Central Interceptor - How does groundwater modelling and instrumentation stack up in the real world

H. Zhao[1]and P. Yee[2]

[1]Beca Limited, P.O. Box 6345, Victoria St West Auckland 1142; PH (64) 9-300-9000; email: hangjian.zhao@beca.com
[2]Ghella Abergeldie Joint Venture, 8 Gloucester Park Road Auckland 1061; PH (64) 9-953-5640; email: pyee@ga-jv.com

ABSTRACT
A new wastewater tunnel referred to as the Central Interceptor (CI) will collect stormwater and wastewater overflows from the Auckland isthmus area and transfer them to the Māngere Wastewater Treatment Plant. This will increase the wastewater network capacity by reducing the overflows and make the system more resilient. Numerical and analytical groundwater flow models representing the spatially varying geological settings and different construction methodologies were developed to assess the potential groundwater inflows and drawdown from the construction of the shafts and tunnels. Potential adverse effects arising from groundwater drawdown were assessed to demonstrate that the construction can meet the consented envelope of effects. The modelling results were also used to inform the construction planning in terms of groundwater inflow control and the setting of suitable trigger levels for groundwater drawdown and ground settlement that is part of a project wide monitoring network. Installed instrumentation includes real time data reporting and visualisation, that facilitates monitoring of the construction and consent compliance, and also provides feedback to the groundwater modelling should model updates be required. This paper highlights the lessons learnt during the construction of the CI through the eyes of installed instrumentation and how groundwater monitoring and modelling could complement each other, including:
1) Groundwater response during excavation of the Māngere Pump Station (MPS) in high permeability aquifers, and
2) Groundwater behaviour during launch of the tunnel boring machine in a confined, controlled environment.

Keywords: groundwater, modelling, dewatering, shafts, tunnels, monitoring

1 INTRODUCTION

1.1 Central Interceptor Project

Watercare Services Limited (Watercare) has obtained designations and resource consents for the construction and operation of a new wastewater tunnel, referred to as the Central Interceptor (CI). In the older parts of central Auckland, wastewater and stormwater currently flow into a combined network of pipes that were designed to direct overflows into nearby waterways. The CI is designed to reduce overflows in the city waterways, and also to enhance the resilience of the network for future urban growth in central Auckland region.

Delivery of the CI will involve construction of a mainline wastewater tunnel that will run between Māngere Wastewater Treatment Plant (MPS) and Grey Lynn, including multiple shafts, above ground facilities, and two link sewers. The mainline tunnel is 14.7 km long with an internal diameter (ID) of 4.5 m. The tunnel will be constructed at a depth of 21 m to 107 m below ground level (m bgl), including an approximate 1.5 km long crossing beneath the Manukau Harbour at about 15 m depth under the seabed. 16 working and connection shafts with depths ranging approximately between 12 m to 75 m will be constructed along the alignment. Link Sewer B is a 1.1 km pipeline (2.4 m ID) that runs from Rawalpindi reserve and connects to the mainline tunnel at the Mt Albert shaft. Located further south, Link Sewer C is a 3.2 km pipeline (2.1 m ID) that starts at Pump Station 25 and connects to the mainline tunnel at one of the May Road shafts.

1.2 Groundwater Modelling and Assessment

Construction of the CI will encounter groundwater during the excavation and completion of shafts, boring of the main tunnel and link sewers by tunnel boring machine (TBM) as well as mining of short sections of connecting adits. Groundwater control measures are therefore required to create workable conditions so that the excavation and construction works can be undertaken in a safe environment.

In order to prevent or minimise groundwater from entering into the shaft excavations, low permeability cut-off walls (e.g., secant piles, diaphragm walls, drilled casings etc.) will be constructed around the perimeter of the excavation, with walls normally penetrating down to the top of lower permeability rock to form a lateral cut off to flow from higher permeability basalt and / or compressible sediments. This allows groundwater inflow to be managed via conventional sump pumping.

The mainline tunnel and Link Sewer B and C will be constructed using earth pressure balance (EPB) tunnel boring machines (TBM and Micro TBM) that can excavate the tunnels and simultaneously erect a gasketed precast concrete segmental lining or conventional pipe jacking support utilised for both link sewers. The tunnel sections are discretised into mandatory closed-mode zones and zones where "open-modes" of operation are allowed. During "closed-mode" tunnelling, the earth and groundwater pressures acting on the excavation face are balanced by the pressure of the conditioned soil stored inside the excavation chamber and therefore negligible groundwater inflows to the tunnels are expected. However, in other areas where open-mode is allowed, or at locations where cutter head intervention is required, the face pressure is lower than the hydrostatic pressure, some groundwater seepage into the tunnelling face is expected and will be managed as part of the soil conditioning process at the face, and then removed as slurry.

To understand groundwater inflows and to assess the potential effects that may arise (e.g., drawdown and associated risk of settlement or impacts on surface water bodies etc.), numerical groundwater modelling representing the spatially varying hydrogeological conditions and different construction methodologies was undertaken. In coordination with the overall construction programme, the models in some locations were developed to allow simultaneous excavations at multiple shafts, so the potential for cumulative effects could be considered.

Potential groundwater inflows are assessed to inform the construction planning in terms of groundwater inflow control, and the calculated groundwater drawdown is used for setting of suitable trigger levels for construction monitoring. The groundwater modelling work is complementary to the instrumentation and monitoring, which is then used to monitor the actual inflows and the effects to the receptors, and to confirm that effects are within the consented envelopes.

1.3 Compliance and Construction Monitoring

The regional resource consents for the CI project specify a range of conditions that are to be met. As one of the conditions, a Groundwater and Settlement Monitoring and Contingency Plan ('M&CP') is required to detail how groundwater and settlement effects arising from construction of the shafts and tunnels will be monitored and managed.

Construction monitoring has been undertaken utilising a combination of telemetered and manually read instruments, including vibrating wire piezometers to measure groundwater levels within varying lithological units, as well as settlement monitoring pins (SMP) and utility monitoring points (UMP) installed around each shaft and on critical assets. Additional inclinometers and extensometers have been installed immediately around the footprint of each shaft to measure lateral and vertical changes during each stage of shaft excavation. In addition, convergence prisms and ring convergence monitoring systems have been installed to measure convergence of the shafts and tunnels during excavation.

The instruments are used to monitor the influence of shaft and tunnelling activities and are set with trigger levels at 80% (green), 100% (amber), 120% (red) and 150% (black) of the modelled results. All data is collated and presented on a real-time data platform (Geoscope), that can instantly provide email notification when a trigger level exceedance occurs. During construction, data is reviewed on a weekly basis to validate the design assumptions and as a compliance requirement under the consent conditions. Where trigger levels are exceeded, the specific Trigger Action Response Plan (TARP) is adhered to.

2 SHAFTS CONSTRUCTION IN A HIGH PERMEABILITY AQUIFER AT MĀNGERE PUMPING STATION (MPS)

2.1 Design of Māngere Pumping Station

The MPS shafts were constructed as a dual cell (Figure 1), consisting of two adjacent and intersecting circular shafts, with a Diaphragm Wall (D-Wall) installed as the first element of support prior to the construction of the permanent shaft lining. The D-Wall was designed to leak and cope with the earth pressure, along with providing effective temporary support during shaft excavation. A length of approximate 133 linear metres of D-Wall was constructed for the two circular shafts. The two shafts are separated into the Inlet shaft (14.4 m ID) and the Main shaft as a Wet and Dry Well (28.4 m ID). The D-Wall provides at least 8 m to 10 m cut-off below the base of the deepest excavation, embedding into competent ECBF rock. Since completing the excavation, an internal cast in-situ wall (1.5 m thick) has been formed to restrain the full hydrostatic pressure.

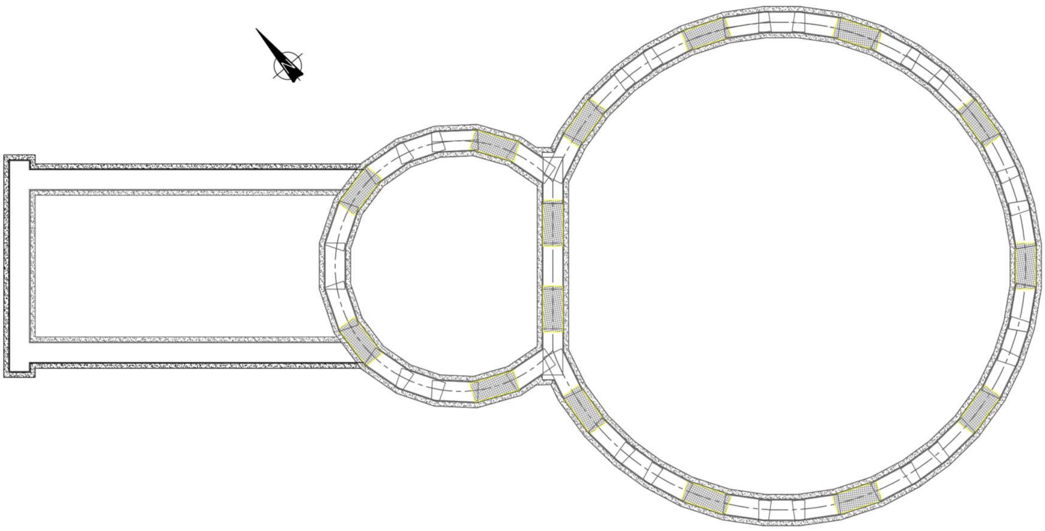

Figure 1: Māngere Pump Station shafts layout showing the temporary support diaphragm wall support and extended confinement box

2.2 Initial groundwater modelling

A 3 D finite difference groundwater flow model was developed, based on a purposely built geological model, to consider the impacts of construction on groundwater in a complex and variable geologic setting. The hydrostratigraphic units include volcanic tuff and basalt, Tauranga Group Alluvium (TGA), Kaawa Formation (newly named as Tāmaki Makaurau Formation[1]), Parnell Volcaniclastic Conglomerate (PVC) and East Coast Bays Formation (ECBF) (Figure 2).

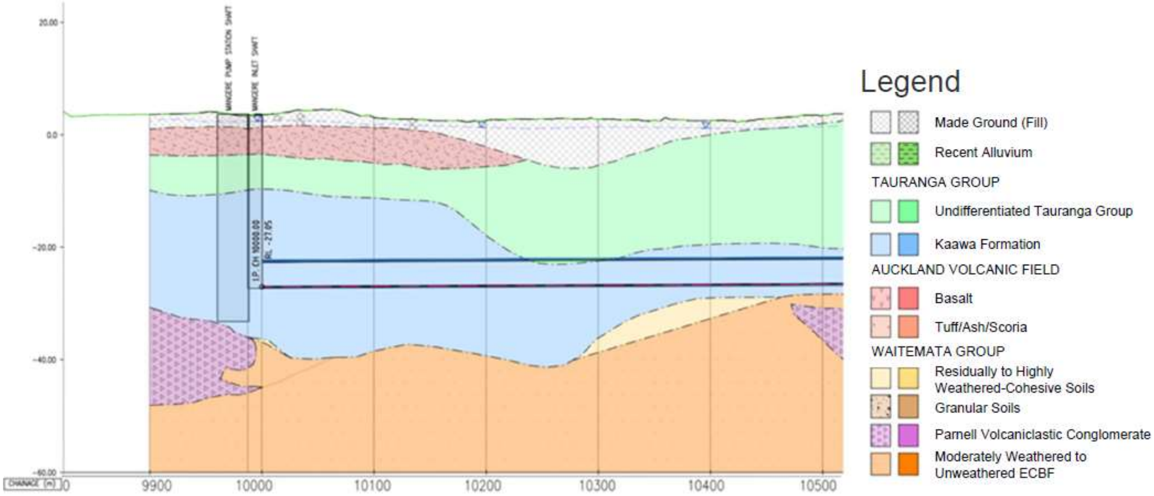

Figure 2: Māngere Pump Station geological cross section

Kaawa Formation is a regionally important water supply aquifer. A constant rate test in the Kaawa Formation was undertaken at 45 L/s and resulted with a drawdown at distance of up to 640 m away, and this confirms generally high permeability expected for this critical water supply aquifer. PVC that is interbedded in the ECBF consists of coarse debris flow deposits with volcaniclastic materials. The PVC is much stronger, but more brittle with a permeability that could be orders of magnitude higher than the host ECBF and these zones are likely to be preferential flow pathways which are challenging to model. The TGA generally has a lower permeability, i.e., not expecting significant groundwater flows, however, the compressible nature of the alluvium makes it critical to understand the drawdown response to assess the risk to the assets at surface.

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[1] "Kaawa Formation" used herein as a more familiar name.

The model was calibrated to average groundwater levels and a transient pumping test undertaken in the Kaawa Formation. The modelling suggested peak groundwater inflows of up to 13 L/s, but typically less than 1 L/s for the base case scenario where the PVC was assumed to have the same permeability as the host ECBF (Beca, 2019). Because there was a risk of higher permeability in the PVC, modelling also considered an upper bound case with groundwater inflows to the shaft of 60 L/s. The project team took a proactive decision to increase the cut-off provided by the D-walls to help manage this, though modelling still suggested even in this case flows rates of 50 L/s could occur.

2.3 Construction challenges

A groundwater inflow of up to 26 L/s was observed during construction, that was followed by drawdown trigger exceedances at nine piezometers. The groundwater flow model was back calibrated to the observed pumping rate and drawdown observations recorded to date. The model, calibrated to the observed inflow rate, suggests a permeability of PVC (i.e., of the order of 10^{-5} m/s) that is higher than the original value adopted, but lower than the upper bound scenario presented in the initial modelling (Beca,2020).

The updated model was also utilised to assess the potential benefits of applying mitigation measures comprising a drainage blanket, with active sump pumping and passive relief wells within the shaft excavation. These mitigation measures, in conjunction with refined design analyses to confirm allowable pressure on the base slab, were expected to allow for some reduction in pumping rates as the construction staging allows. Modelling indicated a 25 to 50% reduction in pumping rates could be achieved at key stages.

2.4 Construction solutions

Excavation of the Māngere shafts commenced in August 2020, with approximately 35,000 m³ of material removed. The main shaft (28.4 m ID) extends 41.0 m bgl and the adjoining inlet shaft (14.4 m ID) extends to a depth of 38.0 m bgl. Final excavation levels were achieved in October 2020 for both shafts.

As excavation of the main shaft advanced to within 2.5 m of the final excavation depth a significant increase in groundwater inflow into the main shaft was observed (5th October 2020), initially in isolated areas flowing through at the base of the D-wall and with additional excavation, within the centre of the shaft. The groundwater inflow is anticipated from the Kaawa Formation via vertical fractures within the PVC providing a preferential flow path around the D-Walls, corresponding to groundwater drawdown observed in monitored piezometers installed within the deeper Kaawa Formation, PVC and ECBF (Figure 3) exceeding all respective trigger levels. The piezometers installed within the compressible TGA observed limited to no groundwater drawdown and remained within their trigger limits.The main shaft initially experienced groundwater inflows peaking at 26 L/s, reducing over time. Once the final excavation depth was reached, formation of the main shaft base slab was set with four 250 mm diameter relief wells and pumps installed, reducing the hydrostatic pressure exerted on the base slab. Continued pumping of groundwater is being undertaken at an average rate of ~16 L/s (lowering steadily) and is expected to continue around this rate until the permanent lining and dividing wall is installed and base slab can take full hydrostatic pressure.

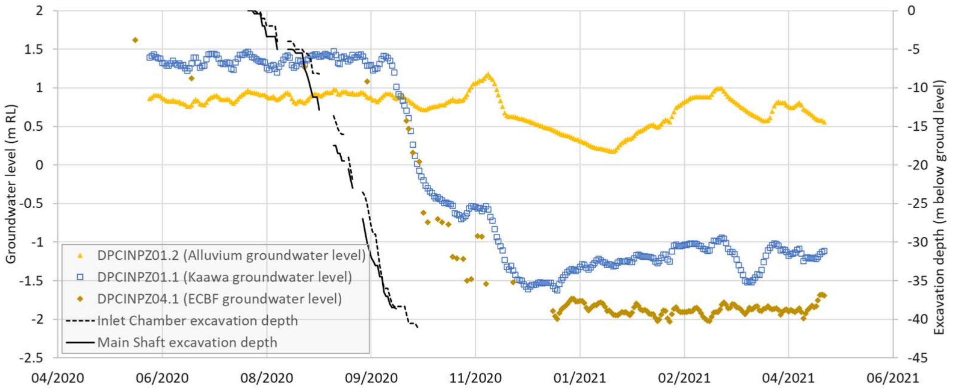

Figure 3: Monitored groundwater level of select piezometers surrounding the Māngere shafts in relation to the excavation depths of the inlet and main shaft

Additional vibrating wire piezometers and electrical conductivity instruments were installed in response to the large groundwater inflows and drawdown at MPS. Three shallow piezometers were installed within the site footprint to confirm the drawdown within the compressible alluvium, as an early warning for risk of ground settlement. Shallow groundwater levels remained stable upon review and mirrored the surrounding shallow piezometers installed. Two electrical conductivity monitoring instruments were also installed in shallow open standpipes and confirmed no change in groundwater salinity was occurring. Two deep piezometers were installed to the south and east of the site to get a better understanding of the magnitude and extent of the drawdown within the Kaawa Formation, this was particularly important as a number of private wells abstract water from the Kaawa Formation to the east and south of MPS shafts.

2.5 Monitoring observations

Figure 3 above provides an insight into the groundwater levels within the various geological units against the shaft excavation depth. The extensive groundwater drawdown of the Kaawa Formation and ECBF is in line with the groundwater inflows observed within the shaft. A delayed and limited groundwater drawdown of the upper compressible TGA is less extensive and in line with the settlement observed around the shaft. Monitored shaft array/building SMP's and the UMP's installed along a critical asset, the Western Interceptor located within 20 m of the shaft footprint, observed settlement within their trigger limits and differential settlement of no steeper than 1 / 10,000.

The groundwater drawdown observed to the east of the site was limited upon review and the southern deep piezometer was significantly influenced by the Māngere Waste Water Treatment Plant (MWWTP) activity, with groundwater drawdown not directly linked to the active dewatering at MPS.

Monitoring data is regularly reviewed and compared with modelling results to check the assumptions and provide additional observation datasets for model update.

3 GROUNDWATER CONTROL FOR TUNNEL BORING MACHINE LAUNCHING

3.1 Groundwater modelling

It is impractical and of little value to develop a groundwater model that encompasses the whole mainline tunnel alignment, instead, critical locations along the alignment were selected and modelled using a series of 2D analytical models and the existing 3D numerical groundwater flow models developed for the shafts. During "closed-mode" tunnelling, negligible groundwater inflows to the tunnels are expected. However, as a result of pressure reduction at the tunneling face (e.g., open-mode, or cutter head intervention), some groundwater seepage into the tunnelling face may occur, therefore a greater drawdown is expected at the tunnel invert. Particularly, this pressure control becomes more critical for the tunnel launch at MPS where there is greater potential for large inflows and associated risk of materials running into the face given the permeable and unconsolidated nature of Kaawa Formation.

3.2 Challenge and solution

The TBM was launched at MPS from the inlet shaft into the Kaawa Formation. The successful launch of the TBM commenced on 9th August 2021 and was initially within the confinement box shown in *Figure 2*. Soon after launching the TBM on 17th August, all New Zealand moved into alert level 4 lockdown restrictions.

The confinement box is a purpose designed and built 9.3 m x 17.6 m structure, contained by 1.2 m thick x 2.8 m long overlapping D-Wall panels that extend to an approximate depth of 47 m bgl. The purpose of the confinement box is to provide a complete groundwater cut-off, to allow the TBM to be launched in the "dry" and inadvertently provided a safe haven for the TBM during the lockdown restrictions.

Dewatering was undertaken within the confinement box via two dewatering wells below the tunnel invert level (i.e., -26.7 m RL) as the TBM exited the inlet shaft. With the surrounding groundwater level lowered below the tunnel invert level (-27.0 m RL), all checks for the TBM and concrete segments could be installed and verified safely within a controlled environment.

3.3 Monitoring Observations

Groundwater monitoring instruments were established within and beyond the confinement box. With the dewatering wells and the D-Wall acting as a cut-off to lateral groundwater inflows, the groundwater level in the Kaawa Formation within the confinement box was lowered, and it was observed to rapidly respond to pumping (i.e., pump shutdown test showing rapid rise and fall of levels when pumping stopped and resumed). The groundwater level outside of the confinement box (TBMCZPZ02.1) observed an initial depressurisation due to dewatering within the confinement box, but did not experience full groundwater drawdown, instead stabilised in March 2021 (Figure 4). As the TBM advanced beyond the confinement box, a short-term increase in pressure was also observed from the TBM face pressure (3 to 3.6 bar) as it passed within close proximity (10 m) of the vibrating wire piezometer (TBMCZPZ02.1_29.3 m bgl), followed by a gradual descent in groundwater levels and stabilisation as the segment annulus is grouted in place immediately approximately 12 m behind the TBM face.

Figure 4 also shows induced fluctuation of the groundwater within the confinement box between September 2021 to February 2022, where the pumps were temporarily turned off to check and validate the segmental ring support performance.

Thereafter, the TBM advanced beyond the confinement box and has currently advanced over 2,500 m. Monitoring data are regularly reviewed on a weekly basis to monitor and confirm the effects rising from the tunnelling.

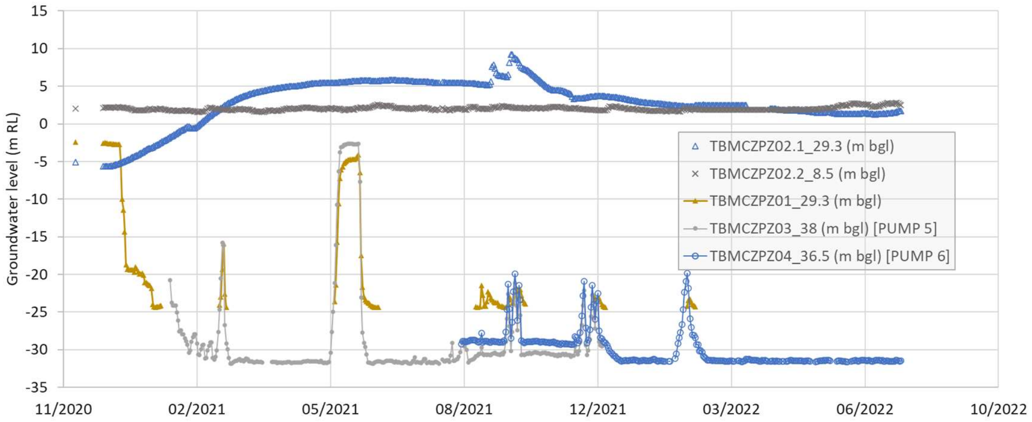

Figure 4: Groundwater level response to pumping in preparation for TBM launch.

4 CONCLUSION

With a robust understanding of the hydrogeological setting, groundwater modelling can be used in a systematic approach to understand the hydrogeological environment, quantify the potential effects that may arise and to help inform groundwater control measures. The models developed for CI have a focus of representing the hydrostratigraphic units and the understanding of the hydrogeological conditions on a regional scale. Test pumping and groundwater observations at Māngere site are of great use and importance to improve the understanding of the site-specific conditions. The more reliable model allows for a better estimation in groundwater inflows and drawdowns, also to adequately simulate the variation in groundwater control measures (i.e., increase the wall embedment depth) and assess the associated effects. Back calibrating the model to the observations also helps to provide the confidence that the proposed groundwater control measure would be effective.

Extensive and real-time monitoring network has been established at the shaft sites and along the tunnel alignments. Not only do they provide informative datasets for conceptualisation, model development, and calibration, but also serve as the eyes of the project to validate the modelling assumptions, to identify potential local variations, therefore providing feedback to the modelling and initial assessment. More importantly, it is an invaluable asset to monitor the effects from the construction and provide early warnings of risks that may potentially arise from the construction. Whilst modelling helps to quantify the groundwater inflows and potential effects on the environmental receptors, it isn't the end of the journey. Instead, it is the starting point. Being complementary to each other, groundwater modelling and monitoring work together as an effective tool to better understand the local conditions and therefore to respond to construction risks.

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6 REFERENCES

Beca (2019). "Māngere Pump Station –Assessment of Groundwater Effects" Revision 1.
Beca (2020). "Māngere Pump Station – Revised Assessment of Effects" Revision 2.
Geoscope-Central Interceptor instrumentation online platform, Sixsense.