Fault System as discussed previously for the 1980’s hydraulic head distribution.

The last feature of interest on the potentiometric surface for the onshore South Strzelecki Terrace is a local depression defined by the Woranga 12 monitoring bore. This local depression was also noted by the SKM report (January 2004). It suggests that local onshore water extraction has a local influence on the potentiometric surface. With only 20 monitoring bores used in the onshore region for this investigation, it remains possible that there may be other onshore water extraction sites that will have a local influence on the potentiometric surface but were not captured in this report.

In summary, by the mid 1990’s the main impact on the Upper Latrobe Aquifer System is from dewatering of the coal mines in the Latrobe Valley and oil and gas production in the offshore Central Deep, with minor influences appearing from onshore water extractors. The impact of mine dewatering in the Latrobe Valley appears to be mainly contained to the North Strzelecki Terrace. It is unclear to what degree water level decline along the coastline of the North Strzelecki Terrace at this time is due to coal mine dewatering, offshore oil and gas production or a combination of both. More data is required to constrain this question. The impact of offshore oil and gas production from the Central Deep is largely constrained to the Central Deep and Seaspray Depression with a reduced but still regional impact on the South Strzelecki Terrace. Recharge on the western edge of the Seaspray Depression locally diminished the impact of pressure depletion of the Seaspray Depression. A minor local depression in the potentiometric surface onshore in the South Strzelecki Terrace suggests that onshore extraction has a local influence on the potentiometric surface.

For the present day and within the constraints of this study, there are no pressure data available for the offshore so the potentiometric surface map is limited to the onshore portions of the study area (Figure 11). The shape of the potentiometric surface is similar to that described for the mid 1990’s previously but with a continued general decline of hydraulic head values regionally. On the North Strzelecki Terrace, the same saddle occurs near the townsite of Sale as was previously discussed for the mid 1990’s, but the hydraulic head is further reduced by about 7m and the geographic location of the saddle has broadened and shifted slightly to the west. This favours the hypothesis that by this time offshore hydrocarbon production is having a contribution to reducing water levels on the North Strzelecki Terrace. The same ridge of high hydraulic head occurs on the west side of the Seaspray Depression, but the hydraulic head along the coastline is now reduced to about 0m. The hydraulic head from the onshore South Strzelecki Terrace is reduced from the mid 1990’s by 7 to 10m. No additional speculations can be made about the impact of fluid withdrawal on the Upper Latrobe Aquifer System from the present day potentiometric surface map other than confirmation of a continuation of the regional water level decline. Offshore data need to be accessed and added, and preferably more onshore water level data need to be added to better constrain the potentiometric surface.
Figure 11. Upper Latrobe Aquifer System hydraulic head distribution at present (2004).
An alternate view is to make a difference map between the hydraulic head distribution for the virgin state of the aquifer and the current state; as shown in Figure 12. Since the present state of hydraulic head is unconstrained by data in the offshore, the difference map is valid only for the onshore. This shows that the maximum onshore water level decline, occurs along the coastline within the Seaspray depression. This is dampened westwards by the resilient high hydraulic head ridge that is likely attributed to effective recharge over a large subcrop area. The trend here is clearly an eastward increase in “total water level decline” that must be strongly related to offshore hydrocarbon production. There is a similar trend across the onshore part of the Strzelecki Terrace but with the magnitude of decline being less than within the Seaspray Depression. This is probably due to partial damping effects of the Darriman Fault System and related structural features. While the impact of offshore hydrocarbon production is less in an absolute sense, the effect appears to extend, at a lower level, further westward than it does in the SeaSpray Depression. This is probably because on the South Strzelecki Terrace, the Latrobe Aquifer only outcrops/subcrops along a narrow band at the western basin edge, and at a topographically lower elevation, making recharge less effective than it is within the Seaspray Depression to the north. Finally, on the North Strzelecki Terrace the decline pattern is opposite to that in the Seaspray Depression with a westward increase in “total water level decline” from approximately the Sale 13 well. This trend must be strongly attributed to Coal Mine dewatering. East of the Sale 13 well, there is an eastward increase in “total water level decline” that shows the impact of offshore production. It should be noted however, that the “total water level decline” along the coastline north of the Rosedale Fault System is much less than within the Seaspray Depression. Further offshore there is some evidence that pressure decline has occurred across leaky (transmissive) spots of the Rosedale Fault System. For example, pre-development pressure monitoring of the Sole field (north of the major east-west fault dividing that field from the major centre of oil and gas developments to the south) found a drop of some 310 kPa (some 30m of head) between 1973 and 2002; this was interpreted to be a result of production from fields across the fault to the south and the regional depletion of the Latrobe Aquifer (OMV Australia 2003).
Figure 12. Upper Latrobe Aquifer System total water level decline between virgin conditions and 2004.
Possible Explanations for Water Level Declines

Based on the above analyses (mean drop in onshore water levels, the inflow-outflow analysis based on abstraction rates from various sources, and the emergent spatial pattern of pressures across the region), we can test several alternative causal explanations. In doing so, we recognise that any combination of these causes may operate simultaneously to some degree, but the emphasis here is a consideration of magnitude of the local and regional effects.

Climate Change

An alternative hypothesis for falling water levels is reduced rainfall over the period of decline. An examination of long-term records from the region by the Victorian Greenhouse Strategy (Whetton et al. 2002) found that since 1950, Victoria’s average maximum temperature increased by only 0.11°C per decade, and there were no trends in rainfall evident over the period 1880 to date. Wetter conditions were noted during the 1970s and drier conditions in the 1990s.

However, aquifer response to climate involves many factors, particularly when confined aquifers are considered. A more robust test is the comparison of other deep, regional aquifer responses in Victoria over the same period. SKM (1999e) performed such a comparison between the Dilwyn Formation in the Otway Basin and the Latrobe Group of the Gippsland Basin. Both basins are passive margin basins along the south coast of Victoria, have experienced the same marine transgressive cycles and have similar lithographic sequences. Major regional aquifers occur onshore in both formations and are of about the same age. Both aquifers are deeply buried along the coast and strongly confined. Both formations have similar recharge sources at their margins, and are of a similar size.

Hydrographs from monitoring bores selected on the basis that they were away from the basin margin, had reasonably long records of water levels, were intact and screened at depth in the relevant formation. Over the past three decades, water levels declines in the Dilway Formation were an order of magnitude less than the declines observed in the Latrobe Formation. This result fails to support the hypothesis of climate change.

Abstraction for Irrigation

At the regional scale, the volumes abstracted for irrigated agriculture are a very small fraction of total fluid abstracted. However, the localised nature of this abstraction has two implications in consideration of regionally declining water tables. The first is the recognition that given the apparent degree of regional compartmentalisation, and the great distance between irrigation abstraction and areas with falling water levels, indicates the extremely low likelihood that irrigation abstraction is influencing water levels at the regional scale. The obverse of this conclusion is that localised irrigation abstraction has the potential to add significantly to local water level declines. This phenomenon would be equivalent to the localised drawdowns around offshore wellfields, in combination to any regional effect due to offshore abstraction.

Land Use Change Leading to a Reduction in Aquifer Recharge

The relationship between rainfall, land use (particularly different vegetation types) and potential groundwater recharge is now well understood across Australia (Walker
et al 2002). The most significant of these contrasts in recharge rates among land uses is between forests or tree plantations and annual pasture: with rainfall up to about 900mm/yr, recharge rates can be 1% and 20% of rainfall, respectively. The difference in recharge between native forest and an established tree plantation is small, however, with neither type permitting much recharge in low to medium rainfall zones.

SKM (1999) looked at changes in the area of tree plantations and native forest cover in the Latrobe Group recharge areas, and found only a minor net change (0.8%) in the tree cover of recharge areas and (0.7%) net increase in the Gippsland Basin overall. The effects on recharge at the regional scale would be minimal.

More locally, the mapped outcrops of the Latrobe aquifer associated with the recharge in the Yarram district are more restricted, and one might hypothesise that intensive afforestation of those lands, while not significant at the regional scale, might be enough to impact on the local water levels. However, no such intensive afforestation is reported.

Mine Dewatering

The lowering of water levels in the aquifers of the Latrobe Valley was deliberate, well-documented and acknowledged. The original analysis of regional trends in this report suggests that while the impacts of that activity have spread eastward past Sale, they seem reasonably confined to the north of the Rosedale Fault, toward what appears to be a similar decline propagating from the east along the North Strzelecki Terrace. Thus, it is difficult to attribute the falling watertables of the Seaspray Depression or the Yarram area to the southwest over the past decades to mine dewatering in the Latrobe Valley. Neither would mine dewatering explain falling Latrobe Aquifer water levels at places far to the east of Sale such as the wells near Bairnsdale.

Offshore Abstraction

Based on a regional analysis, the widespread changes in aquifer pressures and water levels, both in magnitude and pattern, are clearly associated to some large but geographically variable degree with offshore oil and gas production. At locations such as Bairnsdale and the onshore part of the Seaspray Depression, no other hypothesis seems to even remotely explain observed declines. The widespread consistency in the rates of decline at places well-removed from abstraction for other purposes amplifies this conclusion, as does the record and rate of onshore declines south of the Rosedale Fault System that predate significant development of irrigation supplies.

By the same token, the apparent (at least partial) compartmentalisation of the aquifer indicated by the patterns of regional head decline, makes the local attribution of degree to competing causes of decline very difficult when only sparse data is available. The analysis offered in this report, for example, could not confidently determine whether the watertable falls over the past 20 years generally were 30% or 70% due to offshore abstraction as opposed to local abstraction for irrigation or coal mine dewatering. Were we to ignore any compartmentalisation or other local effects and based culpability solely on the proportion of water abstracted over the past 30 years, then one might attribute up to 80% of regional watertable falls to offshore abstraction. This is not an entirely valid assumption, however. Complicating factors include proximity of abstraction, local or regional compartmentalisation (at least
partial), geographically variable degrees of onshore recharge, variable degrees of vertical leakage from the overlying aquifer, and significant variation in the Latrobe aquifer thickness. These contributing factors result in the contribution of various extractors on the water level declines to be geographically variable. One simply cannot apportion impact per extractor for the basin as a whole.

**Recommendations for Further Investigations**

We recommend the following:

1. Conduct a detailed pressure decline study of the Gippsland Basin including the offshore area north of the Rosedale Fault using all onshore and offshore relevant wells and historical production and pressure data. A better appreciation of the basin’s structural and lithological complexity is required, followed by an integrated regional reservoir and aquifer modelling study that incorporates this added detail.

2. Review the current groundwater level and formation pressure monitoring network, including an assessment of required refurbishment of wells.

3. Identify critical monitoring wells and install pressure transducers and loggers to measure water levels and pressures at more frequent and regular intervals.

4. Conduct a comprehensive risk assessment study of potential subsidence in the coastal region, including petrophysical measurements on core and subsidence modelling.

5. Review the option to use satellite-based subsidence monitoring technology.

6. Development of an integrated decision support and groundwater management system for the Gippsland Basin.

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