Determination of Groundwater Inflow Rates for Longwall Mining, German Creek, Bowen Basin, Queensland

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ABSTRACT

Semi-confined, trachy-andesite sills which overlie the German Creek Seam, within the critical tensile strain zone, form major groundwater hazards to longwall mining at the German Creek underground mines. The water contained in these aquifers is normally neutral, but highly saline.

Techniques used to detect aquifers include routine air-lift pumping in exploratory drill holes, downhole geophysical and geological logging and upstage packer testing. Hydraulic constants are calculated from pump-out and pump-in test results. Hydraulic parameters for the calculation of mine inflow rates are determined from pump-out test results because these tests appear to be more representative of aquifer drainage during goaf dewatering than pump-in testing.

During mining of the first longwall block at Central Colliery, caving fractures intersected overlying aquifers after the longwall had retreated 40m, and mine water inflow rate rapidly increased from less than one litre/sec to 25 litres/sec. The amount of water pumped out of the mine during first panel extraction was 140 megalitres with drawdown occurring over an area of 168 hectares.

In the Southern Colliery area approximately 324 megalitres of highly saline water which is actively stored in the Aquila Sill area will be pre-drained from six well points prior to longwall mining. With effective pre-drainage from surface drill holes, maximum inflow rate into the mine during initial goafing can be reduced from 165 litres/sec to about 45 litres/sec.

INTRODUCTION

The German Creek Project in Central Queensland comprises an open cut operation and two underground mines. The third longwall panel is currently being mined at Central Colliery and heading development from highwall entries for first panel extraction is in progress at Southern Colliery.

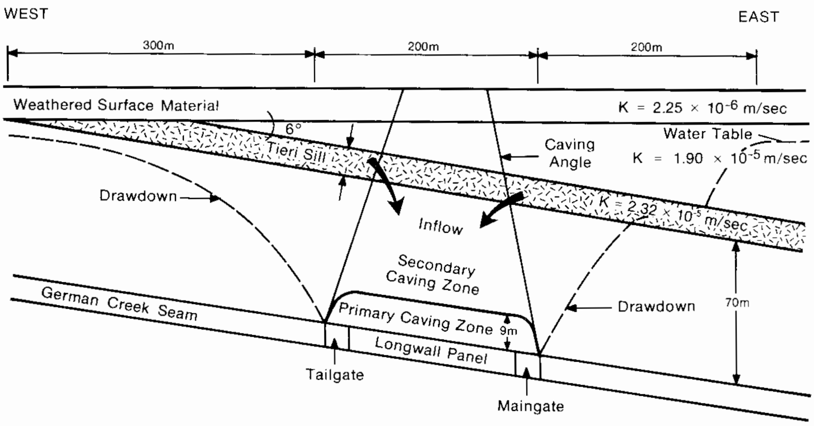
GEOLOGY AND HYDROGEOLOGY

The site areas are within the Late Permian German Creek Formation which contains 8 coal seams interbedded with massive sandstone, siltstone and claystone, dipping from 5 to 10 degrees to the east. The proposed depth cover for underground mining varies from 45m to 350m. Coal is mined from the German Creek Seam which ranges in thickness from 1.8m to 3.2m.

The main aquifers overlying the German Creek Seam are moderately to highly permeable, semi-confined, trachy-andesite sills which range in thickness to 15m. Underground local flow is downdip, with faults forming barriers to groundwater flow in a west-east direction. Faults may form secondary aquifers with flow occurring along strike. Aquifers are recharged from rainfall on subcrop areas.

The three main aquifers in the Central Colliery area are the Tieri Sill, Surface Unconfined and Monoclinal Fault aquifers (Figures 1,2). The strata dip east at about 6 degrees and the Tieri Sill forms a semi-confined aquifer with updip recharge occurring from the west. The Monoclinal Fault aquifer recharges in a north-south direction along fault plane joints but acts as a groundwater barrier in a west-east direction, due to the presence of low-permeability fault gouge.

Figure 1: Generalized section through 301 longwall block, Central Colliery



The four main aquifers which have been investigated in the Southern Colliery area are the German Creek Alluvial, Aquila Sill, Tieri Seam and Grasstree Fault aquifers (Figure 3). The Aquila Sill is the main aquifer with air-lift flow rates to 37.5 litres/sec being recorded from intersecting drill holes.

Figure 2: Generalized section through Monoclinal Fault, Central Colliery

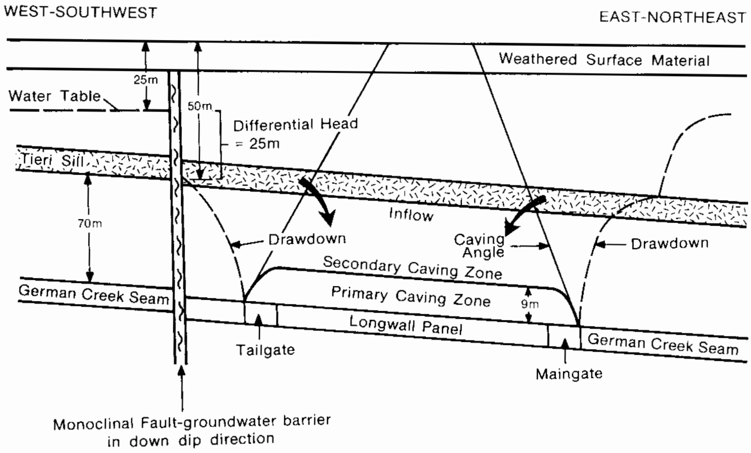
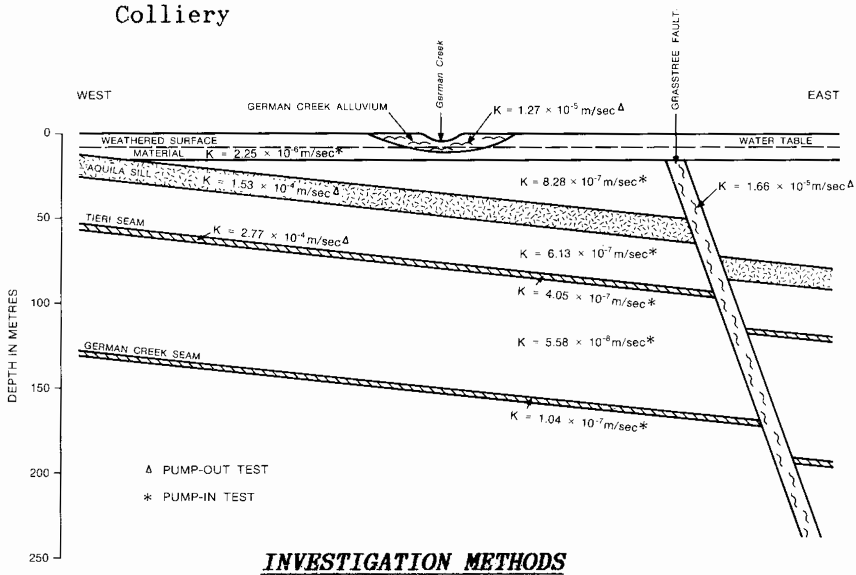


Figure 3: Generalized section through 600's panels area, Southern Colliery



INVESTIGATION METHODS

Prior to longwall mining limited information was available on groundwater properties. During first panel extraction at Central Colliery drawdown was monitored in 39 exploratory drill holes and hydraulic parameters were determined.

Aquifer constants have been calculated from pump-out and pump-in test results. Groundwater data have been analysed to determine flow rates and pumping capacities during longwall mining.

Routine air-lift pumping has been done in all recent exploratory holes to delineate the extent of aquifers.

PUMP-OUT TESTS

Water was air-lifted from aquifers for periods from 6 to 27 hours and flow rates recorded by V-notch weir. Drawdown was monitored in observation holes located at different radii from the production holes and recovery was measured in production and observation holes. Drawdown and recovery data were analysed using the Jacob and Theis Methods ([1],[2]).

Jacob Method

Drawdown or recovery is plotted against elapsed time on a semi-log graph. Residual drawdown, which is the difference between the observed water level during the recovery period following pumping and the non-pumping water level, can also be plotted against the ratio of time after starting to pump by time after stopping pump (t/t'). Formulae for calculating aquifer constants are given in Table 1.

Table 1: Formulae used to determine aquifer constants

Test Type	Method	Transmissivity, T (m^2/day)	Storativity, S (Ratio)	Permeability, K (m/sec)
Pump-out	Jacob	$T = \frac{1.584 \times 10^4 Q}{\Delta h}$	$S = \frac{1.559 \times 10^{-3} T\ to}{R^2}$	$K = \frac{T}{b \times 86400}$
Pump-out	Theis	$T = \frac{6875\ Q\ W(u)}{h-ho}$	$S = \frac{2.778 \times 10^{-3} t\ Tu}{R^2}$	$K = \frac{T}{b \times 86400}$
Pump-in	Open-end	—	—	$K = \frac{Q}{5.5\ r\ H}$
Pump-in	Packer	—	—	$K = \frac{Q}{2\pi LH} \log_e \frac{L}{r}$; $L \geq 10r$ $K = \frac{Q}{2\pi LH} \sinh^{-1} \frac{L}{2r}$; $10r > L \geq r$

T is Transmissivity in m^2/day

Q is flow rate in m^3/sec

Δh is change in drawdown per logarithmic cycle of time

W(u) is well function (exponential integral) obtained from type curve

h-ho is drawdown in metres at time t

S is storage coefficient

to is time intercept in minutes to zero drawdown

R is radius from production hole to observation hole in metres

t is time in minutes
u is variable from type curve

K is permeability in m/sec
b is aquifer thickness
r is internal radius of casing or radius of hole tested in metres
L is length of test section in metres
H is corrected differential head of water in metres
loge is natural logarithm
$\sinh^{-1}$ is arc hyperbolic sine

Theis Method

Test results are plotted as drawdown or recovery in the observation hole, against time in minutes from the start of the test, on a log-log graph. Type curves of W(u) (well function) against 1/u (variable) are plotted as log-log graphs from values in [2]. The curves are then matched and values of W(u) and u are determined for corresponding values of drawdown and time. Formulae are in Table 1.

PUMP-IN TESTS

The full column of strata above Central and Southern Collieries was tested.

Open-end Tests

These tests are normally done in unconsolidated or weathered material [3]. The hole is fully cased and the amount of water accepted by the ground through the open bottom is recorded. The permeability is obtained from the relation in Table 1.

Packer Tests

In packer tests a section of hole is isolated with a single (downstage testing) or double (upstage testing) packer arrangement. Testing is normally done upstage at constant test intervals. Packers are inflated pneumatically from a nitrogen cylinder. Water is then pumped down the hole within drill rods and the flow rate and pressure are recorded. Five consecutive tests each of ten minutes duration are normally completed for each stage, with the first three tests done at increasing pressures and the last two tests done at decreasing pressures. Permeability values can then be interpreted in terms of laminar flow, turbulent flow, dilation, wash-out and void filling [4].

Prior to determining permeability values (Table 1), the differential head values need to be corrected for friction losses in the system which include flow meter, packer and rods.

AQUIFER CHARACTERISTICS

CENTRAL COLLIERY

Aquifer constants were determined from drawdown data measured in observation holes during goaf dewatering and aquifer drainage (Table 2). Mine pumping rates were recorded.

Table 2: Aquifer Constants, Central Colliery

Aquifer	Transmissivity (m^2/day)	Storativity (Ratio)	Permeability (m/sec)		Specific Yield, Storage (Ratio)
			Range	Average	
Surface	11.60-29.36	10^{-3}-10^{-4}	9.26×10^{-6} to 2.33×10^{-5}	1.90×10^{-5}	0.0044
Tieri Sill	22.14-37.86	10^{-3}-10^{-4}	1.97×10^{-5} to 3.02×10^{-5}	2.32×10^{-5}	0.0044

Pump-in tests conducted in 4 drill holes gave average permeability values of 2.25×10^{-6} m/sec for surface weathered material, 1.86×10^{-6} m/sec for the Tieri Sill and 1.25×10^{-7} m/sec for the remaining strata.

The average salinity of Central Colliery mine water is 13000 parts per million, total dissolved solids.

SOUTHERN COLLIERY

Six pump-out tests were completed to determine groundwater parameters for the four main aquifers (Table 3).

Table 3: Summary of pump-out test results, Southern Colliery

Aquifer	Transmissivity (m^2/day)	Storativity (Ratio)	Permeability (m/sec)	Specific Storage (Ratio)
German Creek Alluvial	10.97	10^{-5}	1.27×10^{-5}	—
Aquila Sill	161.44	10^{-3}	1.53×10^{-4}	0.0023
Tieri Seam	63.17	10^{-4}	2.77×10^{-4}	—
Grasstree Fault	9.47	10^{-4}	1.66×10^{-5}	—

Pump-in tests on strata between aquifers gave permeability values ranging from 8.28×10^{-7} m/sec to 5.58×10^{-8} m/sec. Testing indicates that the Tieri Seam is not an aquifer below a depth of about 80.0m.

Salinites range from 2000 to 6000 parts per million, total dissolved solids for near-surface aquifers, and 12000 to 16000 parts per million for deéper, semi-confined aquifers.

INFLOW RATES AND DRAINAGE

Mine inflow rates are dependent on aquifer permeability and height of aquifer above mined seam. Aquifers with permeabilities greater than 10^{-5}m/sec can be successfully pre-drained with a well point system (Table 4).

Table 4: Permeabilities and drainage systems (after [5])

	K, m/sec: 1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}
Drainage	Good drainage						Poor drainage		Practically impervious			
			Well points			Vacuum well points		Electro-osmosis				
Direct determination of K	Direct testing in situ, e.g. field pumping tests-reliable; experience required											
	Constant head permeameter-reliable			Reliable		Falling head-much experience necessary			Permeameter-fairly reliable-experience necessary			
Indirect determination of K	Computations from grain size distribution, surface area and porosity											
				Horizontal capillary test						Computations from consolidation test		

At German Creek, permeability values from pump-out tests appear to be more representative of aquifer drainage during goaf dewatering than pump-in test results. Hydraulic parameters for inflow calculations are obtained from pump-out tests. Darcy's equation can be used to relate flow rates from aquifers of different permaebilities once caving characteristics have been established.

$$Q = Ki\ A$$

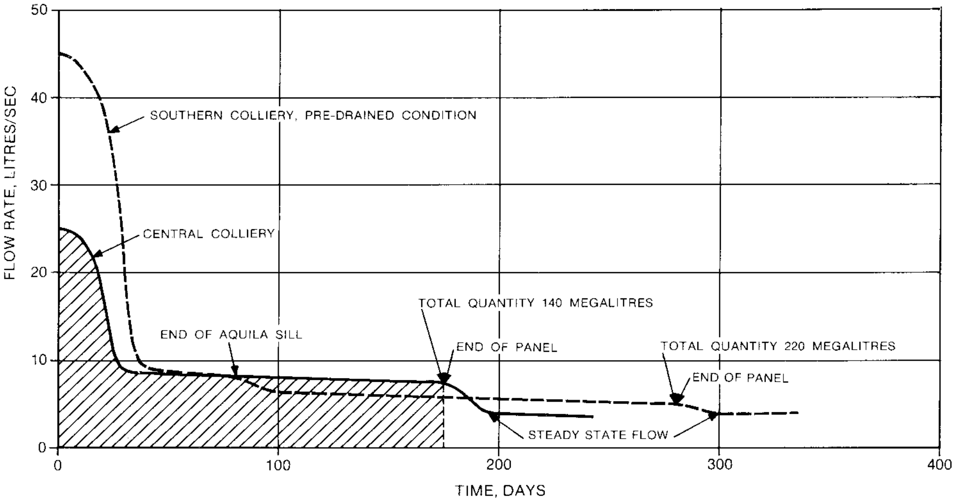
where
Q is flow rate in m^3/sec
K is permeability in m/sec
i is hydraulic gradient
A is cross-sectional area in m^2

The minimum horizontal tensile strain at which interconnection occurs between an overlying aquifer and the mined seam is 10mm/m, and generally corresponds to a depth of cover less than 130.0m.

CENTRAL COLLIERY

The first longwall block was 1200m by 200m. Caving fractures intersected overlying aquifers after the longwall had retreated 40m, and mine water inflow rate rapidly increased from less than one litre/sec to 25 litres/sec (Figure 4). Monitoring of the water table in 39 exploratory drill holes indicated that initial drawdown was occurring over an area of 79 hectares. Aquifer constants were determined from drawdown data. By extrapolating the drawdown cone to the end of the panel, and using a specific yield value of 0.0044 for volume of aquifers dewatered, the calculated inflow during first panel extraction was 120 megalitres at an average flow rate of 7.9 litres/sec. The amount pumped was 140 megalitres with total drawdown occurring over an area of 168 hectares.

Figure 4: Monitored inflow rate, 301 Longwall Panel, Central Colliery and average, calculated inflow rates, 600's Panels, Southern Colliery



During initial caving, 6000m^2 of aquifers directly overlying the panel were exposed to caving fractures. The hydraulic gradient changed from 0.10 to 0.22 as fractures extended upwards from the German Creek Seam to the overlying aquifers. Using an average aquifer permeability of 2.0 x10^{-5} m/sec in Darcy's equation the calculated initial inflow rate was 26.4 litres/sec. The initial inflow rate measured by V-notch weir was 25 litres/sec.

Initial inflow rates during second panel extraction were similar to the first panel. A significant decrease in flow rate occurred as second panel extraction approached the first panel goaf. Updip aquifers in this area were previously drained during first panel extraction.

SOUTHERN COLLIERY

Highest inflows will occur during mining below the Aquila Sill aquifer which overlies part of the colliery. The Aquila Sill at Southern Colliery has an average permeability determined from pump-out testing of 1.53 x 10^{-4}m/sec compared to 2.32 x 10 $^{-5}$m/sec for the Tieri Sill in the Central Colliery area. The maximum recorded flow rate at Central Colliery has been 25 litres/sec. With comparable caving fractures and artesian head conditions at Southern Colliery, inflows of 165 litres/sec during mining below the Aquila Sill can be expected. Because such flow rates would be difficult to handle underground, a pre-drainage system, installed from the surface, has been designed. Approximately 324 megalitres of highly saline water is actively stored in the Aquila Sill area as determined from the specific storage. This water will be pre-drained from six well points. With effective pre-drainage maximum inflow rates into the mine can be reduced from 165 litres/sec to about 45 litres/sec (Figure 4).

CONCLUSIONS

Saturated igneous sills which overlie longwall panels, are a serious groundwater hazard in the German Creek area. Rapid increases in flow rate occur during initial goafing as tensile fractures intersect aquifers within the critical tensile strain zone.

Confined aquifers have been located by routine air-lift pumping in exploratory drill holes, downhole geophysical and geological logging, and upstage packer testing. Hydraulic parameters for calculations of inflow rates have been determined from pump-out tests.

Aquifers with permeabilities greater than 10^{-5}m/sec can be successfully pre-drained with a well point system, prior to longwall mining.

The groundwater in the minesite area is generally neutral but highly saline.

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