

Management of Groundwater System for Citylink Tunnels, Melbourne

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Abstract: The management of the groundwater system in the vicinity of the Citylink Tunnels is concerned with protecting private and public assets above the tunnels.

The regional geology consists of the Yarra Delta Sediments and basalt flows overlying the Melbourne Mudstone bedrock. The Yarra Delta sediments comprise a number of alluvial and marine sedimentary deposits. The alluvial deposits are typically granular in nature and produce important aquifers. The marine deposits are more recent in age and are susceptible to consolidation settlement.

The groundwater management includes monitoring of over 100 standpipes and vibrating wire piezometers, monitoring of over 500 survey pins, and monitoring and control of the groundwater recharge system. The groundwater recharge system consists of 5 permanent recharge wells, 10 passive recharge wells and a Water Treatment Plant. The monitoring data is stored in Microsoft® Access 2000 and GIS software package. ArcView is used to assist in assessing the behavior of the aquifers and settlement rates. The use of a database and GIS software tools allow rapid and easy review of a vast volume of data to show groundwater and ground surface trends.

INTRODUCTION

The Citylink Tunnels were constructed in the late 1990's and consists of two tunnels, known as the Burnley Tunnel and Domain Tunnel, and form an integral part of the Melbourne Arterial network.

The geology and groundwater encountered during excavation of the Citylink Tunnels instigated a number of design and construction modifications. The modifications included the development of an expanded permanent groundwater management system that comprises of the control of permanent groundwater recharge, and monitoring of groundwater levels and ground surface settlement.

The permanent groundwater management system includes monitoring of over 100 standpipe piezometers and vibrating wire piezometers, monitoring of over 500 survey pins, and monitoring and control of the groundwater recharge system. The groundwater recharge system consists of 5 permanent recharge wells, 10 passive recharge wells and a Water Treatment Plant.

In addition to the monitoring data collected on the surface, groundwater inflow and external hydrostatic pressure data is collected from within the tunnels.

The permanent groundwater management system includes the management of a vast volume of data that is used to plot settlement and groundwater level trends and is used to generate groundwater drawdown contours and

settlement contours. Database and GIS software is used to assist in managing and interpreting the groundwater management data.

A secondary system of shallow passive recharge to maintain the groundwater regime is utilized around South Bank Interchange. This secondary system is not discussed in detail in this paper.

REGIONAL GEOLOGY AND HYDROGEOLOGY

The main geological units from youngest to oldest are:

- Quaternary units of the Yarra Delta Group represented by:
 - Coode Island Silt (Q_c)
 - Holocene Alluvium (Q_{ha})
 - Newer Volcanics (Q_{nv})
 - Fishermen Bend Silt formation (Q_f)
 - Moray Street Gravels formation (Q_m)
- Tertiary Port Phillip Basin units represented by:
 - Werribee Formation (T_w)
 - Older Volcanics (T_{ov})
 - Brighton Group (T_b)
- Silurian Siltstone and sandstone of the Melbourne formation (S)

Detailed descriptions of the main geological units are discussed elsewhere (Golder 1997, Short *et al* 1999, Hutchison *et al* 1999). The geological units that are pertinent to the groundwater management system are the Coode Island Silt, Moray Street Gravels, Holocene Alluviums and Silurian bedrock.

A brief description of the geology is as follows:

- The Silurian bedrock, consisting of moderately to highly jointed, interbedded siltstone and sandstone, was folded, faulted and intruded by igneous rocks during the Mid-Devonian.
- Alluvial sand, gravel and lenses of silt and clay were deposited in deep erosion valleys in the Silurian bedrock. These alluvial sediments were deposited during a period when the sea levels were much lower than today, and are known as the Moray Street Gravels (MSG).
- Another valley was cut down into the Silurian bedrock during the Holocene and alluvial sands and gravels were deposited into this valley to become known as Holocene Alluvium (HA).
- Typically overlying the MSG and HA is the Coode Island Silt formation (CIS). The CIS was deposited in a moderately shallow marine or estuarine environment.

The CIS is a highly compressible soil, and susceptible to secondary consolidation (sometimes referred to as creep in the literature). The effects of secondary consolidation of CIS are well documented in the geotechnical literature.

The CIS is also susceptible to primary consolidation settlement through groundwater lowering. Groundwater lowering results in a decrease in pore pressures and an increase in the effective weight of the soil in the zone of groundwater drawdown and leads to primary consolidation of the soil. The consolidation of the CIS is governed by the increase in effective stress (ie the drawdown), thickness of the CIS, its' compressibility and the length of time over which the increased loading is

applied.

A typical section of the Yarra Delta sediments in South Melbourne are shown on Figure 1.

The impact of the regional geology and hydrogeology was summarized by Golder 1997 as “*The hydrogeological interaction between the underlying bedrock, the alluvial aquifers within the various old courses of the Yarra river, the effect of drainage to the tunnels and the presence of highly compressible clay (Coode Island Silt Formation), combine to provide a complex geotechnical environment.*”

TUNNEL CONSTRUCTION

The Citylink project was delivered under a build-own-operate-transfer (BOOT) arrangement. An overview of the design process and development is provided by others (Short et al, 1999, Talyor et al 1999) and an ‘*observational approach to design and construction*’ was adopted.

The Citylink Tunnels consist of two tunnels, the longer (and deeper) tunnel called the Burnley Tunnel and the other, the Domain Tunnel. As well as passing under some of the city’s prime business areas and heritage parklands and bridges, a section of tunnel travels beneath the Yarra River. The locations of the Tunnels are shown on Figure 2.

The tunnels consisted of cut and cover tunnel sections and driven tunnel sections. The tunnels are both

Figure 1 Typical section of the Yarra Delta sediments

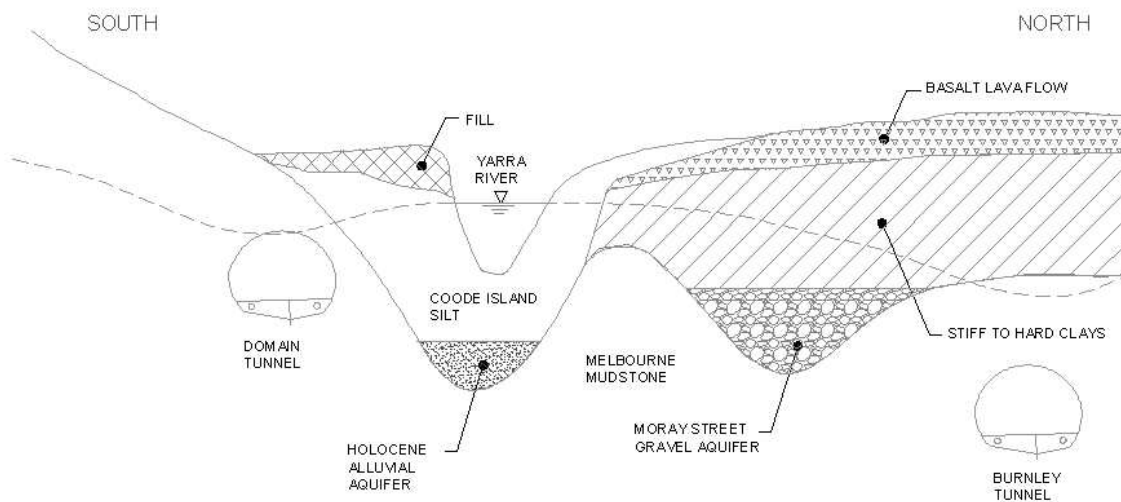
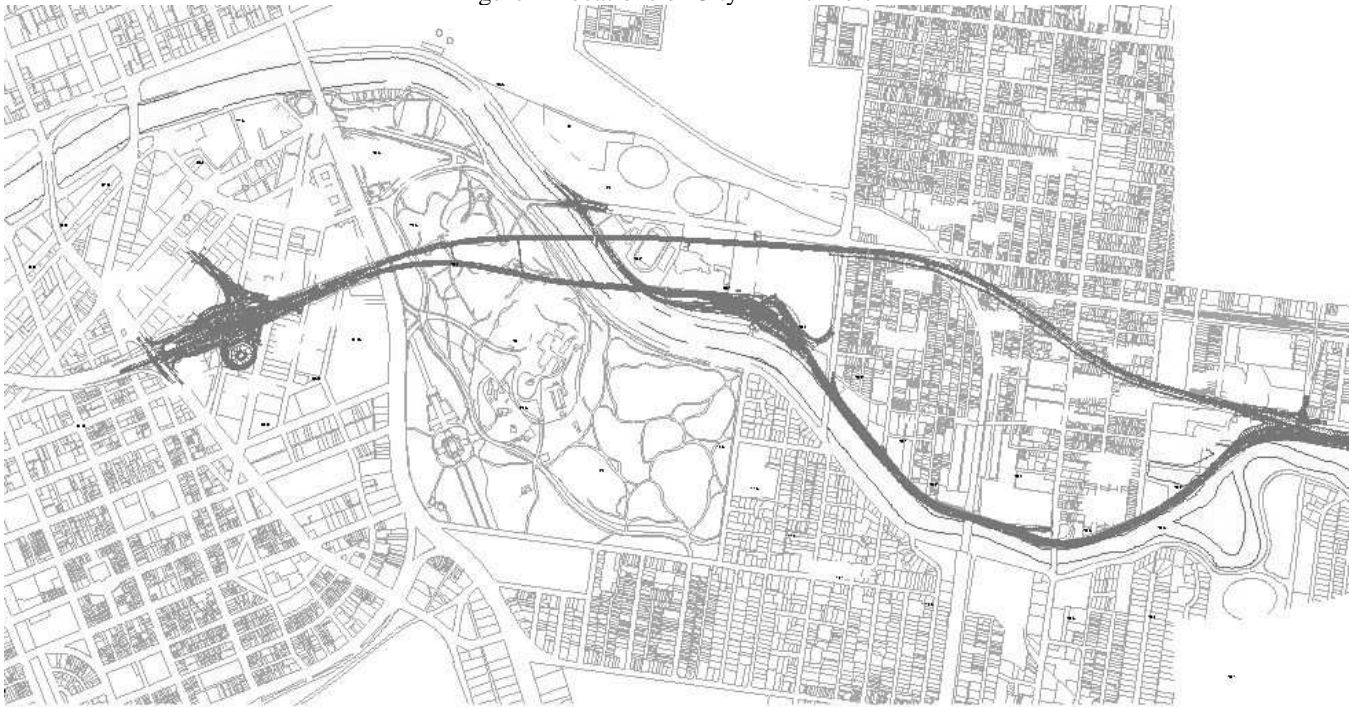


Figure 2 Locations of Citylink Tunnels



approximately 16m wide and 9m high. A modified ellipsoid shape was adopted for the tunnels because it efficiently accommodates the traffic envelope and various appurtenances and is efficient for roadheader excavation and tunnel support.

The driven tunnel section of the Burnley Tunnel was constructed by excavating a centrally located shaft, known as the Swan Street Shaft and two teams working in opposite directions excavated the tunnel using roadheader machines.

Significant groundwater seepage was encountered during the excavation and the tunnel liner detail was modified to a tanked liner and thickened concrete floor (Adams *et al* 1999).

The Burnley Tunnel is up to 60m below the ground surface level and is 3.6km in length. The Domain Tunnel is 1.6km long, with the invert reaching RL -20m

The final permanent design of the tunnels included drained and undrained (tanked) sections.

The Domain Tunnel and Burnley Tunnel were open to the public in April 2000 and December 2000 respectively.

INFLUENCE OF TUNNELS ON GROUNDWATER SYSTEM

As a consequence of groundwater inflows during tunnel construction, groundwater drawdown occurred in the local aquifers and Silurian bedrock. As previously

mentioned the CIS overlying the tunnels and aquifers is susceptible to settlement through groundwater lowering and a number of modifications were made during construction to control groundwater drawdown and these modifications include:

- Sections of the tunnel liner were modified from drained liner to a tanked liner, the tanked sections were lined with a full water proofing membrane;
- A number of recharge wells were installed to pump water back into the local aquifers.

Other modifications made during construction include:

- Rock anchors were installed to support the liner against increased hydrostatic pressures and increase the tunnel liner integrity.
- Installation of settlement monitoring points

The installation of rock anchors has penetrated through the water proofing membrane in the tunnel causing some seepage in the tanked tunnel sections.

Groundwater inflows within the tanked and drained sections of the tunnels are collected within tunnel drainage system and pumped to the ground surface.

Ongoing grouting through the tunnel liner has further reduced the groundwater inflow into the tanked sections of the tunnels.

Five permanent deep recharge wells are now in operation and recharge water into the HA and MSG aquifers. Initially, the recharge water used potable water. CityLink Melbourne Limited (CityLink) recognized that this was

an inappropriate use of potable water and undertook to find an alternative source of recharge water.

In 2002 Citylink Melbourne Ltd constructed a Water Treatment Plant (WTP) adjacent to the Swan Street Shaft at a cost of \$1.3million dollars (The Age 2002). The WTP receives water pumped from the drainage system in the tunnels, treats the water, and then pumps the recycled water to the permanent recharge wells and re-injects it back into the aquifers.

The modification works during tunnel construction have assist in reversing the groundwater drawdown observed in the HA, MSG and Silurian.

Since 2002 Maunsell Australia Pty Ltd has managed the management of the groundwater system in the vicinity of the Citylink Tunnels.

POST CONSTRUCTION - GROUNDWATER MANAGEMENT SYSTEM

The groundwater management system for the Citylink Tunnel consists of managing groundwater recharge flows, collecting groundwater monitoring data, populating a database, reviewing tunnel inflow, groundwater and settlement trends and assessing these trends against management targets. Monitoring data for key instruments and the groundwater assessments are presented in a report issued to the State Government (or there representative) at regular intervals. The reports are currently issued monthly.

MONITORING DATA

As part of the groundwater management system, the following is undertaken:

- At the surface:
 - Monitoring of about 100 standpipe piezometers and vibrating wire piezometers
 - Monitoring of about 500 survey settlement pins
 - Monitoring and control of 5 permanent deep recharge wells
 - Monitoring of 10 shallow passive recharge wells
 - Monitoring of total recharge flow from the WTP.
- In the tunnels:
 - Monitoring of external hydrostatic pressures on the tunnel liner
 - Monitoring of tunnel floor movement
 - Monitoring of groundwater inflows in drained and tanked sections of the tunnels
 - Monitoring of tunnel drainage pump data.

Currently, the groundwater monitoring data is collected manually and at frequency ranging from weekly to every 6 weeks.

Monitoring of some instruments date back to 1992.

DATABASE

During construction the monitoring data was stored in Microsoft ® Excel¹ due to its ability to produce charts and widespread use. However, it was considered that Excel was not a suitable database to store and assess the groundwater data as a long term system. The data set recently passed 100,000 numbers and is growing. It was deemed appropriate to search for a suitable database.

Microsoft ® Access 2000 was adopted as the database for the groundwater data as:

- It is able to process large volumes of data;
- Compatible with most software packages;
- Readily available (with Microsoft Professional Office 2000);
- Provides different levels of security, allowing the database manager to check and correct data, and allow users to enter data only.
- Provides a switchboard manager enabling easy navigation around the database.

To assist in managing the input of data two data input templates were developed within Access. The first template allowed the user to populate a large volume of data into the database quickly, such as survey data. The second template allows the user to enter single data values. This template displays previous data readings and flags if the most recent data is approaching or exceeding management target limits. Flags and management target limits will be discussed further later on.

The data input templates reduce the raw reading into more meaningful data. For example, groundwater levels in standpipe piezometers are recorded as depth from ground surface level to groundwater level and the data input templates reduce this data to a RL of the top of groundwater. In addition to reducing the raw data, the database calculates the rate of change of the reduced value since the previous reading.

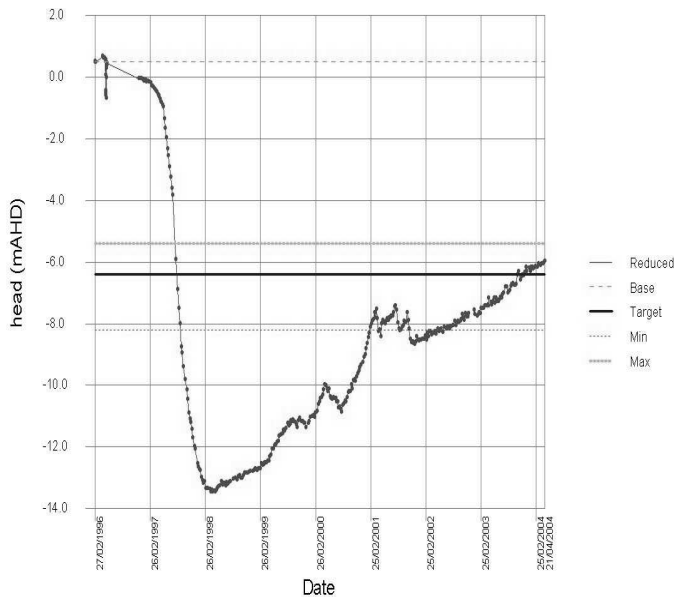
The management system consists of four management target levels:

- Maximum level;
- Target level;
- Minimum level; and
- Maximum rate of change.

The Target level is a nominated level at which the actual data should be heading towards. The Maximum level and Minimum level are upper and lower bound limits respectively. The Maximum rate of change is the upper limit of change between two consecutive readings. An

¹ Microsoft ® Access 2000 and Excel are property of the Microsoft Corporation

Figure 3 Groundwater Management Target Levels



example of the management target levels is shown on Figure 3.

Flags operate on two levels:

- Orange flag; and
- Red flag.

Both the reduced level and rate of change can raise a flag. If the reduced level is closer to the maximum level or minimum level than the target level, an orange flag is raised and provides a warning that the reduced level is moving away from the target level. If the reduced level

moves outside the maximum or minimum level then a red flag is raised and provides a warning that the reduced level is outside management target levels. The same applies to the maximum rate of change.

The philosophy behind the two color flag system is to allow early identification of data trending away from the target level and provide an opportunity to make changes to the system, ie increase or decrease recharge flow. Not all instruments have target levels due to the reading accuracy and error margin associated with particular instruments. For example, some inflow monitoring instruments have an accuracy range of $\pm 50\%$.

ArcView is able to quickly produce charts for groundwater data and settlement data. It is able to produce contours of groundwater drawdown and settlement, see Figure 4.

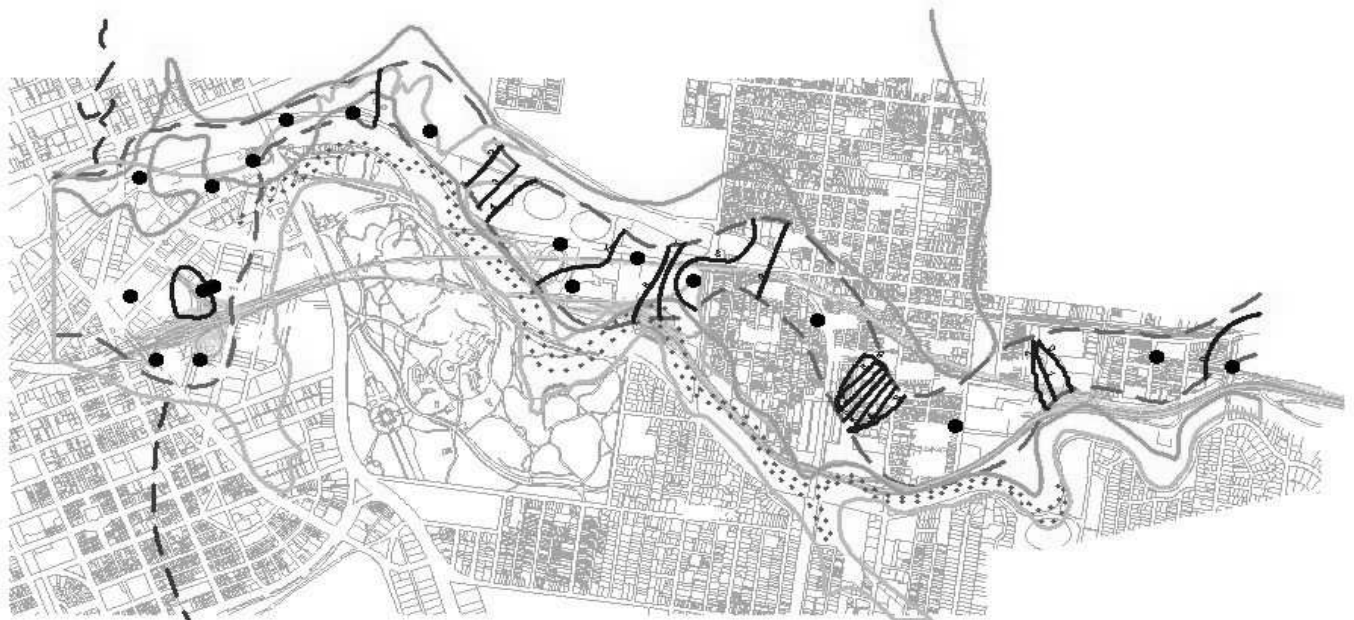
Groundwater drawdown contours are generated in ArcView where the drawdown is the difference between the current groundwater level and the pre-construction 'base level'. The base levels have been assigned based on results of historical data and groundwater modeling undertaken by Golder Associates during construction.

ONGOING MANAGEMENT ISSUES

The existing monitoring network will be progressively reduced as groundwater recovery occurs.

Ongoing improvements to the recharge system include automation of recharge system with telemetry support, the use of dataloggers in the tunnel, and investigating methods of increasing the operating life of recharge wells.

Figure 4 Groundwater drawdown contour



Upgrading of the database will require significant input due to the non-compatibility between ArcView 3.1 and the upgraded current version, Version 8.

CONCLUSIONS

The management of the groundwater system in the vicinity of the Citylink Tunnels is concerned with the protecting the Tunnels themselves as well as private and public assets above the tunnel. The groundwater management system will be an ongoing process for the life of the tunnels.

The groundwater management system is primarily concerned with monitoring the behaviour of the groundwater in the important aquifers and ongoing settlement of compressible soils.

The monitoring data is stored in Microsoft Access 2000 and the GIS software package ArcView (version 3.1) is used to assist in assessing the behavior of the aquifers and settlement rates. The use of a database and GIS software tools allow rapid and easy review of groundwater and ground surface trends. Developing and implementing management target levels assist in reviewing and assessing vast volumes of data.

I have been actively involved in developing and implementing a system for the management of the groundwater system. I was initially involved in developing and populating of the database, collecting data and over the last year have managed this project.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the support and input from Brian Chandler and Rob Day of Maunsell Australia Pty Ltd. The author also wishes to thank David Harper and Citylink Melbourne Ltd for permission and support to whilst publishing this paper.

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