

Managing Impacts of Large Artificial Sediment Loads In Rivers: A Case Study

HELEN LOCHER and ROBERT KELLER

Research Scholar Associate Professor

Co-operative Research Centre for Catchment Hydrology

Department of Civil Engineering

Monash University, Melbourne, Australia

INTRODUCTION

The fate of mining-derived sediments in river systems is a management issue in many parts of the world, due to excessive sediment loads and, frequently, the transport of heavy metals associated with the sediments. A major study is underway, examining the impacts of mine wastes from a copper mine on the King River system on the west coast of Tasmania, a state of Australia. Between 1916 and 1994 the mine continuously discharged its waste sediments (tailings) into the Queen River, a tributary of the King River, at an average rate of 1.5 million tonnes per year. Since 1992 flow in the King River has been controlled by a hydro-power scheme which has been shown to significantly influence the transport, deposition and remobilisation of tailings in the lower King River.

The mine ceased operation in December 1994. The present study combines hydraulics, geomorphology, and water chemistry to evaluate how the river has responded to artificial changes in the sediment load, how a regulated flow regime influences sediment transport in the river, and how the controlled flow can be exploited to minimise long term environmental damage both within the river system and in its receiving body, Macquarie Harbour.

First results from the study are presented in this paper. Characteristics of the mining-derived sediment load and the response of the river to its imposition is first described. The influence of power station operations on sediment transport within the lower King River is then illustrated. Finally, the minimisation of environmental impacts in the river and harbour system is discussed.

RIVER RESPONSE TO ARTIFICIAL SEDIMENT LOADS

The King and Queen Rivers are naturally gravel bed rivers, whereas the mine tailings (waste rock from which the copper concentrate is separated) are a coarse silt/very fine sand which has progressively fined over the years as milling processes have improved. Since the 1980s the tailings have had a median grain size of $11\mu\text{m}$ as shown in Figure 1.

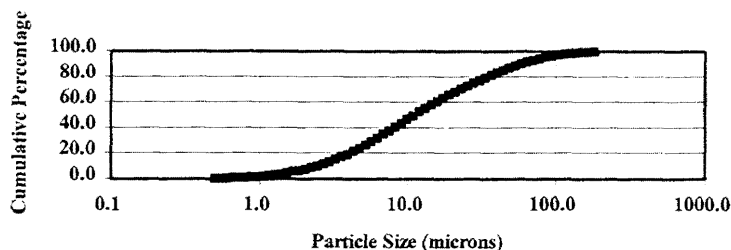


FIGURE 1: Tailings Particle Size Distribution

Field measurements of suspended load have shown uniform vertical distributions with median grain sizes of 7-8 microns, which indicates that most of the suspended material is wash load derived from the mine rather than resuspended bed material (Colby 1963). The wash load is transported through the river system and deposited in a 250-hectare delta where the river meets Macquarie Harbour. The coarsest fraction of the mining wastes is deposited in the river system, with bank deposits having a median grain size between 0.1 and 0.2mm and bed deposits varying between 0.1 and 1.0mm.

Table 1 summarises the status of mining-derived sediment in the river system in 1994, when tailings were still being discharged into the Queen River. Data which could not be obtained, mainly due to access problems, are indicated with a question mark. Reaches 1 to 4 of the King River are progressively downstream of the Queen River confluence, with the delta situated at the downstream end of Reach 4. The total sediment storage (river bottom and banks) within a river reach as well as the measured suspended sediment concentration, clearly correlate with the gradient of that reach.

Field observations of the bank deposits show them to be uniformly mine tailings, whereas bed deposits are a mixture of natural river gravels, tailings and

Reach	Ave. Grdt.	Ave. Ave.			Bank Tailings		Bottom Tailings		Max. Meas'd Susp.Sed.Con. (mg/L)
		L (km)	W (m)	D (m)	Vol. (m ³) (x1000)	Size (mm)	Vol. (m ³) (x1000)	Size (mm)	
Queen R.	0.012	13.2	15	1	<1	?	<1	?	55,000
King 1	0.014	5.1	30	?	<1	?	<1	?	14,600
King 2	0.0008	7.5	40	1.5	113	0.22	706	1.2	?
King 3	0.0004	2.1	50	1.5	1,637	0.14	1,600	0.20	3,700
King 4	0.0003	6.4	80	1.5	428	0.10	10,190	0.16	3,100

TABLE 1: Summary of Study Reaches

mining slag. Bank deposits in Reach 3 are in a levee configuration, with bank growth occurring through successive high flow events overtopping deposits of the previous event. Reach 4 is tidal with up to 9m of infilling in the river bed.

Extensive field work has been carried out to document conditions in the river prior to the mine ceasing operation. In addition to comprehensive surveys, bed load samples have been collected using a Helley-Smith sampler. Suspended sediment has been continuously monitored with turbidity meters. Changes in bank form are continuously monitored with erosion pins, which have shown scour or deposition depending upon their position relative to river bends. Scour chains indicate cumulative scour of up to 32cm, even though the adjacent erosion pin has shown a net scour over a four month period of only 3cm.

Bed load measurements made prior to the cessation of mining are summarised in Figure 2. Station numbers increase in a downstream direction with Station 11 located in Reach 2, Station 13 in Reach 3, and Stations 16, 18, and 20 in Reach 4. There is a general trend for higher bed load rates at the further downstream stations, contrary to intuition since these river gradients are flatter. For Stations 11 and 13 there appears to be no correlation between bed load and discharge, whereas there is reasonable correlation for Stations 16, 18, and 20.

These observations were investigated further by examining the influence of prior discharge conditions on the measured bed load transport rates. The results are presented in Figure 3 for Stations 13 (Reach 3) and 18 (Reach 4). Each data point in this figure is labelled with the total volume of water discharged in megalitres during the 72 hour period prior to the measurement time. Table 1 indicates that Reach 3 is characterised by low volume storage of bottom tailings compared with Reach 4. Figure 3 indicates that, for Station 13, the measured

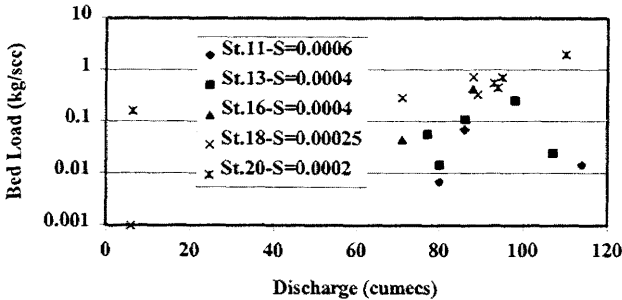


FIGURE 2: Summary of Bed Load Sampling

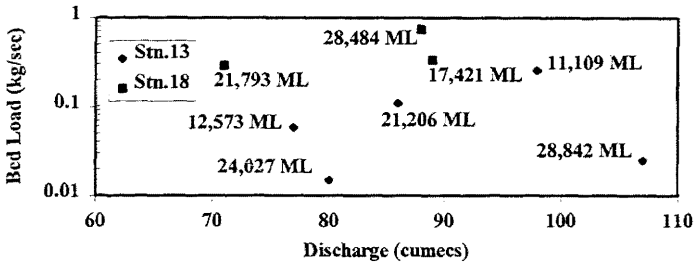


FIGURE 3: Bed Load Correlated with Prior Discharge Volumes

bed load transport rate was much higher when the discharge was relatively low during the preceding 72 hours. Evidently, sediment settled out during the low discharge period, creating a temporary storage which was being transported during the sampling period. Sediment supply is apparently limited and care will be necessary in comparing predicted and measured sediment transport rates.

No field data have yet been collected since the mine permanently ceased discharge of its wastes into the river system. On-going monitoring will enable determination of the short-term river response. Surveying of river cross-sections, measurement of erosion pins and scour chains, and bed load and suspended sediment sampling will enable a comparison pre-and post-mine discharges.

INFLUENCE OF REGULATED FLOWS

The response of the King River system has changed dramatically following the commissioning of the King River Power Station. Despite average flows not being significantly altered, peak flows have dropped from 830 to 240m³/sec. Power requirements are such that normally, the station is run intermittently, leading to corresponding sudden changes in the river discharge.

Figure 4 shows measured suspended sediment concentrations during two cycles of operation of the power station (P.S.). The flow rate was 78m³/sec during power station operation and 6m³/sec with the power station turned off.

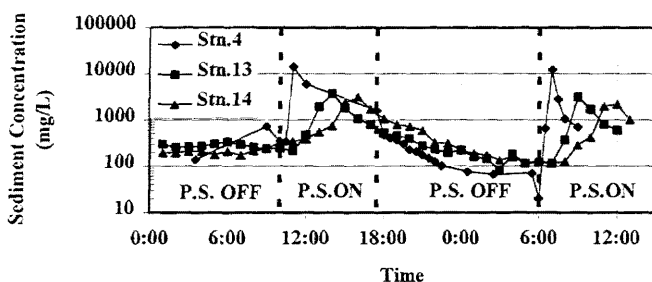


FIGURE 4: Influence of Power Station Discharge on Suspended Sediment Concentrations

Concentrations rose by two orders of magnitude following start up of the power station, evidently due to an initial flush of sediment which had deposited while the station was turned off. The movement of this sediment wave downstream is clearly depicted in Figure 4 by the progressively later peaks with distance downstream. Sediment exhaustion effects are evident as the initial sediment flush subsides and a lower suspended sediment concentration is transported at the constant flow rate released from the power station.

At this stage, sediment concentration data only have been obtained from field exercises such as that shown in Figure 4. Considerable difficulty has been experienced in obtaining concurrent flow data for the entire river, as Reach 4 is tidally influenced. This problem is being tackled using MIKE-11, an unsteady flow modelling package developed by the Danish Hydraulics Institute, to model the river so that net sediment loads can be determined. In this way, the net scour or deposition within different river reaches can be determined.

MINIMISING ENVIRONMENTAL IMPACTS

Concurrent geochemical work has shown that the presence of suspended sediment in the river has a strong influence on water quality as heavy metals bind to the sediments. The present study has enabled an understanding of the power station's role in the transport of sediments while the mine was still operating.

With the power station off, tailings settle out, the lowering water level leaches metals from the mining-derived sediment banks, and there is no dilution of metal-laden Queen River water. Startup creates an initial flush of stored sediments and water with high metal concentrations, threatening aquatic life in Macquarie Harbour. Ideally, the station should be shut down as rarely as possible, minimising sediment accumulation, and, when startup occurs, come up to efficient operating level very slowly, to dampen the initial flush of water.

The next stage of this study will elucidate the role of river sediments following mine closure. Suspended loads will decrease because the sediment source will be the coarse fraction of the tailings, stored in the bed and banks. Because the bank material is consistent in size with the bed sediments, suspended loads will be elevated only following station startup and during major storm events. Because the station has vastly reduced peak flows, the bank storages in Reach 3 will no longer be inundated and will stabilise. Hence, the long term source of sediments will be the river bed in Reach 4. Since station commissioning, bed load transport in Reach 4 is predicted to have increased with the frequency of exceedance of the bed material transport threshold.

SUMMARY AND CONCLUSIONS

This paper has presented initial results of a major study of the impact of mining wastes on a river system. Surveys conducted prior to mine closure have indicated that large quantities of mine-derived sediment are stored within the river system. These tailings are highly mobile as indicated by the large increases in suspended sediment load with induced increases in river discharge. The power station plays an important role in the transport of tailings, and operating guidelines are identified which minimise environmental impacts. Analysis of current measurements will determine the response of the river to the sudden cessation of tailings input and the best use of a controllable discharge.

REFERENCES

- Colby, B.R. (1963) "Fluvial sediments - a summary of source, transportation, deposition and measurement of sediment discharge". *Bulletin of the United States Geological Survey*, 1181A.