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# Goulburn River Pump Station Geotechnics - Sugarloaf Pipeline Project

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## ABSTRACT

The Sugarloaf Pipeline project is an important element in the Victorian Government's response to the challenges of climate change, long-term drought and Melbourne's growing population. The 70 km long Sugarloaf Pipeline is capable of delivering water from the Goulburn River in central Victoria to Sugarloaf Reservoir, just north east of Melbourne in order to help alleviate Melbourne's water shortfall. Two pump stations form part of the project, one located at the start of the pipeline on the Goulburn River and a High Lift pump station positioned part way along the alignment. The Goulburn River Pump Station consists of two major shafts and an intake pipeline structure constructed up to 9m deep in saturated ground conditions, which consist of coarse alluvial sands and gravels. This paper focuses on the geotechnical considerations for the investigation, design and construction of the underground structures at the Goulburn River Pump Station site, in particular the innovative approach used to define the challenging and complex ground conditions. The use of advanced investigation tools such as sonic drilling and seismic refraction is highlighted, as this enabled the development of an informative 3D ground model. The paper also presents project benefits achieved through providing geotechnical monitoring and construction phase support facilitated through an alliance project structure.

**Keywords:** sugarloaf pipeline, Goulburn River, sonic drilling, seismic refraction, underground structures.

## 1 INTRODUCTION

The location of the Goulburn River Pump Station (GRPS) is on the southern bank of the Goulburn River, approximately 200m west of Killingworth Rd and approximately 5 km north of the township of Yea. The locality of the GRPS is presented in Figure 1.

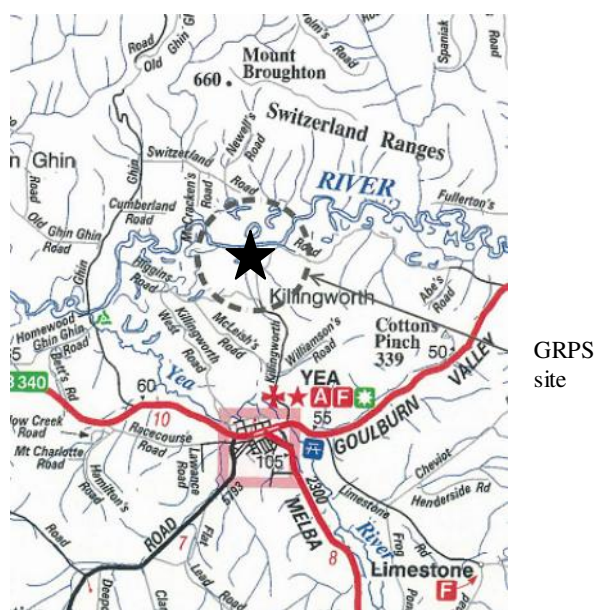


Figure 1. Location of GRPS site

The Goulburn River Pump Station (GRPS) forms the head of the project works, pumping water from the Goulburn River and delivering it to the Sugarloaf Reservoir via pipeline. The water captured by the

GRPS is transferred from site via a 1750mm diameter welded steel pipeline. The Sugarloaf transfer pipeline is aligned generally in a north-south direction and extends from the Goulburn River at Yea to the Sugarloaf Reservoir at Yarra Glen, covering a total length of approximately 70 km.

The GRPS contains the following structures:

- A wet well shaft with an internal diameter of approximately 17.25m and depth of approximately 10.5m below existing surface;
- A River Inlet Shaft Structure on the banks of the Goulburn River;
- A 2438mm ID concrete intake pipe of 90m length connecting the inlet shaft and wet well;
- Two pump station control buildings (positioned adjacent to the wet well shaft);
- Two rectangular valve pits (positioned adjacent to the wet well shaft); and
- Associated infrastructure, including pipe work connections, access roads and hardstand areas.

GHD formed part of an alliance team to design and construct this important project in partnership with Melbourne Water, John Holland and SKM.

The layout of the major structures is presented in Figure 2.

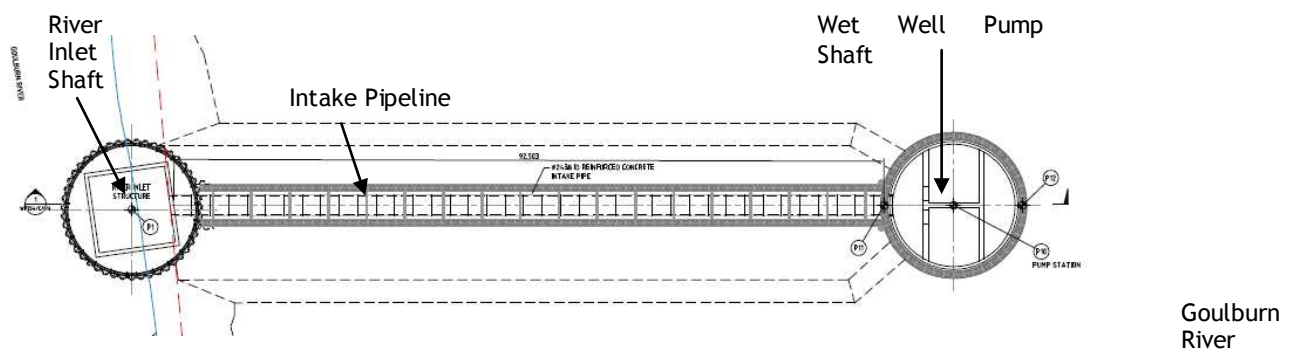


Figure 2. Positional layout of major structures at GRPS site

## 2 GEOLOGICAL SETTING

The bedrock geology of district is predominantly characterised by quartz sandstones and mudstones that have been extensively folded and faulted during the Early to Middle Devonian period.

At the GRPS site energetic erosion of the uplands occurring over more recent geological time scales has resulted in the formation of an alluvial flood plain and deposition coarse sands and gravels adjacent to the existing Goulburn River.

Approaching the site entry along Killingworth Road bedrock is visible in road cuttings, occurring as steeply dipping sequences of Devonian sedimentary rock. At the entry to the pump station site the topography dips down into the floodplain and the rock is buried beneath thick sequences of Quaternary alluvium.

Within the GRPS the topography is typically flat, with approximate elevations of between RL 162m to 163m (AHD). The alluvium covering the weathered bedrock varies in thickness across the site extending in places to in excess of 30m below ground surface level.

## 3 INVESTIGATIONS

### 3.1 Preliminary Drilling and Geophysical Exploration

Preliminary drilling undertaken in the early part of 2008 revealed the presence of thick alluvial deposits overlying weathered sedimentary rock. Initial drilling was undertaken using conventional wash boring

and cable tool type methods; however sampling was generally slow and problematic due to the coarse nature of the saturated alluvial soils.

To develop a conceptual model for the top of rock level, which would allow targeting of further boreholes, a geophysical survey was completed following the initial drilling using seismic refraction methods. The buried rock topography generated from the seismic survey data is presented as Figure 3.

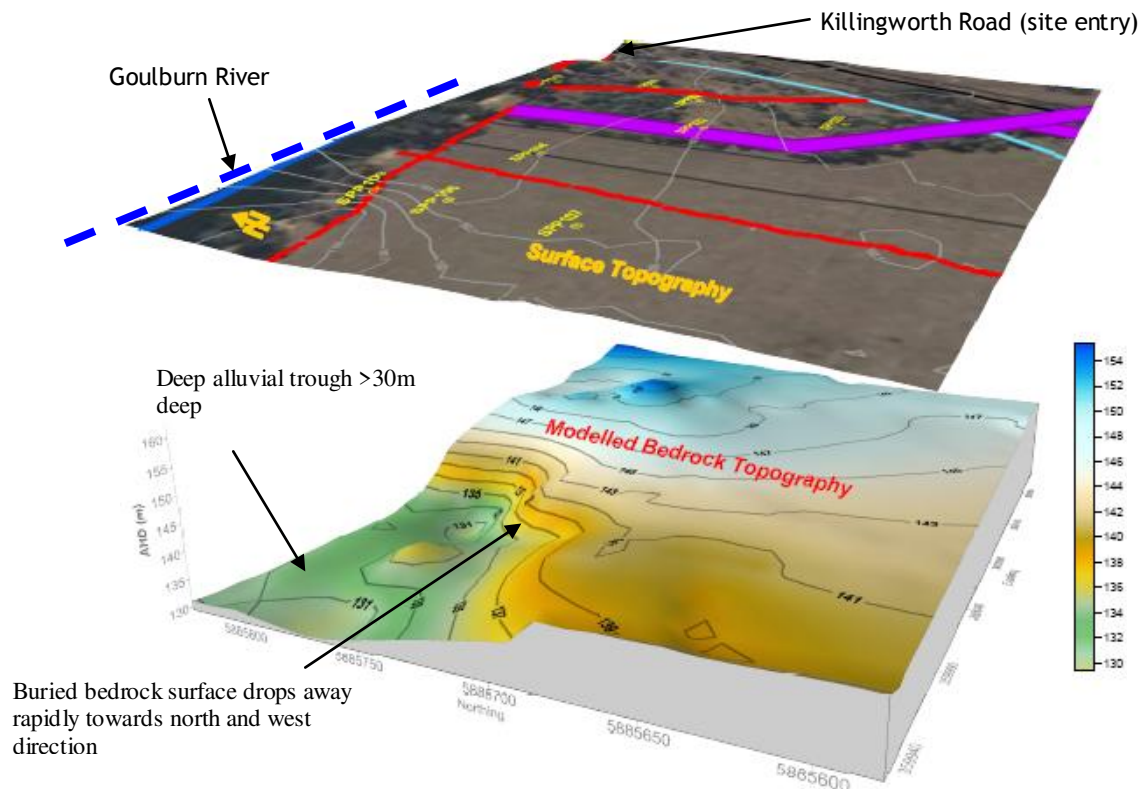


Figure 3. Buried bedrock topography determined from seismic survey

### 3.2 Detailed Investigations

A final round of detailed geotechnical and hydrogeological investigations was carried out in August 2008. The investigations were targeted to the final design location of the GRPS, which following analysis of the seismic data had been positioned as far as practicable towards the area of higher rock head to assist in forming a water cut off for the wet well shaft design while limited the length of the transfer pipeline as much as possible.

To overcome drilling difficulties and maximise the recovery of representative samples ten deep boreholes up to 35m in depth were drilled using a combination of sonic drilling and HQ triple tube diamond coring techniques. Sonic drilling techniques were used to advance the borehole through the upper alluvial horizon and were typically terminated on encountering bedrock. The sonic drill used in the alluvial materials collected of a 'semi-disturbed' continuous sample that allowed for interpretation of larger gravel and small cobble materials within the subsurface profile (Figure 3).



Figure 4. Soil samples showing alluvium particle size range collected using sonic drilling

Upon reaching bedrock level in selected boreholes the gravelly sediments were cased and a rock coring drill rig was used to advance the holes to the target depth.

At the time of the investigation the Boart-Longyear sonic drilling rig was newly commissioned to Australia and had completed only a handful of previous projects. Due to the new nature of the sonic technology it was elected to extend a few selected boreholes to full depth using the sonic rig. Although the sonic drilling method was able to penetrate the bedrock and collect 1m continuous sample runs, the rock recovered was generally badly shattered and disturbed by the sonic drilling and detailed logging of the recovered rock core could not be undertaken. Open standpipes were installed into selected boreholes to monitor the standing water level and to allow testing of the hydrogeological conditions.

#### 4 SUB SURFACE CONDITIONS

The geology of the site consists of a thick sequence of alluvial sediments overlying weathered sedimentary rock. The eroded rock surface slopes down from south to north, towards the Goulburn River. Rock levels at the Wet Well Pump Shaft were found to vary, deepening to the north and west but were typically around RL 146.4m (AHD) or 16m below existing surface level. Near the River Inlet Structure positioned on the bank of the Goulburn River, the rock level falls away to approximately RL 132.4m (AHD). The subsurface conditions can be subdivided into distinct units from shallowest to deepest as summarised in Table 1.

In addition to the description in Table 1 above changes in lateral and vertical facies are evident within the lower sand / gravel mixture layer. This illustrates changes in the depositional environment, consistent with meandering alluvial stream deposits. The distribution and relative thickness along the axis of the wet well, intake pipeline and river intake structure is presented in Figure 4. The site contains a relatively shallow unconfined water table, contained within the permeable Unit 4 alluvium. Groundwater observations taken during the investigations found the standing groundwater table to be approximately 4.5m to 5.0m below the existing ground surface level. There was little apparent difference in groundwater levels between Unit 4 (alluvium) and Unit 5 (siltstone) units.

Table 1: Subsurface Conditions

Unit	Soil Type	Description
1	SANDY SILT (ML)	Topsoil layer of approximately 0.3-0.4m thick
2	CLAY (CL)	Mottled, very stiff to hard consistency, minor sand fractions, extending to approximately 1.7-2.5m depth across the site
3	CLAYEY GRAVEL (GC)	Brown, sandy with some weakly cemented conglomerate zones. Typically dry and dense. Variable thickness but typically less than 1.0m thick
4	SAND and GRAVEL mixtures (SP-GP)	Consisting predominantly of variably graded sand and gravel mixtures, with minor clayey lenses. A very coarse basal gravel layer rests directly above the bedrock, containing rounded quartz and indurated sandstone particles typically ranging in size from coarse gravel to cobble sized. The thickness of this layer typically ranges between 0.3m to 1.0m thick
5	WEATHERED SILTSTONE (Bedrock)	Upper surface of the rock has undergone significant chemical alteration resulting in a weathered horizon (XW-HW) with frequent clayey zones. The thickness of this weathered horizon varies but is typically 2-3m. The insitu rock strength is heavily dependent on weathering class. Rock strength was generally logged as being between high to medium, where slightly weathered or fresh (SW & FR), and of low or medium intact strength for distinctly weathered core (DW [HW to MW]).

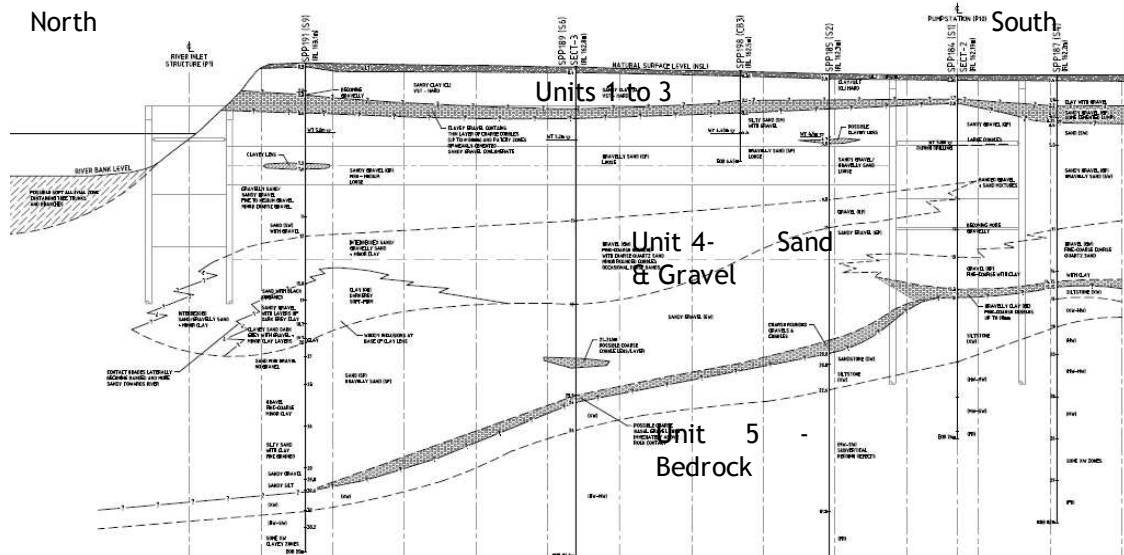


Figure 5. North-south cross section of subsurface conditions along axis of GRPS structures.

## 5 GEOTECHNICAL ANALYSIS

An analysis of the major geological units was carried out to determine parameters for design. In general thin layers such as the top soil (Unit1) and the Clayey Gravel (Unit 3) were ignored in the analysis.

A lower stronger sub unit (4b) was identified in the gravelly alluvium (Unit 4). The saturated soils below approximately 5m in depth in Unit 4 were found to demonstrate higher seismic ‘S’ wave velocities. These velocities gradually increased from around 280 m/sec at a depth of 5m below existing ground level to 450 m/sec at the base of the unit. The increase in velocity can be attributed to increasing

confinement and corresponding densification of the granular materials occurring with depth. Higher strength parameters (increasing linearly with depth) were generally accorded to the deeper saturated materials within Unit 4.

The bedrock horizon was also subdivided into two separate geotechnical domains with the upper layer (5a) representing the weaker weathered horizon overlying stronger less weathered rock (5b). The dominant units along with a summary of the geotechnical parameters derived from field and laboratory testing are summarised in Table 2. Where a range is given the number in parenthesis indicates the value adopted for the final design.

Table 2. Geotechnical Parameters

Unit	Bulk Unit Weight $\gamma_{sat}$ (kN/m <sup>3</sup> )	Shear Strength Su (kPa)	Effective Strength Parameters		At Rest Earth Pressure (Ko)	Elastic Moduli		Poisson's Ratio	
			Cohesion C' (kPa)	Friction Angle $\phi'$ (degrees)		Eu (MPa)	E' (MPa)	vu	v'
2	17-20 (20)	100	-	-	0.5	30	-	0.5	-
4a	16-20 (19)	-	0	36	0.41	-	30	-	0.25
4b	16-20 (19)	-	0	36-40	0.41-0.36 (0.41)	-	30-90 (30)	-	0.25
5a	20-23 (20)	(100-300) 100	-	-	0.5	30	-	0.4	-
5b	24-27 (25)	(500-5,000) 1,000	-	-	-	-	-	-	-

Analysis of the permeability testing conducted on open standpipes (rising/falling head tests) typically returned values between  $10^{-4}$  m/sec to  $10^{-5}$  m/sec for the Unit 4 alluvium material. Below the upper weathered horizon permeability of the fractured siltstone rock was found to be in the order of  $3 \times 10^{-6}$  m/sec. Groundwater modelling was carried out for the Wet Well Pump Shaft using SEEP/W, which predicted inflows of 3.55m<sup>3</sup> per day, based on one dimensional flow through the shaft base.

## 6 KEY GEOTECHNICAL ISSUES AND DESIGN SOLUTION

Due to the presence of the highly permeable alluvium layer extending up to approximately 15-20m depth it was proposed to construct the wet well shaft using a circular secant pile wall penetrating into the weathered siltstone rock to form a water cut-off. Excavation of shaft was then undertaken through the centre of the pile ring in the dry. The cut-off length of the secant pile socket design required a 3m penetration into the weathered siltstone rock to limit water flow through the base of the excavation. Due to the sloping bedrock geometry pile lengths were longer in the northern and western parts of the structure, with the maximum pile design length extending to around 23m below ground surface.

As the alluvium layer dipped downwards toward the river reaching a depth of 30m, construction of a water cut-off was not practical for the River Intake Structure. The temporary works design adopted for this structure utilised steel sheet piles driven to an approximate founding depth of 14m below river level. The structure was designed for wet excavation techniques with a mass concrete plug being placed sub-aqueously prior to dewatering.

The inlet pipeline has a design invert level of RL 154m and is positioned approximately 9m below the existing ground surface in the saturated alluvium. To overcome groundwater inflow difficulties and enable support of the pipe trench in saturated unstable ground a two stage construction approach was adopted. The first stage involved battered open cut excavations through Unit 1 to 3 materials to approximately 3m depth and forming of a 5m wide bench on either side of the pipe trench to enable establishment of a CFA piling rig. The remainder of the excavation was supported using 750mm diameter secant piles to form a vertical pipe trench, which was constructed and excavated in short progressive boxed panel sections to limit groundwater inflow problems.

## **7 CONSTRUCTION OBSERVATIONS**

During construction alliance geotechnical engineers visited the site on a regular basis to inspect the conditions exposed during excavation. Construction typically proceeded well with the subsurface conditions observed validating the geological model.

Piling for the Wet Well pump shaft and Intake pipeline trench utilised 750mm diameter secant piles, which were installed by Vibropile using rigs of up to 80 tonnes capacity. In general the interlock between the soft hard piles was good with only minor leakage observed during excavation of the shaft and trench wall. For the Wet Well Pump Shaft groundwater was effectively controlled by the use of the secant pile wall keyed into the underlying rock, limiting groundwater inflows to less than 4.5 m<sup>3</sup>/day (0.05 litres/second). This result was broadly in agreement with the low yields predicted by the SEEP/W model.

Piling of the River Intake Structure was completed by Wagstaff using a circular coffer wall configuration. Piles were vibrated into place to attain the required embedment depth. Although originally designed for wet excavation, following installation of the sheet piles and removal of soft river sediment, water was pumped out to assess whether base seepage through the alluvial materials of Unit 4 was tolerable and a dry construction method could be attempted. After viewing the shaft base conditions it was determined that sandy soil was fairly tight and the slow seepage inflows observed were deemed to be manageable by pumping. Excavation proceeded in the dry, with additional bracing rings designed and installed to counterbalance the external hydrostatic loads. Shaft base groundwater inflow rates could not be accurately measured due to leakages in the clutches of the sheet piles; however the total water ingress was modest and able to be controlled with a single pump.

## **8 CONCLUSIONS**

The use of a staged multidisciplinary investigation utilising geophysical methods and state of the art sonic drilling technology enabled accurate definition of the ground model at the GRPS site. In particular use of sonic drilling proved valuable in recovering representative samples to assessing the fines content of the gravels and evaluating strength and permeability characteristics and the combination of using perpendicular seismic refraction survey lines and investigation boreholes to develop a 3D ground model to assess the variability in bedrock topography.

Design of the structures concentrated on groundwater control strategies by adopting a deep secant pile wall socketed into rock for the Wet Well Pump Shaft and allowing for flexible wet excavation techniques for the River Intake and Inlet Pipeline Structures. Construction of the deep shaft structures and intake pipeline were successfully undertaken in difficult ground conditions comprising saturated alluvial sands and gravels.

## **9 ACKNOWLEDGEMENTS**

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## **REFERENCES**

Sugarloaf Pipeline Alliance 2009, "*Goulburn River Pump Station – Geotechnical and Hydrogeological Report*" Prepared by Sugarloaf Pipeline Alliance for Melbourne Water, January 2009