memorandum

TO	Chris Simpson	FROM	Parviz Namjou
		DATE	17 February 2015
RE	QUESTIONS REGARDING THE THREE KINGS DEVELOPMENT		

The following memo addresses the matters raised following your review of the groundwater modelling results submitted on 23 December 2015 and our subsequent meeting on 28 January 2015. The main matters are summarized below:

- Effects of Fill placement on groundwater level rise predictions
- Sensitivity of the groundwater model for the crater to variations in permeability of the basalt/scoria
- Effects of cessation of the quarry pumping on flooding potential within the Meola Catchment
- Assess other potential groundwater flow paths from the crater

Effects of fill on groundwater level rise predictions

Following the development and the placement of Fill, there will be some changes in the configuration of recharge to the basalt/scoria aquifer in the locality of the quarry. Under the existing conditions most of the recharge occurs across the quarry area directly through the scoria and basalt (causing sharp responses to rainfall events). Following the development and the placement of Fill, most of the recharge will be diverted through the soakage system to the aquifer.

The following two scenarios were run to assess the effects of Fill placement on the long-term groundwater levels and groundwater level rise during a 100y rainfall event.

1) A groundwater modelling analysis was carried out to assess the effects of any increase in recharge as a result of the placement of Fill and soakage devices on the long-term groundwater levels for post development conditions (no pumping). For this scenario it was conservatively assumed that all rainfall over the development area will be recharged via soakage holes (100% of rainfall). Note that the recharge rate in basalt and scoria for the calibrated pre-dewatering groundwater model is 83% of the rainfall (PDP 2015). The sensitivity result indicates that such an increase in long-term recharge through soakage devices causes only 0.1m rise in groundwater levels under post development conditions (without any quarry pumping). Therefore the placement of Fill and soakage devices is unlikely to have any significant effects on the long-term groundwater level which was measured to be at about RL56.5m under pre-dewatering conditions.

2) Additional groundwater modelling analysis was carried out to assess the effects of Fill placement on the predicted water level rise after a 100y rainfall event. In one scenario the Fill was placed over the development area (from the surface down to RL40m) and in the other scenario no Fill was assigned. The permeability of the Fill for this analysis ranges between 1×10^{-7}m/s and 2×10^{-5}m/s. However the model is not sensitive to variations in permeability of the Fill. The infiltration rates for the event (PDP 2015) are assumed to be the same for both scenarios.

The predicted water level rise in the cone for the above two scenarios for the centre of the crater is shown in Figure 1. The results indicate no significant changes (<2%) in the predicted water level rise.

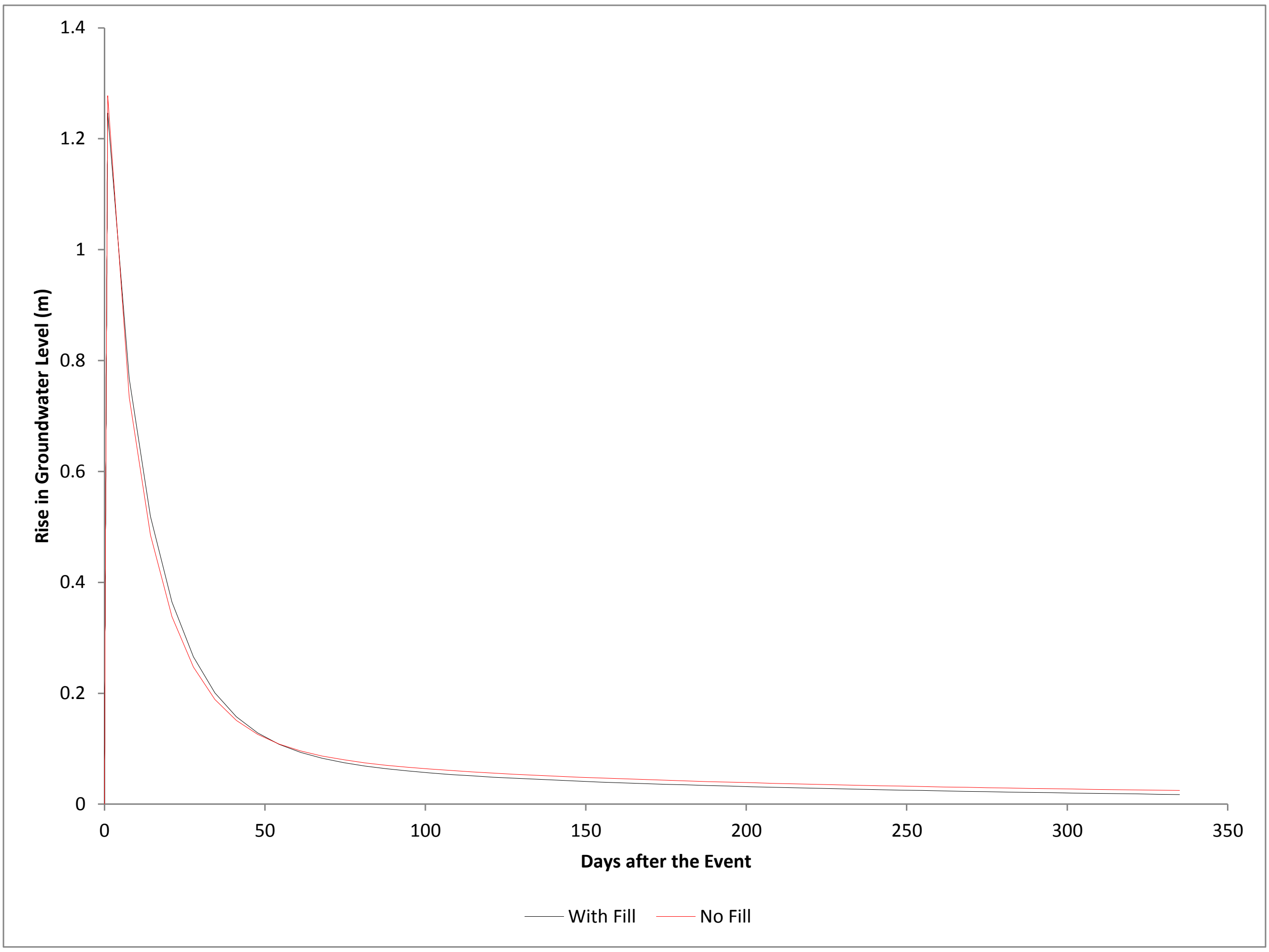


Figure 1: Effects of the Fill Placement on Predicted Groundwater Level Rise after 100y Rainfall Event

Sensitivity of the model to variations in permeability of the basalt/scoria

A sensitivity analysis was carried out to assess the effect of basalt/scoria hydraulic conductivity on the predicted groundwater level rise for a 100 year rainfall event. The basalt/scoria hydraulic conductivity has been assessed and calibrated as part of the previous groundwater take consent (PDP 2003, 2005 a&b). The calibrated hydraulic conductivity value is 2 x 10^{-4}m/s. The calibrated hydraulic conductivity for the basalt outside the cone within the Western Springs aquifer based on the GAS study is 9 x 10^{-4}m/s (PDP 2005c). Considering the higher proportion of the scoria in the cone, the applied lower permeability (2 x 10^{-4}m/s) is considered to be conservatively realistic and lower limit and any lower value for the bulk permeability of the cone is unlikely to be realistic.

However, as a sensitivity check effects of 50% reduction (k=1 x 10^{-4}m/s) and 100% increase in the basalt/scotia hydraulic conductivity (k=4 x 10^{-4}m/s) was assessed and the results are shown in Figure 2. The reduction in permeability by 50% doubles the calibration error (the difference between measured and calculated heads increases by about 0.5m). For this scenario the predicted groundwater level rise as a result of a 100y rainfall event is 1.44m

(0.2m more than predicted using the calibrated model). The 100% increase in permeability reduces the magnitude of the groundwater level rise by about 0.1m (Figure 2).

The above results which are summarised in Table 1, show that uncertainty analysis of the basalt permeability within the acceptable range has no significant effect on the predicted rise in groundwater levels.

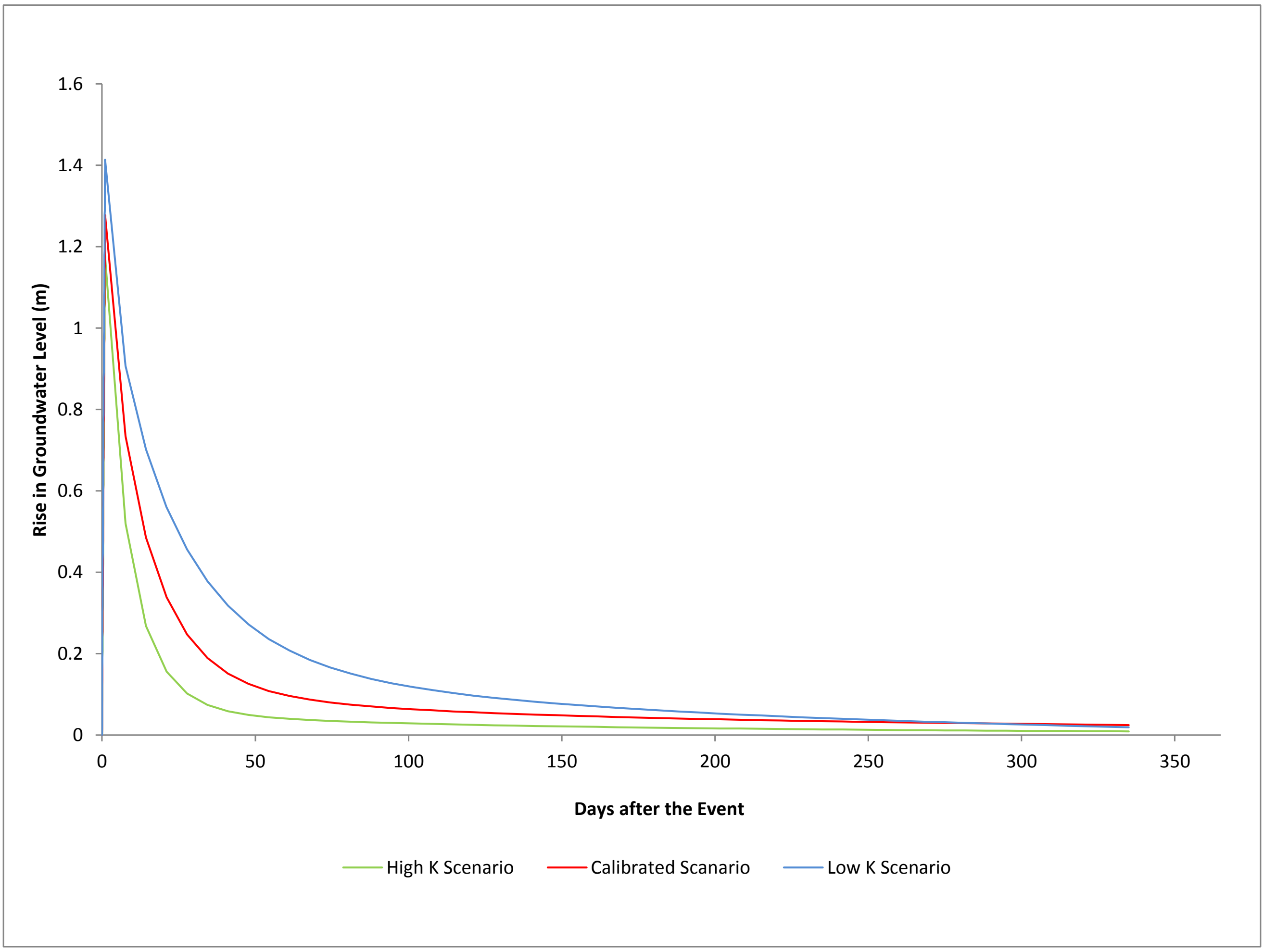


Table 1: Uncertainty Analysis – Effect of Basalt/Scoria Hydraulic Conductivity on Predicted Groundwater Level Rise for 100y Rainfall Event

Scenario	Hydraulic Conductivity of Basalt/Scoria (m/s)	Rise in GW (m) for 100y rainfall event
High K	4×10^{-4}	1.17
Low K	1×10^{-4}	1.44
Calibrated Model	2×10^{-4}	1.25

Effect of cessation of pumping on flooding potential within the Meola Catchment

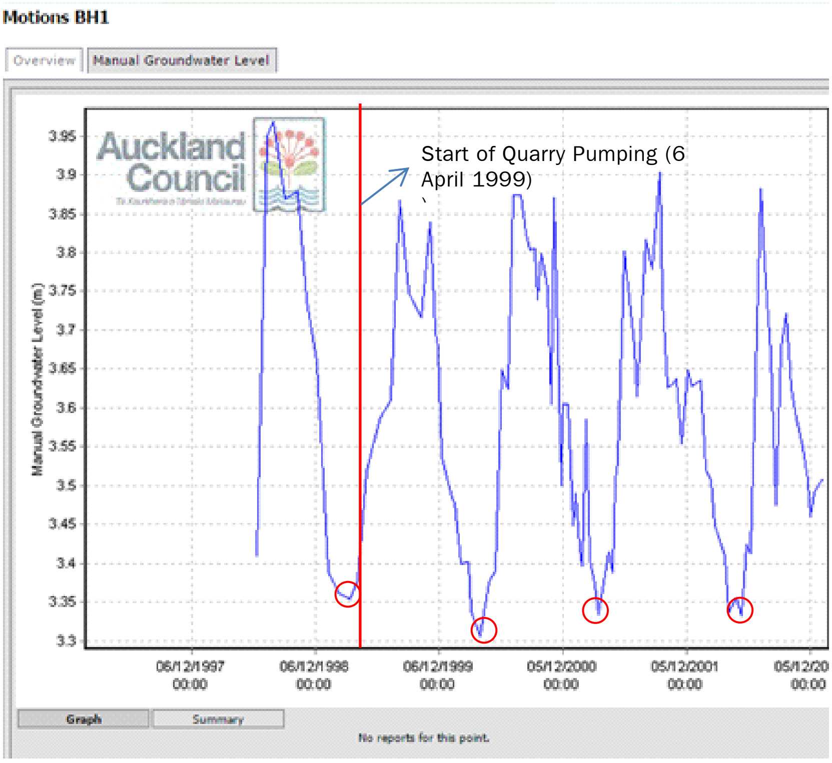
Under pre-dewatering conditions, the groundwater within the cone was flowing through the tuff ring breach (on the north side of the crater) and contributing to the groundwater flow within the Western Springs aquifer before discharging to the harbour.

This section discusses the effects on groundwater levels in the Western Springs Aquifer from resuming natural outflow from the crater. In particular, it makes assessment on the net change in aquifer groundwater levels that may become evident as a result of any changes in recharge to the Western Springs Aquifer during the period of quarry dewatering. Changes to recharge from changes in landuse in the catchment are the focus of the assessment.

The historical groundwater level hydrographs for two monitoring bores in the basalt at Meola Rd and Chamberlain Park are shown in Figure 3. These bore are located in the lower Western Springs catchment areas and are most suitable for this assessment. The low annual groundwater levels in dry conditions before and after the dewatering (6 April 1999) are shown on the hydrographs. The results indicate that the quarry pumping and subsequent reduction of about 2500m^3/d throughflow in the Meola aquifer has had no significant effect on the groundwater levels in lower catchment areas.

Since the onset of dewatering, the extent of imperviousness within the catchment has changed very little. Figures 4a and 4b show the Meola Catchment before and after the quarry dewatering. The catchment was almost completely developed prior to the onset of dewatering; therefore the only changes in the impervious area have been minor. Based on the historical records (Auckland GIS system), 14.8ha of the catchment was developed since 1999 while 0.55ha of developed area has been transferred to open space (parks) during this time. With a total catchment area of 1510.2ha, the above increase in imperviousness represents less than a 1% change. Such a small increase in imperviousness (potential increase in soakage holes and infiltration rate) is unlikely to have any effect on the groundwater levels.

As part of GAS study (PDP 2005c) various recharge scenarios for the Meola groundwater catchment were tested (using the GAS calibrated model). The results showed that increasing the groundwater throughflow for maximum probable development (MPD) is unlikely to cause any significant increase in the extent of the shallow groundwater zone (areas where depths to groundwater is less than 2m). For the MPD scenario, the recharge fraction for residential areas within the Meola aquifer boundary was increased to reflect the potential maximum level of imperviousness. This resulted in an increase of about 8,000m^3/d in the groundwater throughflow. However, based on the modelling results, the extent of the shallow groundwater zone for the above MPD scenario was increased only by about 1%. It was concluded that a high aquifer transmissivity and the aquifer capacity to accommodate more recharge prevents any significant increase in extent of the shallow groundwater zone for the above scenario (PDP 2005c).



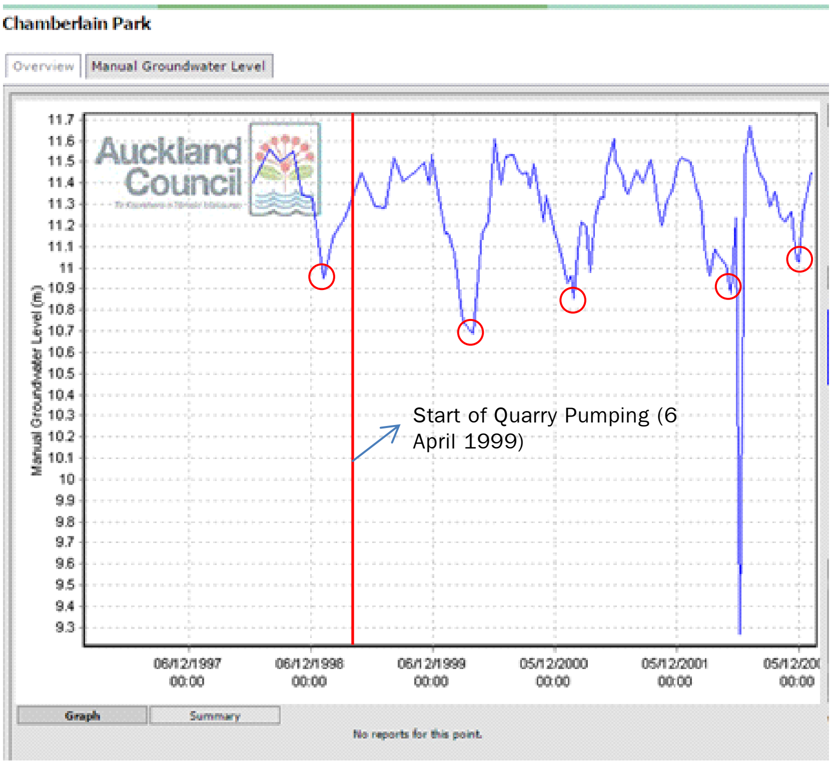


Figure 3: Historical Groundwater Levels Hydrographs, top: Meola Rd monitoring bore, bottom: Chamberlin Park bore (note the groundwater levels at in mRL, source: Auckland Council monitoring data)

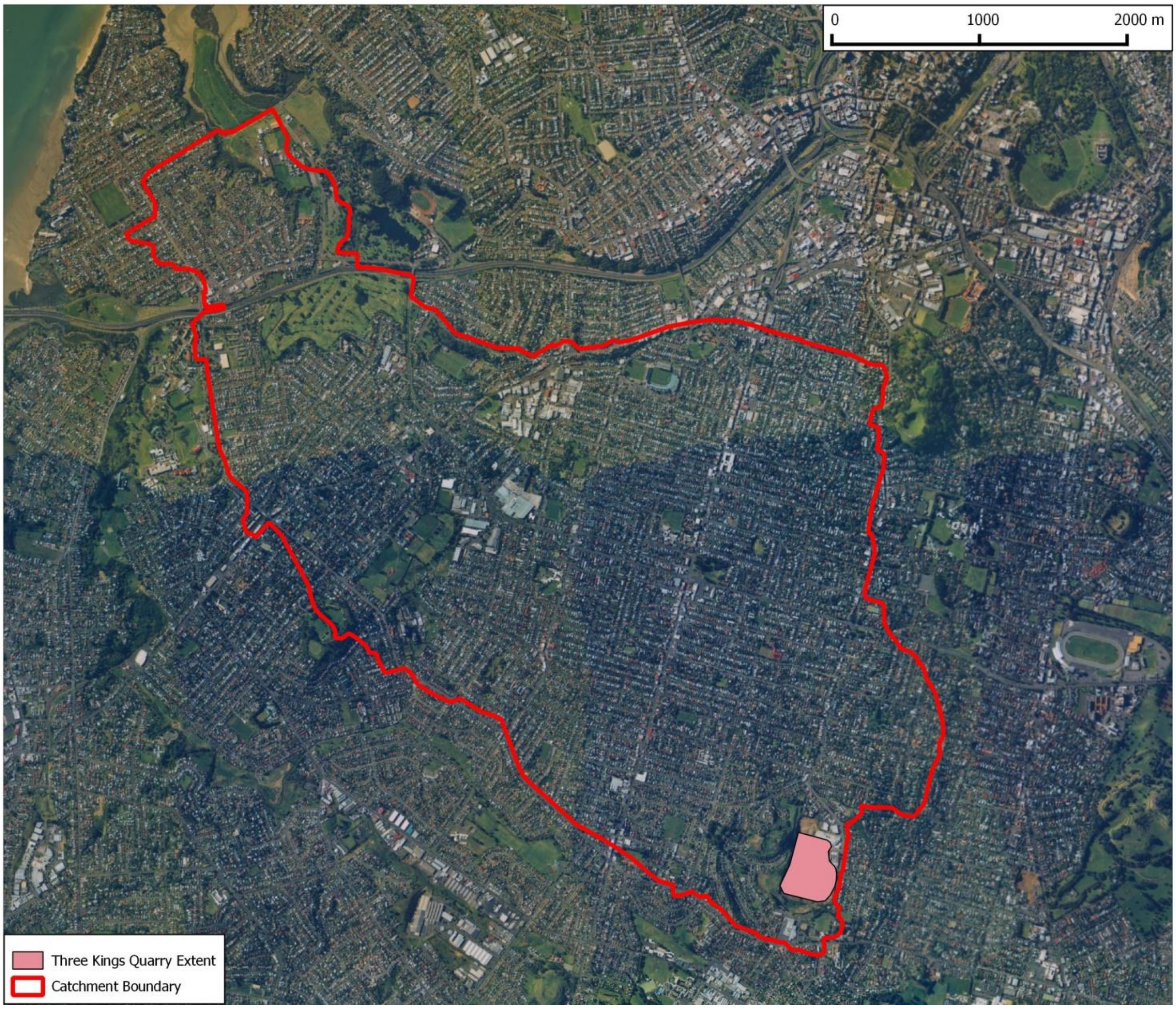


Figure 4a: Extent of land development in the Meola Surface Water Catchment in 1996, 3 years before dewatering.

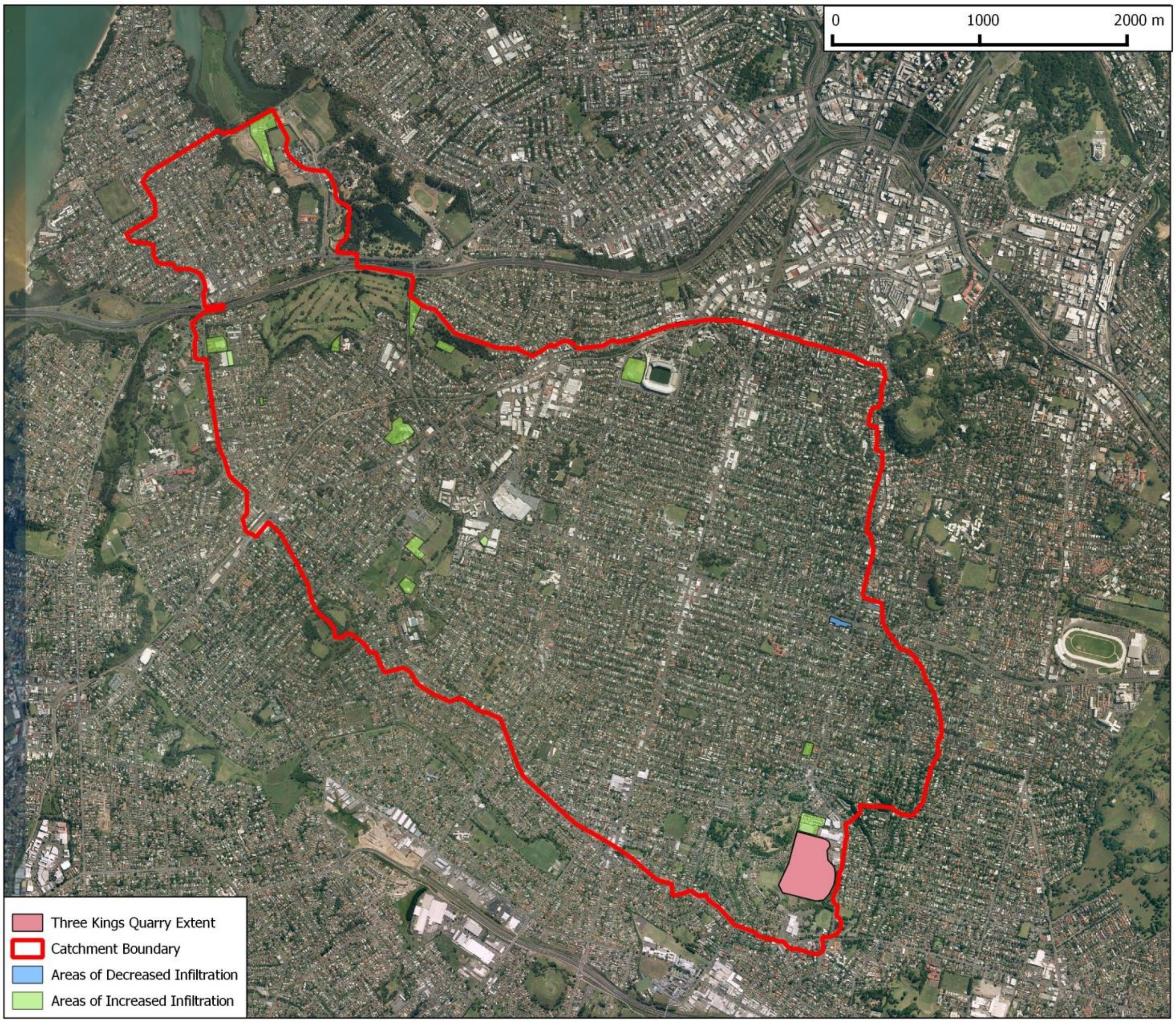


Figure 4b: Extend of the land development in 2012. Areas of increased infiltration (new development) are marked in green, and decreased infiltration (an increase in park lands) marked in blue.

Potential for other groundwater flow paths from the crater

The following section outlines potential for other groundwater flow paths from the crater to develop following the cessation of the pumping in addition to the northern tuff ring breach. The geological map and schematic geological cross sections are shown in Appendix A.1.

The Three Kings crater sits within the Waitemata and Tauranga Group sediments. Tuff blown out during the initial stages of eruption sits on top of these deposits and forms a bund-like feature, referred to as a tuff ring, around the crater. Previous work suggests that basalt lava filled a moat between the cones and the Tuff/Waitemata bund and this can be seen in boreholes located toward the southern, eastern, and northern edge of the crater (boreholes 6, 6A, 18, 18A, 19, 11A, 11B).

Breaching of the tuff ring has been discussed in earlier work (PDP 2003 and 2008). The breach of the northern boundary of the crater can be seen in boreholes 6 and 6A and borehole 7 where a lava flow exits the crater and continues down to Meola and Western Springs.

Potential flow paths to the East

It was suggested that the basalt of the Greater Onehunga Aquifer found in BH12 is potentially connected to the Three Kings Complex through a breach of the tuff ring along the south-eastern boundary of the crater. This suggestion is based on the proximity of basalt in boreholes 12A and 12B outside the cone to the east with that seen in boreholes 19, 11A and 11B within the cone. This would imply that the crater aquifer extends in this direction, and any associated groundwater flow will be influenced by changes to the quarry workings. As investigated in PDP (2008) this postulation is not supported by the available lithological information (Figure 5) which suggests that the tuff ring is likely to be continuous in this area.

Examination of the bore logs in the eastern side of the cone suggests that a breech in this area is not likely. The main reasons for this are as follows:

- Boreholes 10A and 10B which lie between borehole group 19, 11A, and 11B, and borehole group 12A and 12B show no basalt (Figure 5), but instead tuff sitting directly on non-extrusive sediments (Tauranga Group). This indicates a lower permeability tuff bund between the two basalt flows;
- The basalt in boreholes 12A and 12B is covered by approximately 25m of tuff and non-extrusive sediments and at lower elevation to that seen in crater. Tuff would be the first deposit in the formation of a new volcanic complex. The fact that these overly the basalt outside the crater would indicate (assuming the tuff originates from the Three Kings complex) that this basalt is from another, older volcanic centre, probably One Tree Hill or other centres to the east.
- In addition examination of the groundwater data indicate a lack of connection between the basalt inside and outside the crater in this area. To the east, groundwater level in BH12 (in the basalt) is significantly higher than those in the crater (around 51m RL compared with around 34m RL) and remains unaffected during the dewatering period (PDP 2008).

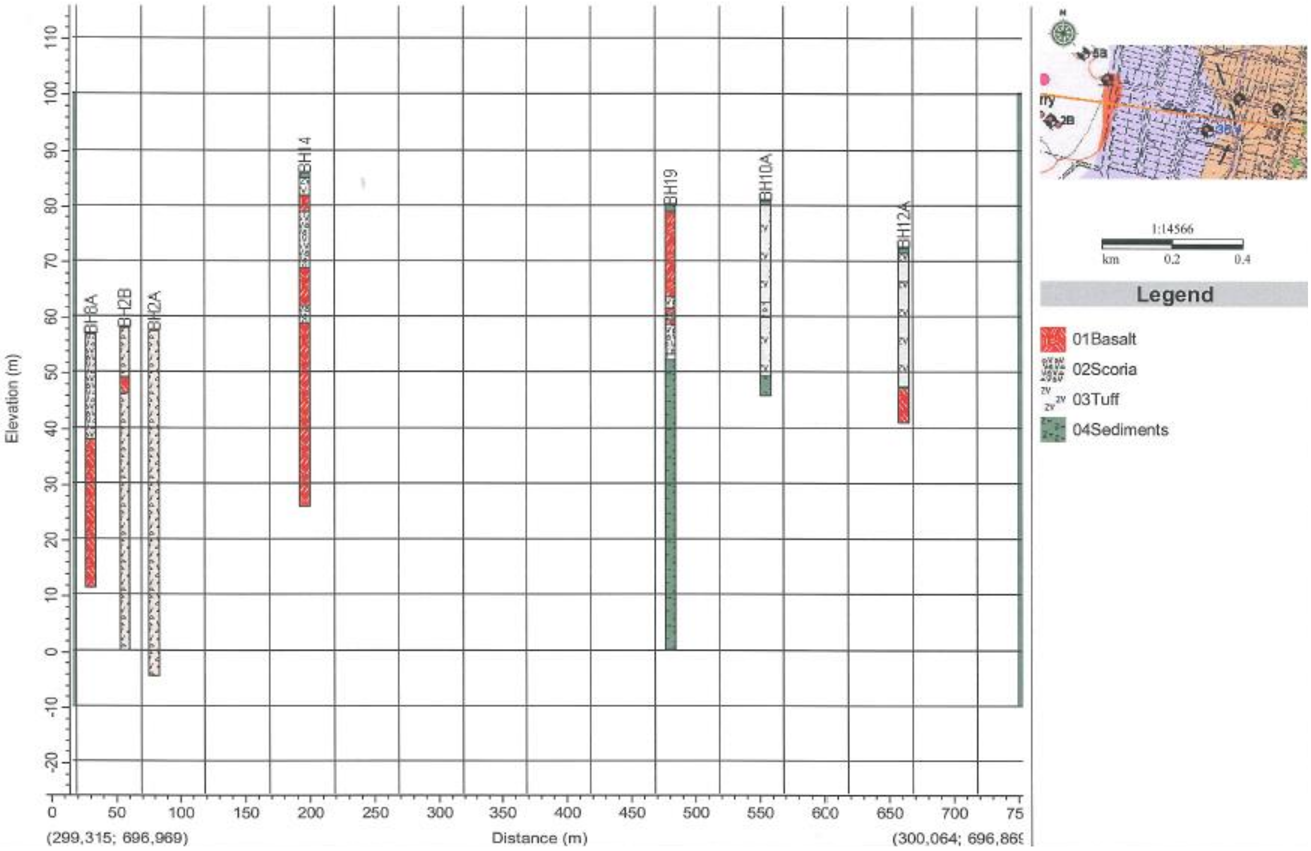


Figure 5: Relationship between lava flows east of the quarry pit

Potential flow paths to the south east

Similarly, any groundwater flow path to the south east is not supported by the field data. Despite basalt being present in BH25, BH15, located closer to the crater edge shows tuff over Waitemata Group and an absence of basalt. In addition, tuff would be the first deposit in the formation of a new volcanic complex. The fact that tuff overlies the basalt in BH25 outside the crater would indicate that this basalt is from another, older volcanic centre, probably One Tree Hill or other centres to the east.

In borehole 25, groundwater levels deep in the Waitemata Group do suggest a response to pumping (being around 37m RL), but those in the overlying basalt and shallower sediments are significantly higher than this (just under 50m RL). The dewatering of the lower Waitemata Group sediments in borehole 25 has been interpreted to indicate the presence of the higher permeability disturbed sediments at this location. Despite effects being seen in the sediments underlying the basalt at this location, the maintenance of a high vertical head gradient between the basalt and the underlying sediments would suggest low vertical connectivity (PDP 2008). It is considered, therefore, that the potential for leakage out of the crater following recovery of water levels, through the disturbed sediments and into the overlying basalt will not be significant.

Potential flow paths to the south

A spring is noted in an historic aerial photo taken in 1940 (Figures 6A and 6B) at an elevation of about RL60m and it is suggested that it may represent a potential groundwater flowpath from the crater towards the southeast. However, Bore BH22 (Appendix A.1) drilled approximately 50m from the spring's original location shows that the basalt is discontinuous between the Three Kings Complex and basalt located to the southwest. This indicates that the original lava flow cannot have exited the cone in this direction, and thus the basalt aquifer cannot extend in this direction.

The location of the spring is close to the location of a Waitemata Group paleovalley along Oakley Creek. This suggests this spring may have been sourced from a separate groundwater system within ECBF (or overlying perched layers within the tuff).

Based on this information, therefore, the northern breach is considered to be the only significant groundwater outflow from the crater.

Figure 6A: Aerial photo (1940) showing the location of the spring in relation to the Three Kings Volcano.

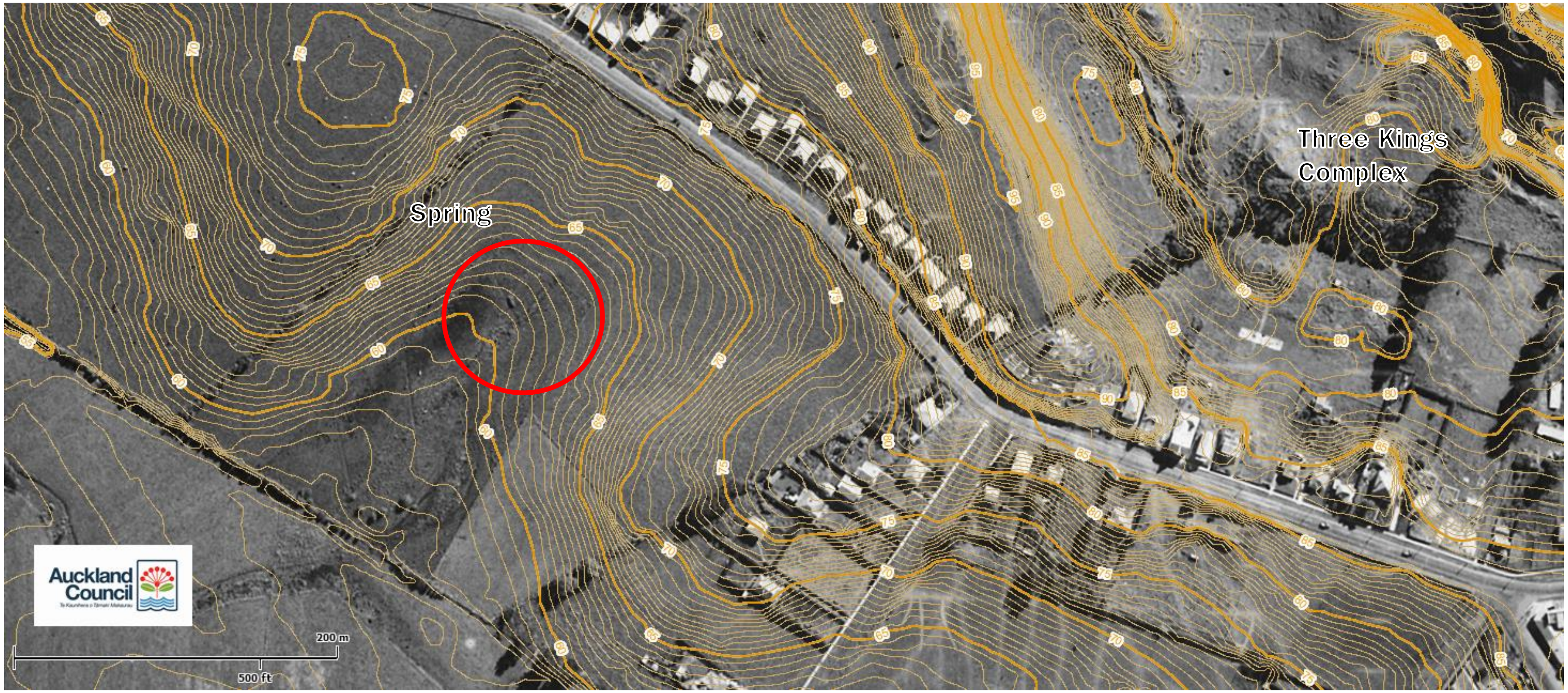


Figure 6B: Contours of the area showing the spring

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Appendix A.1

Geological Map and Schematic Geological Cross Sections