Hydrogeology before and after Dam Removal on the Dee River near Mount Morgan Gold Mine Queensland

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ABSTRACT

Dams constructed on the Dee River near Mount Morgan gold mine in Queensland have been removed for safety reasons. The hydrogeological equilibrium of the Dee River corridor could change after their removal; this could influence flow, sediment and contaminant transport from the mine-site, and may have long term environmental impacts.

A conceptual hydrogeological model was used to develop a numerical model GOLDER-TDRAM (Tailings Dam Removal Assessment Model) to simulate sediment concentration and groundwater recharge. The paper presents a comparison of modelled hydrogeology and sediment transport before and after a dam was removed.

The simulation results show that, after dam removal, suspended sediment concentration increased and groundwater recharge decreased in the reach above the dam. Lower groundwater levels resulting from reduced recharge have potential to de-saturate tailings-rich sediments in the river. This could oxidise sulphides resulting in acid drainage and heavy metal mobilisation. As a result the sediments were removed.

1 INTRODUCTION

The Mount Morgan mine is 32 km south-west of Rockhampton in Central Queensland. The Dee River flows between the mine and town and is part of the Fitzroy River catchment. Mining started in 1882, since 1990 mining reduced to tailings reworking. Approximately 20% of tailings and waste rock has been reprocessed and deposited into the open cut.

Six dams were constructed in the Dee River to supply water for mining; they also trapped sediment and tailings. The Dee River is impacted by Acid Mine Drainage, direct deposition of tailings, and sediment eroded from the mine area and natural catchments. Dissolved contaminants have been traced for up to 50 km downstream.

In 1993 the state government accepted responsibility for environmental impacts. Subsequent rehabilitation includes, a lime dosing plant, removal of three Dee River dams, and on-going monitoring. The dams and aspects of the rehabilitation works are shown in Figure 1 (Srivastava 2004).

The dams were over 100 years old and were removed because they were regarded as unsafe. This paper describes the changed sediment transport and hydrogeology associated with removal of one of the dams (Dam 6A). The techniques and experience are applicable at other mines where tailings dams may have to be removed for safety and environmental reasons during closure and decommissioning phases after mining.

An in-house GOLDER–TDRAM (Tailings Dam Removal Assessment Model) version 1.0 was developed using sediment transport equations coupled with instantaneous surface water/groundwater interaction equations to focus attention on possible hydrogeological changes.

2 CONCEPTUAL MODEL

The reach of the Dee River considered is a section across Dam 6A. The effective catchment area above the dam is 96 ha. The river upstream of the dam had significant tailings accumulation from No 2 Mill Tailing Dam while the reach below the dam included sediment from natural and mine catchments. The tailings dominated sediment above the dam is finer grained than sediment below the dam. Upon removal of the dam the river is incised by erosion and re-deposition occurs in the downstream reach. The results are more uniform grain size, water depth, flow velocity and shear velocity across the upstream and downstream reaches.

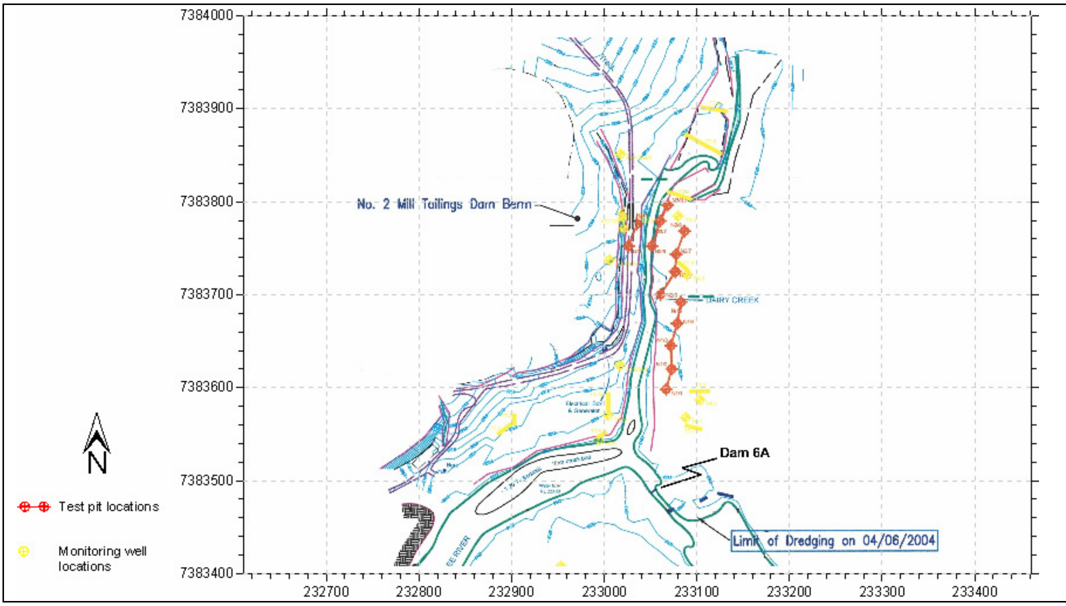


Figure 1 Dee River Dam 6A & Rehabilitation Works (After Srivastava, 2004)

Hydraulic conductivity, and percentage oxidisable sulphur were measured in test pits shown in Figure 1. The hydraulic conductivity of tailings was between 5.5 to 8.2×10^{-8} m/sec, river bed sediment, below the dam, between 2.2 to 3.8×10^{-6} m/sec. Average catchment hydraulic conductivity was from 3.8 to 7.2×10^{-5} m/sec.

Hydraulic conductivity is influenced by sediment size distribution and mineral precipitation. Groundwater exchange with the fractured rock aquifer is influenced by hydraulic conductivity and river stage. Following dam removal groundwater interaction with the river and possibly contaminant transport will change. The impacts have been tested using GOLDER-TDRAM, a numerical model that combines sediment transport and groundwater recharge equations. Envisaged conditions are summarised in Figure 2 and the scenarios are summarised as:

Scenario A: Investigates normal flow conditions and high flow conditions (as may be experienced after rainfall) at the instant of dam removal.

Scenario B: Investigates normal flow conditions and high flow conditions (as may be experienced after rainfall) long after dam removal, when the sediment has been redistributed.

3 GOVERNING EQUATIONS

Sediment concentration (turbidity) is calculated using:

$$F_1 = \varsigma \exp(-\varsigma - 3.2\varsigma^2 + \frac{2}{3}3.2\varsigma^2)$$ Eqn 1 (Modified after Gelfenbaum and Smith 1986)

$$F_2 = \frac{1}{1+10.0X} \qquad X = \frac{1.35\mathbf{Ri}}{1+1.35\mathbf{Ri}}$$ Eqn 2 (Modified after Gelfenbaum and Smith 1986)

$$\bar{c}_r = \frac{AX_e^5}{1+\frac{A}{0.3}X_e^5} \qquad X_e = \frac{u_{*s}}{v_s}\mathbf{Re}_p^{0.6}$$ Eqn 3 (Modified after Garcia and Parker 1991)

Instantaneous grounwater exchange is calculated from:

$$R_{eU/D} = \frac{2\left(K_t or K_b / K_c\right)}{2.3026}(H_2 - H_1)(RI)$$ Eqn 4 (Modified after Rorabaugh 1964 and Rutledge 1998)

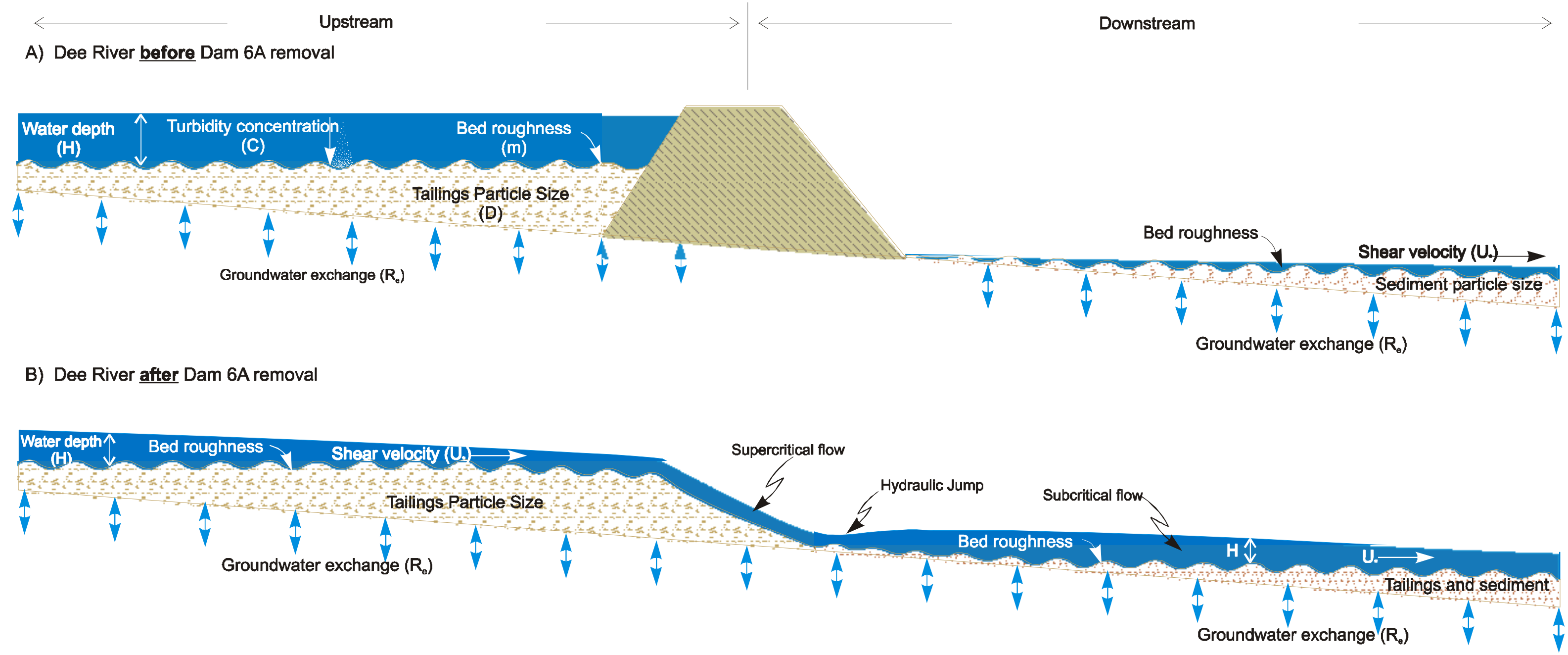
Parameter definitions are given in Table 1, while parameters values from field measurement (except shear velocity which was determined using a flume) are listed in Table 2.

Table 1: Parameter Definitions

	Definition	Unit
Ri	Gradient Richardson number	
ç	Dimensionless sediment concenbtration (turbidity)	
$\overline{C}_r$	reference concentration of suspended sediment averaged over turbulence	
Re$_p$	Particle Reynolds number $\sqrt{RgD}D/\nu$	
R	Sediment submerged specific gravity $R = \frac{\rho_s}{\rho} - 1$	
g	acceleration of gravity	$[L/T^2]$
D	grain size (usually in mm or μm)	[L]
ν	kinematic viscosity of water	$[L^2/T]$
ρ_s	sediment material density	$[M/L^3]$
ρ	water density	$[M/L^3]$
ζ	z/b; dimensionless reference bed elevation	
z	boundary-attached upward normal coordinate	[L]
b	reference distance above the bed where sediment entrainment is specified; b/H << 1	[L]
H	cross-section averaged flow depth (river) or flow thickness (turbidity current)	[L]
u_*	$\sqrt{\tau_b / \rho}$, shear velocity	[L/T]
u_{*s}	$\sqrt{\tau_{bs} / \rho}$, shear velocity due to skin friction	[L/T]
τ_b	bed shear stress	$[M/L/T^2]$
τ_{bs}	bed shear stress due to skin friction	$[M/L/T^2]$
v_s	particle terminal fall velocity in quiescent water	[L/T]
A	1.3×10^{-7} (Garcia and Parker Constant)	
R_{eU}	Groundwater recharge from upstream area	[L]
R_{eD}	Groundwater recharge from downstream area	[L]
K_t	Hydraulic conductivity of tailing materials (upstream bed)	[L/T]
K_b	Hydraulic conductivity of bed materials (downstream bed)	[L/T]
K_c	Average hydraulic conductivity of shalllow aquifer in the catcment	[L/T]
RI	Recession Index	[T]
H_1	Cross-sectionally averaged ground water discharge depth at critical time as extrapolated from pre-event stream flow recession	[L/T]
H_2	Cross-sectionally averaged ground water discharge depth at critical time as extrapolated from post-event stream flow recession	[L/T]

Table 2: Parameters Used in the Models

Parameter	**Upstream**	**Downstream**	**Upstream**	**Downstream**
Scenario	**A) Before Dam Removal**		**B) After Dam Removal**	
Tailings or sediment specific gravity R+1	3.1	2.6	3.1	2.8
Particle size D (mm)	0.08	0.2	0.07	0.1
Head (flow depth)				
high (following rain) (H_2) (m/21days)	3.8	0.8	3.2	2.6
low (normal flow) (H_1) (m/21 days)	1.8	0.4	1.6	1.5
Bed roughness (e.g. ripple height) m (mm)	25	12	18	8
Shear velocity U_* (cm/s)	40	4	20	12
Skin Friction U_{*s} (cm/s)	38	3.8	18	10
Hydraulic Conductivity				
Tailings (K_t) (m/sec)	8.0×10^{-8}		8.0×10^{-8}	
River bed sediment (K_b) (m/sec)		3.6×10^{-6}		3.6×10^{-6}
Average catchment (K_c) (m/sec)	6.8×10^{-5}	6.8×10^{-5}	6.8×10^{-5}	6.8×10^{-5}
Kinematic viscosity of water at 25°C cm^2/s	0.0089			
Recession Index (RI) (days)	21			



Components	Symbols
Surface water depth	H
Groundwater recharge (exchange)	R_e
Suspended tailings concentration	C
Particle size	D
Bed roughness	m
Shear velocity	U_*
Skin friction	U_{*s}

Subscripts	
Before dam removal	A
After dam removal	B
Upstream	U
Downstream	D

Conceptual Relationships

$H_{AU} > H_{BU} > H_{BD} > H_{AD}$

$R_{eAU} > R_{eBD} > R_{eBU} > R_{eAD}$

$C_{BU} > C_{AU}$

$C_{BD} > C_{BU}$

$D_{AD} > D_{BD} > D_{BU} > D_{AU}$

$U_{*BU} > U_{*BD} > U_{*AD} > U_{*AU}$

Assumptions

- Steady, equilibrium, open-channel flow over an erodible tailings in the channel bed.
- Depth of water varies between domains and is denoted by (H). Depth is also a driving force in groundwater interaction.
- Shear velocity is denoted with U_*, Skin friction with U_{*s} and $U_* > U_{*s}$
- Sediment is assumed to be uniform in each domain but differs between domains with size D
- Two instantaneous evaluations with low and high water levels are assumed to represent normal flow and flow after rain
- Tailings contain reactive and leachable components that can contaminate surface or groundwater

Figure 2 Conceptual Model Sections

4 RESULTS AND DISCUSSION

Results of the sediment transport calculations are given in Figure 3. They show:

Scenario A: Immediately after dam removal, high shear velocity and fine grain size results in high suspended sediment concentration upstream reach. Density stratification gives some reduction in sediment load. Coarse sediment and low shear velocity in the downstream reach give little suspended sediment. At lower flow depth there is a slightly higher proportion of suspended sediment.

Scenario B: hydrology has equilibrated following dam removal, flow depth, shear velocity and sediment size are more evenly distributed. This results in reduction of suspended material in the upstream reach and increase in the downstream reach. Density stratification, particularly in the downstream reach is significant.

These graphs show the potential for fine tailings to be transported as highly turbid water in the increased flow conditions that could follow dam removal.

The results of groundwater surface water interaction calculations are given in Table 3.

Table 3: Predicted Groundwater Recharge

Parameter	Upstream	Downstream	Upstream	Downstream
Scenario	A) Before Dam Removal		B) After Dam Removal	
Predicted Groundwater Recharge (m) (normalised over catchment per year)	0.043	0.38	0.034	1.06

The results show that before dam removal the stream bed above Dam 6A had low potential to recharge the surrounding aquifer while downstream the recharge potential was higher. After dam removal recharge in the upstream reach reduced further due to the lower hydraulic head while in the downstream reach it increased due to increased hydraulic head.

The upstream reach contained some eight metres of sediments derived from tailings, these may contain sulphide minerals. Under lower groundwater levels the sulphides could oxidise releasing acid and associated heavy metals in solution. A parallel geochemical study found that there was little environmental or geochemical risk associated with the sediments in their undisturbed state, despite this the threat posed by lowered watertable dictated that the sediments should be removed. Sediments were therefore dredged for up to 200 m upstream and deposited into the open cut mine.

5 CONCLUSIONS

After removal of Dam 6A on the Dee River sediment redistribution has a minor influence on the hydrogeological characteristics of the streambed. The greatest influence is due to hydraulic head redistribution which reduces groundwater recharge to the surrounding aquifer in the upstream reach while recharge is increased in the downstream reach.

These changes have implications for stream bed and bank sediments that were saturated when the dam was in place. Under lower recharge groundwater levels will drop giving potential for sulphide bearing tailings to oxidise. Despite an indication of low geochemical risk if the sediments remained undisturbed, hydrogeological model results identified a risk and the sediments were removed.

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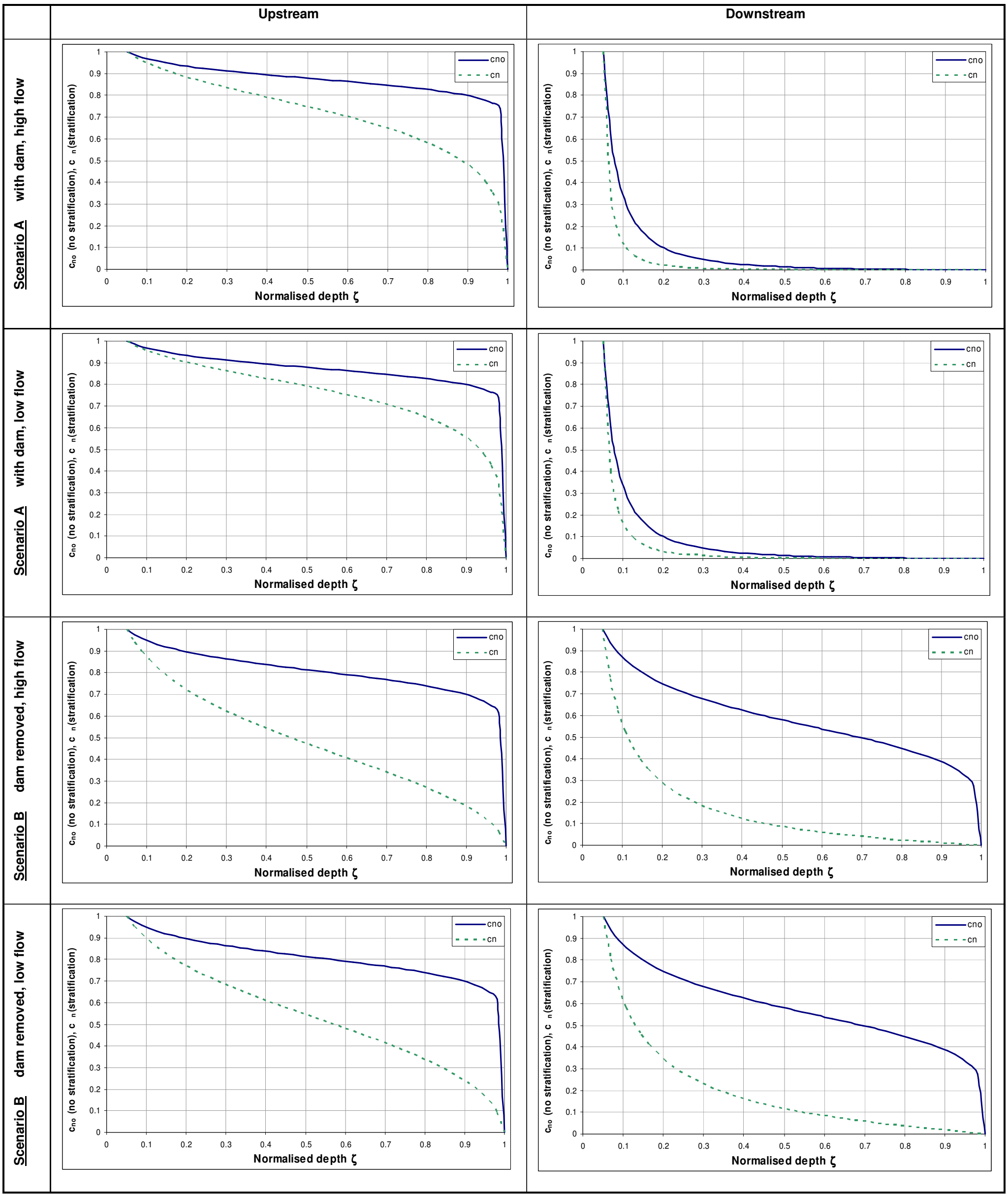

Figure 3: Sediment Transport Model Results