# Latrobe Valley Shallow Geothermal Project

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The Latrobe Valley Shallow Geothermal Project (LVSGP) aims to demonstrate fluid circulation and heat extraction from moderate temperature groundwater resources at less than 1,000 m depth in the Latrobe Valley and establish the technical and commercial viability of this renewable resource for small-scale electricity production.

Hot Dry Rocks Pty Ltd (HDR) undertook a Geothermal Systems Assessment (GSA) to assess the potential for moderate temperature geothermal energy targets within the Morwell–Traralgon area of the Latrobe Valley, onshore Gippsland Basin, Victoria. The principal risk areas addressed in the GSA include the presence of an adequate thermal insulating cover sequence (hence adequate temperatures for geothermal prospectivity), the presence of a suitable reservoir unit (a sedimentary aquifer), and the availability of water.

Successful demonstration of the LVSGP will translate to similar geological settings in Australia and overseas.

Keywords: Latrobe Valley, Geothermal Systems Assessment, Hot Sedimentary Aquifer

## Introduction

Geothermal exploration aims to identify areas where the main components of a geothermal system are present or can be engineered. Namely: the availability of water, in situ permeable aquifers or rock units and elevated temperatures at drillable depth.

Hot Dry Rocks Pty Ltd (HDR) is the operator of the Latrobe Valley Shallow Geothermal Project (LVSGP). The aim of the LVSGP is to install a 500 kW (gross; 350 kW net) pilot electrical power generator to demonstrate the potential of using moderate temperature groundwater to generate baseload electricity. The generator is being developed and constructed by HDR's partner in the LVSGP, Green Thermal Energy Technologies (gTET).

In November 2010 the Victorian Government's Department of Primary Industries (DPI) awarded HDR a $217,500 grant under the Energy Technology Innovation Strategy (ETIS) Sustainable Energy Research & Development (SERD 2) program to progress the LVSGP.

A key element of this grant was a Geothermal Systems Assessment (GSA) of the coal-bearing

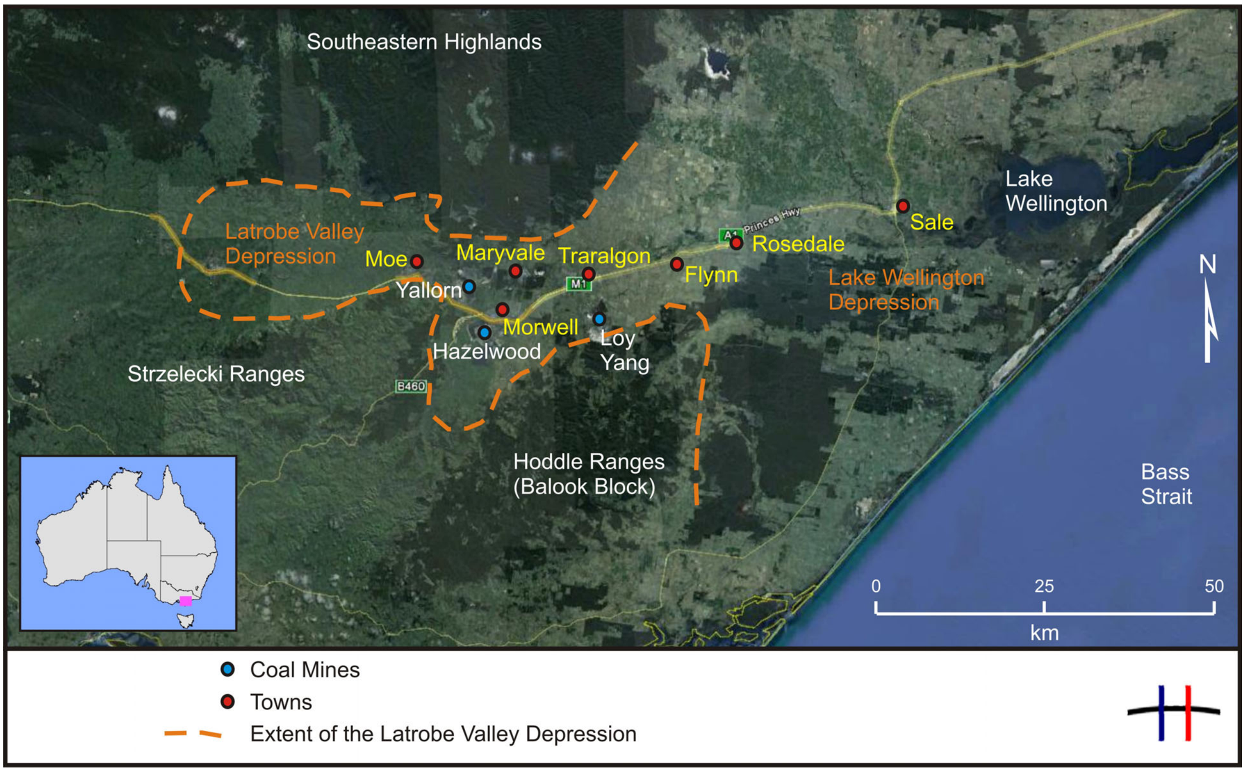


Figure 1: Location of the Latrobe Valley (background image courtesy of Google Earth).

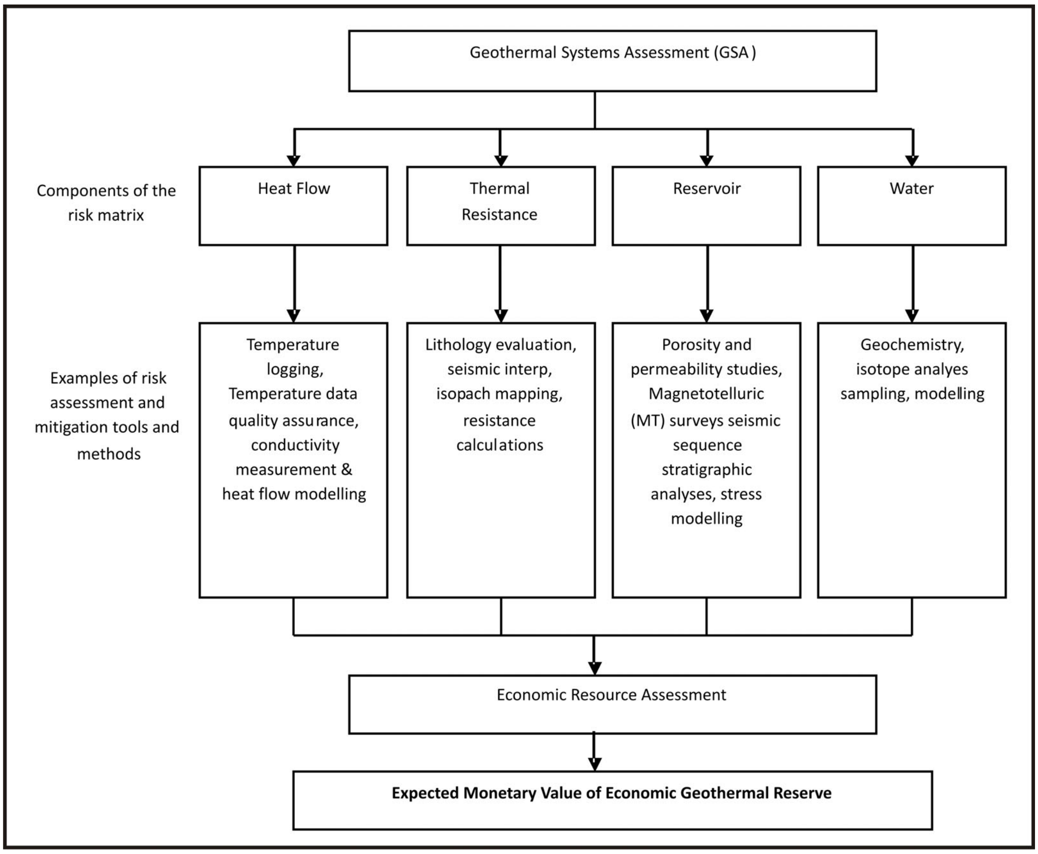


Figure 2: The GSA Framework as described by Cooper and Beardsmore (2008).

region of the Morwell–Traralgon area of the Latrobe Valley. This assessment was primarily based on existing geotechnical datasets. However, HDR undertook a Precision Temperature Logging (PTL) work program to provide further data on the sub-surface temperature profile of key areas. A key deliverable of the GSA was to identify a preferred site for the initial LVSGP exploration bore.

Since the LVSGP is targeting hot water shallower than 1,000 m, the project falls outside the regulations of the Victorian Government's Geothermal Energy Resources Act (2005). However, the project is still subject to the usual planning and environmental legislation and regulation.

## Location

The study area of the GSA broadly covered the coal-bearing sequences of the onshore Gippsland Basin, Victoria—specifically the Morwell–Traralgon area of the Latrobe Valley (Figure 1), located approximately 140 km ESE of Melbourne.

Brown coal resources are prevalent throughout the Latrobe Valley, extending from Moe to Rosedale, and include open-cut coal mines at Loy Yang, Hazelwood and Yallourn. These include large coal resource areas yet to be allocated for development. The coal mining industry dominates the Latrobe Valley landscape, both geographically and politically, being a major employer in the region. Strategically, the Latrobe Valley is the centre of Victoria's electricity generating industry, supplying approximately 85% of Victoria's electricity needs.

## The geothermal potential of coal-bearing basins

The most prospective regions for high geothermal temperatures are those that have geological units of sufficiently low conductivity (high thermal resistance) in the cover sequence combined with high heat flow. Thick intervals of coal- and clay-rich sequences provide excellent thermal insulation properties; thus heat is trapped below the sequences. Coal-rich sequences are also commonly interbedded with sandstone horizons that often have excellent reservoir characteristics, such as high porosity and permeability. The coincidence of elevated temperature and shallow reservoirs makes an ideal geothermal energy target.

Occurrences of relatively high temperature groundwater flowing at high yields from shallow depths in the Latrobe Valley are well known. Jenkin (1962) noted two bores with elevated temperatures in the Maryvale area, one of which recorded a well yield of 69.5 L/s at 70 °C from a depth of 524.5 m.

## Geothermal Systems Assessment

The Geothermal Systems Assessment (GSA) offers a holistic approach to delineating geothermal resources with a methodology synonymous to that proposed by Magoon and Dow (1994) in their Petroleum Systems Analysis volume. The GSA framework (Figure 2), first described by Cooper and Beardsmore (2008), addresses principle geological risks at basin or tenement scale. Further detailed work at a play scale is recommended to progress exploration in areas that a GSA might highlight.

Four critical geothermal risk areas relate to four geological factors. These are summarised below:

1. Heat flow: Probability that heat flow measurements or assumptions reliably characterise the play under investigation. Estimated from geographic coverage and 'uncertainty' of heat flow estimates.
2. Thermal resistance: Probability that thermal resistance and heat transfer mechanism beneath the level of well intersects are as assumed (purely conductive, convective component, advective component).
3. Reservoir: Probability that reservoir properties and volumetric extent are as assumed. Estimated from geographic coverage, data type and reservoir type. Includes void connectivity and prevailing stress regime.
4. Water: Probability that water supply or chemistry will not adversely impact on the project.

The GSA methodology assesses each component of the risk matrix, and places a confidence rating on the data used based on experience and current understanding of the area of interest. Some aspects of risk in the geothermal system share varying degrees of co-dependence. For example, heat flow and thermal resistance risk share a common link via rock thermal conductivity measurements.

By understanding and quantifying the risk elements of each critical technical area, steps can be taken to mitigate the risk prior to significant expenditure (being proactive rather than reactive). For example, if heat flow is uncertain, it can be measured prior to significant expenditure.

## Available data sets

### Well data

Many petroleum wells, coal bores and water bores have previously been drilled within the Latrobe Valley (Figure 3).

Hydrogeological data were sourced from several publications and included information such as groundwater models, well pump tests, and core porosity and permeability estimates. However, the vast majority of hydrogeological data known to exist for the region are non-published, proprietary information not available for this study.

### Seismic data

Seismic data in the Latrobe Valley are relatively

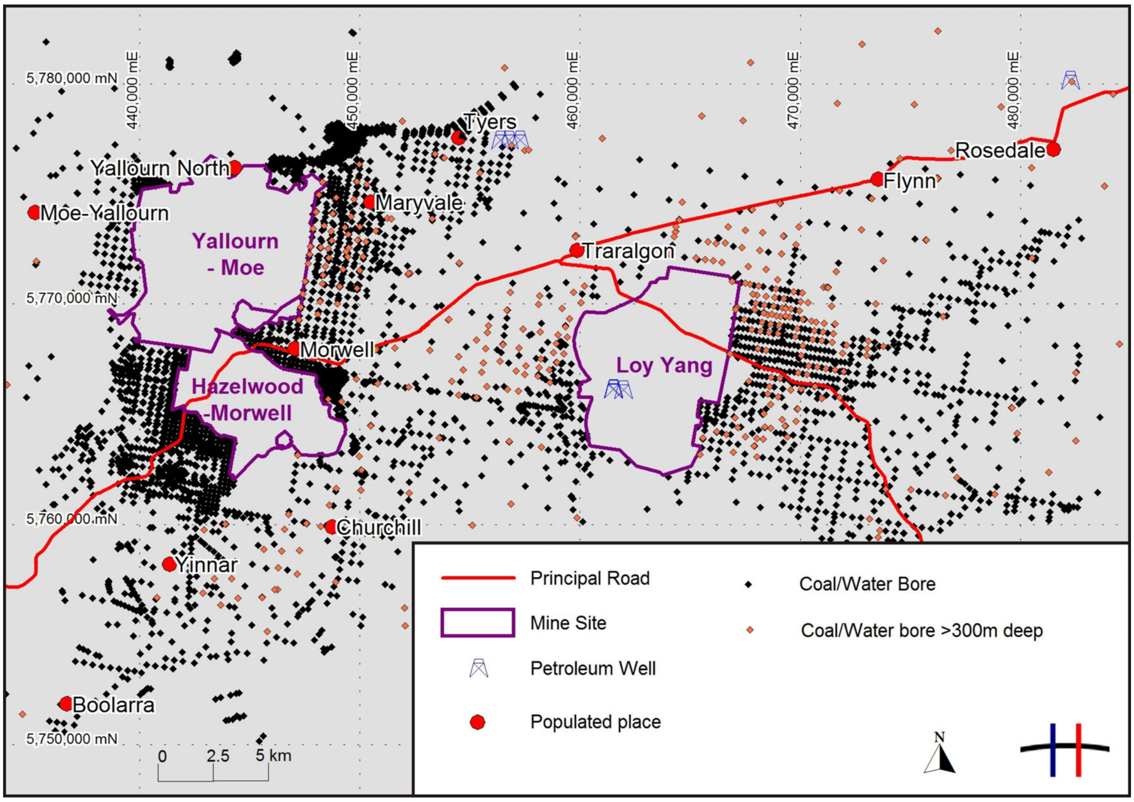


Figure 3: The geographical distribution of all petroleum wells and coal/water bores in the Latrobe Valley.

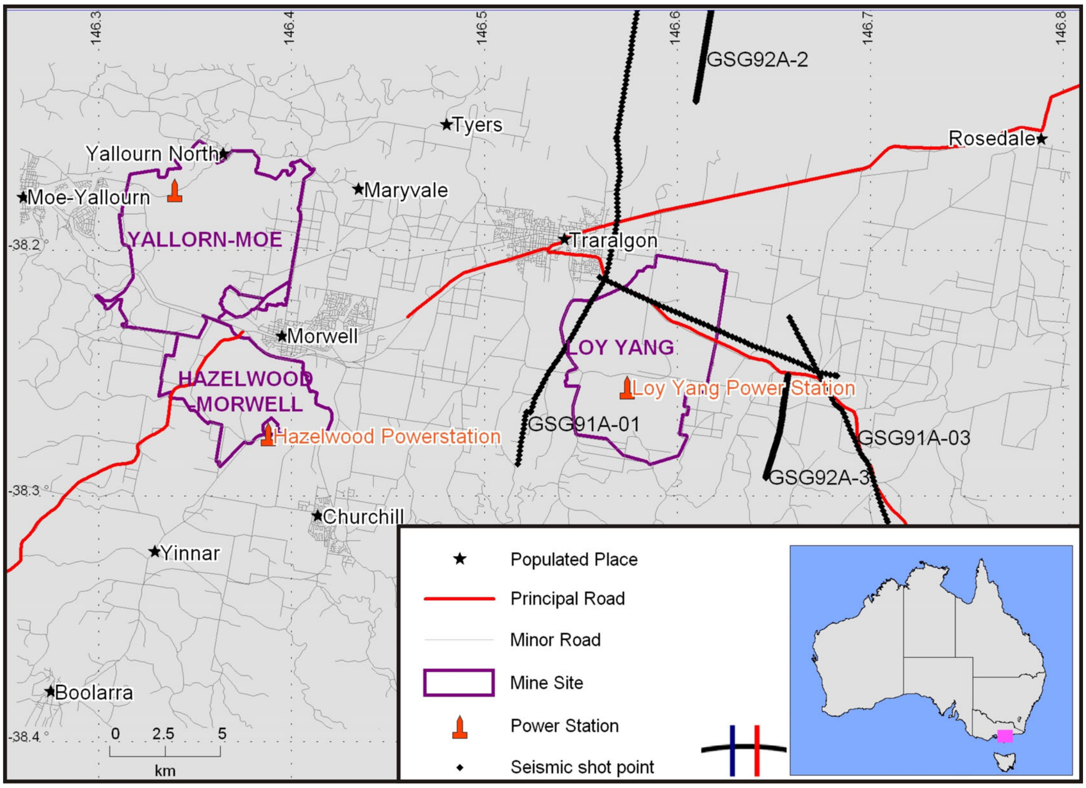


Figure 4: Location of seismic lines in the Latrobe Valley.

sparse with just four regional reflection seismic lines acquired in 1991 (Figure 4). The lines (GSG91A-01, GSG91A-03, GSG92A-2, GSG92A-3) have data to a depth of 3.8 seconds TWT and are of reasonable quality, although quality deteriorates at depths greater than 1 second TWT, probably due to signal attenuation through the Cainozoic coal succession. However, a number of key reflections and faults beneath this depth remain interpretable.

### Latrobe Valley Coal Measures 3D Model data

HDR was able to interrogate DPI's 2003 Latrobe Valley Coal Measures 3D Model to quantify the depth to base Cainozoic and estimate the cumulative thickness of coal sequences in the area. DPI released a revised Latrobe Valley Coal Measures 3D Model in May 2011. The new model covered an expanded geographical area, included previously confidential datasets, and incorporated geotechnical data collected between 2003 and 2011.

## Geology of the Latrobe Valley

The Gippsland Basin was formed during the Jurassic–Early Cretaceous continental breakup of Gondwanaland in the initial phase of the rifting of Australia from Antarctica (Duddy, 2003). During this rifting E–W orientated en echelon grabens formed along southern Australia and rapidly filled with sediments. The Gippsland Basin began to rapidly subside as a result of crustal extension and fluvial non-marine sediment loading. The separation of Antarctica from Australia along western Tasmania in the mid-Cretaceous (~95 Ma) resulted in the Gippsland Basin becoming a failed rift (Duddy, 2003; Webb et al., 2011).

In the Late Neogene (~10 Ma) the Gippsland Basin was subjected to tectonism and deformation associated with the Kosciuszko Uplift (Webb et al., 2011). This period of tectonism reactivated early rift features converting them to features of compression. Throughout the Cainozoic post-rift failure, the Gippsland Basin became a rapidly subsiding sag basin (Holdgate, 2005; Webb et al., 2011).

The Gippsland Basin covers 56,000 km², of which approximately 16,000 km² is situated onshore, and contains a succession of non-marine Cretaceous to early Cainozoic sediments (Holdgate et al., 2000). A generalised cross section of the onshore Gippsland Basin is presented in Figure 5.

## Temperature Data

One of the primary aims of a GSA is to quantify the value and uncertainty of the temperature of key reservoir targets. Direct measurements of temperature at the target depth are rarely available for geothermal energy projects targeting resources down to 5,000 m depth. However, the LVSGP is targeting shallow reservoirs previously drilled at depths <1,000 m and thus directly measured datasets are available.

Temperature data are important pieces of information for assessing the commercialisation of any geothermal resource. However, caution should be maintained with respect to the validity of pre-existing temperature datasets as they are usually collated for other purposes—most notably petroleum exploration—and collected as ancillary data.

Temperature data reported in petroleum and coal/water bore reports are often of unknown quality. Petroleum 'bottom hole temperature' (BHT) are usually recorded a short time after the circulation of drilling fluid in a hole, and therefore represent disturbed thermal conditions. Likewise, temperature logs collected immediately after drilling has ceased in other types of bores are prone to similar errors.

Historical data from a number of boreholes in the Latrobe Valley suggest that elevated temperatures at shallow depths are a common occurrence. Driscoll (2006) conducted a geothermal assessment of Victoria and collated all published temperature data from boreholes drilled in Victoria. A core component of that particular study was establishing the source of temperature data reported in earlier reports and borehole completion reports. However, in many instances, the process of how and when data were collected could not be verified. Much of the temperature data collected from coal and petroleum reports are thus of unknown quality. This information is critical since well temperatures measured during the drilling process can underestimate the virgin rock temperature of the formations at depth.

Discussions between HDR and a number of engineering and coal companies yielded further temperature data that were only recently made available. However, once again, the details of how the data were recorded were not provided.

## Thermal resistance

Thermal resistance is the 'blanket' that traps heat underground. It is synonymous with the 'trap' and 'seal' concepts of petroleum systems analysis. Thermal resistance ($m^2K/W$) is the cumulative sum of overburden thickness (m) divided by thermal conductivity (W/mK). A geothermal prospect must have an adequate 'thermal blanket' to retain heat at depth. This is best provided by a thick sequence of low conductivity lithologies such as coals, carbonaceous shales or fine-grained siltstones.

The Latrobe Valley hosts a world-class brown coal deposit comprising up to five individual seams, each in excess of 100 m. These thick multi-stacked coal units—the Hazelwood Formation, Yallourn Formation, Morwell Formation and upper portions of the Traralgon Formation—are widely distributed throughout the Latrobe Valley. HDR's thermal conductivity analysis in DPI's Geothermal Atlas of Victoria (2010) confirmed the brown coal sequences exhibit low conductivity and thus provide excellent insulatory cover.

HDR calculated that approximately 350 m cumulative thickness of coal would provide insulation properties to achieve a 90 °C temperature.

Given the plethora of geotechnical data confirming the thickness and lateral extent of thick coal measures in the Latrobe Valley, the known presence of elevated temperature in the Latrobe Valley, and the directly measured thermal conductivity results from the coal measures, HDR is confident that thermal resistance poses a low risk.

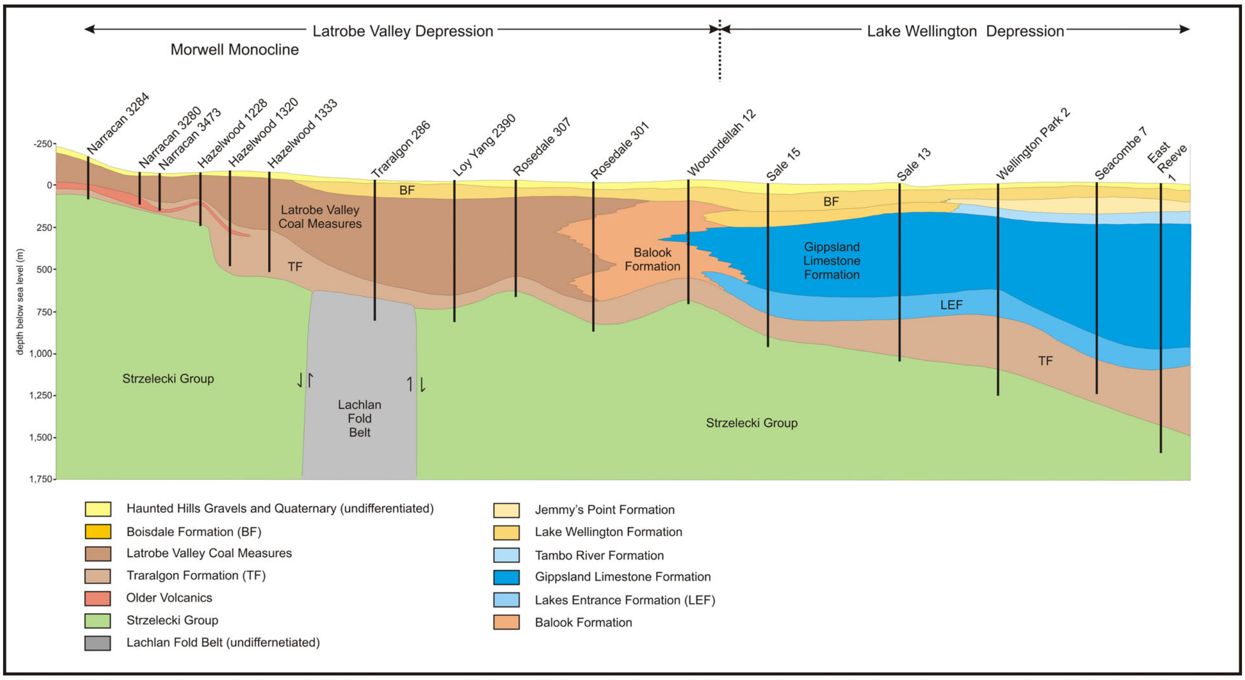


Figure 5: Generalised cross section across the Latrobe Valley (modified from King et al. 1987).

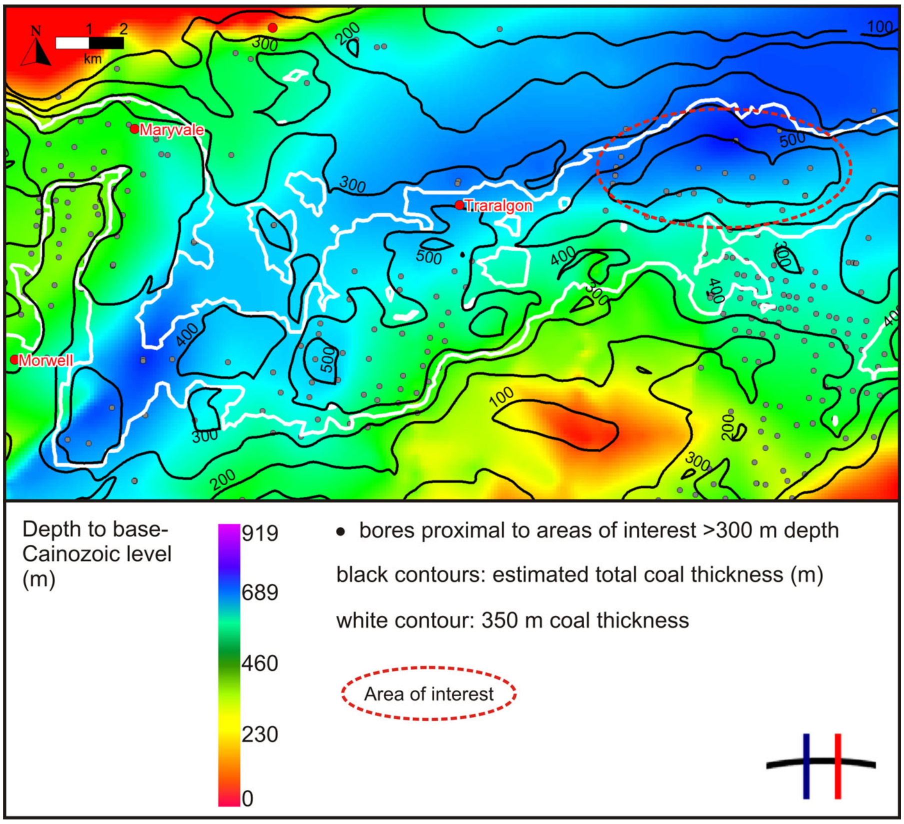


Figure 6: Contour of the 350 m cumulative coal isopach (white line) based on DPI's 2011 Latrobe Valley Coal Measures 3D Model, superimposed on an estimated depth to base-Cainozoic level (basement) colour grid in the Latrobe Valley (values indicate metres below ground level). The areas with a purple hue indicate the thickest Cainozoic sequences. The main area of interest delineated, based on the sedimentary succession thickness and cumulative coal thickness, is east of Traralgon.

## Precision Temperature Logging

In light of the temperature data issues, HDR undertook Precision Temperature Logging (PTL) in late May 2011 to confirm prior reports of the subsurface temperature regime.

HDR interrogated DPI's 2011 Latrobe Valley Coal Measures 3D Model to identify the most geologically favourable area for exploratory drilling, namely where the Cainozoic sedimentary fill is thickest and where the cumulative coal measure thickness is greatest (Figure 6). The most prospective area based on the geological constraints was immediately east of Traralgon where the cumulative coal thickness was predicted to exceed 350 m and the sedimentary fill equates to approximately 800 m.

Boreholes in excess of 300 m depth were selected since shallower wells might be affected by both diurnal and seasonal effects and by abnormal climatic trends. Details of the selected bores are included in Table 1 and Figure 7.

| Bore Number | Logged Depth (m) | Maximum Temperature (°C) |
|---|---|---|
| Loy Yang 1675 | 628.0 | 63.2 |
| Loy Yang 2268 | 439.9 | 52.2 |
| Loy Yang 2269 | 244.9 | 35.0 |
| Loy Yang 2390 | 683.0 | 62.6 |

Table 1: Temperature data collected from the Precision Temperature Logging work program.

### Results

The temperature profile from the Traralgon–Flynn area (Figure 8) were encouraging and showed a steep and steady increase with depth through the coal-rich sequence.

Loy Yang 1675 is shown in detail below as an example of further analysis of the PTL data.

Loy Yang 1675

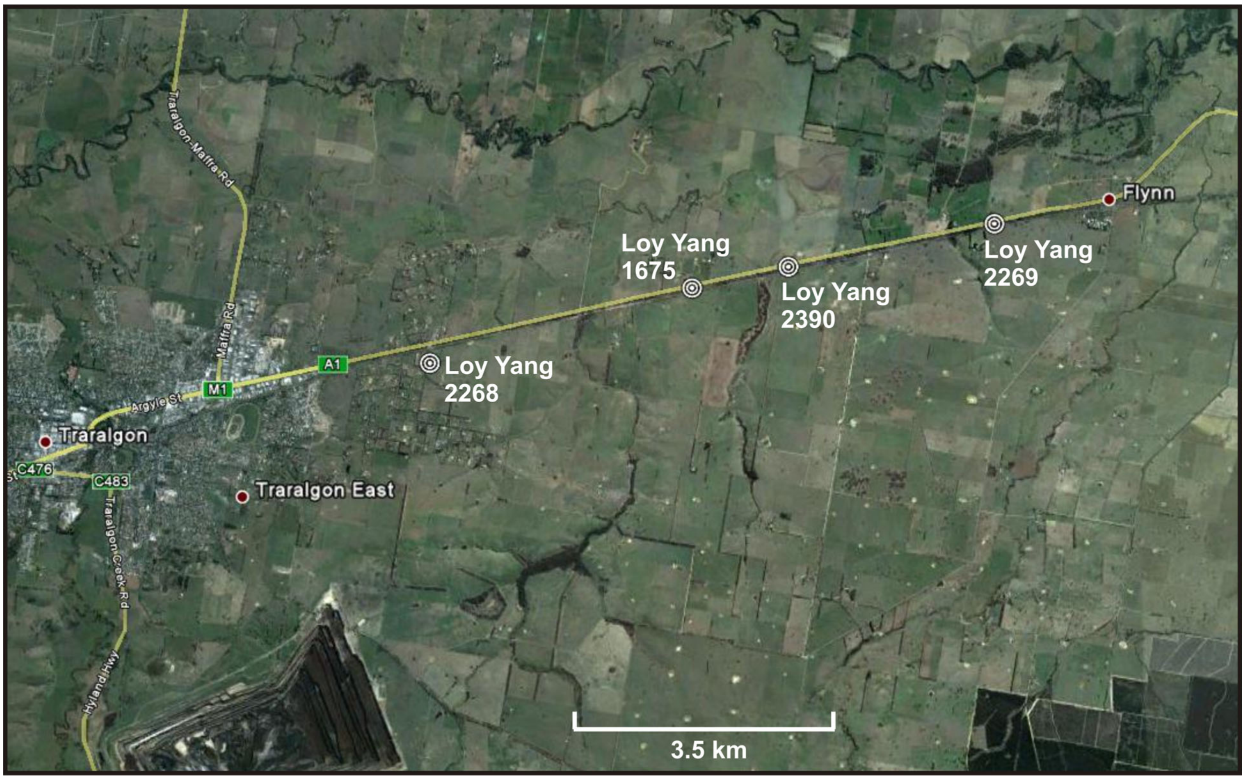


Figure 7: Precision Temperature Logging was performed on four bores in the Traralgon–Flynn area (background image courtesy of Google Earth).

The precision temperature log and derived thermal gradient log for Loy Yang 1675 are shown in Figures 9 and 10. Whilst the bore is 825 m deep, our temperature probe met an obstruction at 628 m, where a temperature of 63.2 °C was recorded, and was unable to descend any further.

The temperature gradient log (Figure 10) indicates approximately 250 m of coal-rich sediment had been penetrated down to 628 m. DPI's 2003 Latrobe Valley Coal Measures 3D Model (Figure 6) had suggested over 350 m of coal-rich sediment would be penetrated at the bore site, and HDR thus initially anticipated that a further ~100 m of coal might lie between 628 m and 825 m. DPI subsequently supplied wireline logs for the Loy Yang 1675 bore down to a total depth of 825 m. These logs include the Gamma

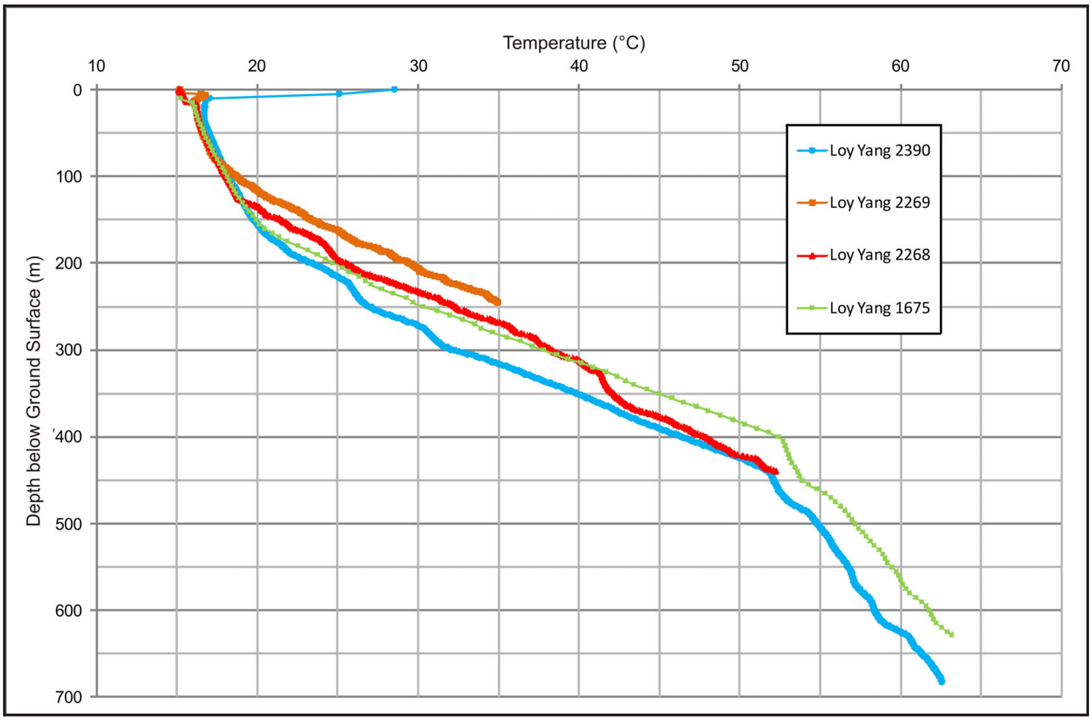


Figure 8: Precision Temperature Logs for the four Loy Yang bores.

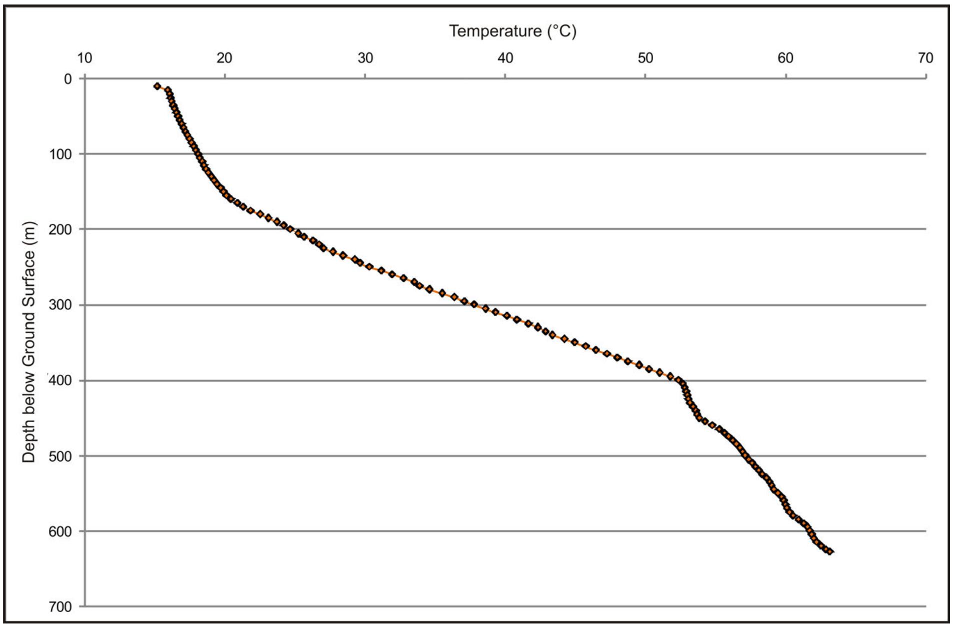


Figure 9: Precision Temperature Log for the Loy Yang 1675 bore. The maximum temperature of 63.2°C was recorded at 628 m.

Ray (GR) which can be used as a proxy for delineating lithologies in a bore. The GR log strongly suggested that the deeper stratigraphic section comprises sandstone, siltstone and carbonaceous mudstone rather than coal-rich lithologies. HDR therefore considered 350 m cumulative coal thickness unlikely. It is likely the temperature at the base of the Cainozoic will be ~75 °C at that location.

Evidence from the other three Traralgon–Flynn bores suggested a similar geological scenario, where the cumulative coal thickness interpreted from wireline logs is substantially less than the 2003 Latrobe Valley Coal Measures 3D Model suggests.

## Reservoir

Reservoir risk has many guises, and is dependent on the type of geothermal resource being targeted. In the case of the LVSGP, the target is a hot sedimentary aquifer (HSA). The key criteria for an HSA are porosity, permeability, transmissivity (i.e. permeability x aquifer thickness), storage and yield. These criteria determine reservoir ‘deliverability’ and whether sustainably high groundwater production and injection flow rates can be achieved for an economically viable geothermal power plant. HDR estimates that a flow rate of approximately 100 L/s will be required for target production levels for the LVSGP.

Within the study area the lowest technical reservoir risk lies with HSA targets of the Traralgon Formation. Favourable properties include its likely existence below the minimal target isotherm and its indicative primary porosities and permeabilities. The greatest uncertainty lies with its actual thickness, which can strongly impact reservoir transmissivity. Ideally, a reservoir thickness in the order of 100 m is required.

## Working fluid

For the proposed geothermal plant, if the target of 100 L/s is sustained then the amount of fluid cycled though the aquifer would be in the region of 3.2 GL/year. Existing hydrogeological evidence (e.g. porosity, permeability) indicates that units of the Traralgon Formation Aquifer System can act as high-yielding aquifers.

Across the entire onshore Gippsland Basin a significant long-term trend of declining water table levels has been recorded (GHD, 2010). However, the proposed geothermal electricity generation operation will involve reinjection of the water in a ‘closed loop’ circuit and its potential impact in terms of pressure effects are expected to be contained to the local site (on the order of 100s of metres radius). To properly evaluate potential production/injection effects HDR intends to complete numerical aquifer modelling to simulate the response of the aquifer to the proposed production-injection scenarios over a 20-30 year operation life span.

The Stratford Groundwater Management Unit (GMU) covers the LVSGP groundwater resources. The Stratford GMU has been fully allocated, thus HDR will be required to trade water entitlements if consumption of groundwater is necessary.

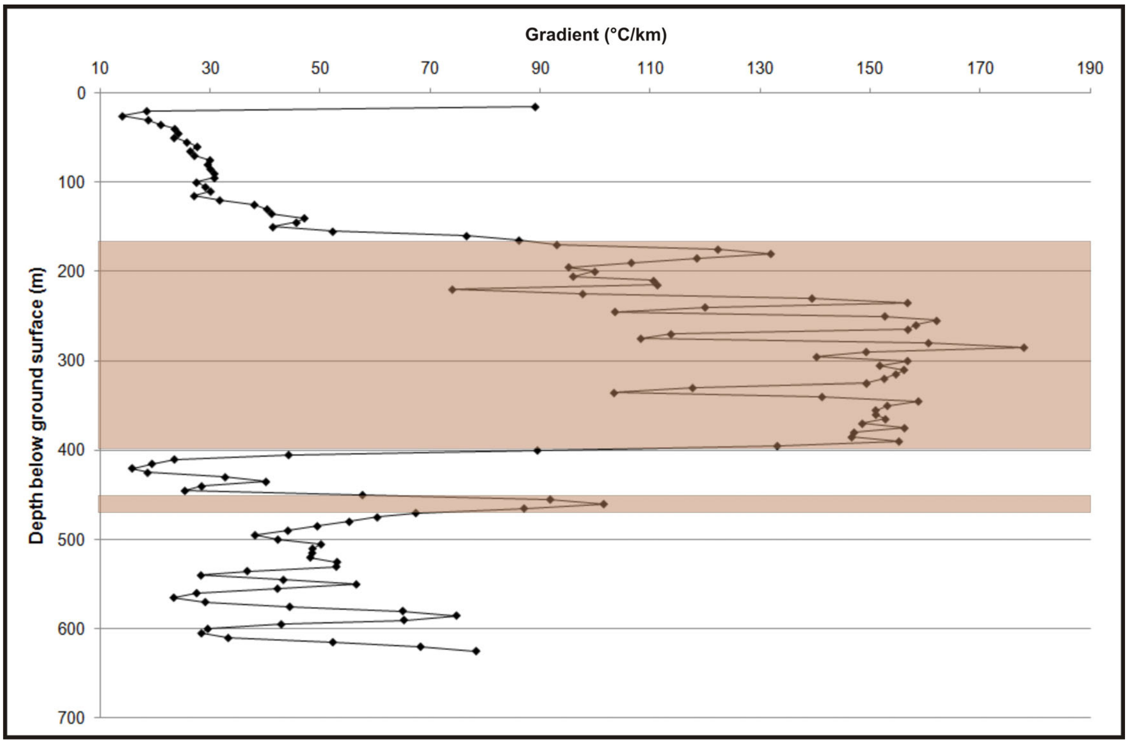


Figure 10: Temperature gradient profile of Loy Yang 1675. Brown shaded areas indicative of coal-rich sequences, at total thickness of ~250 m.

## Results

The GSA identified thermal resistance as the greatest risk in that the total coal thickness is uncertain down to the base Cainozoic. To mitigate this risk HDR chose to target an area with existing boreholes into the Traralgon Formation. A productive HSA reservoir at a temperature of 70–75 °C is the lowest risk geothermal target within the Cainozoic section of the Latrobe Valley. Existing borehole data suggest that such reservoir conditions occur in the vicinity of Maryvale.

gTET is designing an optimal power generation system for the LVSGP.

## Conclusions

The principle findings of the LVSGP GSA are:

1. A lack of quality, reliable temperature data from deep wells in the Latrobe Valley required that HDR undertake precision temperature logging (PTL).
2. The target geothermal resource for the LVSGP is groundwater at 70–75°C from 600–700 m.
3. HDR considers the risk of insufficient reservoir temperature as low for the LVSGP since the target temperature has previously been intersected in a bore within the target depth interval and location.
4. HDR considers the lowest technical reservoir risk for the LVSGP to be the lower Traralgon Formation. Favourable porosity and permeability attributes are likely to exist within the 600–700 m target depth. The greatest uncertainty lies with its actual thickness which can strongly impact reservoir transmissivity. A reservoir thickness on the order of 100 m is targeted.

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