The environmental history of bucket dredging in Victoria

By PETER DAVIES, SUSAN LAWRENCE, JODI TURNBULL, IAN RUTHERFURD, JAMES GROVE, EWEN SYLVESTER

The introduction of bucket dredges from New Zealand in the 1890s provided a much-needed boost to the mining industry in south-eastern Australia. More than 50 dredges operated in Victorian river valleys each year during the peak of the industry between 1908 and 1913, with a subsequent revival from the 1930s to the 1950s using larger plant. At least 101 bucket dredging installations worked in Victoria during the 20th century. The dredges, however, had a major effect on river valleys and soon became widely known as 'desolating dredges'.[1] This paper presents a general synthesis of the bucket dredging industry from an environmental perspective. In particular we consider the effect of dredging on waterways, and efforts by local communities and authorities to limit adverse effects.

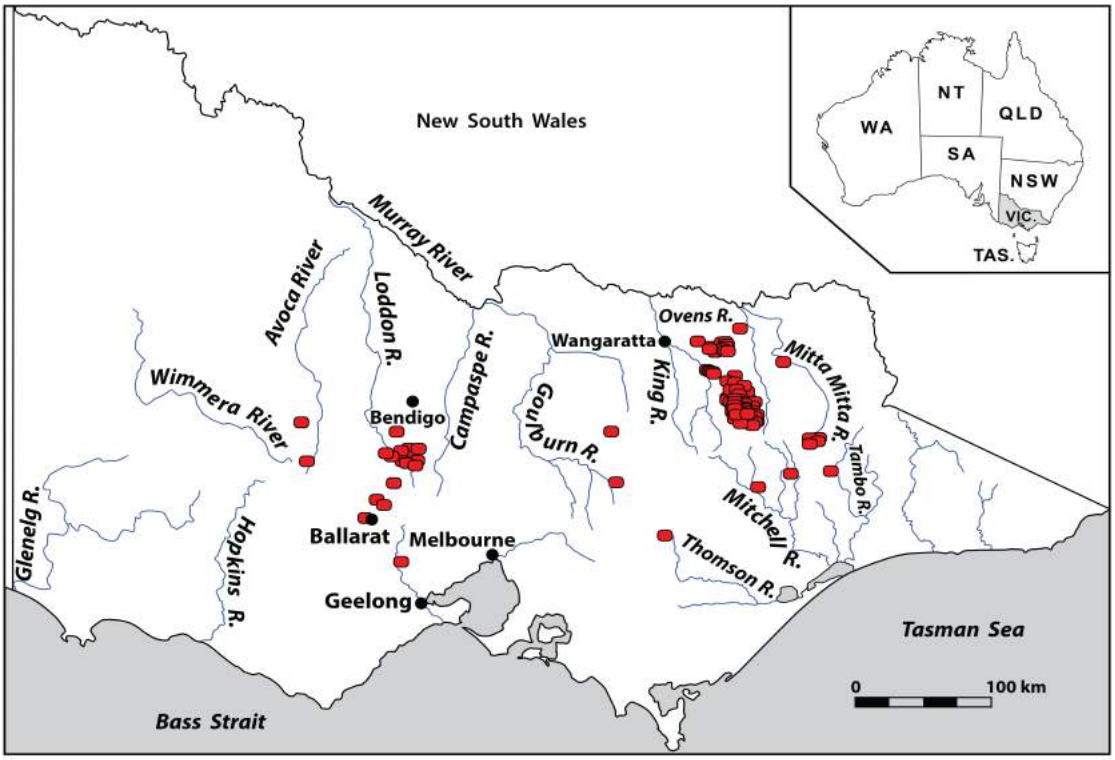
Gold dredges were widely used in Victoria while tin dredges operated in all the eastern states and Tasmania. Bucket dredging facilitated a revival in metals mining at a time when other methods were in decline. In north Queensland, dredging for tin began soon after 1900 and continued to inflict environmental damage into the 1980s,[2] while in Tasmania, several bucket dredges were a used for tin mining in the early years of the 20th century.[3] Australian expertise was also applied in Thailand and elsewhere in south-east Asia from 1906 onward.[4] Despite the excitement, the economic benefits proved to be limited and the scale of damage was a catalyst for legislation to control mining waste.[5] Research presented here is part of an ongoing multi-disciplinary project investigating the impact of historical gold mining on riverine environments,[6] and builds on previous local studies and provides a regional overview of a major part of the industry.

Bucket dredges could operate profitably and successfully even when gold yields per volume of alluvium were very small. In 1913, for example, the 51 dredges in Victoria averaged 1.6 grains of gold per cubic yard[7] of material treated. In that year alone the industry produced 52,211 ounces of gold from almost 15 million cubic yards of alluvium.[8] Labour requirements for dredges were modest in the early period. The cost of operation, including wages, firewood, stores and maintenance, could generally be met on a gold yield of 15 to 20 ounces per week.[9] At the same time, the need to process large quantities of low-grade alluvium in order to be profitable meant that extraordinary quantities of waste material or tailings were also produced. For the period 1900 to 1915, for example, a total of 150 million cubic yards of sand, gravel and silt were processed and mobilised by bucket dredging in Victoria.[10]

The total gold yield for bucket dredging in Victoria for the period 1900-55 was around 1 million troy ounces, or 33 tons. Historically the Victorian gold province has yielded approximately 2,500 tons of gold since the first payable discoveries in 1851, which is about 2 per cent of all the gold ever mined globally.[11] In comparison, gold

production in New South Wales was about 520 tons.[12] Around 40% of Victoria's gold production derives from primary quartz-vein deposits and 60% from alluvial gold deposits. Most of the latter production has been from shallow alluvial placers, with about 20% (300 tons) of alluvial gold coming from 'deep palaeoplacers'.[13] The total gold yield from bucket dredging in Victoria thus represents about 1.3% of total Victorian historical production.

Figure 1: *Location of bucket dredges in Victoria.*



Source: data from: *Annual Report of the Secretary for Mines* 1901-19; *Gold and Mineral Statistics* 1920-55.

Environmental histories of dredging

The history and development of bucket dredging is well documented in the research of mining historians Brian Lloyd, Gilbert Ralph, Ray Supple and Barry McGowan.[14] Studies in the geology of alluvial auriferous deposits and the geomorphology of dredge-affected rivers are also important sources of information.[15] Victorian gold mining was well documented in the 20th century, with the Mines Department publishing annual reports and detailed goldfields statistics. Beginning in 1905 the Sludge Abatement Board in Victoria reported on efforts to regulate waste from dredging and prevent damage to waterways.[16] Mining company records are preserved for several later cases but not earlier operations,[17] while dredges were also the subject of frequent newspaper attention.[18] Mining engineers reported on improvements in dredging technology and efforts to mitigate its environmental effects in journals including the *Mining and Geological Journal*, *Mining and Engineering Journal* and *Chemical Engineering and Mining Review*.[19]

The bucket dredging industry developed in south-eastern Australia towards the end of the long mining boom that began with the discovery of payable gold in 1851. Increasingly, scholars are expanding the study of gold mining to include consideration of its environmental impacts. Warwick Frost and Don Garden have discussed detail about the initial rushes,[20] while Ian Rae has analysed the spread of contamination from mercury, arsenic and cyanide as mining became more industrialised.[21] Barry McGowan has provided a more detailed discussion of the destruction caused by both sluicing and dredging at the end of the nineteenth century in both Victoria and New South Wales.[22] The history of Victoria's sludge controversy and efforts to regulate sludge abatement have been described by Lawrence and Davies, who have published widely on the relationships between water, rivers and mining.[23] In this context it is appropriate to examine the historical role played by bucket dredging as a controversial and often damaging part of the mining industry.

In New Zealand, where dredging was first developed, there is a substantial literature on the history of the industry including geographer Terry Hearn's work on its environmental effects.[24] Bucket dredging techniques were developed in New Zealand from the 1860s and had spread to Italy and Siberia by 1890 and Australia by 1900. By the early 20th century dredges had been established in the Philippines, Thailand, Mexico, Colombia, Brazil, Chile, Peru, Burma, and French and Dutch Guiana.[25] Dredging was also widespread in the United States, with operations in California, Montana, Alaska, Idaho, Oregon and Colorado.[26] Up to 500 bucket dredges were in operation around the world by this time, including over two hundred in New Zealand alone.[27] Later in the century dredging was employed in Papua New Guinea,[28] while it was also used extensively for tin mining in Malaya.[29]

The environmental history of mining in south-eastern Australia has parallels with other Pacific Rim countries that participated in the nineteenth-century gold rush.[30] The scale and intensity of mining impacts in Victoria are comparable to those in California,[31] New Zealand[32] and the Klondike.[33] The Klondike was characterised by a substantial dredging industry, as the timing of the rush in the late 1890s coincided with the development of dredging technology. Additionally, the occurrence of rich gold deposits in the gravels of large sub-Arctic Rivers made the region ideal for dredging, and the industry flourished for decades.

Dredging technology

The principle and practise of mechanically dredging harbours, river mouths and shipping channels to maintain access for maritime vessels was well established by the 19th century,[34] and bucket dredging worked on similar principles. The earliest gold dredging began in New Zealand in 1863 when a spoon dredge was built for working the Molyneux (Clutha) River in Otago. In the early 1870s small dredges driven by current wheels were made, but they proved unable to dredge heavy deposits and deeper ground.[35] Improvements in dredge design continued to be made over the following years, including the 1881 adoption of a crane with a steam-powered bucket ladder based on British technology, to clear silt from harbours.[36] The first fully designed

steam-driven, self-powered bucket dredge in New Zealand was the *Dunedin,* which began operating on the Clutha River near Alexandra in 1881. It could lift 150 tons of gravel per hour from a depth of 25 feet.[37] The dredging industry boomed in New Zealand from 1895 and by 1902 there were more than 240 dredge companies listed, mostly in Otago and Southland.[38] Dunedin became the world's leading centre of dredge design and production, with New Zealand engineers maintaining a worldwide reputation well into the 20th century. Archaeologists Neville Ritchie and Ray Hooker identify continuous bucket dredges as New Zealand's greatest contribution to alluvial gold mining technology.[39]

Operations began with the excavation of a basin in which a flat-bottomed barge or pontoon was built with a deck to support the dredge plant. Alternatively, the dredge could be launched from a river bank to operate directly in the stream. Machinery on deck was usually enclosed within a shed of galvanised iron, with a wood-fired boiler and steam engine powering machinery. Water was diverted or pumped from the river into the pondage to float the dredge, which consisted of an endless chain of large iron or steel buckets mounted on a long inclined frame or ladder fitted with rollers. The ladder was hinged at the rear end and supported by cables from a gantry above the deck of the pontoon at the front end, which allowed it to be raised or lowered to control the depth of the excavation face. The moving chain of buckets excavated and lifted alluvial material, with positioning of the pontoon controlled by winches and haulage lines anchored to land at the front and sides. In the early 1900s buckets varied from 4 to 6 cubic feet in capacity, lifting on average around 7400 cubic yards per week from a depth of up to 30 feet. Dredges of this scale could work about one acre per month.[40] By 1910 steam-powered dredges ranged in cost from £3,000 to £8,000, the price increasing in proportion to their size and power.

Alluvial material from the buckets was tipped into a hopper and then passed through a perforated cylindrical rotating screen or trommel. Screens ranged from 18.5 to 33 feet in length and 6 to 12 feet in diameter, set at an incline or fall towards the stern. Perforations consisted of thousands of small holes up to ½ inch in diameter. The finer material (and gold) was washed by water from high pressure jets through the holes and onto sluice tables below. The larger, coarse material was delivered out of the lower end of the screen to a tailings elevator and stacked at the stern of the dredge as overburden. Gold saving tables used a variety of surfaces, including calico riffles, coconut fibre matting and wooden or iron slats on a wide, gently inclined table, to trap the gold. The riffles that created turbulence, winnowed the less dense waste mineral particles, separating them from the denser gold. Mercury was also employed at times to improve the rate of gold amalgamation, although the full extent of its use is uncertain.[41]

While the basic principles of bucket dredging remained constant, there was rapid technological development of the industry in response to the varying nature of auriferous alluvial deposits and increasing environmental controls. In 1917, for example, the Public Works Department developed a modified dredge that ran along a short railway track beside Bendigo Creek at Huntly. The intention was to scoop out sludge from the creek, de-silting it in the process, extract the residual gold and use the

tailings to build a levee bank parallel with the cut. The dredge was described as 'an enormous imposing structure' with a span of 100 feet and weighing 110 tons. The endless chain of 30 steel buckets cut into the red-brown creek deposit and carried it down a chute to a caterpillar conveyer of 66 iron plates and then out the far side of the dredge to form the levee bank. The railway track was laid in short sections, with the rear sections taken up and relaid at the other end of the line after the dredge had passed. The machine shifted 300 cubic yards of earth per hour and cut a distance of one chain per day.[42]

During the second phase of bucket dredging from the 1930s, electricity replaced steam as the primary power source to drive winches, pumps and other equipment.[43] Electric lights, for example, were provided early on to permit three-shifts working around the clock, and steel hulls came to replace timber pontoons. As dredges became larger and more powerful they used larger buckets to excavate more material from greater depths, and the discharge of waste material was also refined. The earliest method dumped rocks and cobbles on top of finer material, producing a coarse surface on which nothing would grow, but this method was soon replaced with silt distributors or elevators to redeposit the fine material in an even layer on top of the dredged ground.[44] The Briseis Company was the first in Victoria to use a conveyor to divert topsoil from processing and deposit it at the rear of the dredge over the coarse tailings.[45]

Bucket dredging was one of several alluvial mining technologies employed in the early 20th century. Mining techniques evolved in response to the nature of auriferous deposits, available finance, topography, and regulations imposed by authorities. Pumped hydraulic sluicing, for example, used a centrifugal pump, either stationary or mounted on a barge, to raise gravel and washdirt into sluice boxes from where it was delivered into embanked settling ponds which retained the gravel and sludge. Gravitational hydraulic sluicing used a jet of high-pressure water to excavate the working face of a claim and wash the deposit into sluice boxes, with the sludge released into the nearest waterway. Some hydraulic sluicing plants used jet elevators employing the venturi principle to raise, process and stack tailings, mostly in smaller waterways that larger plants could not reach.[46] Other less common operations in Victoria included rotary hydraulic plants at Beechworth and Maryborough.[47]

Bucket dredging in Victoria

It is uncertain when the first bucket dredge began operating in Australia although the potential profit to be made from the industry was well understood by the 1890s. Miners from New Zealand brought with them the relevant technical skills and experience to initiate bucket dredging, while J.B. Jaquet's 1898 report to the Department of Mines and Agriculture reviewed the industry in New Zealand and its potential for introduction to New South Wales.[48] In Victoria a Hydraulic Sluicing and Dredging Association was formed in 1899 to advance the interests of the industry.[49] In the same year dredging was established in New South Wales when the Turon River Gold Dredging Co. floated its No.1 plant using a 20-hp engine,[50] and by 1900 there

were 16 dredges operating in New South Wales.[51] In Victoria the Acting Secretary for Mines and Water Supply, Mr J. Travis reported in 1899 that bucket dredging had already produced 200 ounces of gold.[52] By 1900 there were at least six dredges operating in Victoria, including the Ovens and Buckland Gold Dredging Co. and the Goulburn River Proprietary Dredging Co..[53]

The industry developed quickly and was in full swing by 1905, when the Victorian Mines Department recorded 26 bucket dredges in operation that produced 28,485 ounces of gold for that year alone.[54] The peak years of operation were 1908 to 1913, when more than 50 bucket dredges were at work each year in Victoria and the average annual gold yield for the period was 56,874 ounces. By this stage the volume of material processed by dredges generally ranged between 5,000 and 13,000 cubic yards per week.[55] Bucket dredging declined from this point, as requirements for the First World War made materials and workmen harder to secure. By the mid-1920s the industry had withered to only a handful of dredges still operating.[56] Higher gold prices and more efficient technologies prompted a revival in the 1930s-50s when a smaller number of dredges were operated, though each of them was larger and more efficient than those previously operated. The last bucket dredge to operate in Victoria was a small plant on Porcupine Creek near Maldon (Fig. 2). It ceased production in 1984 and today remains *in situ* in its dredge pond.[57]

Figure 2: *Porcupine Flat bucket dredge*.

Source: Photo courtesy photo P. Davies.

At least 101 bucket dredge installations were recorded by the Mines Department as operating in Victoria between at some stage between 1900 and 1955. Figure 1 shows these were in two main regions: the Loddon River and its tributaries in central Victoria and along the Ovens and Buckland Rivers in the north-east. Smaller numbers of bucket dredges were also employed at several locations in Gippsland and in the Ballarat district. At least half of all bucket dredges in the state operated upstream from Myrtleford along the Ovens valley near its junction with the Buckland River.

The effect on rivers

The impact of bucket dredging on the environment differed in several important ways from that of other alluvial mining methods that preceded it. The earliest alluvial workings occurred along and in streams but thereafter mining methods generally focussed away from streams to locate on hill slopes and floodplains. In contrast, bucket dredging was focussed on rivers in partially confined situations where there were valley flats or floodplain pockets that could be easily isolated for inundation and had a good supply of water. Some bucket dredges in the early years of the industry worked directly in river channels. Rivers suffered both direct and indirect impacts:[58] at times the course of a river would be diverted around the area to be worked, and re-instituted in a straightened, channelized form, while both river bed and river bank could be excavated to considerable depths over tens or even hundreds of acres in extent.

Dredging also had considerable impact on the lower reaches of rivers, especially in the early years of the industry, by adding further to the already extensive problem of mining 'sludge' that filled streams and covered floodplains all over Victoria.[59] Over the decades since the beginning of the gold rush, sludge had been constantly discharged from mining areas. The silt, sand and gravel first filled in the deep waterholes in the riverbeds and then raised the beds themselves, often by several metres. Once the channels were choked, subsequent flooding pushed the sludge out over the floodplains and covered thousands of hectares of land. By the start of the twentieth century, as other branches of gold mining started to wane and the rivers slowly began to clear, dredging added a new load of sediment.

Protest and regulation

In the first few years of operating, bucket dredges were only minimally regulated. Leases in the early 1900s included covenants intended to reduce the release of tailings but these were of minimal effect, and dredges were permitted to work in river channels. A number of bucket dredges operated under the old miner's right system, based on the post-Eureka legislation of 1855. These were small cooperative groups working a maximum area of 5 acres and their registration conditions imposed no restrictions on the disposal of sludge or tailings.[60] Community outcry about the damage caused was rapid and widespread causing landowners and downstream councils to quickly organise lobby groups to protest against the destruction of farmland and rivers. By August 1901, landowners in Wangaratta were meeting to discuss legal

action to block dredging on the King River, and in the same month the Kiewa Valley Anti-Dredging League began writing to local councils seeking support for their campaign to keep dredging out of the Kiewa Valley.[61] Similar organisations followed along the Murray River at Corowa and the Loddon River in central Victoria. In Gippsland, the Mitchell River and River Lands Protection Association was formed to oppose sluicing and dredging in the district.[62] Politicians were besieged by delegations of farmers from all over the state, including the Loddon, Leigh and Tullaroop valleys, and the towns of Shepparton and Nagambie on the Goulburn and Elmore on the Campaspe.[63] A substantial delegation of downstream stakeholders from all over the north-east visited the Minister for Mines to express their concerns. It was led by MLAs from Wangaratta, Benalla and Corowa, and included representatives from several local councils, recreational fishing groups, and water supply trusts, and was widely reported in papers from Ballarat to Bairnsdale and Omeo.[64]

Having recently spent £8 million on water supply and irrigation that was now threatened with dredge pollution, Parliament was sympathetic and at last passed measures to control mining waste, first in the *Mines Act* (1904) and then the *Act to further amend the Mines Acts* (1907). This included the creation of the Victorian Sludge Abatement Board (SAB) in 1905, charged with monitoring the industry and imposing fines. The SAB introduced several measures aimed at both controlling the discharge of sediment into streams and remediating the sites that had been dredged.

By 1906 leases for bucket dredges in Victoria included a range of stronger environmental protections and operating provisions, although dredging in rivers continued. Operators had to build, use and maintain sludge paddocks, settling basins or precipitating tanks to impound sludge and filter the water before it was returned to the creek or river. They also had to maintain the bank of the watercourse at the height and alignment it had been prior to dredging. Discharge was not to contain more than 75 grains of poisonous matter per gallon or more than 800 grains per gallon of insoluble material such as clay. There were also restrictions on tree cutting and timber removal, covenants to maintain river crossings for people and stock, and regulations to ensure the dredge pond was of sufficient size to allow the effective settling of sediment held in suspension.[65] Dredge operators also had to remove logs from the river and stack gravel either side of the channel. The 1907 *Act to further amend the Mines Acts* strengthened the 1904 legislation to give greater protection to land and waterways 'against injurious mining operations' but did not prohibit dredges from operating within waterways.

Dredge operators were now also expected to actively remediate the ground they had worked. Topsoil had to be stripped in advance, stockpiled, and replaced when dredging was finished. The soil was to be redeposited on top of the dredged material and was to be re-seeded with approved grasses. This was a marked improvement on the previous approach in which the topsoil, excavated first, either washed away or ended up dumped at the bottom of the re-worked ground to be covered by the rocks and cobbles brought up from lower in the alluvial beds.[66] Initial efforts at re-soiling dredged areas had only mixed success, as the technique worked best in a good depth of soil and where a belt conveyor could distribute the soil on top of the dredged ground.

Part of the problem was that dredges were often working in heavily mined river flats where the original topsoil had been removed, leaving little to be stockpiled by the dredges.

Companies had to modify their dredges to meet re-soiling requirements and this also took time. The Briseis Company in north-east Victoria was the first to re-soil effectively,[67] their plant being equipped with a belt conveyor that allowed most of the surface soil overburden to be stripped in advance and re-deposited at the stern of the dredge without being processed on board. Several other dredges had some success when using loam shots to divert overburden for top spreading. By 1909, however, there were still nine bucket dredges working directly in the channel or bank of the Ovens River and its tributaries.[68] Revegetation efforts suggested that native grasses did better than exotics and experiments with fruit trees on remediated ground were promising.

Leases for bucket dredging were issued by the Mines Department on both Crown and freehold land. The Crown was, in effect, custodian of gold in the ground and charged 5 shillings per acre per year for Crown land to be dredged. On private land, however, dredge masters negotiated directly with owners and purchased the land outright before dredging commenced - typically paying up to £9 per acre, substantially in excess of the value for farming purposes.[69] If no private agreement could be reached for compensation, dredge masters negotiated with owners in the Warden's Court. Communities were now also able to limit the effects of dredging by preventing areas from being dredged at all. From 1909 leases being refused over land valued at more than £3 per acre, generally safeguarded agricultural land,[70] while it also proved possible to have whole stretches of river exempted from leasing. Community groups in north-eastern Victoria took advantage of the new powers of the SAB and successfully lobbied to have dredging kept out of the King valley and most of the Kiewa valley.[71]

Regulation and decline

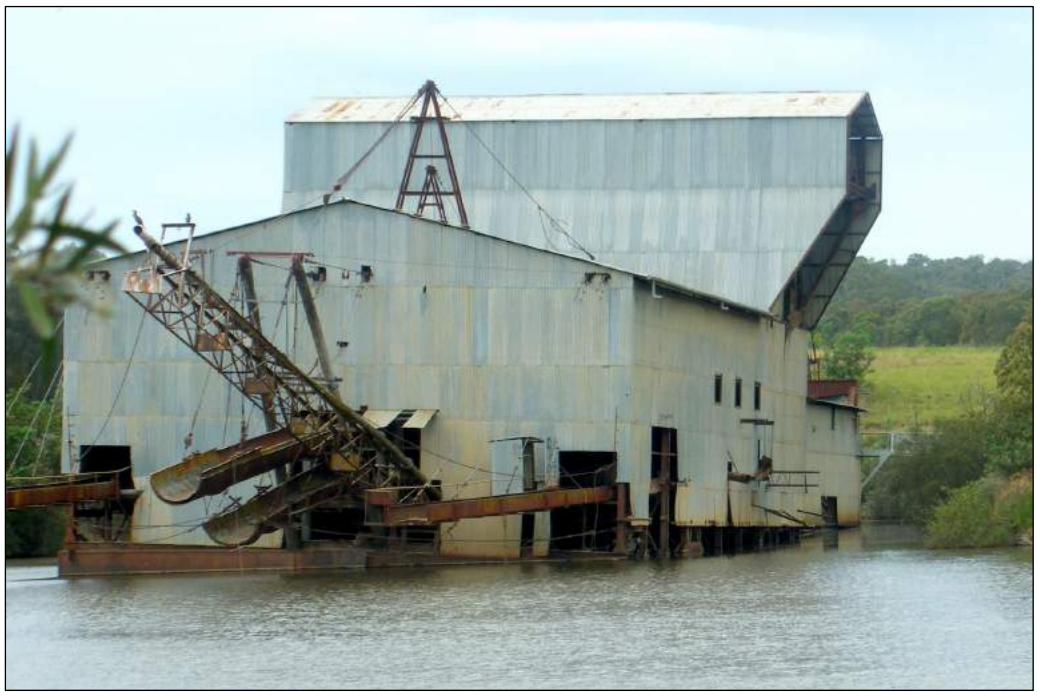
From the 1930s, dredge operators faced higher costs to build and maintain tailings ponds and carry out remediation. The Mines Department actively promoted the industry and was optimistic that bucket dredging would not only yield gold, dividends and employment but would transform otherwise useless land into good grazing and agricultural acres. Farmers, however, were not convinced, and the Ovens Valley community groups around Myrtleford successfully resisted a revival of dredging on the fertile river flats.[72] A brief review of the major dredges demonstrates, however, that despite more stringent environmental controls dredging was often still highly destructive and only marginally profitable.

The Cocks Eldorado Company (1935-54) was the largest dredge in Australia up to that time, processing 31 million cubic yards of alluvium for 61,266 ounces of gold between 1935 and 1954.[73] It operated along Reedy Creek between Beechworth and Wangaratta. The company constructed six sludge dams covering 70 acres for settling the slum and employed a gang of 26 men for conservation works and water settlement. The dredge was held in positive regard at the time as it worked land degraded by

earlier mining and produced £10,000 of gold to the acre.[74] Reviewing the industry in 1939, D.R. Dickinson of the Mines Department defended the dredge works at Eldorado that had left the land almost useless for agriculture, asserting that the remediated areas were 'in no worse condition than when taken over by the company' and that there was little scope or value in trying to resoil them. The land was already degraded by previous mining and it would have been uneconomic to fully rehabilitate the land to its pre-mining state because its subsequent value as farming land would have been less than the cost of rehabilitation.[75]

In the Loddon valley at Newstead, the Victoria Gold Dredging Company (1938-48) developed an operation from the late 1930s to meet strict conditions of the Mines Department and the State Rivers and Water Supply Commission. Its successor company, Central Victoria Dredging, transferred the dredge to nearby Amphitheatre and erected a smaller plant at Jim Crow Creek (Fig. 1). The combined yardage of the three operations was 33,081,021 cubic yards for a total gold yield of 174,494 ounces and represented one of the most sophisticated operations in the state in terms of rehabilitating dredged land.[76] Serious efforts to avoid environmental damage recognised the 'devastation' caused to streams and flats by earlier dredging operators.[77] As such, at the lease area at Newstead, which covered high quality farmland and affected numerous landholders, the company was required to strip and redeposit the overburden, and to control effluent discharged into the Loddon to no more than 50 grains of sediment per gallon. The dredge alternated between stripping the topsoil and dredging the underlying seams of auriferous gravel. Coarse gravels were discharged over the stern of the dredge to rest on the bottom, with the sandy wash deposited above.

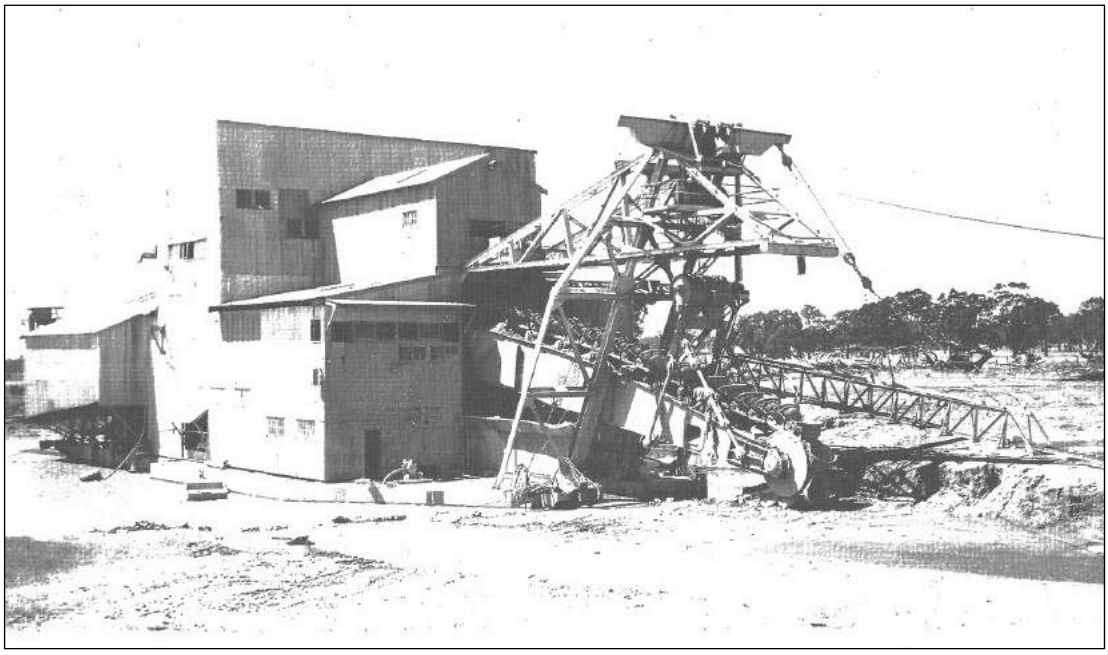
Figure 3: *Cocks Eldorado dredge*.



Source: Photo courtesy S. Lawrence.

The soil and clay overburden were redeposited on top of the ground by belt conveyor to form the new surface. After consolidation and settling, the land was levelled with plough and bulldozers and resown with grasses. Control of effluent was achieved in several ways: first, the company built a large slum dam on a terrace above flood level into which used water from the dredged area was pumped; and after settling, the water was returned to the dredge pond. A long levee bank was also constructed to provide a floodway for the Loddon and to prevent flooding of the dredged ground. A new river channel, 1 mile long, was also excavated to divert the Loddon from its course to permit dredging of the original bed and banks without polluting the river with sludge.[78] The new channel, 80 feet wide and 15 feet deep, remains the primary course of the Loddon today.

Figure 4: *Newstead dredge operated by the Victoria Gold Dredging Company*



Source: Photo courtesy R. Southern.

The Tronoh dredge at Harrietville (1942-54) was one of the largest and last bucket dredges to operate in Victoria. The company leased 880 acres along the Ovens River, paying landowners an average of £20 per acre and issuing them shares in the company. The dredge was constructed by Thompsons Engineering and Pipe Company of Castlemaine and weighed almost 5,000 tonnes, with pontoons 290 feet long and an overall length of 550 feet. The bucket ladder supported 122 buckets, each of 20 cubic feet capacity and could reach a depth of 130 feet. Power to drive all the pumps and motors came via a State Electricity Commission line from Bright, and a high voltage cable delivered power on board.[79] By the time it ceased operating in May 1954 the dredge had worked about 156 acres and processed more than 19 million cubic yards of material for 53,814 ounces of gold. Despite its scale and sophistication, however, the Tronoh dredge barely covered the cost of operation, with gold yields never meeting the initial test results.[80] The problem was that the dredge was too large and too expensive to mine the available land profitably, so it was subsequently dismantled and shipped to

Malaya to work tin deposits. The Mines Department insisted that all the defunct dredging companies along the Ovens were obliged to complete remediation of their workings, including levelling, resoiling and replanting dredged ground. In the case of the Tronoh Company, however, only a small portion of tailings at the southern end of the lease were levelled and replanted.[81]

The implementation of environmental controls described above made dredging more expensive. The Newstead dredge worked gold deposits that were viable for two decades despite the added costs of re-soiling and channel diversion and became the industry showpiece as a result. At Harrietville the gold deposit was less valuable and the Tronoh dredge ceased operations after only a few years, not fulfilling its obligations to remediate the site and leaving the kind of devastated landscape characteristic of abandoned mines throughout Australia.[82] Once the environmental cost was more fully transferred to industry, dredging lost its appeal.

Conclusion

The number of rivers affected by dredging is much smaller than the hundreds, if not thousands, of small creeks and gullies sluiced in the nineteenth century. Nevertheless, the continuing effect on those dredged rivers is profound. This is demonstrated most clearly in the Ovens River in north-east Victoria, one of the most intensively dredged waterways in Australia, and the site of numerous environmental battles. Recent geomorphological analysis of the channel form, bank fabric and floodplain condition of the Ovens has demonstrated that it is still responding to the disturbance of dredging and the process of recovery is ongoing.[83] The river has become less sinuous due to the increase of sediment caused by dredging, and in places has been artificially straightened. The channel boundary remains prone to erosion, thus supplying more sediment to downstream reaches. Piles of tailings remain in places even a century after dredging, leaving the floodplain surface still very uneven. However, dredged areas also show a layer of fine material above tailings, which derives from floodplain inundation after dredging ceased, providing evidence for some recovery of the waterway. Centuries more of flooding will be needed to fully restore the soil that has been lost.

At a time when gold mining was in decline, bucket dredging offered a welcome revival by creating both local employment, and profits to dredge operators. The early development of the industry represented a classic speculative boom that mirrored the earlier boom in dredging that had swept through New Zealand several years before, with the process generating a rush of undercapitalised and ill-considered enterprises that swamped regulatory authorities and created anxiety in local communities. Dredges appeared rapidly in numerous goldfields regions and particularly in the north-east of Victoria, but because the industry concentrated on river valleys, it was a direct threat to agriculture and water supply. As observers began to realise the extent of the damage to water quality and farmland they rallied support to impose greater regulation. Some dredging companies made a virtue of their remediation efforts, while others continued to evade their new environmental responsibilities. Ultimately the gold yields were comparatively small but the legacies of bucket dredging have been substantial. The

rivers damaged by the industry will never be the same again but it has also left legislation that continues to inform the regulation of mine waste in Australia.

Endnotes

[1] 'The Desolating Dredges. Alleged Ruinous Effects in the Ovens Valley', *The Age*, 21 January 1909, p. 6c; 'The Desolating Dredge', *The Age*, 18 June 1912, p. 10e.

[2] Jan Wegner, 'Sludge on Tap: Queensland's First Water Pollution Legislation, 1944-1985', *Environment and History*, vol. 15, 2009, pp. 199-216.

[3] Edward Edwards, 'Notes on Tin Sluicing in Tasmania', *Transactions of the Australasian Institute of Mining Engineers*, vol. 15, 1911, pp. 267-300.

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