DEPRESSURISATION OF THE CLEVELAND ST UNDERPASS

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ABSTRACT

Between May and July 2014 the Cleveland St Underpass on the Eastern Distributor, Sydney was successfully resurfaced using open grade asphalt some 15 years after motorway construction. To undertake this work required temporary depressurisation of the surrounding aquifer so that the motorway could be kept dry throughout the work period. Key to the project was rapid depressurisation such that works could be completed during night shift and within tight work hours dictated by RMS minimising disruption to one of Sydney's busiest motorways. Surface monitoring of groundwater levels was also required to ensure the drawdown beneath adjacent structures was within acceptable limits established from review of construction records and historical data. The successful depressurisation of this section of the motorway was the culmination of 4 years of research, modelling, testing, permitting and monitoring. This paper describes the staged approach performed over 4 phases of investigation, testing and monitoring of the novel solution to dewatering that was utilised to make resurfacing possible.

1 INTRODUCTION

The Eastern Distributor is one of Sydney's busiest motorways near the Cleveland St Underpass (CSUP) has experienced groundwater entering the pavement surface for an extended period. This has resulted in adverse performance of the pavement surface, has delayed resurfacing and has been attributed to damage to some of the utilities pits.

This area has been the subject of various episodes of maintenance, attempted remedial works, investigations and assessments. PSM was initially engaged to review the existing studies to identify a feasible dewatering strategy, which was then advanced to design, trials and ultimately implementation

2 BACKGROUND

The Eastern Distributor is a 6 km long motorway was constructed during the period 1997 to 1999 for a cost of $780M. Traffic volumes are around 25,000 per day and up to 5,300 vehicles per hour forming a vital link to Sydney AirPort. It was privately built and owned and is operated by Airport Motorway Limited.

The motorway includes a "parkway" section from the southern tunnel portal to south of Todman Avenue. This parkway consists of a depressed motorway formation located below the original ground surface and surrounding road infrastructure with various architectural and landscape features.

The focus of this paper is the section of the parkway referred to as the Cleveland Street Underpass or CSUP. This encompasses the length of depressed motorway located in vicinity of the Cleveland Street bridge with a total length of about 420 m. The CSUP section is tanked with the base of the pavement slab situated about 2 to 3 m below the water table.

The parkway design varies along the length of the motorway. Within the length of the subject site, there exist three typical cross sections though there is some variability throughout relative to the road grade and proximity to the Cleveland Street Bridge structure. The configuration at the underpass itself is shown in Figure 1 and Figure 2. Of particular note is the use of a 'floating' system where the diaphragm walls do not extend to bedrock. This design was adopted to provide minimal disruption of regional groundwater flow across the site given the importance of the Botany Sands Aquifer and to reduce adverse groundwater effects given the population density of the area. Also shown in Figure 2 is the approximate level of the water table, an underlying low permeability peat layer and the pressure relief mechanism comprising transverse strip drains every beneath the pavement slab connected to pressure relief pipes. The underdrainage system was situated at 6 m centres along the CSUP section. The overlying Cleveland St Bridge is founded on central piles that extend to bedrock.

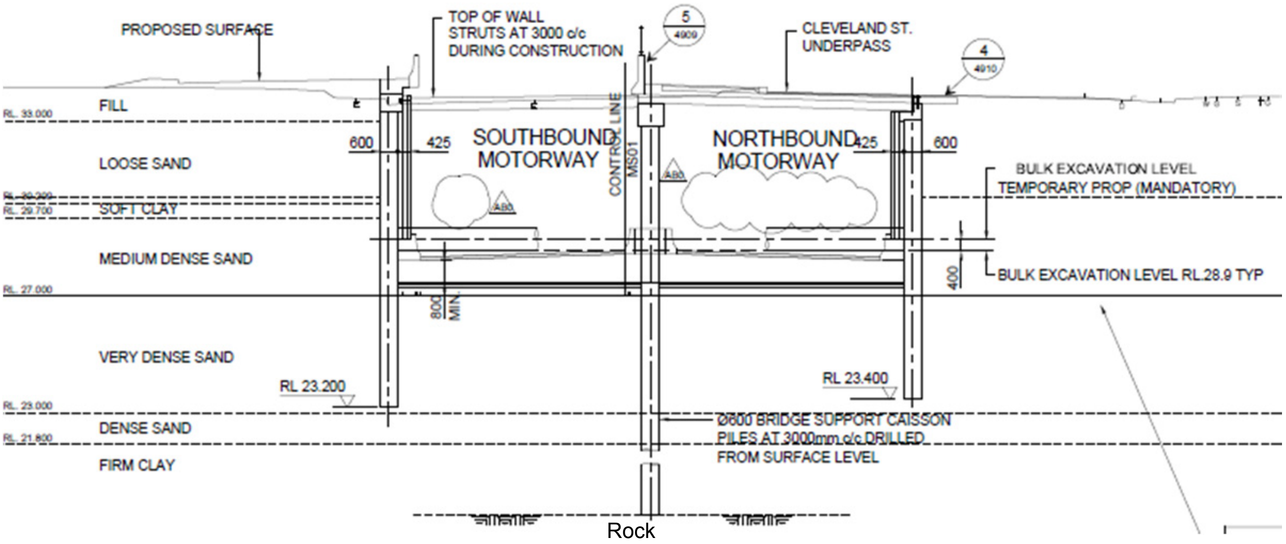

Figure 1 – Underpass Structure – Typical section

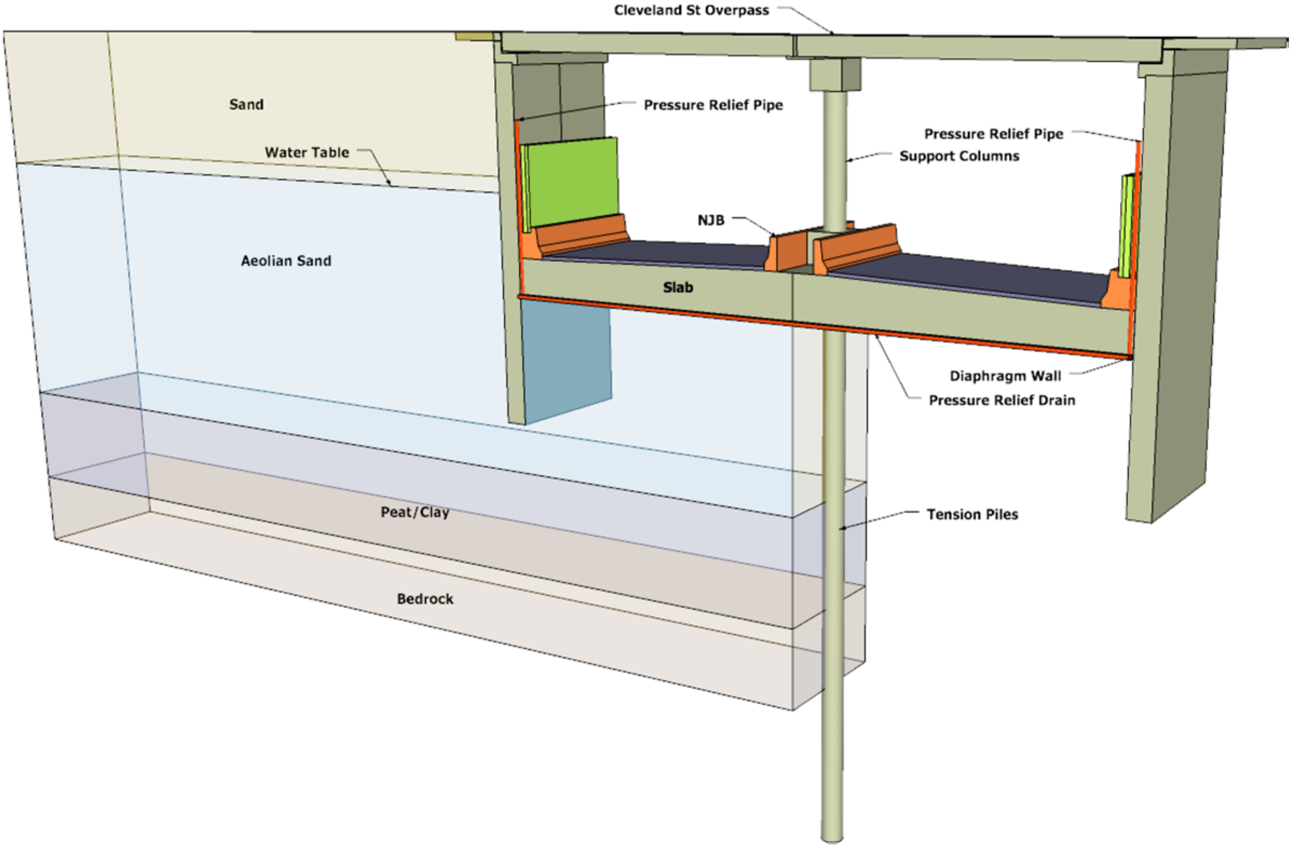

Figure 2 – Underpass Structure – 3D geometry

Several years after construction water ingress at CSUP was noted in a number of locations. This ingress was manifest as surface weep points at differing locations of the CSUP pavement constructed from open grade porous asphalt (OGA). Continued seepage over time resulted in local pavement degradation and surface loosening, through the original OGA has survived 15 years which exceeds typical exceeds typical resurfacing intervals for this type of surface. Localised patching of these areas was undertaken using dense grade asphalt (DGA) due to the presence of seepage and the inability to lay OGA. The longevity of the patch was less than expected due to the build-up of seepage pressure, which loosened and eventually separated the asphalt from the slab.

A number of studies were conducted by others to investigate the cause of seepage and possible remediation. The findings of these studies were essentially:

- The cause and location of seepage could not be conclusively defined
- It was unlikely that seepage could be prevented
- The preferred resurfacing option was to repeat the use of OGA so that seepage pressures would be relieved
- It was envisaged that the seepage that did occur would flow through the OGA and be collected at the perimeter scupper drains and not be manifest at the surface.

While the use of OGA was accepted as a solution, the placement method required the motorway to be dry. At this stage of the works, PSM was asked to look at possible ways by which the motorway could be made dry to facilitate OGA placement.

Key criteria for all of the works was minimising the risk of closure of the Eastern Distributor beyond approved the shutdown duration.

2.1 GROUNDWATER CONDITIONS

CSUP is located within the Botany Sands Aquifer comprising unconsolidated Quaternary age sediments overlying a deeply incised eroded bedrock surface. In this location, the sediments of the Botany Basin may be divided into three main units:

- An upper aquifer unit comprising approximately 15 metres of aeolian sands.
- A middle aquifer unit comprising approximately 5 metres of peaty and silty clays; and
- A lower aquifer unit comprising interbedded estuarine/alluvial sands, peats and clays.

This simplified geology is depicted in Figure 2.

The groundwater flow direction in this part of the Botany aquifer is to the south-west, with groundwater discharge to the Alexandra Canal. Regional flow is to the south-west and south towards Botany Bay.

Figure 3 presents groundwater levels at the site prepared by Jewell and Associates from a composite of sources. These contours show that the groundwater across the CSUP site varies by approximately 3 m.

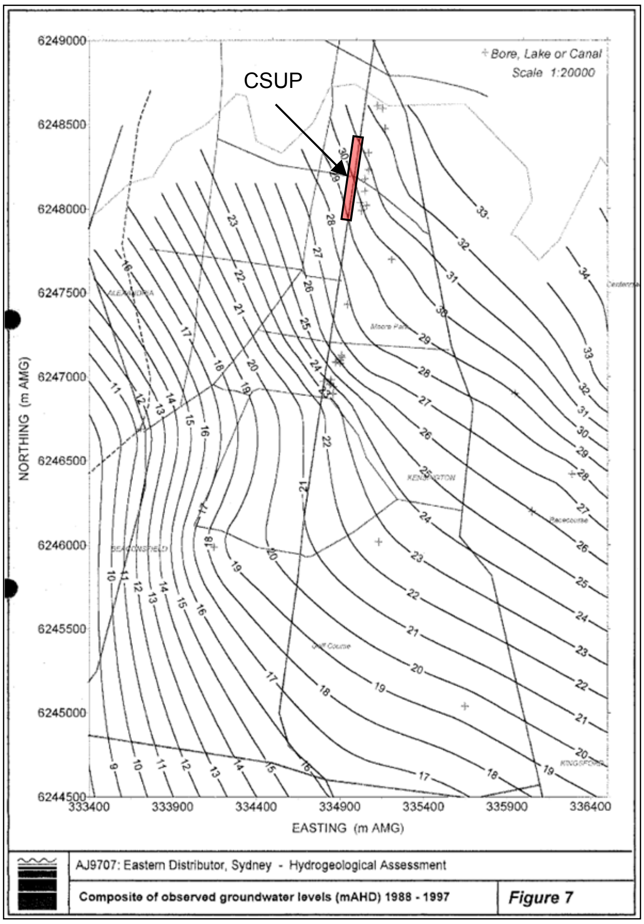

Figure 3 – Composite observed groundwater levels 1988 – 1997 (Jewell (1997))

The design of the motorway at CSUP necessitated temporary dewatering for construction. Consequently, a number of hydrogeological investigations were required including:

- Geotechnical drilling including piezometer construction and some penetrometer testing along the motorway corridor.
- Pumping tests conducted in Moore Park and at Zetland.
- A reinjection trial conducted at Zetland.
- Regional scale numerical modelling studies.
- Local scale analytical and numerical modelling studies.

The investigation identified three primary issues of concern related to groundwater, these being:

- Buildings located within the zone of influence of dewatering.
- Vegetation, particularly large fig trees in Moore Park,
- Groundwater users.

Key consent conditions relating to groundwater for motorway design and construction were:

- A fully tanked structure.
- Building surveys where differential settlement was predicted to exceed 10 mm across the span of a domestic structure, unless otherwise agreed by DLWC.
- Dewatering to be carried out by spearpoints
- All existing registered bores within 400 metres of the excavation to be monitored to the satisfaction of DLWC; this zone to be extended if required, and minimum impact and or provision of alternative supplies to be ensured.

During construction groundwater and settlement monitoring was performed that demonstrated temporary dewatering resulted in settlement impacts to nearby buildings, many of which are of double brick construction and sensitive to settlement. These construction phase groundwater records were highly valued to development of the groundwater model at the site.

3 PROPOSED SOLUTION

PSM considered a number of options to prepare the motorway for placement of OGA in the dry. These were:

- Injection grouting below the pavement to seal seepage areas
- Temporary shallow dewatering immediately outside the diaphragm walls
- Temporary deep dewatering within the median between carriageways

Grout injection was assessed to be unfeasible based on previous attempts made by others. These attempts were typically ‘hit and miss’ with the movement of grout being largely uncontrolled. Ultimately the risk of impacting pressure relief pipes and drainage infrastructure within the motorway was deemed unacceptable.

The temporary depressurisation options, though feasible, were highly disruptive to traffic, risked damage to the motorway by inducing settlement and were extremely costly.

During feasibility assessment of these options it became apparent that an alternative approach of targeted depressurisation rather than dewatering may be possible via pumping performed from the existing relief pipe network. This effectively located groundwater depressurisation to just below the slab level. If successful this approach would have a number of benefits to the project most notably reduced traffic disruption, time and cost. Consequently, a detailed investigation of this possibility was initiated. This investigation required following questions to be answered.

1. Was the pressure relief network constructed as per available drawings?
2. Would the pressure relief network have capacity to sufficiently depressurise the motorway?
3. Could depressurisation be undertaken within the available timeframe (i.e. within each nightshift)?
4. What would be the most efficient means of pumping from the network?
5. Would the pressure relief network be compromised under pumping?
6. How would depressurisation within CSUP be measured?
7. How would potential drawdown impacts on structures outside CSUP be safeguarded?
8. What would be the quantity of water removed during pumping?
9. How would this quantity be disposed?
10. What would be the environmental impacts of the system including water quality and disposal?

It is evident from the above that many of these questions are interrelated. Answering these questions required several parallel investigations, which formed the basis of the detailed feasibility study.

4 FEASIBILITY STUDY

The detailed feasibility study was developed to answer the questions in Section 3 while balancing approval lead times, likely investigation outcomes and investigation costs. It was recognised early that approvals for activities such as water disposal and road closures would require the longest lead times particularly given the significance of the Eastern Distributor to the Sydney Road Network. Consequently, feasibility was undertaken in four phases of increasing complexity, detail and cost as discussed below. The outcomes of each phase shaped the approval, direction and detail of subsequent phases.

4.1 PHASE 1

Phase 1 of the study was to establish the current condition of the site including viability of existing monitoring wells, what the water levels were and how and where pumping could be made viable . This comprised an investigation of the state of existing piezometers and the suitability for monitoring current water levels and response due to potential pumping within CSUP. This investigation included:

- Locating existing wells that survived construction.
- Checking their construction using downhole camera.
- Cleaning and testing of their response under water injection.

Ultimately 12 working wells were identified for establishing current water levels and potential drawdown due to pumping within CSUP as well as the NoW monitoring well GW042158 located in Moore Park.

Concurrently preliminary 2D FEM modelling was undertaken to investigate likely rates of extraction required to depressurise the CSUP slab, the most efficient location for this pumping to be carried out and the likely drawdown at adjacent structures outside the motorway. This was essentially a sensitivity study to investigate the possibility of depressurisation by pumping in general. More details on modelling are in Section 5.

This initial phase of the work was sufficient to establish that a basic monitoring network was available, that existing groundwater conditions were not significantly different to that experienced during construction and that depressurisation was theoretically possible. This provided the impetus to move to the second phase of the work. It was during this phase that the possibility of extraction from the pressure relief network was raised.

4.2 PHASE 2

Phase 2 comprised an investigation of the pipe network to check sizes, geometry, condition etc. This was performed during motorway night shift closures using downhole cameras and water level monitoring. More detailed 3D FEM modelling was also performed to examine the impacts of variation in hydraulic properties, how the observed condition of the pressure relief spacing, diameter and pipe blockages may affect depressurisation performance.

Concurrently the approvals process was initiated comprising:

- Investigate NSW Office of Water (NoW) and council licensing requirements for abstraction and disposal of water.
- Preparation of an Addendum of the Review of Environmental Factors (REF) prepared for resurfacing work to assess impacts of depressurisation activities.

The Addendum REF was prepared as per RMS requirements to specifically deal with potential impacts related to the depressurisation system, including:

1. Additional construction noise, vibration and air quality impacts.
2. Depressurisation of the ground at CSUP and the potential for settlement in the vicinity of structures.
3. Disposal of extracted groundwater.
4. Methods for limiting potential impacts
5. Suggested trigger levels
6. Impacts on water quality

Environmental modelling (including noise) was conducted to answer item 1. The outcomes of the 3D groundwater modelling provided other details to NoW and the RMS including time to depressurise, extracted volumes, likely drawdown outside the motorway and most importantly for NoW, time to full recovery.

4.3 PHASE 3

Phase 3 comprised hydraulic testing of the pipe relief network conducted in a series of trials. Testing during trials examined rate of drawdown and recovery, extraction rates, pumping methods, pipe integrity under pumping and drawdown response within other parts of the pressure relief network and outside the motorway.

4.4 PHASE 4

Phase 4 comprised the full-scale trial implementation of the system to depressurise CSUP to facilitate asphalt removal, placement and reinstatement. Prior to full-scale works two new wells were installed to supplement the existing groundwater monitoring network. Wells were located directly adjacent to CSUP and potentially sensitive structures.

More details are provided below on groundwater modelling and pumping trials.

5 GROUNDWATER MODELLING

Groundwater modelling was conducted in a number of stages reflective of the level of detail available at the time. Essentially three different modelling approaches were employed:

1. A 3D superposition model based on an analytical solution of well drawdown
2. A 2D finite element model of a typical section using SEEP/W
3. A 3D finite element model of sections of the roadway with up to 6 sets of pressure relief pipe pairs

The initial analytical model (Phase 1) was used to examine a single line of wells located along the median. Sensitivity to pump spacing, extraction rate and depth were examined to predict the extent of drawdown under steady state conditions. Results inferred that more closely spaced and shallow depth wells respond quicker with a smaller draw down cone. More widely spaced wells took longer to draw down, required a higher pump rate and resulted in larger draw down. A realisation of the model for a particular case is shown in Figure 4.

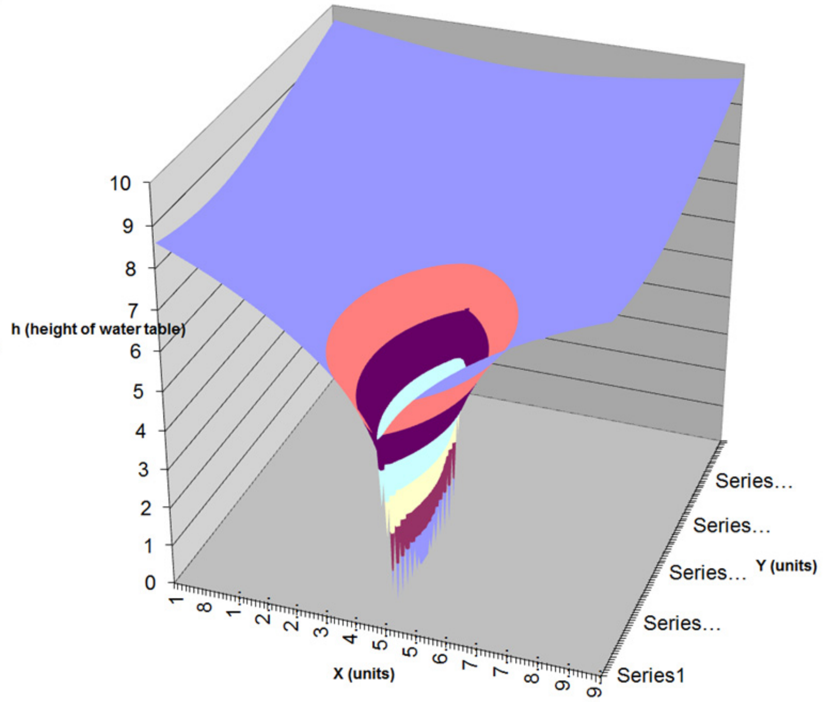

Figure 4 – Analytical estimation of a single lined of wells under steady state

Analytical modelling was supplemented by 2D modelling of a typical section of the motorway at CSUP using SEEP/W by GeoSlope. This model more accurately captured diaphragm wall geometry, site geology and external groundwater conditions. A realisation from this series of models is shown in Figure 5.

Multiple model runs were undertaken to achieve rapid draw down time within the motorway while minimising pump rate and draw down outside of diaphragm wall under the expected range of hydraulic properties.

This work included transient analysis that provided initial estimates of drawdown and recovery times. This is demonstrated in Figure 5 where the time required to achieve full depressurisation beneath the entire slab (in section) is identified on output plots. Also shown in the predicted drawdown outside the motorway adjacent to the diaphragm wall.

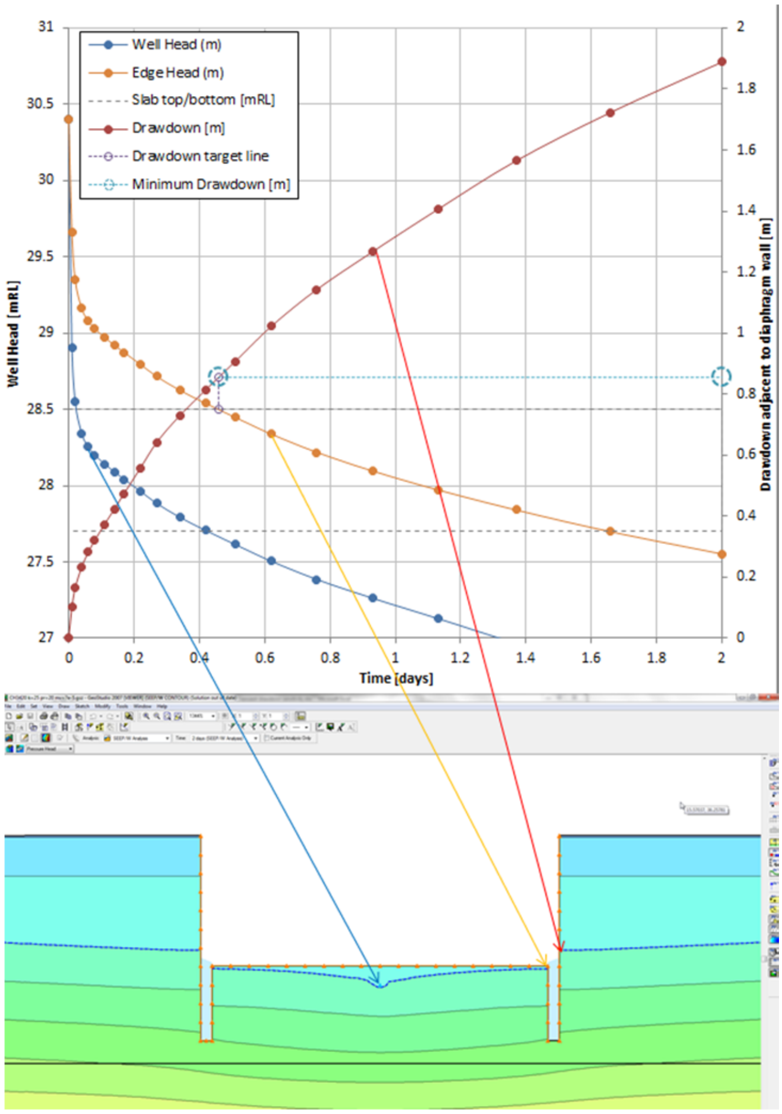

Figure 5 – Finite element 2D analysis of depressurisation by central wells

The initial 2D and 3D modelling indicated that:

- Depressurisation of the motorway was feasible.
- The time required to dewater was up to 1 day.
- The expected drawdown outside the motorway was up to 1 m.
- The depth of extraction needed to be around 1 m below the underside of the pavement slab.

For Phase 2 the potential for dewatering using the existing relief pipe network was assessed. This appraisal was undertaken by 3D Finite Element Model (FEM) modelling using the package ABAQUS with based on the initial estimate of depressurisation performance and assuming a simplified as-built geometry, design ground conditions and estimated of hydraulic properties. This appraisal found that:

- Depressurisation of the roadway was possible for a range of assumed permeabilities assuming a relatively high initial water table and a drawdown within the relief pipes limited to the underside of the pavement slab.
- Depressurisation would take around 20 to 60 minutes.
- Drawdown of up to 1 m was possible outside the diaphragm wall in the long term; and
- Additional drawdown within the relief pipes to a level below the underside of the pavement slab may be required to achieve depressurisation for the entire pavement area.

A realisation of 3D depressurisation of a single relief pipe is shown in Figure 6.

The 3D model was also used to examine non-ideal conditions whereby one or more pipes were blocked or dysfunctional as identified during pressure relief pipe investigations. An example of this type of scenario modelling is shown in Figure 7 whereby two pipes out of 10 (in this case not directly opposite each other) are ineffectual due to a blockage or other issue. Modelling showed that depressurisation was achievable under a number of adverse conditions.

Throughout the process model complexity was chosen to represent the available data at that time. Model improvements were added as data from site was improved and refined including:

- Estimates of hydraulic properties based on original pump tests and subsequent testing of monitoring bores
- Details of pipe diameter, spacing, configuration and connectivity derived from site investigations
- Details of pipe blockage or damage

The 3D finite element geometry was modified to closely match the measured conditions on site. The model was then calibrated to on-site pump test data including drawdown inside and outside the CSUP and extracted volumes. Calibrated values were principally the in-situ hydraulic conductivity (permeability) and the gap beneath the base of the diaphragm wall and the underlying low permeability peat layer. The optimisation package PEST was used to automate the process of parameter estimation and calibration.

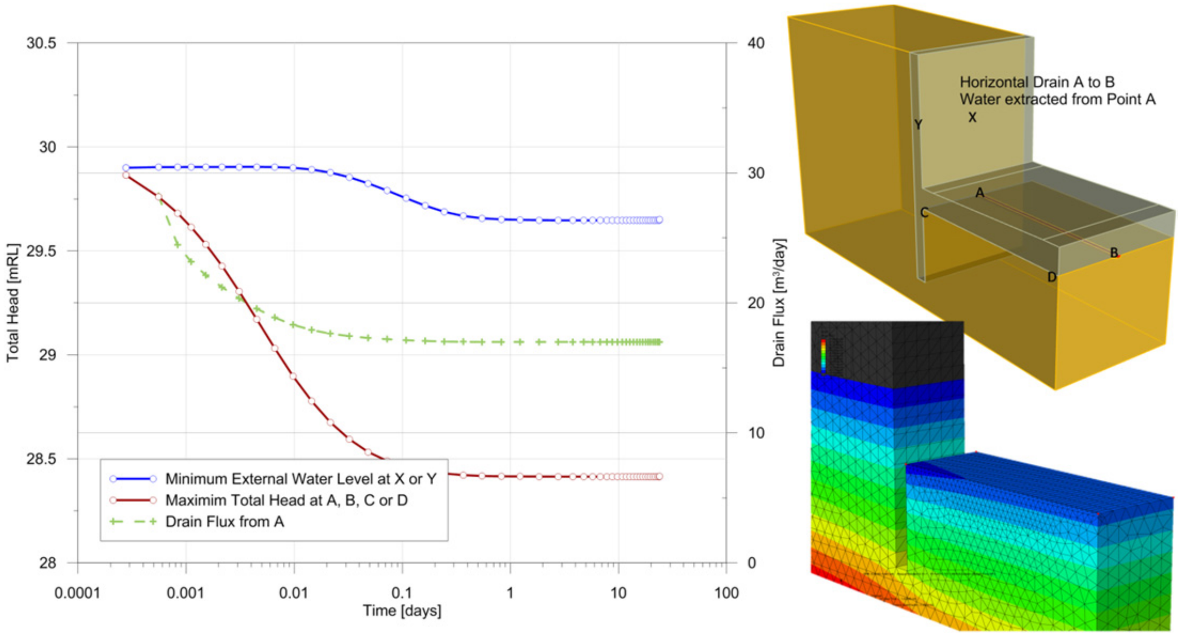

Figure 6 – Finite element 3D analysis of depressurisation by a single pressure relief pipe

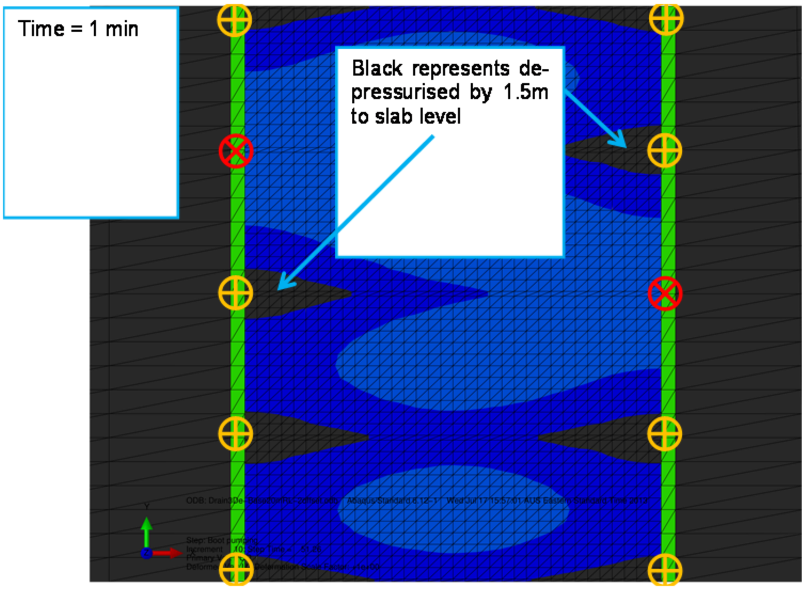

Figure 7 – Scenario prediction for two blocked pipes (in red) after 1 minute of pumping

6 ON-SITE TESTING AND TRIALS

On-site investigations and testing was initiated during Phase 2 of the works. Work was conducted during night shift and examined the following:

- Verification of pipe geometry to 'as built drawings
- Visual inspection of pipe integrity and the connection with the horizontal strip drain below the lab in particular
- The most suitable means of pipe access, pump location and manifold extraction system

Initial investigations revealed that a significant number of relief pipes had been damaged or fouled.

Other items of note were:

- The pipes were connected from one side of the motorway to the other and that damage or fouling by grout on one side effected the opposite pipe
- The method of construction was different to 'as built' drawings with the vast majority of relief pipes being straight and not kinked as documented. This was a significant advantage as it provided more options for water extraction, cleaning and potential modification.
- The connecting horizontal drain was constructed from MegaFlow products and the connection between this and the riser pipe appeared to be sound.

A key outcome of initial investigations was confirmation that the system was likely to facilitate pumping without significant ingress of the in-situ sand or structural collapse.

Phase 3 comprised pump testing of individual and multiple pipes to:

- Assess the efficacy and viability of extraction from the relief pipe network,
- Enable pump equipment methodologies to be trialled including pump type, manifold pressures and type of relief pipe connection,
- Test individual relief pipe for connectivity to subsurface drainage and its counterpart on the opposite of the motorway, maximum extraction rate and any issues associated with extraction such as sediment removal,
- Facilitate calibration of models, such as the 3D FEM model, that can subsequently be used to predict the performance of depressurisation methods across the entire site,
- Assess the ability to depressurise one side of the pavement by pumping on one side of the carriageway,
- Measure the actual drawdown that could be achieved within the relief pipes under alternate pumping scenarios,
- Measure the individual and total extraction flow rates under alternate pumping scenarios; and
- Measure the drawdown response external to the motorway and specifically in South Dowling St northbound.

This work required a number of additional components to be in place namely water disposal and monitoring of groundwater levels outside of the motorway. Water collection and disposal was monitored using existing systems within the Cleveland Street Pump Station. External groundwater levels were monitored using existing wells that had been inspected, cleaned and tested. More details on water disposal are provided in Section 7.

Initially it was unclear as to the most suitable method of pump connection to the relief pipes. There was concern that full vacuum extraction over the entire pipe may cause pipe collapse due to the combination of low internal air pressure and external water pressure. Consequently initial tests were conducted using a smaller diameter hose inserted to the base of the pipes with an air gap. Subsequent testing was undertaken to demonstrate that a full vacuum connection was not only safe but also much efficient resulting in additional drop in water pressure of about 0.5m.

Both vacuum and centrifugal pumps were considered. Vacuum pumping was found to be more appropriate due to suction lift height (around 4m) and the inability to keep air out of the system under centrifugal pumping.

Figure 8 shows the measured response from a staged pumping trial. Initially pumping is undertaken using a smaller diameter hose inserted to the base of the relief pipe with an air gap – termed ‘sump pumping’. After 50 minutes the connection is changed to a fully closed system termed ‘boot pumping’. The response in pipes directed opposite and connected to the extraction points is rapid and relatively large (PSB104 and PSB105) whereas adjacent pipes (PNB102, 103, 110, 111, 112) show a slower and lower response. The external monitoring well, SW6, shows a small drop in level in response to pumping. The road surface is around 28.7 mAHD at it’s lowest point in this location.

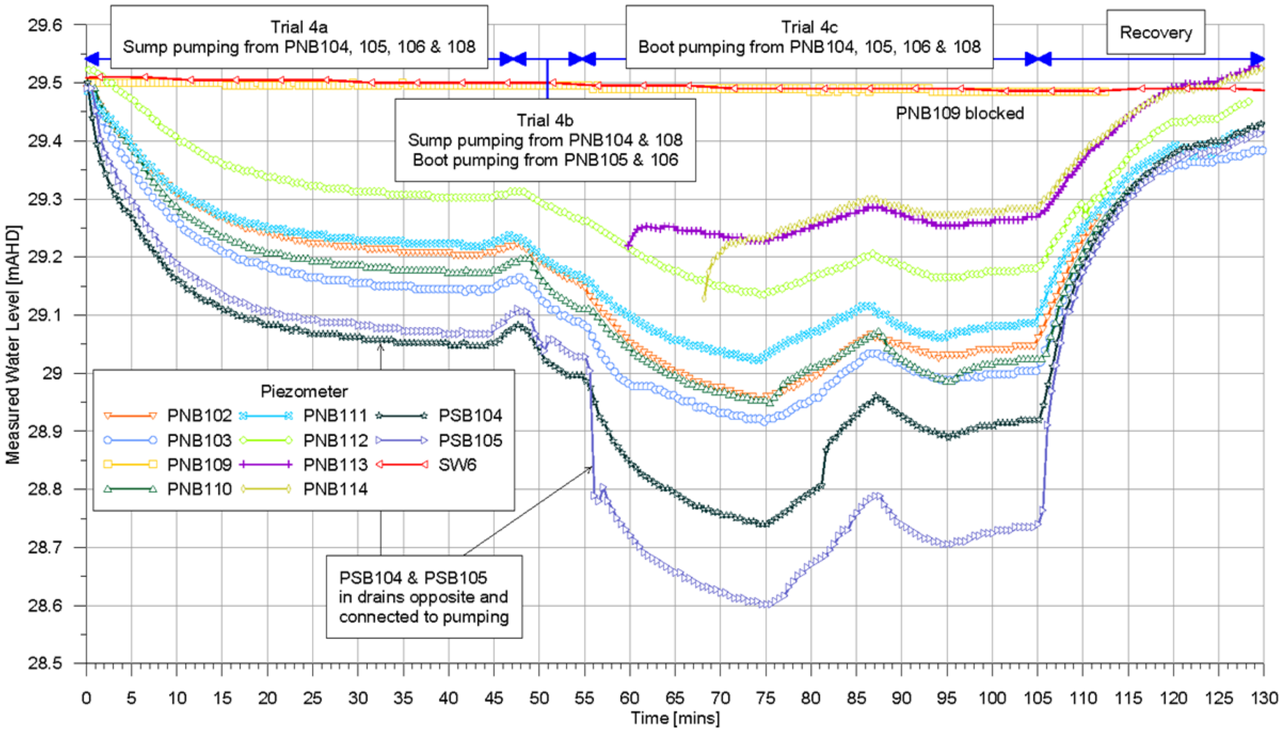

Figure 8 – Measured response of monitored pressure relief pipes and external monitoring well

Subsequent trials examined the impact of expanding the pumping network to all accessible relief pipes this being 10 for the southbound and 12 for the northbound carriageways. Under full scale testing the maximum drawdown was about 2.2 m. Maximum external drawdown was around 50 mm.

Pumping from all available pipes meant that measurements of drawdown within the CSUP were limited to one or two pipes excluded from pumping. These observations were supplemented by visual inspection of the road surface where existing seeps were monitored photographically or videoed. Some key areas of the pavement were exposed during testing to extend visual monitoring over a greater area of pavement. Typical observations are shown in Figure 9.

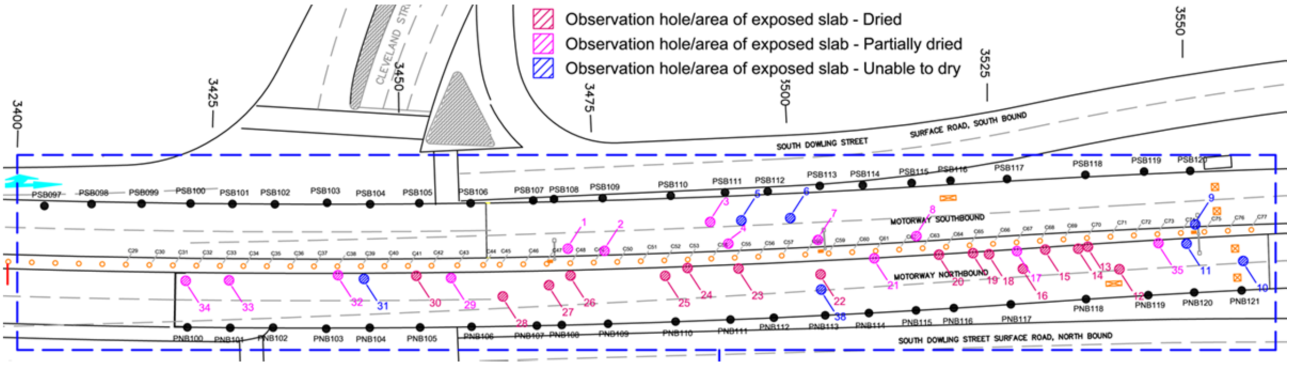

Figure 9 – Visual monitoring of pavement surface during pumping

Additional testing was undertaken to test every accessible relief pipe in terms of integrity (little to no loss of fines upon pumping) and extraction rate. Extraction rates were typically 2 to 4 L/s when pumping from a single pipe and up to 20 L/s collectively.

The main findings from the relief pipe extraction trials were:

- Partial depressurisation of the motorway could be achieved by pumping from existing pressure relief drains
- The impacts on water levels external to the motorway appear to be small
- Depressurisation via pumping can be readily achieved in vicinity of pressure relief drains currently functioning in accordance with their design intent.
- Overall extraction rates when pumping from all accessible relief pipes were around 20 L/s.
- The majority of drawdown is achieved in around 30 to 40 minutes with a reduced rate of drawdown thereafter.
- The zone of influence of the depressurisation varies across the site due to a variety of influences.
- Overall extraction rates are significantly less than the sum of extraction rates from individual pipes, presumably due to a limit in the rate of recharge to the system beneath the diaphragm walls or this may be contributed to by pumping efficacy.
- There is a considerable level of variability across the site based on comparison of drawdown response in drains under symmetric conditions.

It is thought that site variability may be due to a combination of variation in geology and soil properties, variations in the gap beneath the diaphragm walls and changes to flow paths due to the variable geometry along the length of the site. Interactions of stormwater drainage, slab thickening for utilities pits and other geometrical constraints may also be contributing.

Based on numerical assessments and trial experience the following system was adopted for groundwater extraction at CSUP to enable OGA construction:

- Use of a centralised vacuum pump connected to a manifold or large diameter collector pipe.
- Each relief pipe connected to the manifold via a separate collector pipe with a ‘boot’ to cover the entire pipe opening thereby maximising the efficiency of vacuum extraction.
- Groundwater is removed through vacuum pumping and discharged to the existing stormwater system
- The discharge is subsequently collected within the Moore Park stormwater substation for subsequent discharge.

Figure 10 – Vacuum extraction manifold and relief pipe access

6.1 GROUNDWATER DISPOSAL

CSUP is located within management Zone 2 of the Botany Sands Aquifer (see Figure 11). Residents in Zone 2 cannot use groundwater for drinking, watering gardens, washing windows and cars, bathing, or to fill swimming pools. Industrial users in Zones 2 are required to test their bore water annually and provide the results to the NSW Government.

Since August 2003 the NSW Government has operated an embargo on the acceptance of new licence applications to extract groundwater and in June 2007 this was extended to encompass the entire Botany Sands aquifer. The only activities that can be undertaken without a permanent water extraction licence are:

1. Water supply for private domestic purposes.
2. Water supply for urban water supply purposes.
3. Works for the de-watering of construction sites.
4. Monitoring and test bores for groundwater investigation and/or environmental management purposes.
5. Works used for groundwater remediation purposes.
6. Bores on a property that is the subject of a development consent that was granted prior to the date of the embargo.
7. Conversion to a production bore where a test bore licence already existed prior to the embargo.

Due to these constraints CSUP activities required the following approvals:

- A license to extract water from the aquifer in accordance with the NoW Aquifer Interference Policy
- A license to dispose of extracted water.

Based on the modelling and trial results NoW assessed that the method of depressurisation used for CSUP was minimal and no formal extraction licence was required provided that the maximum extracted volume was less than 3 ML/year and the following information recorded:

1. A copy of a valid consent for the project.
2. A report documenting the predicted total volume of groundwater to be extracted at the property – the method of calculation and assumptions used to derive the volume are to be clearly documented.
3. A report detailing the predicted duration of dewatering at the property.

4. A copy of the written authorisation for the disposal of the extracted groundwater.
5. A report describing the groundwater levels beneath the property including at least three repeat measurements from at least three monitoring bores.
6. A report detailing the maximum depth of excavation to be undertaken and the commensurate required lowering of groundwater levels beneath the property.
7. A report identifying the ambient quality of groundwater beneath the property and the treatment to be applied to pumped water prior to disposal – at a minimum treatment must be undertaken to remove contaminants, manage pH and eliminate turbidity.
8. A report detailing monitoring, measurement and reporting arrangements in relation to volumes extracted, groundwater levels and quality, as well as treatment.

If the works were to exceed 3 ML/year then a temporary dewatering licence was required in addition to the above.

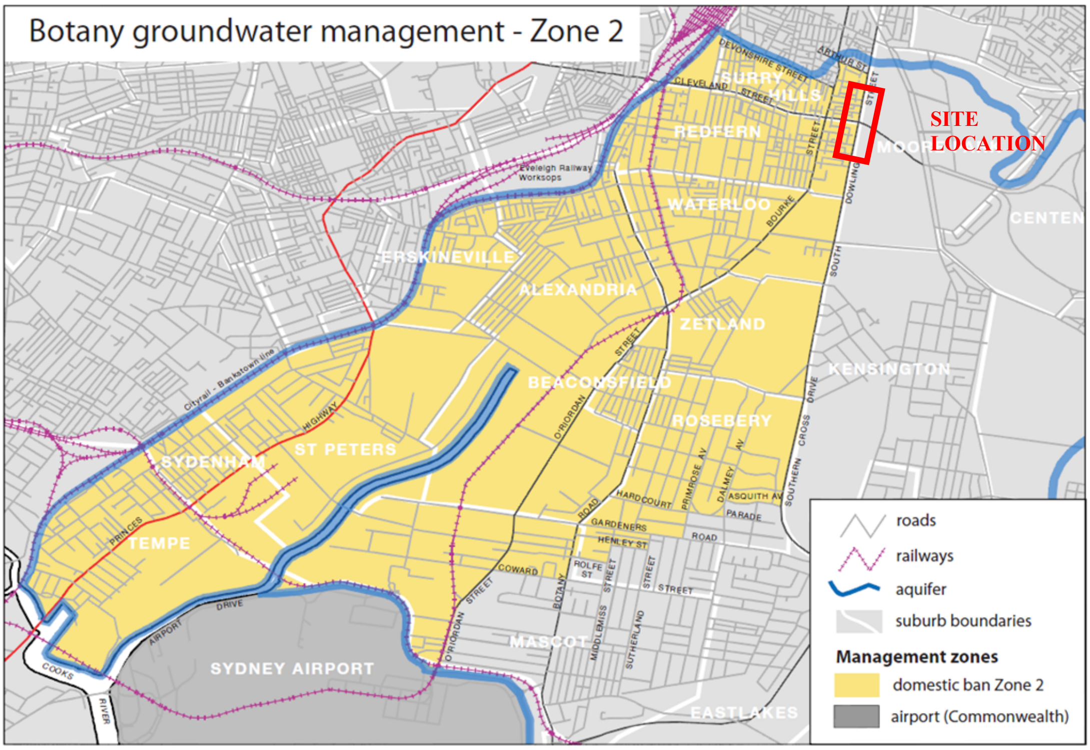

Figure 11 – Botany Groundwater Management – Zone 2 Detailed Map

Disposal was less straightforward with two entities requiring consultation: the NSW EPA and Sydney Water. The most straightforward approach appeared to be a license from Sydney Water to dispose to sewer. However, Sydney Water required an official rejection from the EPA that the water was not suitable for re-use elsewhere. At the same time the NSW EPA's initial position was that evidence be provided that the water was not suitable for disposal to sewer. This catch-22 was eventually resolved through an application to the NSW EPA, subsequent rejection and then granting of a disposal licence from Sydney Water. Water disposal was achieved by pumping from the Cleveland Street Pump Station located in Moore Park to a nearby sewer intake.

Licensing conditions required the following data to be recorded:

- Duration of pumping
- Real-time flow measurements
- Extracted volumes
- Water quality testing of 29 analytes at the commencement of pumping, and end of pumping and every 25,000 L of discharge.
- Changes in the water table in the vicinity of CSUP
- Disposed volumes

A detailed report on many other aspects of the disposal system was also required. Details included holding tank details, sewer diagrams, sewer connection details, pump specifications, flow meter specifications, water quality analytical results and valve diagrams.

The rate of disposal was limited to 15 L/s slightly lower than the expected extraction rate of 20 L/s. The Cleveland Street Pump Station holding tanks were initially lowered prior to the works so that they could buffer this excess over the expected of resurfacing works (around 6 hrs).

7 IMPLEMENTATION OF PAVEMENT REHABILTATION

Pavement rehabilitation was undertaken over 12 night shifts commencing with a full-scale resurfacing trial of 90 m section of the northbound carriageway. Full scale activities required a much longer period of dewatering times than earlier trials to facilitate pavement removal, surface drying, OGA resurfacing and cooling. Key objectives of the first full-scale works were:

- To assess if a full-scale pavement rehabilitation shift can be carried out in the allotted motorway shutdown window.
- To assess the amount of drawdown that can be achieved following depressurisation of all available relief pipes for a full shift.
- To assess the amount of drawdown experienced outside of the tunnel at the groundwater monitoring wells during a full depressurisation shift.

Surface preparation was assisted through the use of a gas powered road heater as shown in Figure 12.

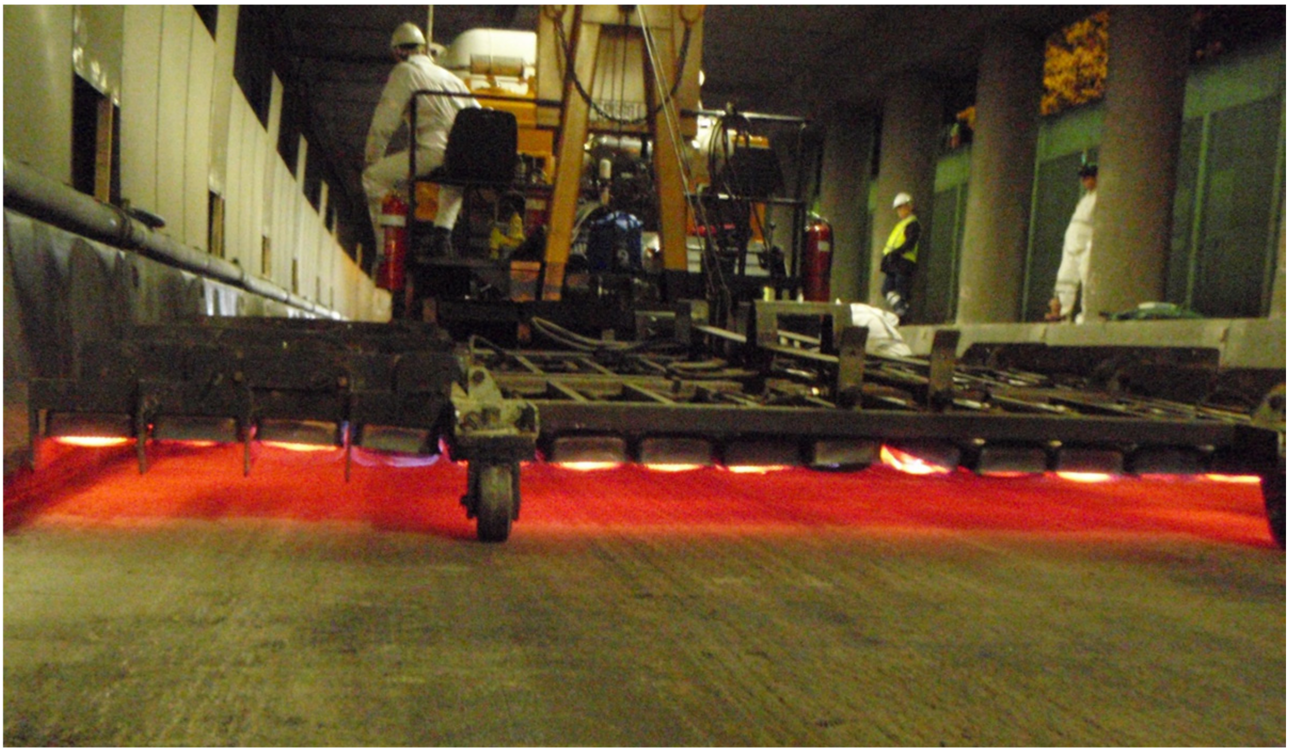

Figure 12 – Surface drying in preparation for asphalt placement

External drawdown triggers and actions were implemented for the production trial. These limits are shown in Table 1. Given the importance of satisfying these triggers a ‘real-time’ monitoring system was developed including Bluetooth networked piezometers inside and external to the parkway.

A second trial of similar length was subsequently undertaken to assess the viability of resurfacing the southbound carriageway.

Table 1 – REF Adopted Trigger Levels

CHANGE IN GROUNDWATER LEVEL OUTSIDE THE PARKWAY	ALERT LEVEL	ACTION	COMMENT
< 300 mm	Green	No action required	This is 6 times larger than previous trial draw down of 50mm.
300mm – 500mm	Amber	No action if level is stabilised and not increasing. If increasing review rate of fall and consider stopping pump	Subject to stage of works and ability to respond. Up to 10 times larger draw down than trial.
500mm – 1,000mm	Red	OK if stabilising. If increasing stop pump and reinstate pavement without depressurisation.	Would require placement of DG Asphalt without depressurisation.
> 1,000mm	Stop Pumps	Stop pumping and reinstate without depressurisation.	Would require placement of DG Asphalt without depressurisation. It is noted that this is 20 times more draw down than the trials. Potentially acceptable for short duration draw down but not assessed to date.

Following the success of these trials the rest of the CSUP was resurfaced in a further 10 shifts.

Tabulated values of extracted groundwater volumes and associated drawdown are provided in Table 2 where Well 1 and Well 2 are the new wells installed as part of the works and located either end of the CSUP section on the adjacent footpath. These values indicate that the reduction in groundwater levels outside the parkway although higher than initial trials were within the amber trigger levels and significantly less than the original construction activities. There are several factors found to influence these results, these being:

- The proximity of external monitoring to pumping with northbound pumping resulting in more drawdown in the vicinity of adjacent properties.
- The duration of pumping.
- The monitoring location.
- The number of consecutive days of pumping.

Table 2 – Drawdown due to production shifts

SHIFT	GROUNDWATER INTAKE DURING SHIFT (KL)	PUMPING DURATION (HRS)	MAXIMUM DRAWDOWN IN WELL 1 (mm)	MAXIMUM DRAWDOWN IN WELL2 (mm)
1	294.6	6.5	185	181
2	254.5	5.6	146	138
3	320.7	6.0	199	205
4	218.3	3.0	161	176
5	259.6	5.6	58	153
6	170.9	3.3	49	114
7	356.3	8.7	239	286
8	519.9	6.8	234	152
9	62.8	2.7	10	19
10	404.0	4.6	127	43

The total extracted volumes shown in Table 2 did not exceed the 3 ML/year limit for unlicensed extraction.

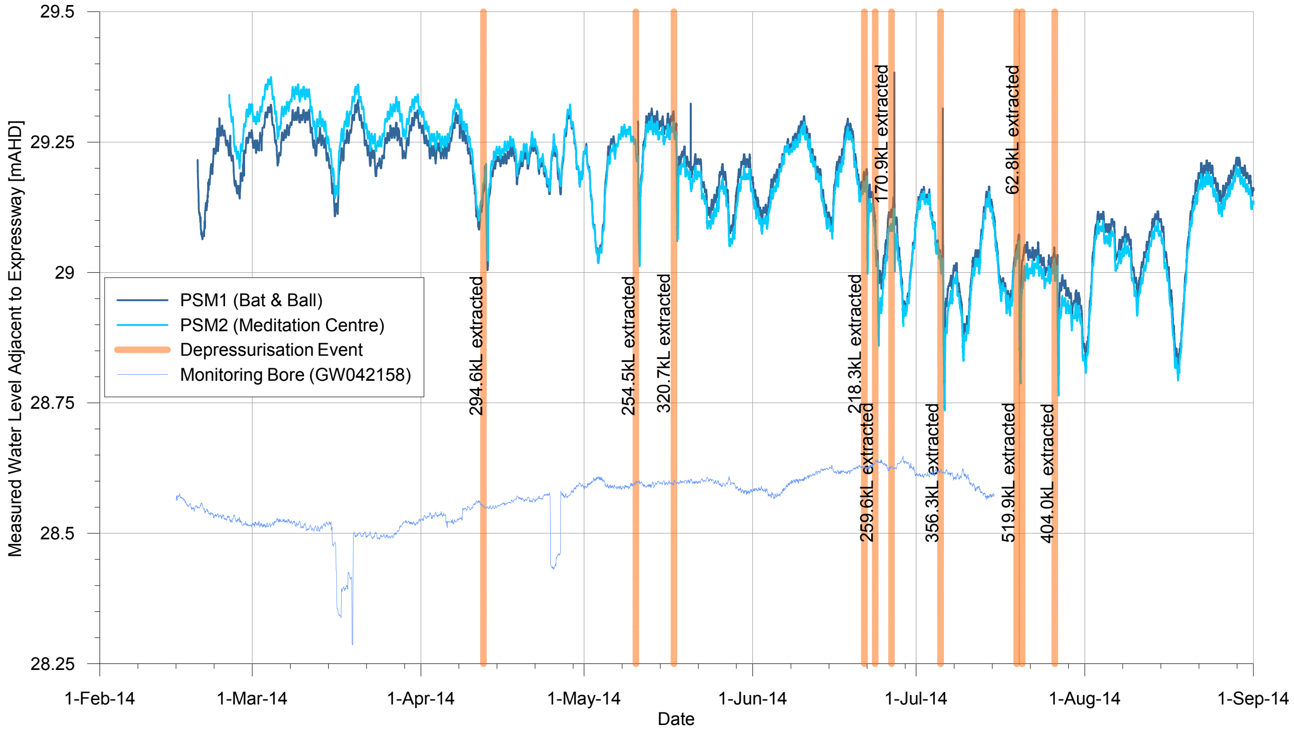

Figure 13 – Comparison of pumped volumes, local drawdown and regional drawdown

Figure 13 compares measured extraction volumes against drawdown for all of the dewatering shifts. Included in Figure 3 are the extracted groundwater volumes at the Cleveland Street Pump Station, drawdown response measured by vibrating wire piezometers at Well 1 and Well 2, and data from a groundwater monitoring bore in Moore Park (NSW Office of Water Groundwater Monitoring Bore GW042158). Bore GW042158 is located about 500m southeast of CSUP and is considered a reasonable reference for the regional groundwater levels during the works period.

Figure 13 and Table 2 show that:

- Dewatering events had a measurable impact on groundwater levels immediately adjacent to CSUP, i.e. in Well 1 and Well 2,
- Dewatering events did not have a measurable impact on groundwater levels in NoW monitoring bore GW042158; and
- The maximum recorded drawdown adjacent to the motorway was around drawdown 286mm in Well 2 during the longest duration pumping event.
- Groundwater recovery to original levels was achieved within approximately 1 week.

The observed drawdowns were below all REF trigger values.

8 CONCLUSIONS

The outcomes of this project were:

- Partial depressurisation of the motorway by pumping from existing pressure relief drains has been demonstrated to be effective.
- The impacts on water levels external to the motorway appear to be small based on monitoring from piezometers.
- Overall extraction rates when pumping from all accessible relief pipes were around 20 L/s.
- The majority of drawdown was achieved in around 30 to 40 minutes with a reduced rate of drawdown thereafter to provide a 6 hour windows for OGA placement.
- The zone of influence of the depressurisation varies across the site due to a variety of influences.
- OGA rehabilitation was achieved in the dry for the entire CSUP area without incident or rework.
- The dewatering and OGA placement was achieved within the designated shutdown periods
- Monitoring triggers did not exceed an amber alert level.
- Groundwater recovery occurred soon after the works.
- Environmental licenses and approvals were supported by physical trials and real-time monitoring.

The work taken was undertaken in several phases that provided increasing certainty of outcome with subsequent activities contingent on the success of preceding tasks. The approach taken was methodical and incremental so as to ensure:

- The integrity of the pressure relief system was maintained
- Works could be undertaken within the closure time frames to minimise disruption on a major Sydney arterial
- Drawdown outside the works was minimised with works halted should limits be breached.

It is envisaged that a similar approach to that described here will be employed for future resurfacing works at CSUP.

9 ACKNOWLEDGEMENTS

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10 REFERENCES

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