MINE WASTE POLLUTION CONTROL AT CAPTAINS FLAT, NEW SOUTH WALES

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INTRODUCTION

Mine waste pollution from Captains Flat mining area in New South Wales, Australia (Fig. 1), had degraded the biology of the Molonglo River, which flows into Lake Burley Griffin in Canberra some 50 km downstream, and reduced the usefulness of its waters. In the absence of immediate remedial works, there was a risk of increased pollution from accelerating erosion of the mine waste dumps and from the collapse of unstable areas.

After discussions between the Commonwealth and New South Wales Governments, a Joint Government Technical Committee was formed in 1974 to enquire into the problem and to recommend remedial measures which would lead to permanent abatement of the pollution of the Molonglo River arising from the abandoned mining area.

THE PROBLEM

Mining commenced at Captains Flat in 1874 and continued intermittently until 1962. During this period 4 Tg of ore was milled to produce zinc, pyrite, lead, copper and gold and 2.5 Tg of mine waste was left piled in dumps covering an area of 0.15 km^2. The waste in the dumps (Fig. 2) contained significant quantities of these heavy metals (Table 1), and the pH was extremely acid - pH 2.8 for the southern dumps and 2.9 for the northern dumps (Craze, 1977a).

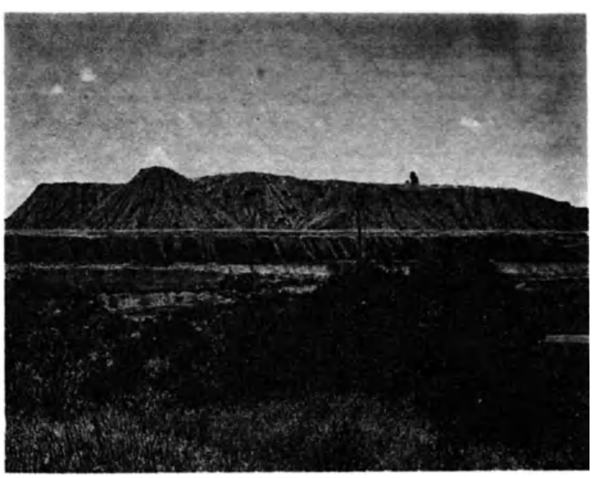

Figure 2: The northern solids dump at Captains Flat.

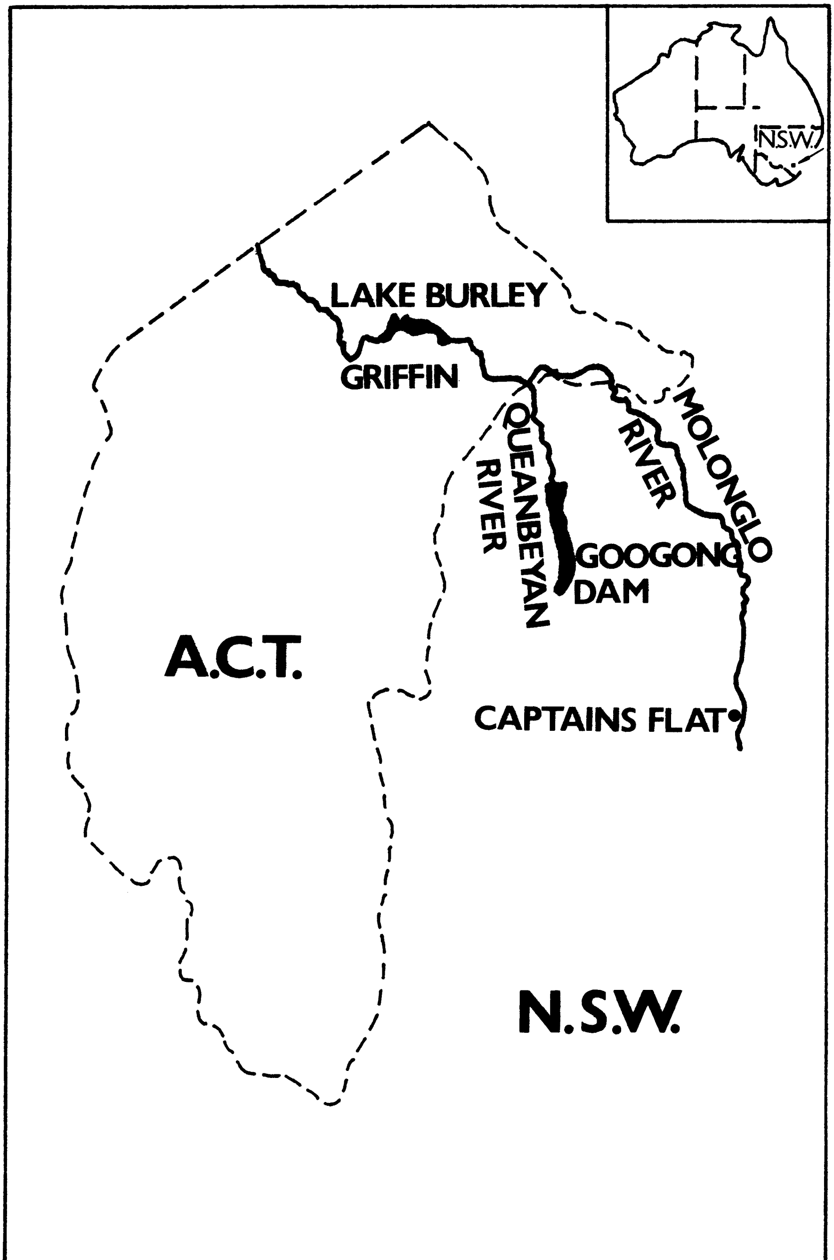

Figure 1: Captains Flat: Location map.

TABLE 1

QUANTITIES OF HEAVY METAL FOUND IN DUMPS
AT CAPTAINS FLAT

Metal	Southern Dumps (%)	Northern Dumps (%)
Total zinc	2.6	1.1
Total lead	0.8	0.5
Total copper	0.1	0.05
Total sulfur	21	17.4
Total sulfur (as FeS_2)	39.5	32.5

The southern dumps contained the finer fraction called slimes which after processing had been pumped as a slurry into earthen dam storage areas. Here the fine fraction settled out and the water either evaporated or was drained for reuse. The coarse fraction from hydrocycloning was piled high to form large dumps, referred to in Table 1 as northern dumps. These dumps besides being unsightly, were also a considerable nuisance as sources of air and water pollution (Fig. 3).

Figure 3: Drainage from the northern slimes and solids dumps passed through the pipe into the Molonglo River, causing it to be polluted and sterile for many kilometres.

They lacked stability along the outer faces and, in 1939, material from the face of one of the northern slimes dams collapsed into the Molonglo River. There was destruction of vegetation along the river valley, particularly on the flats at Foxlow, some 15 km downstream. In 1942, part of one of the southern dumps collapsed, dumping some 30 000 m^3 of tailings into the river. Major flooding of the Molonglo in 1945 carried some of these tailings onto the Foxlow-Carwoola Flats, again destroying pastures. Despite an attempt to remedy the problems by heavy liming, only sparse vegetation has returned in the intervening years (Fig. 4 and Fig. 5).

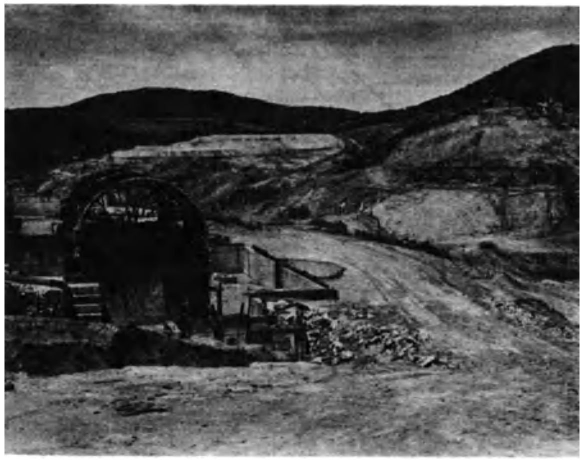

Figure 4: Abandoned treatment works at Captains Flat.

Figure 5: Foxlow-Carwoola Flats, showing the sparse vegetation that has returned after the area was covered to depths of 80 cm in places by mine waste in 1939 and 1945. The waste was washed down the Molonglo River after two slimes dams collapsed at Captains Flat, 15 km upstream.

Much of the tailings lost in these events, and through the continuing erosion of the dumps, exists today as bed load in the Molonglo and Queanbeyan Rivers down to, and including, the floor of Lake Burley Griffin at Canberra.

The extreme acidity of the tailings was a result of oxidative decomposition of pyrite, which was considerably accelerated by *Thiobacillus* bacteria. The chemical reactions resulted in the formation of soluble copper and zinc sulfate, insoluble lead sulfate and sulfuric acid. As most of these reactions require abundant supplies of oxygen and water, it was impossible for acidification to occur through the entire tailings. Generally, it was localised in the top two metres, with a zone of maximum acidity occurring in the top 30 cm. The reaction products, apart from lead sulfate, were readily leached from the dumps, and pH values as low as 1.5 were measured in the runoff.

The maximum levels of metals measured in mine drainage, waters of the Molonglo River, and river sediments at Captains Flat, are shown in Table 2. The heavy metal contamination in the river was so high that it was basically sterile for many kilometres.

TABLE 2

MAXIMUM LEVELS OF METALS MEASURED IN THE SLIMES DRAINAGE, WATERS OF THE MOLONGLO RIVER, AND RIVER SEDIMENTS AT CAPTAINS FLAT

Metal	Mine Drainage ($\mu g\ g^{-1}$)	Molonglo River ($\mu g\ g^{-1}$)	River Sediments ($\mu g\ g^{-1}$)
Zinc	6 200	130	1 800
Copper	720	1.5	1 000
Lead	70	0.7	9 000
Cadmium	8	0.03	3
Iron	5 000	130	60 000
Manganese	1 100	8	1 300
Nickel	2	0.1	40
Cobalt	21	0.1	20
Chromium	1	0.1	105
Arsenic	7	1	-

As a result of the formation of sulfates of iron, copper, lead and zinc, salinity levels were extremely high (31 to 42 mS cm^{-1}). These salt contents caused osmotic pressures of 1 to 1.5 MPa, which were too high for plants to establish in, even under saturated conditions.

The physical properties of the mine waste were also of major importance. Permeability was abnormally low due to cementation of the particles by heavy metal salts. Falling head permeameter tests carried out on cores from the dumps gave saturated hydraulic conductivities, K of 1.2 nm s^{-1} at a bulk density ot 1.31 g cm^{-3} for the southern slimes dump and K of 120 $\mu m\ s^{-1}$ at a bulk density of 1.76 g cm^{-3} for the solids dump. These rates represent rate of water movement of 4 cm and 40 cm yr^{-1} respectively. Further details of dump material are given in Craze, 1977(a).

VEGETATION STABILIZATION

Three main methods of treatment to stabilize tailings and decrease the air and water pollution have been used through the world; 1, covering with rock and slag; 2, covering with chemical and binding agents; and 3, vegetative stabilization. Almost all published research indicates that by far the most promising stabilization method is by the use of vegetative cover. Rock and slag cover do not seal the tailings from water and air. They are also difficult to vegetate. Chemical and other binding agents deteriorate rapidly by weathering. Successful vegetation usually takes many years, and no one to date has managed to grow on tailings anything comparable to those at Captains Flat. James and Mrost (1965) used successfully a technique of spray irrigating mine dumps in South Africa to leach out the heavy metals. For this method to succeed it was important that the precipitation rate did not exceed the infiltration rate of the tailings. At Captains Flat the permeability of the tailings was so low it was practically impossible to leach them without causing increased runoff, erosion and ponding and a raising of the water table. Such water applications could have led to dump collapse.

Lime has commonly been used on acid tailings to raise the pH and lower the concentration of soluble heavy metals sufficiently for plants to grow. Lime requirement tests showed rates of 5.5 and 5 kg m^{-2} to raise pH to 7 for the southern and northern dumps, respectively. Such rates are clearly impracticable and have only a trnsitory effect (Nielson and Peterson, 1972; MacLean and Dekker, 1976). At Captains Flat, additions of lime up to 4 kg m^{-2}, for the purpose of making the tailings suitable for plant establishment, caused short term beneficial rises in pH, but also caused increased complexing of added phosphorus by the heavy metals and by the lime itself (Craze, 1977d). As much as 64% of added phosphorus was complexed in one day by tailings without lime, and with 4 kg m^{-2} of lime, 94% of phosphorus was complexed in one day. Because of the need to rapidly stabilize the reshaped dumps to prevent erosion and pollution none of these long-term direct vegetating techniques were satisfactory.

THE RECLAMATION METHOD

The results of the earlier investigations (Anon., 1974; Craze, 1977 a, b, c) made it clear that vegetative cover could not be established directly on the toxic tailings. After evaluating nine possible reclamation proposals to control the mine waste pollution, the Government Committee recommended one which would permanently abate the problem by preventint erosion and leaching of the mine waste dumps, and by reducing the flow of mine water from the main spring, which was a major contributor of pollution. After closure of the mine in 1962, the mine filled with water and overflowed into the Molonglo River through the air shaft at the Northern end of the workings and from a spring which developed close by after the air shaft was plugged.

In brief, the details of these works were as follows:

The dumps had to be reshaped, and this involved reducing the height of the main solids dump and constructing terraced slopes with grades no steeper than 1 in 3 and no flatter than 1 in 20. These slopes were chosen in order to minimize scouring, to facilitate vegetation and provide surface and internal drainage (Fig. 6).

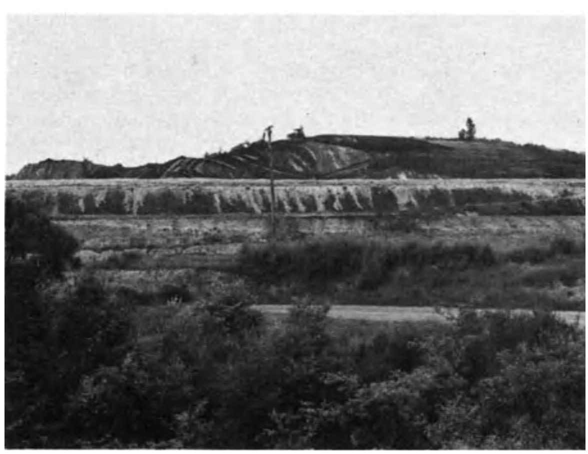

Figure 6: Reshaping the northern solids dump.

The terraced slopes were covered firstly by about 22 cm of compacted clay to seal the tailings from air and moisture and thus prevent acidification. This was followed by 45 cm of rock-fill (shale) to prevent the capillary rise of any toxic substances that might permeate the clay from the underlying tailings and to provide a lateral drainage layer. Finally, 30 cm of soil was added as a top later to sustain a cover of vegetation (for a description of soil, see Craze, 1977a).

This reclamation method provided for lateral drainage beneath the topsoil to prevent build-up of moisture in the dumps, thereby increasing stability, and to reduce leaching. The final covering of soil was to provide a suitable medium in which an adequate cover of vegetation could be rapidly obtained. If any erosion did take place before a dense cover was established, it would be the non-toxic surface soil that reached the river. Trial embankments showed this technique to be successful.

Fertilization and sowing were carried out as soon as possible after placement of topsoil. The grass and legume mixture consisted of cereal rye *(Secale cereale)*, as a quick growing cover crop, Namoi woolly pod vetch *(Vicia dasycarpa)*, red clover *(Trifolium pratense)*, white clover *(T.repens)*, brown top bent grass *(Agrostis tenuis)*, Demeter fescue *(Festuca arundinacea)*, and couch grass *(Cynodon dactylon)*. The seed was sown through a fertilizer spreader and the batters were covered with straw mulch and bitumen. The whole of the restored area was watered by sprinkler irrigation. Fertilizer rates were 60 g m^{-2} of superphosphate, 29 g m^{-2} ammonium nitrate, 20 g m^{-2} potassium sulfate and 0.125 kg m^{-2} of lime, (Craze, 1977b). Further applications of fertilizer are being made in a 5 yr maintenance programme and the area is regularly slashed in order to build up the organic matter in the top-soil. Watering is still carried out through the dry summer and autumn months. All species are still present but some dominate certain areas more than others.

It is necessary to exercise extreme care during the entire works operations in order to avoid incorporating tailings into the covering layers. Special attention had to be paid to washing down equipment when moving off tailings surfaces. The efforts made to minimise accidental incorporation of tailings within the soil zone were largely successful. It has been necessary to ameliorate or replace only a few small areas of soil where plants would not thrive due to the presence of toxic material.

The cost of the works was estimated at $2.5 million (Australian), with provision for maintenance by the Soil Conservation Service of $200,000 over 5 yr.

TABLE 3

ANALYSIS OF WATER FROM THE MOLONGLO RIVER,
AT CAPTAINS FLAT, PRE- AND POST- RECLAMATION

	Pre-reclamation[a]	Post-reclamation[a]
pH	5.3	6.6
EC ($\mu S\ cm^{-1}$)[b]	328	230
SO_4 ($\mu g\ g^{-1}$)	125	65
Zn ($\mu g\ g^{-1}$)	11	6

[a] Values are averaged over 3 and 4 yr, respectively.

[b] EC = Electrical Conductivity

An extended period of rain in September-October, 1976 yielding some 355 mm was recorded when vegetation measures were only partially complete. At the end of this period, over 107 mm fell in a single storm within 3 h. No damage of any significance occurred to any of the work and run-off was minimal due to the design of the works, the stable and loose nature of the soil and the vegetation already established.

There has been a dramatic reduction in the mineral content of the Molonglo River (see Table 3) and algae are beginning to appear in the waters immediately below the mine site. The pH of the water has risen from an average of 5.3 to 6.6. Sulfate and zinc loads have decreased by 50% and the soluble salt level (EC) has fallen 30% and is still improving. Levels in sediments do not show much of a change but as the source of pollutants has been substantially eliminated by covering the dumps, the natural occurrence of river floods will disperse in time and dilute the sediment load. The State Pollution Control Commission with the Department of Mineral Resources, continue to monitor runoff and the Molonglo River.

REFERENCES

Anon., 1974. *Mine Waste Pollution of the Molonglo River.* Final report on remedial measures by the Joint Government Technical Committee. Australian Government Publishing Service, Canberra.

Craze, B., 1977a. Restoration of Captains Flat mining area. *J. Soil Conserv. Serv.* N.S.W., 33: 98-105.

Craze, B., 1977b. Investigation into the revegetation problems of Captains Flat mining area. *J. Soil Conserv. Serv.* N.S.W., 33: 190-199.

Craze, B., 1977c. Heavy metal toxicity problems in the revegetation of Captains Flat mining area. *J. Soil Conserv. Serv.*, N.S.W., 33: 265-271.

Craze, B., 1977d. *The Rate of Phosphorus Complexing on Heavy Metal Mine Tailings from Captains Flat.* Cowra Research Centre Research Report 5/77, Soil Conservation Service of N.S.W.

James, A.L. and Mrost, M., 1975. Control of acidity of tailings dam and dumps as a pre-requisite to stabilization by vegetation. *J. S. Afr. Inst. Min. Metall.*, April, pp. 488-495.

McLean, A.J. and Dekker, H.B., 1976. Lime requirement and availability of nutrients and toxic metals to plants grown in acid mine tailings. *Can. J. Soil Sci.*, 56: 27-36.

Nielson, R.F. and Peterson, H.B., 1972. *Treatment of Mine Tailings to Promote Vegetative Stabilization.* Bulletin 485. Agriculture Experimental Station, Utah University.