16th Australasian Fluid Mechanics Conference
Crown Plaza, Gold Coast, Australia
2-7 December 2007

Impacts of uncontrolled discharge of acid rock drainage from Mount Morgan Minesite on Dee River

N. Tarakemeh[1], H. Zhang[1], B. Yu[1], and C. McCombe[2]
[1]Griffith School of Engineering, Griffith University, QLD 4215, Australia and [2]Dept Natural Resource and Mining, Rockhampton, Australia

Abstract

Uncontrolled discharge of Acid Rock Drainage (ARD) from Mount Morgan mine site accumulated over time poses significant environmental risk on the Dee River downstream. This paper investigates and flow dynamics and the ARD dispersion and dilution along the Dee River for a number of dam-break scenarios, especially to estimate the extent of downstream reduction in concentration in extreme weather conditions. Hydrologic data of Dee River was analysed and a detailed 1-D hydraulic river model was set up using Danish Hydraulic Institute, Mike 11, to simulate the contaminant transport of ARD. Simulation results of different weather condition assessed to be used as resource to proposed management options to minimise the risk of uncontrolled discharge into natural waterways. Results indicate that if dam break occur in a dry to medium season there is a risk of contamination of the downstream catchment. However if dam fails in a medium to wet season downstream concentration will be diluted to minimum 1.8 PSU.

Introduction

Mount Morgan Mine, one of the largest Gold Mines in Australia, located in central Queensland was significant in the context of Australian gold mining history. Gold was extracted for about a hundred years, and the mine closed down in 1981. Acid rock drainage (ARD) is the key environmental concern at the mine site, as it poses significant adverse environmental risk to downstream catchments, the Dee, Don and Dawson Rivers. ARD results from the oxidised sulfide minerals in rocksand soils being mobilised by water moving over or through the sulfide minerals. This sulfidic waste material were dumped across a large area, including the slopes of relatively steep hills in the upper reaches of the Dee River catchment, which has facilitated its oxidisation and transport off site. The total area disturbed by mining activities covers about 270 ha. Sulfide minerals have been exposed to weathering for more than 100 years in some parts of the mine.

The Dee River is a part of Fitzroy River catchment, which flows to the east coast of the continent. Inadequate mine management practices of the past left the Dee River in a poor state, where PH is as low as 2.8 and is associate with high metal concentration, recorded in the Dee River next to the minesite during periods of low flow. While there is no recent evidence of acidic flows extending beyond the Dee River catchment into Don, Dawson or Fitzroy Rivers, there are oral reports of acidic flows extending into the Dawson River when mine was still working. Water quality in Dee River network deteriorated over time due to ARD seepage form Open Cut Pit known as one of the source points, NR&M (2003) [4]. In 2000, as a part of rehabilitation planning for this site, NR&M engaged EWL Sciences Pty Ltd (Jones, 2001) [7] to undertake a contaminant source study where Dee River has been monitored. Rehabilitation Plans aimed to improve water quality downstream and enable greater usage of water resources by preventing overflows from the Open Cut Pit which could carry additional contaminant to the Dee River. NR& M (2003) [4] Gauging stations monitor flow volume (or discharge) and water quality (PH, Conductivity) along Dee River from Kenbula (upstream) to Rannes (downstream).

The impact of dam failure and discharge of acidic flow to the river need to be assessed. In earlier studies, several numerical models have been developed for the purposes of simulating hydraulics, sediment behaviour, and water quality components in rivers. Wei Zenga (2003) [12] introduce a new model–STAND (Sediment-Transport-Associated Nutrient Dynamics)–for simulating stream flow, sediment transport, and the interactions of sediment with other attributes of water quality. In contrast to other models, STAND employs a fully dynamic basis for quantifying sediment transport, thus distinguishing it from the well-known HEC-6 model.

Water quality modelling in river systems, MARS (Model for Australian River Systems) has been developed by Musavi Jahromi (1996) [11]. The MARS-HD module is based on flow continuity and momentum equations. The MARS-AD module is established using a method known as “Quadratic Upstream Interpolation with Convective Kinematics and Estimated Streaming Terms” (QUICKEST).

Todd (2004) [9] compared HEC-RAS and MIKE11 Unsteady Flow Modelling for the Tillamook Valley. He discussed specifically the differences in computation of the channel roughness. His work shows that the computed difference in water surface elevation between the MIKE11 resistance radius and the HEC-RAS hydraulic radius can be accounted for by adjusting the Manning’s.

MIKE 11 has been selected to model ARD transport in Dee River as it is an industry standard for simulating flow and water level, water quality. Flexibility and speed ensure efficient modelling applications for all aspects of river engineering. In-built parameter optimization tools facilitate efficient model calibration and provide uncertainty assessment of results.

The main objectives of this study is to

- To analyse hydrologic data and set up a hydraulic model to simulate the transport of ARD in Dee river.

- To investigate the extent of ARD dispersion and dilution along the Dee River in extreme weather conditions.

Methodology

MIKE 11 is a general river modeling system developed by DHI. It is the most advanced and comprehensive of its type today. MIKE 11 has become industry standard in many countries, including Australia, New Zealand and Bangladesh and in many European countries (Danish Hydraulic Institute). MIKE 11 contains modules for run-off simulations, hydrodynamics, flood forecasting, transport and dilution of dissolved substances, sediment transport, and river morphology as well as various water quality processes.

Conceptual Basis and Model Setup

1- Hydrodynamic Module

The hydrodynamic module (HD), which is the core of MIKE 11, includes an implicit, finite difference computation of unsteady flows in rivers and estuaries. The formulations can be applied to branched and looped networks and quasi two-dimensional flow simulation on flood plains. The computational scheme is applicable to vertically homogeneous flow conditions ranging from steep river flows to tidally influenced estuaries. Both subcritical and supercritical flow can be described by means of a numerical scheme, which adapts according to the local flow conditions. The complete nonlinear equations of open channel flow (Saint-Venant), DHI Mike 11 manual (2003)[5], can be solved numerically between all grid points at specified time intervals for given boundary conditions. The MIKE11 model has three different equations for determining the hydraulic radius in the above equation; the "resistance radius" (R*) (the default method) or one of two different hydraulic radius (Rh) equations, which uses either an "effective flow area" or a "total flow area". "Resistance radius" has been selected for this model.

2- Advection-Dispersion Module

The Advection-Dispersion module (AD), the advection-dispersion (AD) module is based on the one-dimensional equation of conservation of mass of a dissolved or suspended material, i.e. the advection-dispersion equation. The module requires output from the hydrodynamic module, in time and space, in terms of discharge and water level, cross-sectional area and hydraulic radius. The Advection-Dispersion Equation is solved numerically using an implicit finite difference scheme which, in principle, is unconditionally stable and has negligible numerical dispersion. The one-dimensional (vertically and laterally integrated) equation for the conservation of mass of a substance in a solution, i.e. the one-dimensional advection-dispersion equation reads:

$$\frac{\partial AC}{\partial t} + \frac{\partial QC}{\partial x} - \frac{\partial}{\partial x}\left(AD\frac{\partial C}{\partial X}\right) = -AKC + C_2 q$$

where C : concentration
D : dispersion coefficient
A : cross-sectional area
K : linear decay coefficient
$C2$: source/sink concentration
q : lateral inflow
x : space coordinate
t : time coordinate

Climate and hydrologic data around the Mt Morgan mine site analysed to define a set of appropriate upstream inflow conditions. Lateral freshwater inflow downstream from the mine site will be estimated to determine the extent of dilution that is likely to occur. A 1-D water quality model, DHI Mike 11, set up to simulate the contaminant transport process of ARD as a result of dispersion and lateral inflows. Hydrologic scenarios and ARD discharge scenarios developed in collaboration with the NRM staff to represent a range of hydrologic conditions, including those during extreme events.

Data and Method

Relevant data was extracted from the records at gauging stations. These included:

- *flood peak discharges*, for use in flood frequency estimation
- *rating curve*, for use in calibration of the hydraulic model
- *flow velocities*, for use in calibration and test of the hydraulic model

Recorded flood hydrograph in February 2003 use as input to the hydraulic model. Figure 1, shows the flow in various location of the river for flood event on February 2003. Survey data is a critical input to the assessment with the hydraulic model. Details of the survey have been supplied by NR&M.

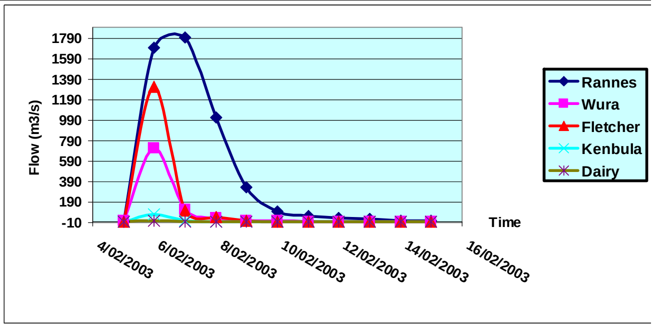

Figure 1: Actual Data for Dee River on Flood Event in 2003.

The ANZECC (2000) [1] guidelines provide *trigger values* for three *ecosystem conditions*, with a different *level of protection* recommended for each condition. Trigger values in the guidelines are concentrations of a chemical that, if exceeded, have the potential to cause problem(s) and so trigger a management response (ANZECC 2000)

A detailed 1-D model, DHI Mike 11, has been set up to simulate the contaminant transport process of ARD as a result of advection and lateral inflows.

In Hydrodynamic stage, Cross-sections of the river were provided for a reach from Kenbula Gauging Station to Rannes. Cross sections are 20 to 25 metres width which became wider in downstream. Typical depth is 5 - 10 metres. Plane coordinates entered in Cross section Editor for the left/right end of the cross sections spaced 5 km along the river. As resistance radius is applied, the levels selected according to variations in section flow width. Upstream of the river is narrow and become wider at Don River confluence. River runs at the slope of 12% to the south.

The bed resistance has been selected Manning's n = 0.05, between three resistance type options in Mike 11:

1. Manning's M (unit: $m^{1/3}/s$, typical range: 10-100)
2. Manning's n (reciprocal of Manning's M, typical range: 0.010-0.100)
3. Chezy number.

Wind effect has not considered in this simulation.

Results and discussion

A detailed 1-D model, DHI Mike 11, has been set up to simulate the contaminant transport process of ARD as a result of advection and lateral inflows.

Model Validation:

Dee River modeled for a flood event in Feb. 2003.To validates the model result, Available data from Wura gauging station is compared with Mike 11 HD, AD result. In Figure 2 Mike 11 hydraulic result for flood event in 2003 is compared with actual flow data for Wura. In Figure 3 Mike 11 advection-dispersion result for flood event in 2003 is compared with actual salinity data for Wura. To adjust the result and get the most consistent result model runs with different Manning value and dispersion coefficient. After calibration of the model, simulation result is in reasonable agreement with the monitoring data.

Mean square error for HD graph that compare Wura actual daily mean flow data and MIKE 11 result is 16%. Mean square error for AD graph that compares Wura actual EC data and MIKE 11 result shows 9 %.

This inconsistency results from insufficient data due to limited number of raw cross section data only at gauging stations. A number of cross section data have been changed in order to increase the model stability. Dee River bed is narrow in upstream and become wider in Rannes. Another explanation of this discrepancy is due to Dispersion coefficient and Manning Value which are not mathematical values and they might be chosen not exactly according to natural case.

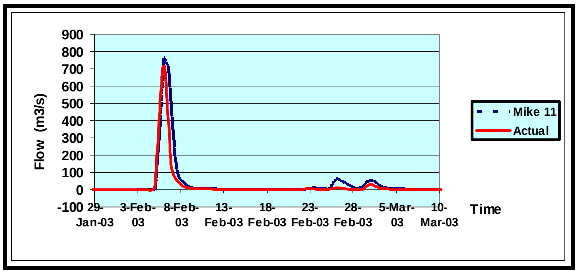

Figure 2: Mike 11 HD Result and Actual Result for Wura: 25 KM

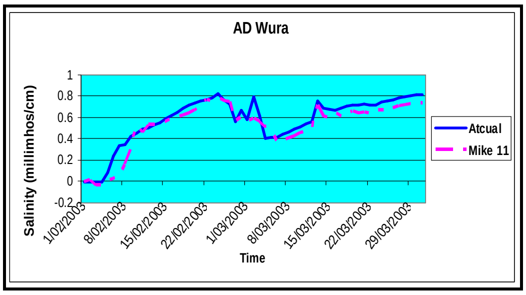

Figure 3: Mike 11 AD Result and Actual Result for Wura: 25 KM

Scenarios Testing

Three scenarios in different weather condition have been defined to assess the impact of Dam failure on downstream concentration.

1- Dry Season Dam Failure with full storage:

This scenario is expected to be the worst case scenario. Minimum flow is assumed for the Dee River, Dairy Creek, Fletcher Creek and Don River. Dam failure would lead to a rise in water level by less that 300 mm (Department of Natural Resource and Mining, Mine Pit Failure Impact Assessment Report, 2003) [4] is about 150 m^3/s.

The initial conditions and boundary conditions are set based on assumptions and results from reviewing available data. For details of boundary set up refer to table 1.

Results indicate that the salinity will be reduced from 13 PSU to 12.67 downstream of the river. (refer to Figure 4)

Boundary Description	Boundary Type	Chainage	Inflow (m3/s)	Salinity (PSU)
open	inflow	0	1	1
source point	inflow	1000	1	0
source point	inflow	5000	150	13
source point	inflow	22000	1	0
source point	inflow	73000	1	0
open	Water level	79000	0.5	1

Table1: Boundary input data (MIKE11)

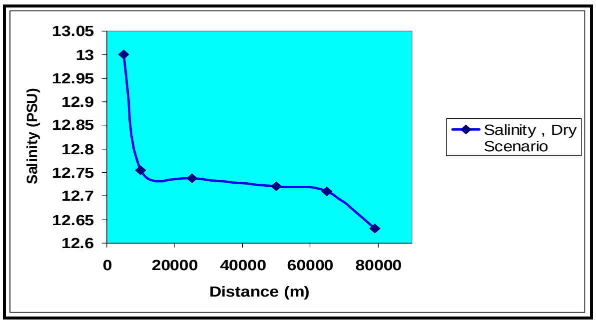

Figure 4: Salinity (PSU) vs. Distance (m)

2- Wet Season (Intermediate flow) Dam Failure with full storage

In this scenario dam failure occurs in an intermediate flow in Dee River, and with minimum to medium inflows from other tributaries fed into the Dee River. Result shows that acidic water will be diluted to 8 PSU. According to Australian and New Zealand (ANZECC) Guidelines for Fresh and Marine Water Quality 2000 (Ref), there is a risk of ARD transport to the downstream and contamination of the whole catchment.

The initial conditions and boundary conditions are set based on assumptions and results from reviewing available data. For details of boundary set up refer to table 2.

Results indicate that the salinity will be reduced from 13 PSU to 8 (PSU) downstream of the river. (refer to Figure 5)

Boundary Description	Boundary Type	Chainage	Inflow (m3/s)	Salinity
open	inflow	0	75	1
source point	inflow	1000	10	0
source point	inflow	5000	150 (3 days)	13
source point	inflow	22000	10	0
source point	inflow	73000	10	0
open	Water level	79000	0.5	1

Table2: Boundary input data (MIKE11)

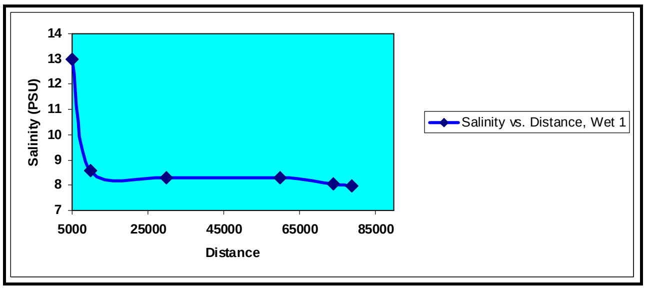

Figure 5: Salinity (PSU) vs. Distance (m)

3- Wet Season (Flood Event) Dam Failure

In this scenario dam will fail during a flood event while flooding occurs throughout the Dee River catchments and its tributaries. Peak flow values from Flood Frequency Analysis were used as boundary data. Result shows downstream concentration will be diluted to 1.8 PSU as a result of dispersion and dilution. There is no risk of pollution transport to downstream catchments. Figure 6 shows the reslut for the salinity reduction along the river.
The initial condition and boundary condition is set based on assumptions and results from reviewing available data. For details of boundary set up (refer to table 3)
Results indicate that the salinity will be reduced from 13 PSU to 1.8 (PSU) downstream of the river. (refer to Figure 6)

Boundary Description	Boundary Type	Chainage	Inflow (m3/s)	Salinity
open	inflow	0	75	1
source point	inflow	1000	100	0
source point	inflow	5000	150 (3 days)	13
source point	inflow	22000	150	0
source point	inflow	73000	900	0
open	Water level	79000	0.5	1

Table3: Boundary input data (MIKE11)

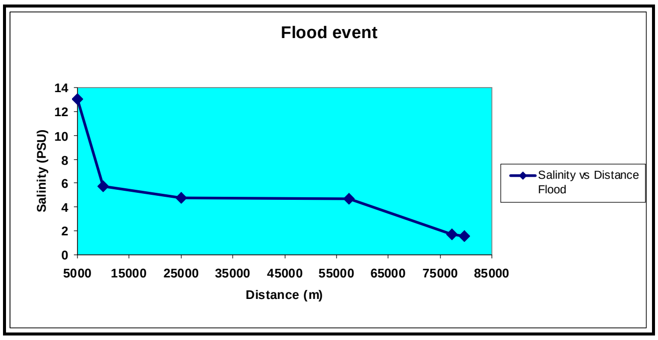

Figure 6: Salinity (PSU) vs. Distance (m)

Conclusion

This paper investigates the impacts of dam failure and acidic water runoff into Dee River at different weather conditions. For this reason a detailed 1-D Mike 11 has been set up to simulate ARD transport along Dee River and calculate the concentration of downstream river as a result of dilution and dispersion. Result indicates that if dam fails in an instance that river has the minimum to medium flow, there is a risk of contamination of downstream catchments. But if Dam fails in a medium to wet season downstream concentration will be diluted to safe margin based on ANZECC 2000. The main concern would be when dam failure occurs during dry season that the river and other tributary fed into river have minimum flow.

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