2006

An Investigation into Underground Mine Interaction with Overlying Aquifers, Huntly East Mine, New Zealand

G. Guy
Solid Energy, New Zealand

W. Gale
SCT Operations, Australia

B. Sinclair
Kingett Mitchell New Zealand

D. Fergusson
Solid Energy, New Zealand

B. Farnworth
Solid Energy, New Zealand

AN INVESTIGATION INTO UNDERGROUND MINE INTERACTION WITH OVERLYING AQUIFERS, HUNTLY EAST MINE, NEW ZEALAND

Glen Guy[1], Winton Gale[2], Brett Sinclair[3], Dean Fergusson[1] and Bill Farnworth[1]

ABSTRACT: In recent years, Huntly East Mine has operated at a depth range of approximately 100 m to 220 m below a Quaternary aged clay, sand and silt aquifer that is connected to a nearby large river system (Waikato River). A key issue for mine planning and environmental management has been the development of mine design criteria to allow efficient mining of the reserves and to maintain the integrity of the aquifer. A case study and back analysis at Huntly East Mine is presented, which investigates the overburden conductivity and the impacts caused by mining-induced caving. The case study includes:

i. computer modelling of the mine geometry, caving and overburden fracture networks created;
ii. field investigation to develop an engineering geological model of the overburden within the goaf to validate the goaf geometry as defined by the computer generated model;
iii. *in situ* field measurement of overburden conductivity in the pre- and post-mining condition;
iv. interference testing across the goaf to determine the level of interconnectivity; and
v. measured water pressure profiles above the mine.

INTRODUCTION

Pillar extraction mining within the Renown and Kupakupa Seams of the Waikato Coal Measures is undertaken at Huntly East Mine, New Zealand. The seam is typically 20 m thick, and extraction is undertaken by double lift and pillar pocketing methods. The location and typical panel layout is presented in Figure 1. An indicative stratigraphic cross section from East Mine is presented in Figure 2.

The mining methods and layout adopted have been developed on the basis of maximising extraction while restricting subsidence and, importantly, maintaining the integrity of the Tauranga Group aquifer which is composed of unconsolidated Quaternary aged sediments.

The Waikato River flows over the mining area and is hydraulically connected to the Tauranga Group aquifer. The depth of mining is variable however recent mining has been within a depth range of approximately 140-230 m. The thickness of the overlying Tauranga Group sediments ranges from approximately 20-40 m. Subsidence over the study area mine panels ranges from approximately 1-1.2 m.

A detailed investigation program was undertaken for panel N51 to study the potential groundwater impacts caused by mining and to obtain information to optimise mining operations. The program included:

i. surface subsidence monitoring,
ii. develop an engineering geological model above the goaf to evaluate the mining induced fracture geometry using post mining drilling above the panel,
iii. monitoring of strata caving using a surface to seam extensometer,
iv. monitoring of water pressure drawdown within the overburden using pre-placed and post emplaced piezometers,
v. packer testing to measure ground conductivity above the goaf,
vi. injection tests to assess fracture connectivity.

[1] *North Operations - Solid Energy New Zealand Limited*
[2] *SCT Operations Pty Ltd*
[3] *Kingett Mitchell Limited New Zealand*

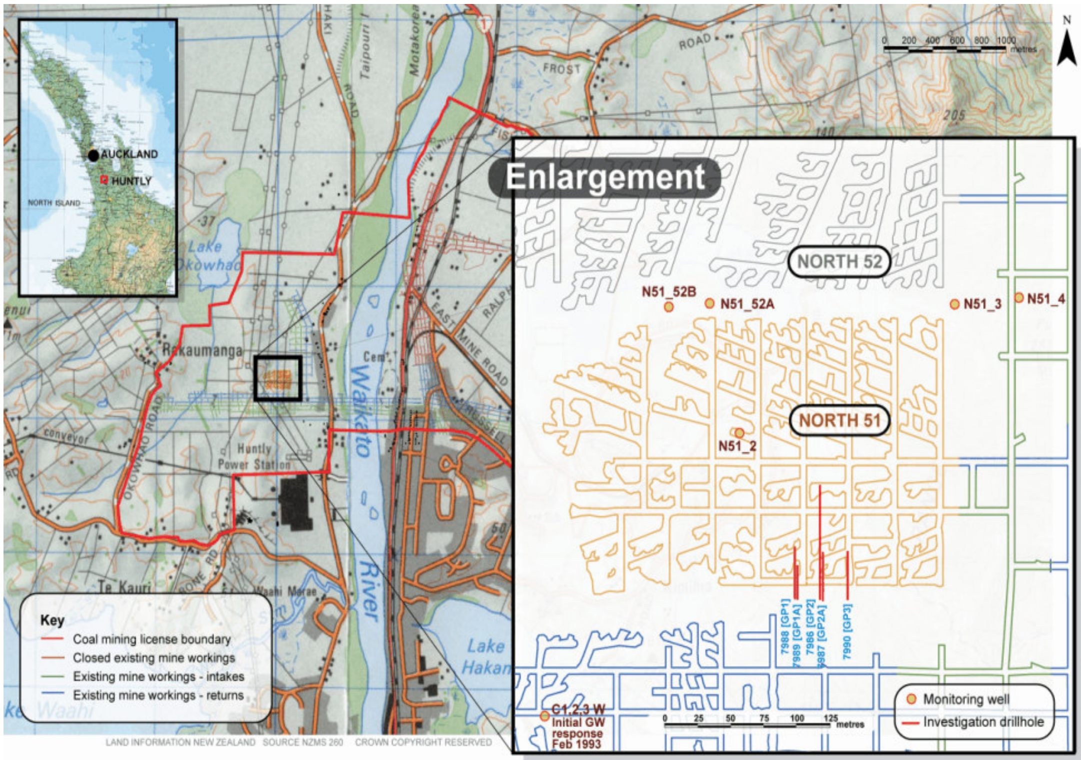


Fig 1: Location and mine layout at East Mine, New Zealand.

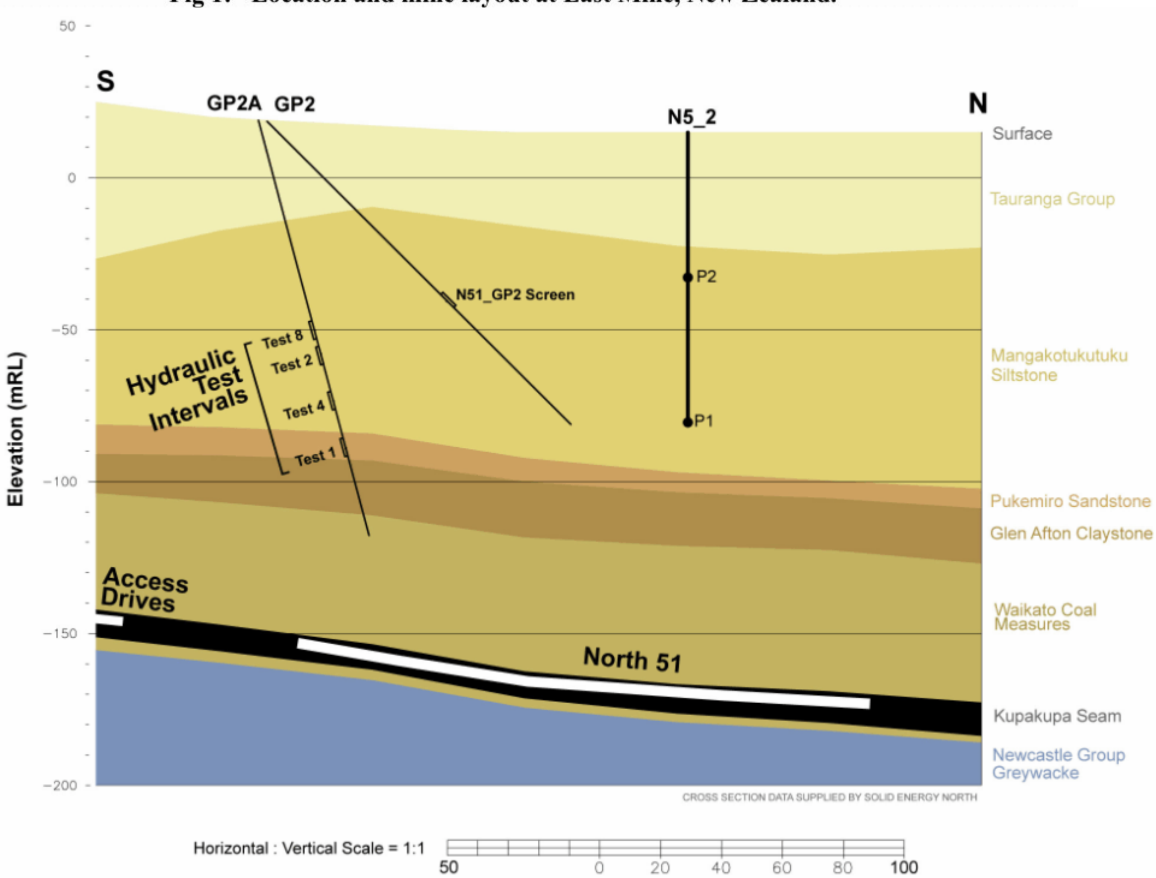


Fig. 2: General stratigraphic section and test borehole locations.

Computer modelling of the caving process, fracture distributions and the hydraulic conductivity above the extraction panel was undertaken prior to the monitoring programs. The results of both the modelling and the investigation and monitoring program have been utilised to assess the mining impact on overburden conductivity. This information also forms part of an ongoing planning process to evaluate the impact of other mining techniques on groundwater flow patterns within the overburden. The results of the field study and the application of computation modelling to predict overburden and conductivity is presented.

OVERBURDEN CHARACTERISTICS AND PROPERTIES

The overburden is composed typically of very weak to moderately strong mudstones and clay rich interbedded fine sandstone and siltstone. Sandstone units exist in the sequence however their properties are variable. The overburden has been characterised on the basis of geophysical logging and laboratory testing of core. An indicative strength profile through the overburden is presented in Figure 3 on the basis of unconfined compressive strength of each unit. The Tauranga Group is approximately 20 m thick above N51.

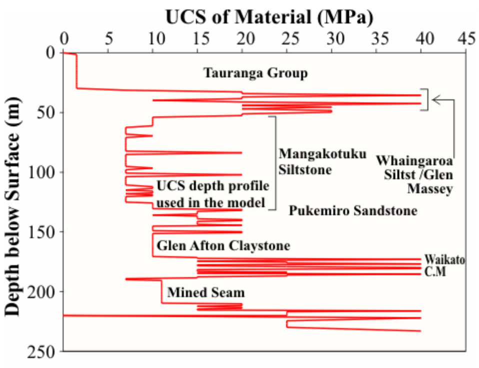


Fig 3: UCS of strata relative to depth based on geophysical data.

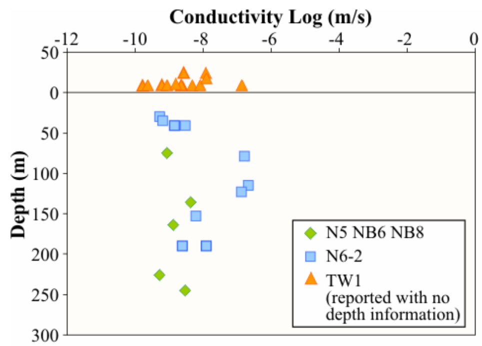


Fig 4: Field packer test data used as background information for insitu conductivity.

IN SITU HYDRAULIC CONDUCTIVITY MEASUREMENTS

Hydraulic conductivity results from packer tests performed prior to mining are plotted in Figure 4 relative to depth. Some of the data was classified on the basis of formation without any depth and these are presented at the top of the plot. The packer interval varied for this data set and as such the results should be seen as indicating the sensitivity sampling a range of possible conductivity within the overburden. The silty sandstone units at Huntly typically have a conductivity of 10^{-6} to 10^{-7} m/s. The conductivity of the finer grained rock matrix is considered to be in the range of 10^{-10} m/s to 10^{-11} m/s, however the rock mass fabric can result in considerable local variation. Undisturbed rock fabric data for the N51 overburden is not available and the values are based on tests performed in nearby drillholes.

Variation from the 10^{-10} to 10^{-11} m/s hydraulic conductivity range in the fine grained strata is typically caused by dilated bedding planes and joint planes in the overburden allowing water movement in the packer zone. Values in the 10^{-6} to 10^{-7} m/s range are inferred to represent structured ground. The data set suggests that the field conductivity of the overburden within the Huntly Coalfield is in the range of 10^{-6} to 10^{-10} m/s. Based on the assumption that there was no bypass around the packers in the tests, the variation within the data set suggests that the packer tests have been performed on a range of fractured and unfractured drillhole intervals in the test programs. This is supported by the results from short test intervals returning a greater range of results than tests performed on longer drillhole sections. It is possible that some fractures are "healed" in proximity to muddy units at the base of the Tauranga Group, however for the purpose of this study the data is taken as indicative of the range of background conductivity.

PRE-INVESTIGATION COMPUTER MODEL

A computer model of the overburden and mine extraction of N51 panel was developed using FLAC 2 dimensional code. Development of this model preceded the field investigation program. The model was undertaken to improve the understanding of caving related fractures and overburden behaviour above the extraction panels. The model allowed an estimation of changes to the overburden hydraulic conductivity induced by caving and subsidence movement. The resultant mining induced fracture geometry generated from the computer model is presented in Figure 5. The induced fracture geometry indicates a combination of:

i. bedding plane shear,
ii. shear fracture of strata,
iii. tension fracture and potential reactivation of pre-existing joint planes.

The planned location of the drillholes for the post-mining hydrological study is presented on Figure 5. It was anticipated that the drillholes would intersect a range of sub-vertical and horizontal mining induced fracture systems.

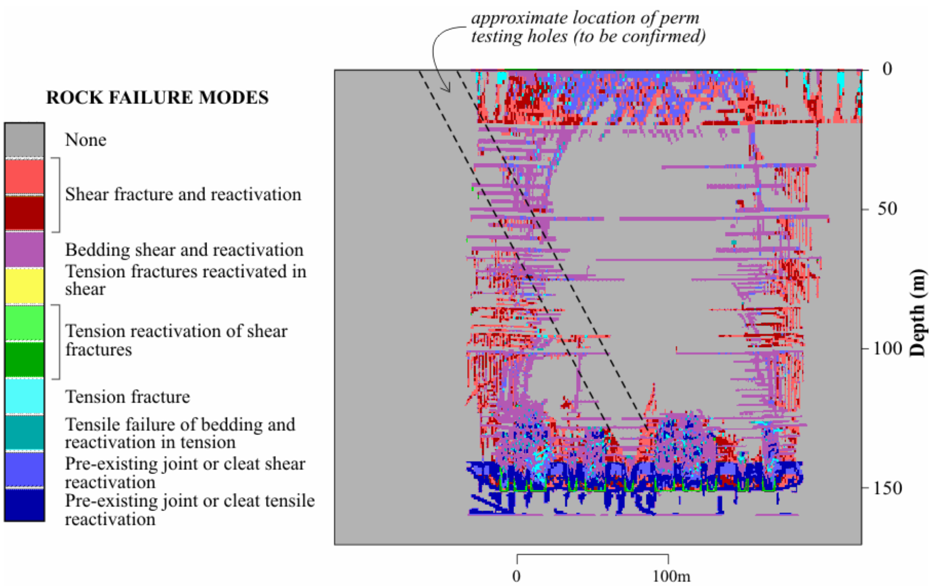


Fig 5: Rock fracture mode about N51 Panel (cross section).

ESTIMATION OF MINING INDUCED HYDRAULIC CONDUCTIVITY

The mining induced changes in conductivity have been assessed on the basis of the fracture apertures and fracture distribution calculated from the ground displacements within the model. The approach used is to calculate the dilation of the strata subsequent to fracture formation and relate this to the aperture of the fracture within which water may flow. This has been done for:]

i. vertical and sub vertical fractures to assess the vertical conductivity, and
ii. bedding planes to assess horizontal conductivity.

The equivalent material conductivity has been calculated from aperture flow within a fracture. The conductivity (k m/s) is estimated from the flow quantity through a 1 m^2 area with unit pressure gradient. This then simplifies to solve k as approximately equal to:

$k = t^3 \times 10^{6}$ m/s
Where; "t" is the hydraulic aperture (m).

It has been assumed that there is one fracture per element in the model and that the aperture is equal to the average dilation less 0.5 mm. This should be considered to be an estimate, and the data has been analysed on the basis of relative impacts.

The model can be interrogated to determine the average vertical conductivity for each one meter layer across the model above the extraction zone. The average conductivity for each succeeding layer is calculated and plotted to give a vertical conductivity profile. This profile does not specifically simulate groundwater flow pathways. It assumes that flow can occur along bedding planes to allow the vertical pathways to be activated with relative ease. The extensive mining induced shearing of bedding planes in the overburden would provide evidence for this situation.

The average vertical conductivity profile over the ribline area is presented in Figure 6 for the N51 modelled geometry. The data is plotted on the basis of a running 5 m vertical section of equivalent conductivity. The results indicate that groundwater flow downward toward the extraction zone would need to occur via a network of vertical and horizontal planes as opposed to any single connection plane.

There appear to be three zones formed.

1. The caved zone where there is direct open flow.
2. A highly fractured intermediate zone linking the caving zone to the overburden above (tortuous zone). This zone is characterised by extensive shear fracturing over the abutment areas.
3. Tortuous flow zone, which has layers of high conductivity separated by zones of low conductivity. Flow in this zone requires an interconnected network of vertical and horizontal fractures to form. Flow would be tortuous and this section forms the effective flow control zone between the intermediate zone and the surface aquifer.

FIELD INVESTIGATION

Five drillholes were programmed to be drilled perpendicular to the goaf edge (Figures 1 and 2), inclined and orientated to intercept the anticipated fracture geometry as indicated from the computer model. Two of the drillholes were positioned within the central part of the underlying mined panel, inclined (55° and 75°) and fully cored and subsequently geotechnically logged to ascertain visual confirmation of the rock mass quality and extent of the fracture geometry. RQDs, fracture intensity and defect orientation were recorded and used to develop a 2-dimensional Engineering Geological model across the goaf zone. This is presented in Figure 2.

Terminal packer tests were undertaken at discrete intervals within the two central drillholes during the drilling process to assess the strata conductivity. Piezometers were subsequently installed within one of the central drillholes and three subsequent instrumentation holes drilled adjacent along the same strike. Piezometers were installed at regular intervals within the overburden to assess:

i. pore pressure changes indicative of fracture connectivity,
ii. the water levels in the ground, and
iii. subsequent long term variation in water levels.

POST MINING WATER PRESSURE AND STRATA CONDUCTIVITY MEASUREMENTS

The results of the N51 terminal packer tests and the regional *in situ* data set were compared and are presented in Figure 7. The consistently high hydraulic conductivity values from N51 clearly indicate the impact of mining throughout the overburden where tested. The data indicates mining induced conductivity in the range of 10^{-7} to in excess of 10^{-6} m/s. The results are interpreted as representing a combination of flow through open bedding planes, mining induced fractures and reworked joint planes. It was not possible to discriminate the vertical and horizontal components of the flow system.

Following the completion of drilling and installation and development of the piezometer network a series of injection tests were carried out using a straddle packer set-up within the central drillhole. Real-time hydraulic head monitors were installed into the remaining drillholes and their response recorded at different injection pressures. Results from injection tests indicated that there was no direct connectivity of the fracture system between piezometer screens positioned at different elevations within the overburden.

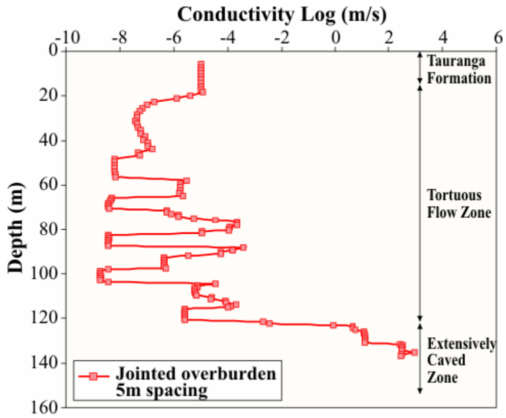


Fig 6: Vertical conductivity profile for N51 panel model.

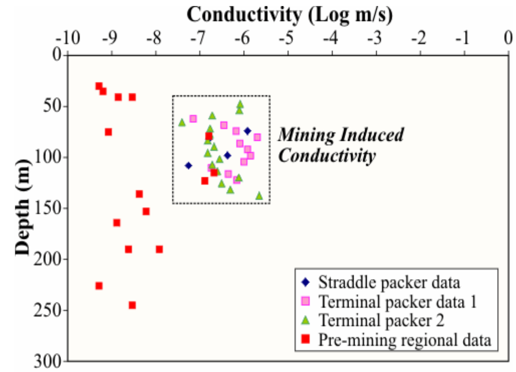
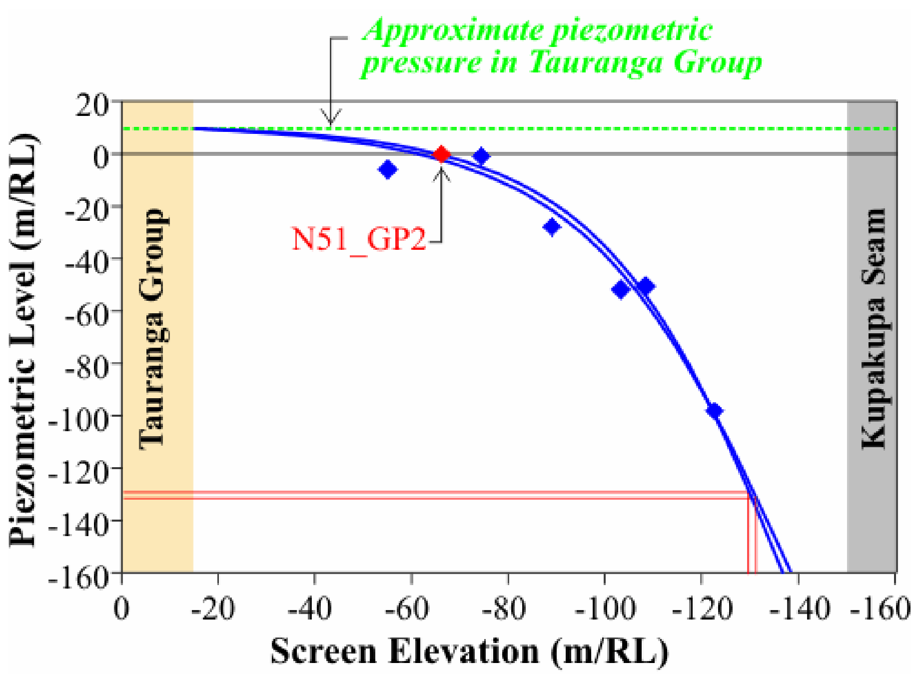


Fig 7: Pre and post mining packer test data from the area.

The piezometers above the goaf provided data on the water pressure distribution from the Tauranga Group to the mine. The results are presented in Figure 8 on the basis of piezometric level (water table level) relative to depth. The results indicate that total head loss occurs in the caved zone, and partial loss extends upward toward the base of the Tauranga formation. These results indicate a significant impact of the mine on the water pressure distribution within the overburden and provide information with which to undertake computer model evaluation.

WATER INFLOW ESTIMATES

The amount of water estimated to result from vertical flow through the goaf in this panel is in the range of 50-120 m^3 /day.



NOTE: Free form best fit curves fitted to data points indicate piezometric elevation coincides with stratigraphic elevation at between -129m/RL and -131m/RL

Fig 8: Piezometric level obtained during the investigation.

BACK ANALYSIS OF RESULTS

Back analysis was undertaken to assess the results of the field investigation and computer model in terms of matching the water pressure profile, field conductivity and water inflow estimates into the panel.

PACKER TEST RESULTS

The packer test data indicates conductivity in the range of 10^{-6} to 10^{-7} m/s. If one assumes this to be an estimate of the vertical conductivity then the inflow would be at least two orders of magnitude too high. Therefore direct use of the packer data above is not appropriate for assessing the vertical conductivity and inflow characteristics of the overburden. The interference testing result is consistent with this interpretation.

COMPUTER MODEL FLOW MATCHING

In order to obtain a better estimation of the overburden vertical conductivity, a back analysis was undertaken using computer modelling to match flow and the water pressure profile obtained from the field study. The model developed for this was a flow model which had a range of conductivity layers above the goaf zone, principally derived from the previous N51 model, and a range of *in situ* conductivity profiles, principally derived from the background testing data. The conductivity distributions above the goaf and for the in situ ground surrounding the panel were varied from the N51 base case to assess the impact that other combinations may have. The aim of this study was to undertake a reality check on the N51 model results and the conductivity estimation process. The use of a simplified flow model allowed a range of options to be evaluated. The model is presented in Figure 9. The assumptions in the model are that the Tauranga Group silt and sand had a uniform conductivity of $5*10^{-5}$ m/s and the horizontal flow at the boundaries was constant. The work program was conducted in two stages. The first stage was to evaluate the most likely *in situ* conductivity profile on the basis of a match to the modelled field data. The second stage was to assess a range of possible situations which need not match the modelled results.

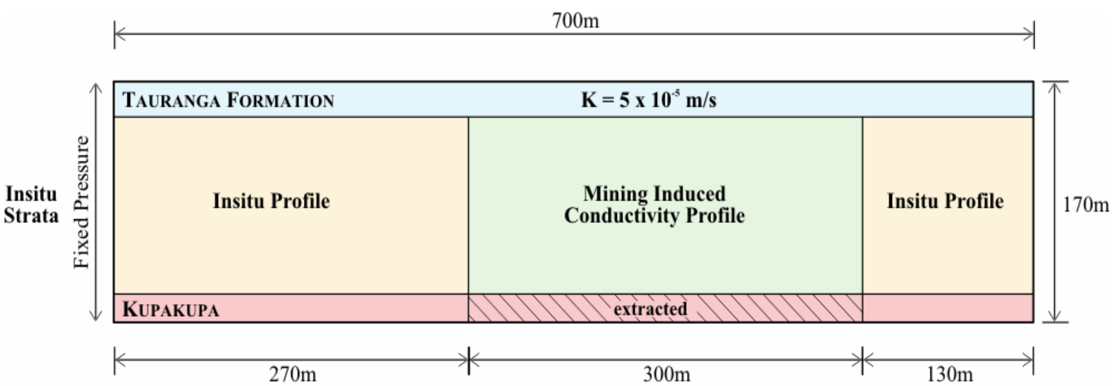


Fig 9: Simplified model for flow and water table matching.

The options assessed were:

1. Most likely upperbound conductivity obtained from the N51 model.
2. Most likely lowerbound conductivity obtained from the N51 model.
3. Assumed no significant conductivity impacts in overburden – overburden in the range of 10^{-7}-10^{-8} m/s.
4. Assumed no significant conductivity impacts in overburden – overburden in the range of 10^{-8}-10^{-9} m/s.
5. Assumed high fracture density in goaf with overburden conductivity approximately 10^{-6} m/s.
6. Best estimate upperbound with two aquitards in the overburden.

The inflow rate for these options is presented in Figure 10 together with an estimate of the likely inflow from initial calculations. The estimate is considered to be "ball park" and for the model result to be close to the estimate is a reasonable result. The inflow rate was calculated as the inflow rate from the model multiplied by the surface area of the panel. The surface area used was 117 000 m^2.

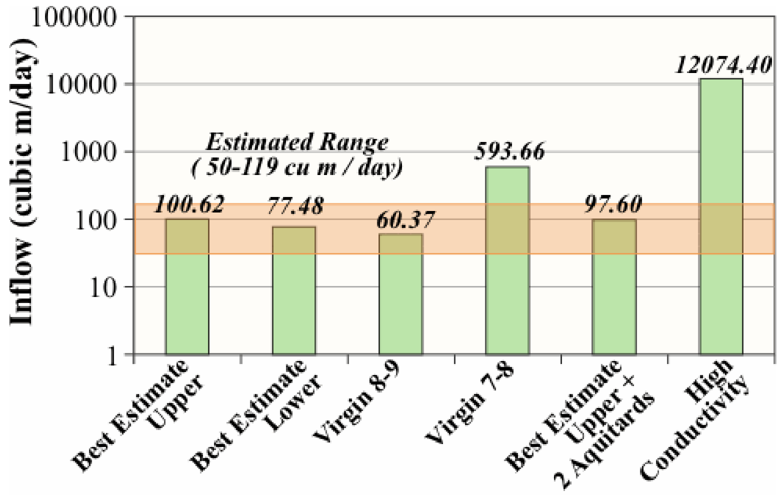


Fig 10: Inflow rates (peak) from models.

MODEL BEST ESTIMATE COMPARISON

The range of conductivity profiles modelled as close to the initial N51 data (adjusted for the increased depth) is presented in Figure 11a and 11b. These profiles cover the range of *in situ* strata adjacent to the extraction panels and that above the extraction panels. The water surface level obtained through the centre of the goaf is presented in Figure 12. The measured water levels are presented for reference. The model results indicate a good match.

The data presented is based on the level of the water table (below ground) above the goaf. An *in situ* condition would be a vertical line at the origin which indicates that the water table is at the surface all the way down the section. As mining occurs out flow into the mine exceeds inflow from the Tauranga Group and reduces the water head at that location. The results indicate that drawdown is occurring virtually to the base of the Tauranga formation. This is confirmed by the measured piezometric gradient from N51 (Figure 8).

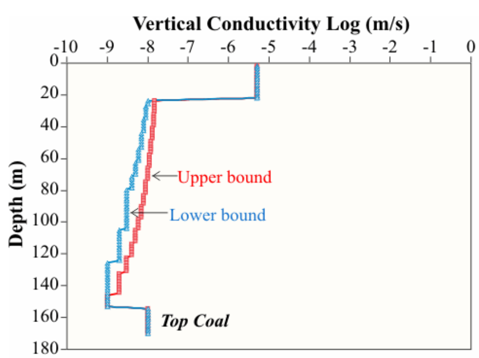


Fig 11a: Insitu conductivity range modelled as "most likely".

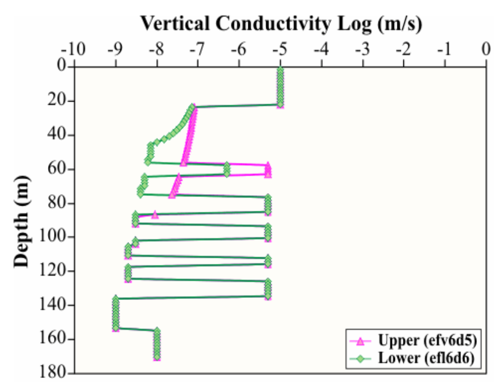


Fig 11b: "Most likely" goaf conductivity range.

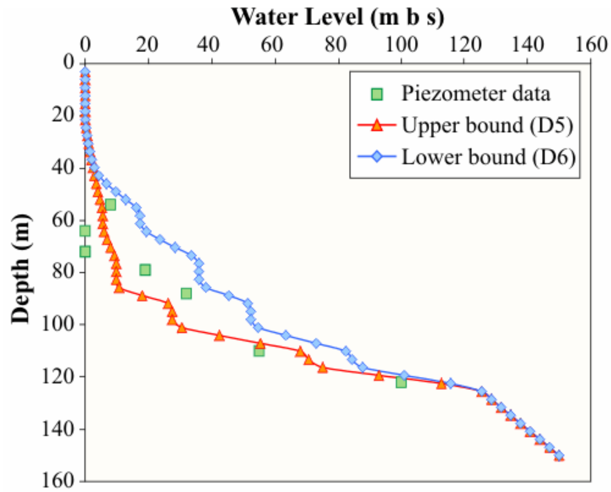


Fig 12: Water level match for "most likely" range.

It appears that the shape of the drawdown curve is similar for the modelled results and the inflow rate is within an acceptable range for this case. Minor variation in the conductivity in the initial 60 m of the model or variation in the Tauranga silts could provide a more refined match, however the key issue is whether the modelled result provides a reasonable match in the first instance. This appears to be the case, and indicates that the conductivity distribution developed in the N51 model provides a good correlation to the actual measurements.

REVIEW OF OTHER CONDUCTIVITY POSSIBILITIES

During the course of this study a number of other conductivity options were assessed. The options were based on combination of measured information and various scenarios which were of interest to assess. The options assessed were:

i. Virgin ground surrounding the panel and a high conductivity within the overburden above the goaf. This was based on packer measurement over the N51 goaf which indicated conductivities of 10^{-5} to 10^{-7} m/s. This value is within the range anticipated for certain sections, but not for the total section. It is likely that the packer data reflects the total horizontal and vertical conductivity and as such cannot distinguish the vertical conductivity component required for this analysis. The results of this option are presented in Figure 13 for the water table section and in Figure 10 for the inflow values. It is clear that this does not provide a good match in terms of water head profile shape, nor inflow potential.

ii. Virgin ground throughout the model except in the caved zone. This model is based on the assumption that there is no significant vertical connectivity in the strata above the caved zone. There were two options modelled, where the strata conductivity varied from 10^{-8} to 10^{-7} m/s and one where the conductivity varied from 10^{-9} to 10^{-8} m/s. The results are presented in Figure 13 and the inflow information is presented in Figure 10. It is clear that the shape of the curves is not correct, although the inflow has be good fit for the lower conductivity profile.

There are many other combinations of conductivity that could be assessed and it is anticipated that various combinations would be able to match the data. Various combinations of vertical and horizontal conductivity within the virgin strata may vary the results. However, this study demonstrates that the results from the earlier N51 caving model provide a credible match in the first instance. The assumption of no significant vertical conductivity other than virgin conditions was not seen as credible. Similarly, the assumption of major connection (10^{-5} to 10^{-6} m/s) was not credible either.

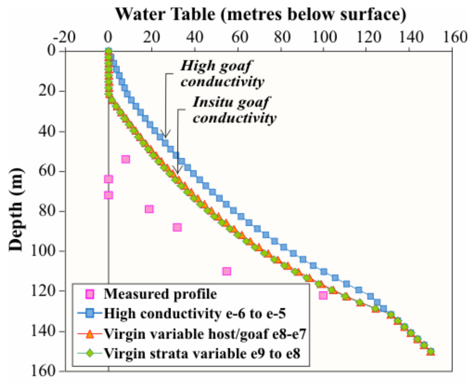


Fig 13: Water table match for the other conductivity profiles modelled.

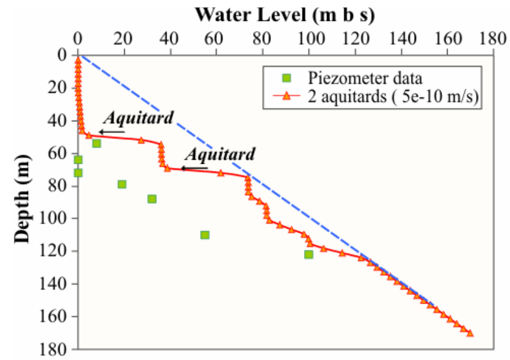


Fig 14: Flow match characteristics for aquitards in the overburden.

The modelled profile is however a combination of these values where there are sections which display high conductivity and sections of low conductivity. The mix of such layering appears to provide the best estimate for the range of options assessed. The results indicate that the mix of vertical conductivity within the tortuous zone will significantly influence the profile and the inflow potential.

EFFECT OF AQUITARDS IN THE OVERBURDEN

For the purpose of this study an aquitard is considered to be a unit which has a significantly lower conductivity than the surrounding materials which can influence the flow system. An aquiclude is an aquitard with conductivity similar to clay or clay rich rock material (i.e. less than 10^{-10} m/s).

On the basis of the background test data, it is possible that clay rich materials exist at least locally under the Tauranga Group. The effect of two aquitards each of 2 m thickness with a conductivity of $5*10^{-10}$ m/s located at (50 m and 7 0m) was assessed to determine the water table characteristics which would result from such units should they exist. The results are presented in terms of water table level in Figure 14. It is clear that where there are significant aquitards, the water table drops dramatically immediately below the unit. Recharge within the goaf zone has to be via horizontal flow, rather than vertical flow from the Tauranga formation. The upper aquitard has the ability to hold the full water head in both instances, and the water pressure below is dependent on lateral inflow and the minor flow through the aquitard.

In general, the profile characteristic of the models with aquitards does not fit the data from N51. This indicates that the overburden rocks, whether clay rich or not, have a significant fracture fabric which allows flow at rates greater than intact clay units. This does not preclude the existence of clay layers within the Tauranga formation which may exist locally and isolate flow from the Tauranga formation.

CONCLUSIONS

The investigation program has provided characterisation of the impact of mining on the overburden. Field data, together with computer modelling, has been used to provide an understanding of the fracture geometry and hydraulic properties above the goaf.

The estimate of vertical conductivity above the goaf of N51 provided by the computer model displays a good correlation with the measured head profile, and provides realistic inflow values.

There are many other combinations of conductivity that could be assessed and it is anticipated that various combinations would be able to match the data. However, the results of this study demonstrate that the computer model developed provided a credible match in the first instance.

The assumption of no significant vertical conductivity induced above the goaf was not seen as credible. Similarly, the assumption of major connection above the extracted zone (10^{-5} to 10^{-6} m/s) was not credible either.

The modelled profile is however a combination of these values where there are sections which display high conductivity and sections of low conductivity. The mix of such layering appears to provide the best estimate for the range of options assessed.

The data suggests that there are no major aquitards within the overburden above the extracted panels, despite the high clay content of the sequence. This indicates that the overburden rocks, whether clay rich or not, have a significant joint fabric which allows flow at rates greater than intact clay units. This does not preclude the existence of clay layers within the Tauranga formation which may exist locally and isolate flow from the Tauranga formation.

The results of this program have been incorporated into the ongoing assessment of other mining options. The use of field measurement to assess fracture geometry, water pressure profiles and overburden caving is seen as an essential part of the evaluation process.