Response of the King and Queen Rivers, Tasmania, to Dramatic Changes in Flow and Sediment Load

*Helen Locher**

ABSTRACT

The King River in Tasmania has been subject to 80 years of mining sediment disposal up until 1994, plus flow regulation for hydro-electric power generation commencing in 1992. About 10% of the mine wastes have remained stored within the river system, with the majority within a delta at the river mouth. The power station has caused a strongly pulsating pattern of sediment transport in the river, particularly major flushes of suspended sediments when the power station comes on line. Suspended sediment concentrations have decreased dramatically since mine closure. Erosion of the river sediment storages is projected take decades to centuries.

1. INTRODUCTION

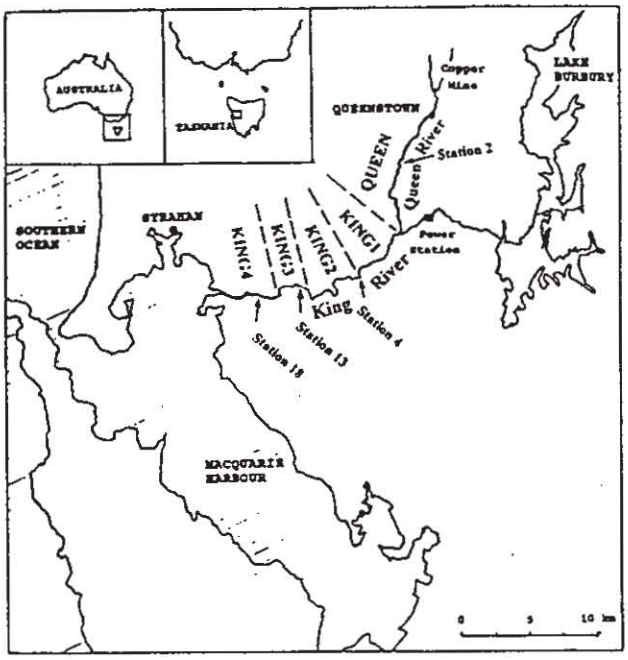
This study aims to determine the physical impacts of mining and hydro-power on the King River system on Tasmania's west coast. This involves identifying the river response to 80 years of tailings discharge, monitoring river response to the cessation of tailings discharge as of December 1994, determining how the regulation of flow which commenced in February 1992 influences river response, and developing future management recommendations for the river system.

This paper presents knowledge gained to date on the storage of mining wastes, the influence of the power station, changes with the cessation of tailings discharge, and future projections for the river system. For detailed methodology and data summaries refer to Locher (1995).

2. SEDIMENT STORAGE

2.1 Sediment Budget

The King River system can be divided into five reaches based on river characteristics, as illustrated in Map 1. Sediment storage within each reach is summarised in Table 1, and can largely be correlated with river gradient. There are little to no storages in the Queen and King1 reaches due to the steep channel gradients. The majority of mining-derived sediments within the river system are stored within reaches King3 and King4. The river storages, totalling 9.4 million tonnes of mining-derived sediments, represent only a fraction of the total sediment discharge from the Mount Lyell Copper Mine in Queenstown, estimated to be 97 million tonnes of tailings and 1.4 million tonnes of smelter slag.



MAP 1 - KING RIVER LOCATION MAP

2.2 Sediment Bank Storages

The extent of sediment bank storage of mining wastes was determined via an extensive augering survey, supplemented by the excavation of a trench perpendicular to the river flow. Identification of sediments as mining-derived was supported by analyses of Caesium-137 and copper concentrations. The majority of bank sediments are stored in reach King3, where banks are up to 7 metres above mean water level. Reach King4 is tidally influenced and the sediment banks are much flatter, only 1-2 metres above mean water level.

Deposition of mining wastes is conspicuous due to devegetation of the sediment banks. Sediment banks

* Co-operative Research Centre for Catchment Hydrology, Department of Civil Engineering, Monash University, Wellington Road, Melbourne VIC 3168

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

consist almost entirely of tailings, a fine silt to fine-sand sized material, lain down on top of natural levee banks during successive flood events during which the levees were overtopped.

Sediments in Storage (Tonnes)					
		BANKS		BOTTOM	
REACH	Average Gradient	Approx. Amount	% of Total in Banks	Approx. Amount	% of Total in Bottom
Queen	0.012	< 1,000	-	< 1,000	-
King1	0.014	< 1,000	-	< 1,000	-
King2	0.0008	180,800	5.18	< 1,000	-
King3	0.0004	2,624,000	75.19	376,000	6.3
King4	0.0003	684,800	19.62	5,558,400	93.7
TOTAL		3,489,600	100	5,934,400	100

TABLE 1 - King River Sediment Storage

Comparison of river planform with an 1898 railway survey shows there have been no major changes in river course, and all presently observed sediment banks are underlain by the original levee banks.

2.3 River Bottom Storages

The extent of river bottom storages was determined by drill coring. Mine wastes have infilled the river bottom by as much as 6 metres within the last several kilometres of the King River. Bottom sediments consist predominantly of smelter slag, a black coarse granular material about 1 mm in diameter, mixed with lesser amounts of tailings and natural river gravels.

2.4 Delta

The vast majority of tailings are stored in the delta at the river mouth, estimated to contain 80-90 million tonnes of tailings. This volume estimate is based on comparison of a 1993 bathymetric survey with a 1930 British Admiralty Chart. Progressive outward growth of the delta can clearly be traced on aerial photographs. Composition of the deltaic material as tailings is based on drill core collection.

3. INFLUENCE OF POWER STATION

3.1 Changes in Sediment Deposition

The power station came on line in February 1992. It has significantly changed the flow regime, most notably by reducing the peak flows to 30% of their previous levels. The reduced flows have stopped the growth of the sediment banks, by eliminating the flood events during which they were overtopped. The power station has also caused increased bottom deposition of tailings at the mouth of the river immediately upstream of the delta, based on comparative cross-section surveys, due to the inability of the reduced river flow to completely flush out the tailings being delivered by the mine. Observational evidence suggests that outward growth of the delta has ceased since the power station came on line, and that deposition is occurring behind the delta with some erosion of the delta face.

3.2 Changes in Sediment Transport

The operation of the power station has resulted in a pulsating pattern of sediment transport as illustrated by a suspended sediment sampling exercise conducted while the mine was still discharging tailings. Suspended sediment concentrations are shown in Figure 1, and station locations are shown in Map 1. Suspended sediment concentrations increased as much as two orders of magnitude following initial start-up of the power station, from several hundred to 10,000 mg/L, although this rise in concentration was not sustained during the period the power station was on due to sediment exhaustion effects. Propogation of the sediment flush and attenuation of the peak is clearly evident at the progressively downstream stations.

The dynamics at the confluence of the King and Queen Rivers have a major influence on the occurrence of the sediment flushes seen in Figure 1. When the power station is on, the flow in the King River restricts transport of the tailings out of the Queen River. Tailings are able to come out of the Queen River into the King once the power station goes off line, but flow in the King River is insufficient to transport the tailings further downstream and so they settle out of suspension. When the power station comes back on line the temporarily deposited sediments are lifted into suspension and transported downstream, and have been associated with major tailings plumes out into the receiving body of water, Macquarie Harbour.

4. CHANGES POST-MINE CLOSURE

4.1 Influence of Power Station

Figure 2 shows a comparative suspended sediment sampling exercise conducted during 1995, after the mine had closed. Suspended sediment concentrations are dramatically lower, averaging 20-40 mg/L and peaking at 160 mg/L. The same flushing effect of the power station is still evident. Interestingly, the highest sediment concentrations are seen at Station 18 rather than Station 4. Suspended sediments collected during the 1995 exercise were reddish and appear to be iron hydroxide flocs precipitating out of solution, a product of the changed water chemistry post-mine closure. The higher concentrations seen at Station 18 may be a

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

FIGURE 1
Influence of Power Station on Suspended Sediment Transport
Pre-Mine Closure - June 1994

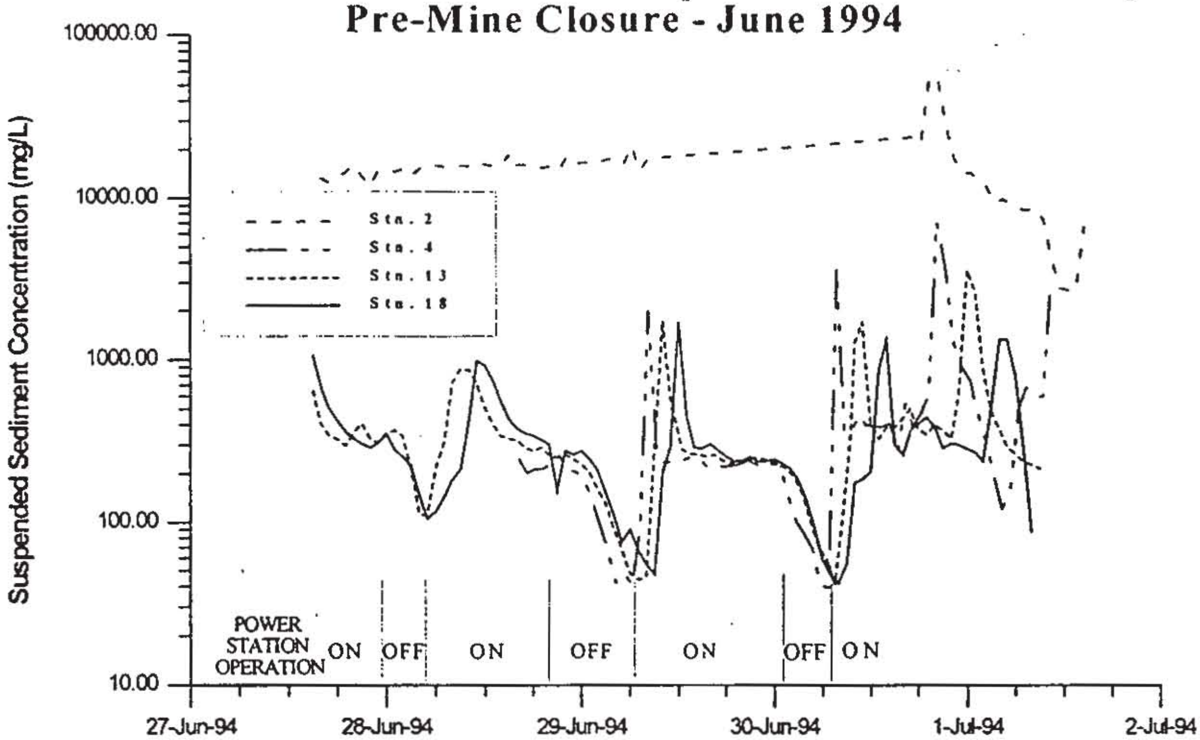
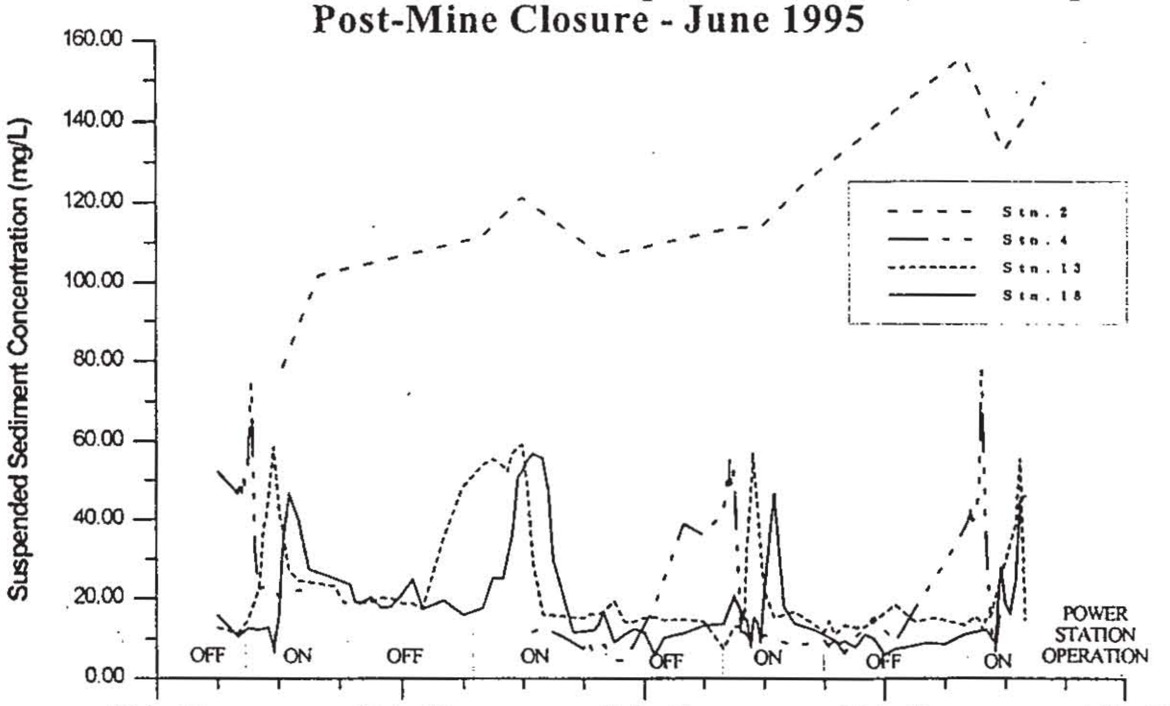


FIGURE 2
Influence of Power Station on Suspended Sediment Transport
Post-Mine Closure - June 1995



Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

result of increased chemical precipitation with distance downstream, or due to the relatively higher availability of sediments within this reach King4. Detailed analyses of the suspended sediment samples and on-going monitoring are required as it is unlikely that the river system has settled into an equilibrium state since the mine has ceased to discharge its tailings.

4.2 Sediment Transport Rates

Table 2 shows a summary of measured sediment transport rates before and after the mine closed. The dramatic decrease in suspended sediment transport rates is clearly evident. There are no significant changes to bed load transport, except for in the Queen River in which the pre-mine closure bed load transport was entirely mine tailings. These transport rates were measured under fairly ordinary conditions of power station operation, with flow ranging from 6 to 110 cumecs, and so they take no consideration of sediment transport during major storm events. Bed load transport rates shown are the maximum measured during normal power station operation.

Sediment Transport Rate (Tonnes/Day)					
		Pre-Mine Closure		Post-Mine Closure	
Station	Reach	Suspended Load	Bed Load	Suspended Load	Bed Load
2	Queen	4,000	189	45	0.01
4	King2	2,000	?	55	0.64
13	King3	2,000	15	73	83
18	King4	2,000	61	90	100
20	King4	?	188	?	37

TABLE 2 - King River Measured Sediment Transport Rates

5. FUTURE PROJECTIONS

Based on the sediment storage locations shown in Table 1, and the measured sediment transport rates summarised in Table 2, a projection of erosion time scales is presented in Table 3. Table 3 ignores the Queen and King1 reaches where there are no significant sediment storages due to the steep gradients. It is assumed that bank sediments, which are mostly fine tailings, will move as suspended load, and bottom sediments which are mostly slag and gravels will move as bed load.

Time scales to erode the sediment storages are seen to depend on the size of the storage; decades for storages in the order of several hundred thousand tonnes, and centuries for storages of several million tonnes. Time scales are deliberately general as erosion will not proceed at the constant sediment transport rates used for this evaluation.

Much of the sediment bank erosion and collapse visible on the King River has been an immediate response to the cessation of tailings discharge. While the mine was still discharging tailings, the older orange-coloured oxidised tailings banks had their river 'faces' regularly coated with the cohesive fresh grey unoxidised silt. Since mine closure this grey silt has dried out and slumped, pulling out sections of the older bank with it.

There are three reasons why bank retreat is unlikely to continue extensively:

1. There is a hardpan coating of iron oxides which forms some stability to the banks faces;

Maximum Erosion Rates					
REACH	Storage Location	Sediment Stored (tonnes)	Probable Transport Mode	Approximate Transport Rate (tonnes/day)	Time Scale for Erosion
KING2	Banks	180,800	Suspended	55	decades
	Bottom	-	-		
KING3	Banks	2,624,000	Suspended	73	centuries
	Bottom	376,000	Bed Load	83	decades
KING4	Banks	384,800	Suspended	90	decades
	Bottom	5,558,400	Bed Load	100	centuries

TABLE 3 - Projected Time Scales for Erosion of Sediment Storages

Rutherfurd, I.D. & Walker, M. (1996). Proceedings of the 1st National Conference on Stream Management in Australia, 19 – 23 February, 1996, Merrijig, Australia.

2. As bank retreat makes the stream widen, stream power will diminish and lessen the energy available for erosion; and
3. The original levee banks should form some sort of natural barrier to erosion.

A realistic maximum distance of bank retreat might be 5m back from the present waters edge. This represents a loss of just over 200,000 tonnes of sediment, or only two months of Mount Lyell's former discharge of tailings.

6. SUMMARY AND FURTHER WORK

The principal findings of this work to date are as follows:

6.1 Sediment Storage

Only a small percentage of tailings remain in the river, the vast majority are in the delta; all slag discharged by the mine remains in the river bottom; and there have been no planform changes to the river system.

6.2 Power Station Influence

The power station has significantly reduced peak flows; it has stopped growth of the sediment banks but caused a short-term increase in bottom deposition at the river mouth upstream of the delta; and it has caused a strongly pulsating pattern of sediment transport.

6.3 Cessation of Tailings Disposal

The suspended sediment load of the river has decreased by orders of magnitude since the mine stopped disposal of tailings, but there is significant chemical precipitation processes occurring and it does not appear to have reached an equilibrium state.

6.4 Future Projections

Erosion of the sediment storages will require time scales in the order of decades and centuries, but it is very unlikely that these storages will ever completely erode at all.

6.5 Further Work

Further work will involve the utilistion of flow and sediment transport models. Mike-11, a one-dimensional unsteady flow modelling package developed by the Danish Hydraulics Institute, has been set up and calibrated for flows in the King River. Sediment transport equations available in the literature are being tested against field measurements of sediment transport. Modelling will be used to answer questions related to river remediation options - for example, what happens to the sediment transport and projected erosion rates if you dredge out the channel or collapse a sediment bank? - and also to project sediment transport rates during major flood events.

7. REFERENCES

Locher, H. (1995) Sediment Transport in the King River, Tasmania. Co-operative Research Centre for Catchment Hydrology Working Document 95/5, Department of Civil Engineering, Monash University, Melbourne.