The missing volume: how much sediment did historical gold mining release into Victorian rivers?

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Key Points

- Coarse and fine sediment has been a major pollutant of Australian rivers and receiving waters since European settlement
- Between 1851 and 1900 alluvial gold mining in Victoria liberated between 1.2 billion and 1.4 billion m^3 of coarse and fine sediment into streams.
- This amount certainly substantially exceeds the post-European erosion rate from hillslopes, river banks, and gullies (estimated at around 300 million m^3 for the catchments affected by gold mining).
- The gold mining sediments are (a) missing from national sediment budget estimates; (b) are now stored on floodplains, and in stream channels, but are largely forgotten.
- The response of streams to gold mining sediment tells us a great deal about the resilience of streams, and their trajectory of recovery.

Keywords

Gold mining, sediment yield, gullying, Sednet, recovery, Victoria.

Introduction

Sediment (both coarse and fine) has been identified as one of the most serious pollutants of rivers, and threatens assets in many receiving waters, such as the Great Barrier Reef (Prosser et al. 2001a; Fabricius, 2005). The arrival of Europeans in Australia saw a dramatic increase in catchment and stream erosion rates (Rutherfurd, 1999). The result was an estimated 4-5 times increase in turbidity and sediment loads of streams and rivers. The last 20 years has seen good progress in identifying the major sources and sinks of sediment since European settlement, at continental scale, using catchment models such as *Sednet* (Prosser et al. 2001b). Such models estimate historical erosion rates from hillslopes, and from instream sources such as gullying and bank erosion, and then estimate delivery ratios at the end of catchment, providing a total sediment supply averaged over more than a century. There has been considerable progress made in improving the relative contribution of sediment from slopes and channels, but these models do not account for historical sources of sediment supplied from past landuses. Most important of these missing sources, in Victoria at least, is historical gold mining. In this paper we use historical records to reconstruct the volume of sediment (sludge) delivered directly to Victorian streams by gold mining between 1851 and 1900. 'Sludge' was the colloquial term used in the nineteenth century for the waterborne waste products of gold mining. Sludge was produced by all branches of gold mining because all mining techniques relied heavily on water in processing wash-dirt and ores, and all used water to carry away the unwanted sand, gravel and clay. Although there are many stories to tell about the impacts, and contaminants carried in this sediment, we confine ourselves here to the volume and distribution of this sediment.

Historical gold mining in Victoria

Gold mining took place in 22 of the 29 major catchments in Victoria (Figure 1). However, mining was most intensive in streams flowing north into the Murray system: the Upper Murray, Mitta Mitta, Ovens, Goulburn, Loddon and Avoca systems. In the south alluvial mining was most intensive in the Mitchell, Thomson, Yarra, and Barwon catchments. Mining in these streams tended to move through distinctive phases as new technologies were developed.

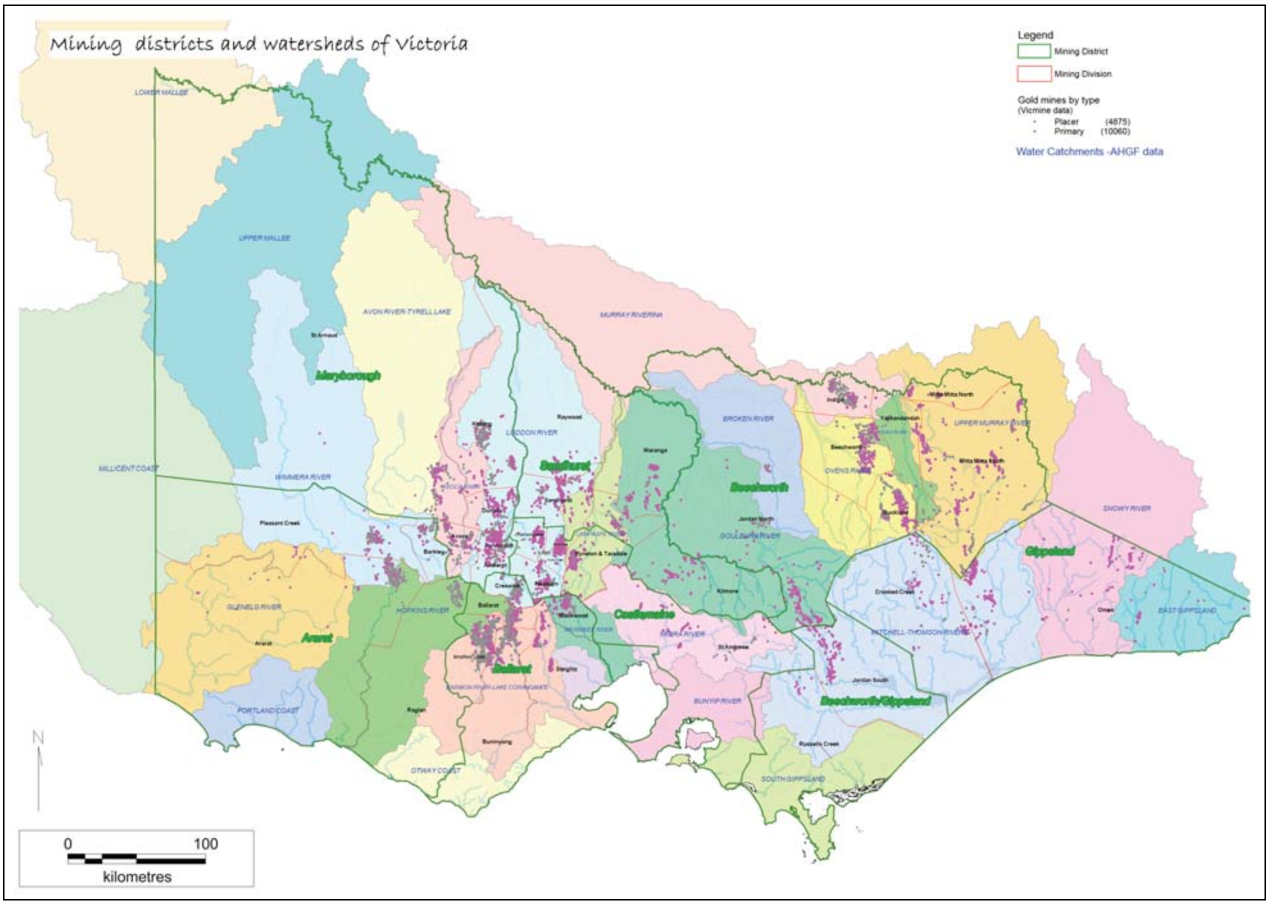

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Figure 1: Major mining areas (pink dots are alluvial deposits, grey dots are placer deposits) and river catchments.

There is abundant evidence that alluvial gold mining liberated large volumes of sediment into Victorian streams, and this evidence is described in Lawrence and Davies (2014). Enquiries into sludge began with a Royal Commission in 1859 and a Select Committee in 1861 to investigate removing sludge from Bendigo, an 1887 inquiry into sludge issues in the colony as a whole, and a final inquiry in 1914. Sludge was a major topic of public debate across Victoria throughout the colonial period. The Bendigo Advertiser carried over 4,000 sludge-related stories between 1855 and 1901. In the north-eastern mining district the major source of damage was sludge from sluicing and dredging. Near Wangaratta, shire councillors estimated in 1875 that 40 km^2 of agricultural land had been inundated by sludge from the sluices upstream at Beechworth. In Melbourne in 1876 the Legislative Assembly heard that hydraulic sluicing at Warrandyte sent sludge into the Yarra River, which silted up Port Phillip Bay and caused problems for shipping. Davis et al. (1997) examined sedimentation in reservoirs in Victoria and found high sediment yields caused by in-stream gold mining. Mining sludge covers 700 km^2 of farmland downstream of Bendigo (Peterson 1996).

Methods

We have not included data from the following mining methods: paddocking, sub-basaltic deep-lead mining, and post-1891 bucket dredging, jet elevator sluicing and hydraulic pump sluicing. Our focus here is thus on placer mining (i.e. direct washing of alluvium) through the 19th century, when the wash-dirt was generally discharged after processing into the nearest waterway. Sediment was excavated and processed by a variety of means, including pans and cradles, puddlers, sluice boxes, compound (quicksilver) cradles, ground sluicing and hydraulic sluicing. We have used the remarkably detailed historical data published by the Office/Department of Mines through the 19th Century, and related sources, to quantify the number of alluvial mining machines on the goldfields each year from 1851 to 1890. We then estimate the amount of washdirt processed by miners using each alluvial mining technique based on contemporary historical sources, including the annual series *Mineral Statistics of Victoria*, and *Robert Brough Smyth's Gold Fields and Mineral Districts of Victoria* (1980), originally published in 1869. From 1855 to 1861 we assume two-thirds of the gold yields recorded were produced by alluvial methods. We also estimate the amount of alluvium released by quartz mining.

Puddler:

A puddling machine or mill consisted of a ring-shaped trough in the ground up to 6 m or more in diameter that was filled with clay and water. A horse dragged a set of harrows or rakes suspended from a cross-beam fixed to a central post to mix the clay and water and loosen the gold. As the contents broke down to a slurry or sludge a valve was opened to release the mix as waste and the heavier gold was recovered from the bottom of the trough. Puddling mills or machines were commonly used in drier areas, with 2000 reported in use at Bendigo as early as 1854 (Davey 1996:53). The peak use of puddlers was in the late 1850s when more than 5000 were in use (Smyth 1980:517). The 1859 *Royal Commission into the Sludge Question* reported that puddlers processed **10 cubic yards per day**, and each puddler on average worked 200 days during the year (about seven months), thus producing 2,000 cubic yards of sediment per puddling mill (including quicksilver cradles) per year.

Sluice boxes and ground sluicing

Ground sluicing was the main method of working elevated ground on the slopes above watercourses, mostly after the 1860s. It involved running a stream of water through a channel in the ground or over a bank into a creek or gully to loosen the overburden and wash-dirt, which was directed into a sluice box or tail-race to retrieve the gold. Sluice boxes and long-toms were simple wooden boxes with riffles at the bottom to catch the gold as it was washed through. Sluice boxes were typically 12 feet in length (3.6 m). Two or three men could wash 20 to 50 cubic yards *each* per day in a ground sluice. In shovelling wash-dirt up into a sluice box, 24 cubic yards per day for a typical crew of four men was regarded as 'a good day's work' (Smyth 1980:131-2), while up to 150 cubic yards in a short winter day was 'not uncommon'. Using a conservative rate **10 cubic yards per sluice per day**, operating for 200 days per year (about seven working months), each sluice could process about 2000 cubic yards per year. This is a conservative estimate and in 1860, for example, a group of four miners at Hurdle Flat near Beechworth washed 'a ton of dirt every five minutes' in a ground sluice, roughly equivalent to 120 yards in a 10-hour day (Board of Science 186;15).

Hydraulic sluicing

Hydraulic sluicing was introduced to Victoria from California in the late 1850s. The technique used canvas hoses (later steel pipes) to deliver water under pressure to mining claims, where it was aimed from a nozzle or monitor to blast away at auriferous gravels that washed into a tail race to recover the gold (Figure 2). Wright reported in 1868 that from 50 to over 100 cubic yards per day could be removed by hydraulic sluicing or 'gravitation' (Smyth 1980:131). Much larger daily quantities, however, were commonly reported in later years, and Beechworth miners often sluiced for eight or nine months of the year, while those in the Mitta Mitta valley could sluice all year round. For example, a hydraulic sluicing claim on Brandy Creek in the watershed of the Mitta Mitta River could wash 2000 cubic yards per day from a face of 18 m to 30 m (Board of Inquiry 1887:xxvi). So we have estimated that each sluice could move of **500 cubic yards per day**, operating for 200 days per year, or 100,000 cubic yards per year.

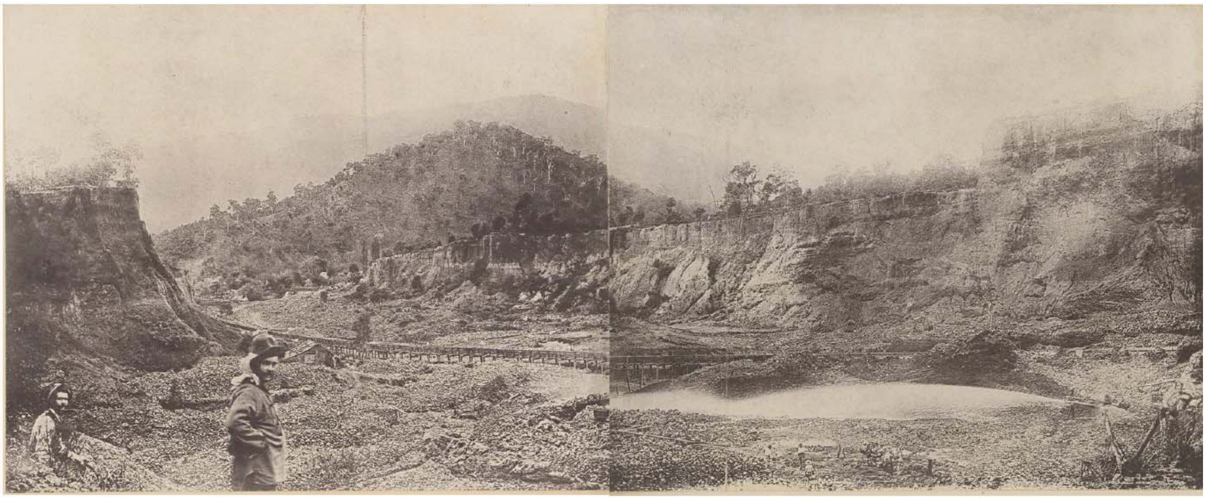

Figure 2: Hydraulic sluicing at the Percival Cochrane Pioneer Mine (Mitta Mitta Catchment) in the 1870s (State Library of Victoria Photograph Collection).

Results

The total volume of alluvial wash-dirt removed by miners in the period from 1854 to 1891 for which we have reliable and detailed historical evidence is 1,061,600,000 cubic yards or 811,646,000 cubic metres. Simple panning and cradling in the first few years of the gold rush in the 1850s likely produced another 20 million+ cubic yards, along with ground and box sluicing that was poorly recorded in the 1850s and 1860s. In addition, quartz crushing and deep lead mining was responsible for several hundred million cubic yards of waste material in the 19th century. Alluvial production during the 1890s can be extrapolated conservatively from the 1880s, giving an additional 300 million cubic yards of alluvium. A likely historical range for the period 1851 to 1900 is thus between 1.6 billion and 1.8 billion cubic yards (1.21 billion – 1.4 billion m^3).

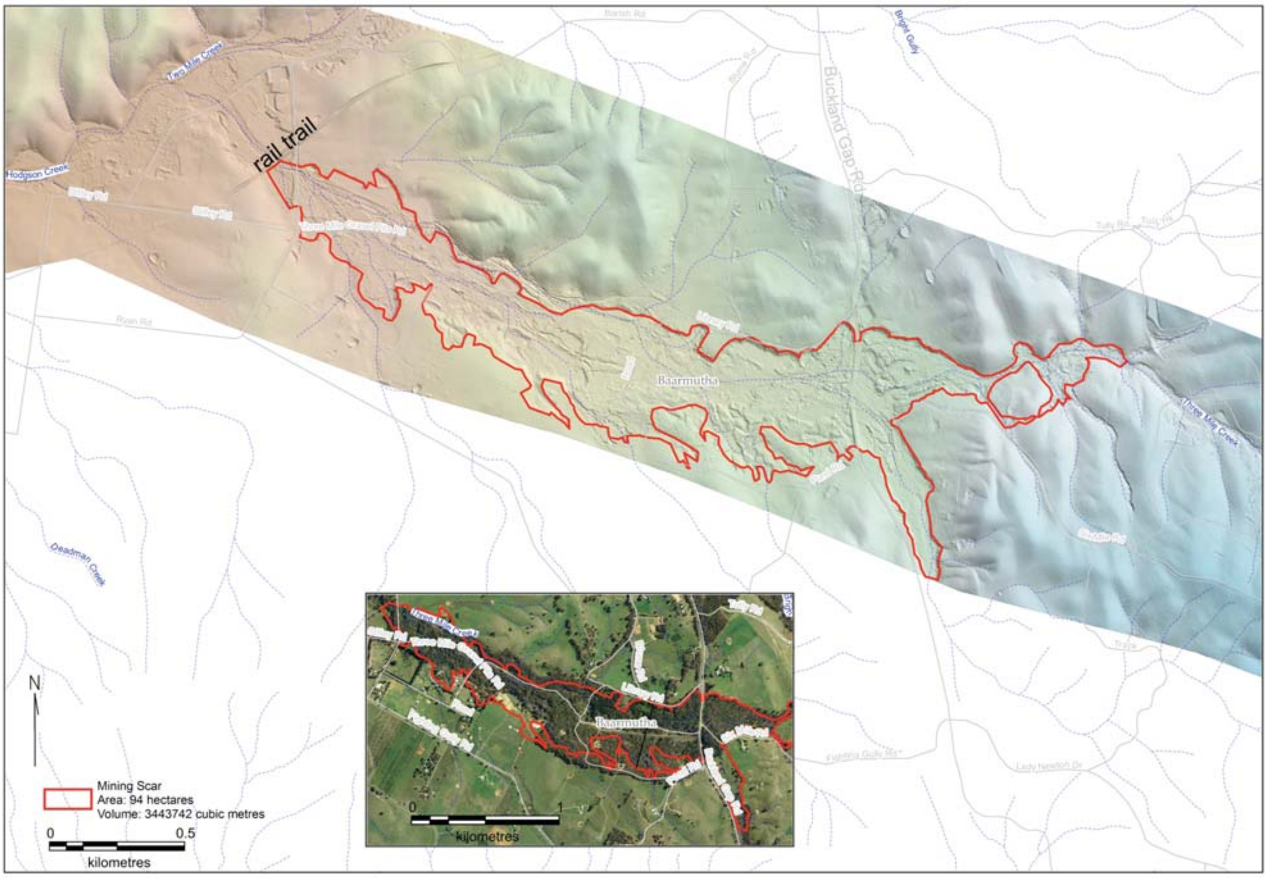

Figure 3: A LIDAR image of the Baarmutha mining area in the Beechworth mining District (5 km south of Beechworth). This is an example of an area sluiced for alluvial gold over an area of 94 ha, to an average depth of 4 m.

The number of sluice boxes recorded on the goldfields increased dramatically from 6202 in 1866 to 19,592 in 1867, which accounts for the spike in alluvium shifted in the late 1860s. The increase relates to the greater availability of water following the 1865-66 drought and possibly a change in recording practice by mining surveyors and registrars. It also reflects, however, the increase in water right licences taken up under the Mining Statute 1865. The legislation created greater certainty for miners to invest in water supply infrastructure, providing 15-year licences for water races. By 1870 more than 300 water-right licences had been taken out in Victoria, which enabled the supply of many millions of gallons of water each day to large numbers of alluvial miners (Dicker 1861-1869). By 1884 there were at least 129 water-right licences still in force, permitting up to 275 million gallons (1238 ML) to be diverted from creeks and rivers on the goldfields every day (Office of Mines 1885:54-5; 1888:67-8).

Hydraulic sluicing with hoses and nozzles represents only a small amount of wash-dirt removed from the period 1854-1891, around 7.9% of the Victorian total. Puddlers represent a larger proportion of wash-dirt from the same period, around 13.5% of the total, with compound cradles another 0.7%. Ground sluicing and sluice boxes account for the great majority of wash-dirt in the period 1854-1891, around 77.8%. Between 1867 and 1891 there were never less than 10,000 sluice boxes recorded in use on the Victorian goldfields, with an annual average of more than 15,000. Our total does not include wash-dirt from panning and cradles or mining waste from quartz crushing and deep lead mining, which probably amounted to several hundred million cubic yards. From 1900, large scale alluvial mining techniques included bucket dredging and jet elevator sluicing but we have excluded these from our calculations.

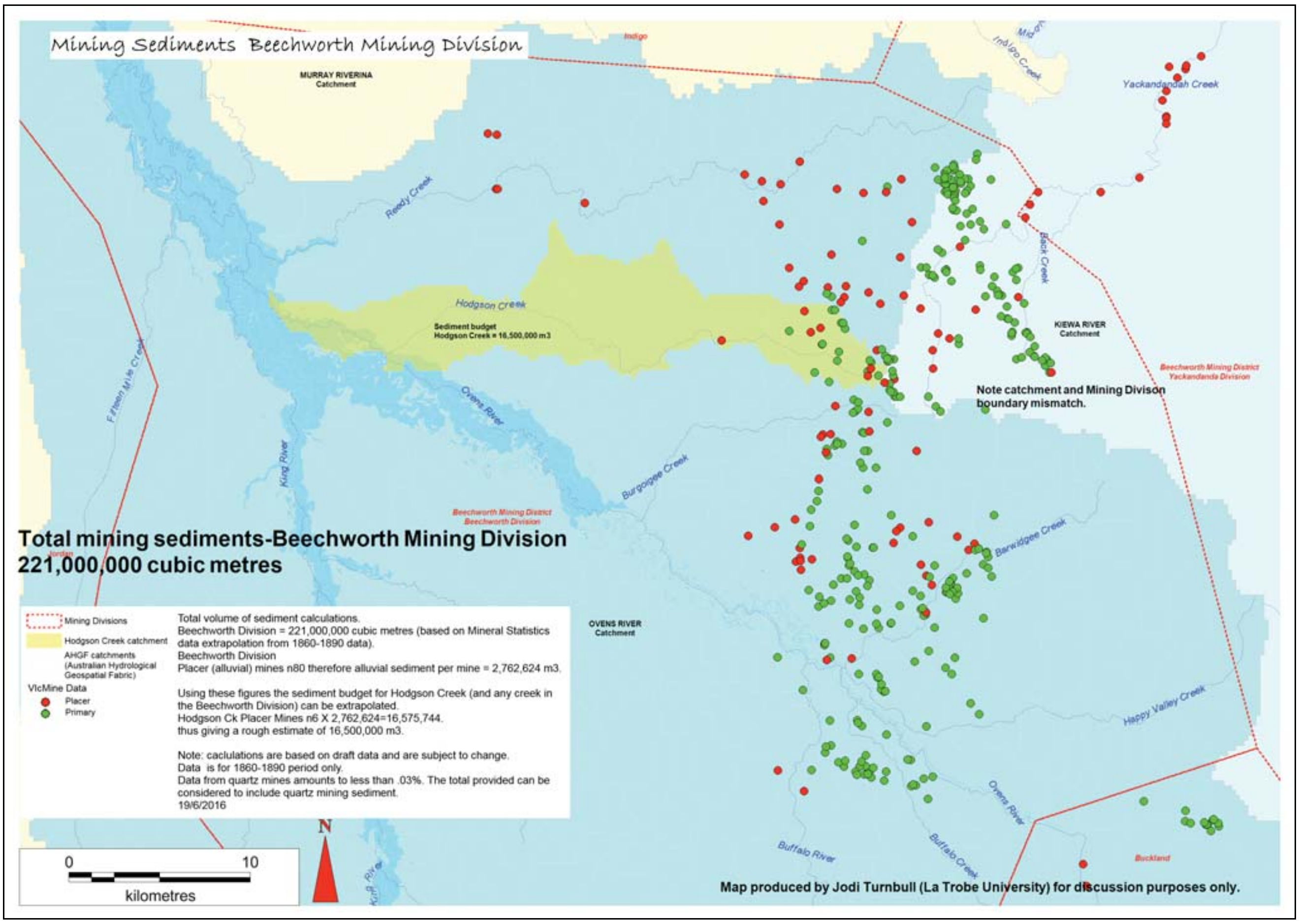

Figure 4: An example of the distribution of mines, and the sediment yield from those mines, in one Mining Division (Beechworth) in NE Victoria.

In order to check the order of magnitude of these figures, we can consider a separate source of information. Quartz mines extracted rock from tunnels, and crushed it in batteries, and flushed the excess sediment into mullock-heaps and waterways. The 1887 Sludge Enquiry estimated that the average quartz mine crushed no more than 4000 tons annually. There were 10,060 quartz mines in Victoria between 1860 and 1960, with an average life-expectancy of five years. Just one year of quartz crushings would produce 40 million tonnes of crushings across Victoria, and over five years, 200 million tonnes. Quartz mines contributed a small proportion of sediment compared to alluvial placer mines.

Table 1: Estimated sediment liberated by crushing in Victorian quartz mines for one year, assuming that 4000 tonnes of ore is crushed and washed away each year.

River Catchments	Total Quartz mines 1860-1960	Estimate of sediment yield from all mines assuming 4,000 t/a
Avoca River	239	956,000
Avon River-Tyrell Lake	28	112,000
Barwon River-Lake Corangamite	2026	8,104,000
Broken River	15	60,000
Campaspe River	522	2,088,000
East Gippsland	40	160,000
Glenelg River	13	5,2000

Goulburn River	539	2,156,000
Hopkins River	196	784,000
Kiewa River	112	448,000
Loddon River	3590	14,360,000
Mitchell-Thomson Rivers	772	3,088,000
Murray Riverina	168	672,000
Ovens River	491	1,964,000
Snowy River	78	312,000
Upper Murray River	572	2,288,000
Werribee River	233	932,000
Wimmera River	344	1,376,000
Yarra River	82	328,000
Grand Total	**10060**	**40,240,000**

Comparison with other anthropogenic erosion sources

The most comprehensive estimate of sediment supplied by water erosion in Victoria is provided by the National Land and Water Resources Audit (2001). Based on the Sednet model, the audit estimates the sediment eroded from hillslopes, river channel banks, and gullies both pre- and post-European settlement. If we take the erosion estimates for the major catchments affected by gold mining (Table 2) the Sednet model estimates a total annual sediment supply to these rivers of about 4.4 million tonnes. If we assume that this yield has continued for 150 years, then that is a bit over 666 million tonnes. Assuming a sediment density of 1.5, this represents about 444 million cubic metres of sediment. This is roughly one third of the minimum 1.2 billion m^3 of sediment estimated to have been released by alluvial gold mining in these catchments. Even if we take all of the estimated erosion from all rivers and catchments in Victoria (1.05 billion m^3) it is still smaller than the minimum estimated figure for alluvial mining erosion. Note also that the Sednet model suggests that the post-European erosion rate (without gold mining) was between 5 and 100 times (average of 30 times) the pre-European erosion rate.

Table 2: Estimated sediment supply from catchment and channel erosion in the major gold mining catchments (estimated by the Sednet model) (NLWRA, 2001, Appendix 1, River Basin Budgets)

Basin number	River Name	Sediment supplied to rivers (t/yr)	Sediment supplied to rivers (total over 150 years)	Ratio European/Pre Euro sediment load
403	Ovens	422,132	63,319,800	24
405	Goulburn	968,068	145,210,200	11
406	Campaspe	443,827	66,574,050	23
407	Loddon	875,014	131,252,100	44
408	Avoca	478,643	71,796,450	40
401	Upper Murray	767,000	115,050,000	8

224	Mitchell	114,800	17,220,000	108
225	Thomson	123,400	18,510,000	5
229	Yarra	133,700	20,055,000	7
233	Barwon	114,200	17,130,000	35
TOTAL	**SUPPLY (t)**	**4,440,784**	**666,117,000**	**Average 30.5**
TOTAL	**SUPPLY (m^3)**	**2,337,255**	**350,588,000**	

Discussion

The mining methods used throughout Victoria through the nineteenth century were extremely effective at delivering sediment directly into streams. Both the Sednet erosion estimates, and the historical gold mining estimates could be in error by as much as 20%. Nevertheless, it is difficult to avoid the conclusion that historical gold mining contributed at least as much sediment to rivers and streams as accelerated erosion from agriculture and post-European erosion of streams and gullies. This volume of sediment (and its associated nutrients) has not been included in estimates of post-European sediment budgets. Alluvial gold mining was wide-spread throughout Australia in the 19th century, and other areas in NSW, Queensland, and South Australia could also be expected to have had high historical sediment yields from this source. In addition, gold miners removed trees from a large proportion of the state for fire-wood, pit props and for other purposes. This removal would also have increased the sediment yield from hillslopes during this time. Many of these areas have since reforested.

We know from contemporary descriptions that gold mining sediment transformed whole landscapes, and certainly degraded rivers. There are abundant contemporary descriptions of floodplains covered by metres of silt, and river channels filled with sand. However, it is also interesting how the impact of mining has been forgotten, is no longer recognized, or in fact, rivers might have recovered to some extent from this massive insult. The long-term impacts (or otherwise) of historical gold mining have important lessons for contemporary stream management.

Conclusions

Using historical records we estimate the volume of sediment delivered to Victorian streams by alluvial gold mining methods is between 1.2 and 1.4 billion m^3 between 1851 and 1900. This is a provisional estimate, but it is probably a minimum estimate as it excludes several major mining methods. This volume is comparable to (and probably exceeds) modelled estimates of all of the sediment eroded from hillslopes, rivers, and gullies since European settlement in Victoria (about 1 billion m^3). The historical gold mining sediments have not been included in estimates of anthropogenic sediment used for national catchment management. Much of this historical sediment is now stored in floodplains, and as slugs of coarse sediment in stream beds. Understanding these historical sources allows us to explore how our streams respond, and potentially, recover, from human disturbance.

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