

Dewatering effects on the Richmond South Trunk Main – geotechnical considerations for design and construction

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ABSTRACT

The Richmond South bulk water main construction project comprised installation of approximately 1km of DN450 PE pipe and associated infrastructure, including rammed steel conduits beneath state highways, and stream crossings in Richmond, Tasman, New Zealand. The conventional cut and cover pipe installation methodology required dewatering, and subsequent discharge and treatment of the water after extraction from the coarse grained Holocene alluvium. A dewatering assessment for an assumed pipe ram launch pit was undertaken in the design stage, and information added to the contract documents.

The construction works began in June 2021 and encountered lithology preventing deeper well pointing, higher groundwater level, and inflows of water into excavations in excess of that anticipated by the design. The higher groundwater level, the different hydraulic conductivity of the soils than those initially assumed in the design, and the timing of the works in the calendar year are identified as key causes of the excessive inflow. The ability of the Contractor to adapt their methodology, then extract and discharge large volumes of sediment laden water in an urban environment became critical for the completion of the works, incurring additional time, cost, and engineering effort to address.

This paper discusses the adequacy of geotechnical investigations and detail of dewatering assessment including sensitivity to input criteria. The implications of unforeseen geotechnical and groundwater conditions, primarily their effect on the practicality of pipe installation works, cost, and contractual arrangements are also discussed.

1 INTRODUCTION

The Richmond South bulk water pipeline project comprised investigation, design and construction of approximately 1km of DN450 PE pipe and associated infrastructure, including, two 600mm rammed steel conduits below State Highways 6 and 60, and two stream crossings. The pipeline is located in Richmond, Tasman, and crosses land of various uses, including state highways, urban residential roads, and green field rural properties.

Geotechnical investigations comprising machine excavated test pits were excavated prior to design in order to obtain an understanding of the near surface ground conditions. A dewatering assessment was undertaken for one of the pipe ram launch pits and anticipated groundwater inflow rates and dewatering effort were developed. A qualitative assessment of potential settlement was undertaken and concluded that dewatering activities would not result in settlement with potential to adversely affect adjacent buildings or infrastructure. Construction of the infrastructure was observed by the designer and geotechnical engineer.

This paper outlines all phases of the project and follows the impact of dewatering considerations throughout the project lifecycle. While details of this case study are specific to the Richmond South works, the intent is to present the considerations and outcomes for a wider engineering application.

2 PRE-CONSTRUCTION

2.1 Geotechnical Assessment and Design

2.1.1 Geological setting

Published geological mapping at the Richmond South site (Geological and Nuclear Sciences Geological Map 9) shows Holocene age Q2a deposits comprising clay-bound gravel with minor fan deposits, commonly known as Hope gravels, in the Nelson, Tasman area.

2.1.2 Investigations and reporting

A geotechnical investigation programme comprising five test pits was undertaken across the site. Test pits were evenly spaced across the alignment and were typically advanced 2-3m below existing ground surface to the proposed pipe invert level and deeper in most instances. Subsurface material was consistent across the alignment and comprised silty coarse gravel with some cobbles and boulders, consistent with the unit description of Hope Gravels description identified in geological mapping.

Four test pits were undertaken in December 2018 (TP1-4), and one test pit in October 2020 (TP5). Groundwater was observed at 2.8m below ground surface in TP5 only and the others were dry. TP5 was located immediately adjacent to the pipe ram launch pit for the SH6 crossing.

The test pit investigation method was selected due to the expected gravelly and cobbly soils, and proposed pipe ram installation methodology. Test pits were limited to 3m in depth due to proximity to highway, commercial and residential infrastructure, and the highly trafficked urban environment. A deep borehole investigation with piezometric monitoring was proposed, however this was deferred to the construction programme rather than prior to design.

2.1.3 Pipe ram launch pit dewatering assessment

The dewatering assessment undertaken aimed to predict the rate of groundwater abstraction required to dewater an assumed 15m long, 3m wide excavated launch pit adjacent to SH6. The analysis used a transient analytical flow model to calculate groundwater inflow rates to a long narrow pit excavated into an unconfined aquifer, after Hazel 2009.

The model required five main inputs: the thickness, hydraulic conductivity and specific yield of the aquifer, the dimensions of the pit, and the water table drawdown in the excavation. Values for each input are summarised as:

1. A saturated zone modelling the assumed aquifer thickness of approximately 10m was used.
2. The hydraulic conductivity of the aquifer was estimated from soil descriptions from TP5. For sand and gravel mixtures, Kruseman and de-Ridder (2000) provide hydraulic conductivity values ranging from 5 to 200 m/d. A sensitivity analysis was undertaken using hydraulic conductivity values of 10 m/d, 100 m/d and 200 m/d to model the impact of various flowrates, which are included in Table 1.
3. An aquifer specific yield of 0.1 was adopted as suggested by Kruseman and de-Ridder (2000). This is a typical value for unconfined sand and gravel aquifers.
4. A pit dimension of 15 m long by 3 m wide was assumed.
5. Water table drawdown ranging from 0.42m (optimistic case) to 1.12m (conservative case). The range of groundwater levels was selected to allow for seasonal and weather influences. The best and conservative cases were noted to be an estimate; it was highlighted that the groundwater level in the conservative case may potentially not be the worst case.

The output of the assessment identified a range of possible flowrates for the excavated pit and are presented in Table 1.

Table 1. Dewatering assessment outputs

Scenario	Groundwater drawdown in excavation (m)	Groundwater inflow (L/s) for range of aquifer hydraulic conductivities (m/day)		
		10	100	200
Optimistic Case	0.42	2	11	19
Expected Case (based on water level observed in TP5)	0.62	2.5	14	25
Conservative Case	1.12	4	23	42

The assessment estimated that the inflow rates in the launch pit excavation could range from 2-42 L/s and a reasonable prediction of 10-20 L/s was provided.

2.2 Contract Documents

2.3 Summary of contract documents

The full dewatering assessment was included in the contract documents for the project, and multiple references to the requirement for dewatering of excavations were made in the technical specification. The output and recommendations from the dewatering assessment were used as a basis of estimating a price during direct appointment of the Contractor. It was agreed during appointment of the Contractor that a reasonable allowance for dewatering works for the duration of the contract was one 150mm pump typically capable of pumping up to approximately 50 L/s, and associated pipes and conventional settlement tank treatment setup. This would allow for the conservative scenario of the assessment.

2.3.1 Resource Consent

Resource consent for the construction works included dewatering requirements, notably two key clauses as follows:

1. An initial drawdown phase shall be allowed at a rate of 106 L/s, with continuous dewatering allowed at a rate of 30 L/s. Continuous pumping rates exceeding these limits are subject to the approval of the local authority's Senior Resource Scientist.
2. Sediment control and/or treatment measures shall be adequate to ensure the visual clarity of any receiving waterway is not reduced by more than 40%, at a point measured 50m downstream of any discharge point, as a result of the dewatering activities.

3 CONSTRUCTION

3.1 Dewatering Methodology and Groundwater Observations

3.1.1 Launch Pit Dewatering

Construction works at the pipe ram launch pit area began in July 2021. The Contractor's initial dewatering methodology for the launch pit excavation comprised the installation of a dewatering well and initiating pumping for a sufficient length of time to draw down groundwater to the required level. The Contractor installed a 150mm diameter dewatering well to 9m below ground surface, with a slotted intake approximately 5m long below the excavation invert.

On installation of the well casing, the Contractor's driller attempted to develop the bore, however, was unable to extract water. The Contractor's driller was experienced in advancing bores for groundwater take in the area. Well pumping was abandoned on the realisation it would not be effective. The Contractor then installed two 0.3m diameter PVC sumps within the excavation to approximately 0.5m below the excavation invert. Groundwater was allowed to equalise within the excavation showing a static groundwater level of 1.6m below ground surface. The final launch pit excavation dimensions were approximately 15m long, 2m wide, and 3m deep. This required a groundwater drawdown of 1.4m to dewater the launch pit excavation.

3.1.2 Trench Dewatering

The typical detail for installation of the DN450 water main required excavation up to 2m depth across the alignment. Prior to the work starting, the trench excavation was anticipated to be largely dry with some areas requiring minor dewatering, as indicated by the water level observed in the test pit investigations. Cut and cover trenching was undertaken with approximately 50m lengths open at any one time. Groundwater was consistently observed between 1.6m to 2m below ground surface and was removed by sump pumping from two 0.3m diameter PVC sumps installed at each end of the trench length.

3.1.3 Stream Dewatering

Dewatering of stream crossings employed an over-pumping diversion of surface water from upstream to downstream and similar sump pumping to the trench installation. Pipe specials with prefabricated PE bends were used as opposed to utilising the pipe deflections to pass under the streams. Pipe specials

comprise a “special” configuration utilising fabricated bends to deviate around an obstruction, rather than using the pipes flexibility or joint articulation tolerance to achieve the deviation. In the case of the Richmond South works, this means the length of trench below the groundwater level could be significantly shortened reducing the dewatering required.

3.2 Ground Conditions Encountered

Ground conditions encountered site-wide to the depth of 2-3m typically comprised coarse GRAVEL with some cobbles and varying silt content to a depth of 3m below ground surface. Layers of clean gravel and cobbles were prevalent throughout the site. Significantly greater groundwater inflow was observed in clean gravel and cobble layers than in silty gravel layers. Ground conditions below 3m were not observed as geotechnical oversight was not present for the advancing of the dewatering bore, and no drillers logs were recorded.

Groundwater conditions observed at the site were significantly different than observed during geotechnical investigations. Groundwater inflow was observed from approximately 1.6 to 2.0m below ground surface across the alignment.

3.3 Effects and Impacts during Construction

3.3.1 Launch Pit Dewatering

When pumping was initiated within the launch pit excavation at SH6 it required three 150mm pumps operating at full capacity of approximately 55 L/s, and two smaller 50mm pumps at full capacity of approximately 8 L/s to effectively draw the water down to the excavation invert level. Total groundwater extraction flowrate during dewatering was assessed to be in excess of 170 L/s for the duration of the pumping.

Groundwater extracted from the excavation was extremely turbid and the Contractor was unable to meet the water clarity discharge requirements set out by the resource consent using conventional settlement tanks. A system of flocculent dosing using purpose-built plant referred to as a “silt-buster” was utilised to treat and discharge water in order to allow dewatering to continue.

Impact to the construction activities primarily comprised a fundamental change of dewatering methodology from bore extraction to sump pumping, this in turn required significant increase in plant including additional pumps, sumps and pipes, treatment of extracted water to meet resource consent requirements, extended duration of the works, and additional cost associated with the time and plant.

3.3.2 Pipe Trench Dewatering

Groundwater inflow during excavation of the pipe trench was common and also noted to rise quickly after rain events. Pumping out of 0.3m diameter sumps within the pipe trench was required. Up to two 150mm pumps operating at full capacity were required to effectively draw down water inflows, corresponding to a total discharge of over 100 L/s.

Where pipe trenches were in an urban area, treatment of the water by flocculent dosing was required, however in rural areas discharge of water to an infiltration pit a suitable distance from the work area was found to be effective. Impact to the construction activities again comprised additional plant including additional pumps, sumps and pipes, treatment of extracted water to meet resource consent requirements, an extended duration of the works, and additional cost associated with the time and plant.

3.3.3 Stream Dewatering

Using prefabricated PE bends instead of relying on pipe deflections to get below the stream crossings allowed the size of the excavations to be minimised. The final excavation was required to be approximately 3m below ground surface and achieve a groundwater drawdown of approximately 1.0m. Even with the reduction in size, up to 100 L/s of water was recorded for the stream excavations.

4 DISCUSSION

4.1 Investigations and Dewatering Assessment

The analytical dewatering assessment comprised two key assumptions for this site, 1) a conservative maximum groundwater level of 2.3m below ground surface, and 2) hydraulic conductivity of the aquifer ranging between 10 to 200 m/day (5×10^{-5} m/s to 2×10^{-3} m/s). The assessment concluded that for a 15m x 2m x 3m excavation, a groundwater inflow rate of 10-20 L/s was considered reasonable.

During construction, groundwater was observed to range from 1.6m to 2.0m below existing ground surface, corresponding to up to 1.4m depth of water to be drawn down from excavations. Using the same assessment methodology and assumptions, and increasing the effective drawdown to 1.4m, a hydraulic conductivity of 1000 m/day or 1×10^{-2} m/s is required to match the observed inflows at the site.

The higher groundwater level at the site does contribute to the increased excavation inflows, however using the assessment methodology, a 0.3m water level increase within the excavation (from 1.12m to 1.42m) results in a modest 10 L/s increase in water inflow. Modification of the hydraulic conductivity of the gravel aquifer to 5 times greater than the conservative case was required to match the water inflows recorded.

4.2 Construction and Contractual Implications

Implications to the construction works of the pipeline were multiple, and these had contractual implications which included:

1. The elimination of borehole investigations prior to design and advancing test pits to 3m only meant the deeper aquifer conditions were unknown prior to construction. The dewatering methodology had to be adapted from well pointing to sump pumping during construction. This incurred additional time and effort for the contractor to procure plant and install the required system. The change in methodology also introduced more turbid water extraction. The well point system was anticipated to return clean water after a short period of pumping. Changing to sump pumping meant a much greater surface area for water inflow and potential to carry fine material from the gap graded silty gravel, resulting in significant fines migration and discoloured water.
2. The greater than anticipated groundwater inflows required additional pumping effort and significant treatment of discoloured water was required to meet resource consent requirements. The Contractor needed to procure more pumps and treat extracted water by addition of flocculants. This increased the plant required, as well as the duration, and cost of the works.
3. The extracted water rate exceeded the resource consent maximum peak extraction rate of 106 L/s. While in this case the increased extraction rate was accepted by the regional authority, the increased extraction rate had the potential to halt work.
4. The change in dewatering methodology and procurement of plant and treatment resulted in a three-week extension of the construction programme.
5. The additional time and materials resulted in a variation cost to the project of 15% of the original contract value.

4.3 Geotechnical and Contractual Risk

Geotechnical risk present from the outset for the Richmond South project had a follow-on effect through the design and construction. The key risk items identified by the case study are:

1. The suitability of investigations to inform not only the permanent works requirements, but also for the adequate consideration of the temporary dewatering works. For the Richmond South works this was understanding the ground conditions to a depth of 9m below ground surface and how these may affect dewatering.
2. Understanding of how a change in soil material properties may affect the proposed works. For the Richmond South works the key items were the sensitivity of hydraulic conductivity with changing soil types and how this in turn affects groundwater take volumes for the proposed excavations.
3. Understanding of the fluctuation of groundwater levels both seasonally and with significant rain events. The Climate and Weather of Nelson and Tasman produced by NIWA (Macara, 2016)

states mean monthly rainfall for the area in July and August to be 78mm and 82mm, respectively, mean monthly rainfall is taken from historical data from 1985 to 2010. Total rainfall of 189mm and 166mm was recorded for July and August 2021, respectively (NIWA, 2021). Rainfall of 2021 was exceptionally high, more than double the mean historical monthly totals. The rise in extreme weather events may become more prevalent because of climate change.

4. Inclusion of appropriate information in the contract to allow the contractor to price geotechnical risks identified, and sufficiently detailed contract clauses to ensure the Principal is sufficiently protected from programme extension and cost escalation.

5 CONCLUSION AND RECOMMENDATION

In conclusion, there were multiple opportunities throughout the Richmond South project where additional information and consideration of risk may have directed decision making to improve the project outcome. The authors are aware of the process that exists in some regions of New Zealand, and recommend the Geotechnical Protocols set out in the Wellington Water Global Dewatering Consent (Wellington Water, 2017) as a good base for decision making and risk management for projects considering dewatering.

For brevity, the protocol is not included in full in this paper however a general flow of decision making in these types of projects, with some adaption from the protocol, could be as follows.

1. Project Planning
 - a. Desktop review by a suitably qualified geo-professional.
 - b. High level risk assessment for the works identifying key unknowns and potential impacts. This may include potential for settlement, volume and rate of groundwater take, discharge of extracted groundwater, seasonal, tidal, or storm event fluctuations, contaminates, or other as identified.
 - c. Categorisation of risk profile of the proposed site into low, medium and high risk.
 - d. Consideration of advanced monitoring i.e., installation of groundwater monitoring systems months or years before the works are planned to take place.
2. Geotechnical Investigation
 - a. Execution of investigations suitable for the identified risk level, considering;
 - i. A suitable ground monitoring method and duration
 - ii. Specific technical inputs required for the design
 - iii. Permanent and temporary works requirements for the proposed work
3. Design
 - a. Determination of the level of design suitable for the site, this may comprise
 - i. Engineering judgement review by an experienced engineer (low risk)
 - ii. Quantitative assessment based on simplified methodologies (medium risk)
 - iii. Numerical model assessment (high risk)
4. Contract Documents
 - a. Review of contract documents by the geotechnical designer to incorporate an appropriate level of detail for temporary and permanent works
 - b. Drafting of a groundwater management plan to be adopted by the Contractor

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