SUSTAINABLE SAND AND GRAVEL EXTRACTION

The Development of a Management Plan for the Goulburn River, Victoria

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ABSTRACT: Deposits of sand and gravel within the streams of the Mid Goulburn River catchment represent a major natural resource. Extraction of this material contributes significantly to the local economy. In certain circumstances, extraction can be beneficial to the streams, however excessive or inappropriate extraction can lead to environmental and stream management problems. The North Central Waterways Management Board identified the need to develop a better understanding of the available sediment yield of the system and of the rate of resource replenishment and to produce guidelines for the management of extraction. This paper presents the results of these investigations.

1. INTRODUCTION

Sand and gravel extraction has occurred from a number of sites, over many years, throughout the 172 kilometres of the Mid-Goulburn River, Victoria between Eildon Pondage and Lake Nagambie (Figure 1). Sand and gravel are valuable economic resources but over extraction often causes many detrimental environmental impacts (Erskine, 1995).

A geomorphic investigation of the Goulburn River Basin by Erskine et al. (1993) identified extraction as a major management issue and called for a moratorium on removal of material from the Goulburn River and tributaries while further investigations proceeded. Sediment input from the upper Goulburn River catchment is limited. Erskine et al. (1993) estimated that Eildon Dam traps about 99% of the inflowing sediment load whilst regulating downstream flows to such a degree that bed load transport rarely occurs. The only minor natural replenishment of sand and gravel is by localised bed load transport, usually induced by the mining itself (Erskine et al., 1993).

Mining contributed significantly to the local economy and in some cases has been undertaken to achieve waterway diversity to meet stream management objectives (Ian Drummond and Associates, 1994). However over extraction can lead to adverse impact on the river system.

Sand and gravel extraction operations need to be undertaken at a level which is within the capacity of a river to withstand and still maintain relative stability of its geomorphic and ecological characteristics (NSW Department of Water Resources, 1992). This is only possible if the rate of extraction is less than the rate of replenishment by bedload transport (Erskine at al., 1985; Collins and Dunne, 1990). Bed degradation or erosion occurs when extraction exceeds replenishment rates causing undermining of public assets, altered bed morphology and bedforms which form important habitat; lower floodplain water tables; reduced frequency of overbank flow and wetland inundation; changed bed material size composition; bank collapse; destruction of aquatic and riparian vegetation; increased bar mobility; and greater frequency of substrate mobility (Erskine et al., 1985; Collins and Dunne, 1990).

2. DATA REQUIREMENTS FOR A MANAGEMENT PLAN

To develop a management plan based on sustainable use the following data requirements were proposed:

i) the location and rates of extraction of existing and proposed extractions;

ii) the location and extent of in-channel sand and gravel deposits;

iii) the nature and frequency of mobility of the bed material;

iv) sediment transport rates and sediment yields; and

v) extraction - induced channel changes over recent years.

The North Central Waterways Management Board and the Department of Conservation and Natural Resources commissioned the authors to undertake the necessary investigations to provide the above information. The nature of these investigations and their results are briefly outlined below.

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

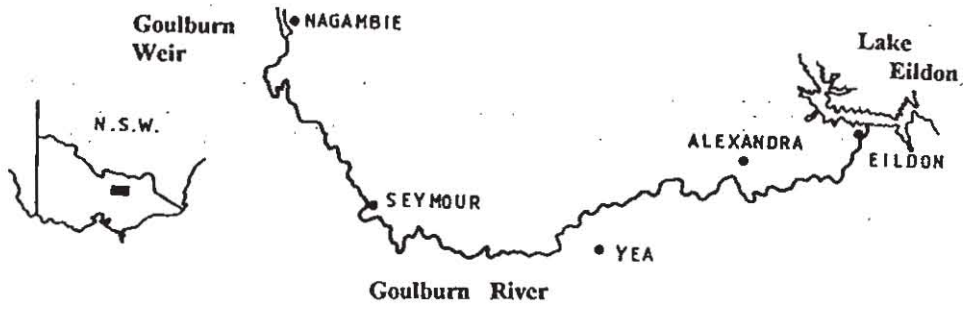

Figure 1 - Index Locality Plan and Study Area.

2.1 Rates of Extraction

While extraction has occurred at many sites on the Mid-Goulburn River for a long period of time, records are incomplete. Since 1982 an estimated 200,000m^3 (14,000 m^3/yr) have been extracted from the study area. While most operators remove relatively small amounts (<1000m^3/yr), 183,486m^3 was extracted at Seymour between 1982 and 1993. Another 10,000m^3 were extracted from one bend for the Hume Freeway construction at Seymour.

2.2 Sand and Gravel Deposits

Low level vertical air photographs were flown of the Mid-Goulburn River between Eildon Pondage and Lake Nagambie during winter low flows to determine the location and extent of in-channel sand and gravel deposits. Field inspections were also undertaken to confirm aerial photograph interpretation. There are presently no deposits within the study area where removal would result in a stream management benefit. Monitoring has been recommended to determine whether there is any future change in this condition.

2.3 Nature and Frequency of Mobility of the Bed Material

Investigations of the bed material of the Mid-Goulburn River were undertaken at Thornton, Breakaway Road, Molesworth, Trawool, Seymour and Hume Freeway (Figure 2) for the following purposes:

i) to determine whether the bed is armoured;

ii) to quantify the difference in grain size characteristics between the armour layer and substrate;

iii) to determine the frequency of mobilisation of the armour layer; and

iv) to compare the grain size characteristics of the armour layer at extracted and non-extracted sites.

An amour layer is a layer of gravel on the river bed surface that is usually one grain diameter thick and is both coarser and better sorted that the underlying substrate (Gomez, 1984; Erskine, 1992). It may be mobile or immobile under the current hydrologic regime (Erskine et al., 1985).

Armour layers are important for preventing excessive bed scour and thereby stabilising the channel and reducing sediment transport (Lagasse et al., 1980). When armour layers are extracted, bed degradation and sediment transport are initiated and continue until a partial armour layer reforms (Lagasse et al., 1980; Erskine et al., 1985).

The result of the bed material sampling are shown in Table 1. The grain size characteristics of the armour layer and the underlying substrate are significantly different, indicating that they are distinct sediment populations. The mean size (mm) of the armour layer ranges between 2.29 and 9.48 times greater than the substrate. Hean and Nanson (1987) reported similar but slightly smaller ratios on NSW rivers.

The Mid-Goulburn River is presently discontinuously armoured. A gravel armour layer is usually present on riffles and bars. Pool sediments were not sampled. Erskine et al. (1993) found that the Mid-Goulburn River exhibits nine alternating reaches of straight and meandering channels. Armouring is best developed in the meandering reaches where there are many point bars. Armouring is an important process which is currently contributing to the stability of the Mid-Goulburn River.

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SITE	SEDIMENT TYPE	GRAPHIC MEAN SIZE[1] (ϕ)	INCLUSIVE GRAPHIC STANDARD[1] DEVIATION (ϕ)	INCLUSIVE GRAPHIC SKEWNESS[1]
Eildon (1)	Bedload	0.45	0.73	-0.63
Thornton (2)	Armour Layer	-5.47	0.80	0.15
	Substrate	-3.19	2.29	0.33
Breakaway Road (3)	Armour Layer	-5.45 to -5.65	0.66 to 0.78	0.14 to 0.40
	Substrate	-3.45	2.40	0.32
	Riffle Tail	2.23	0.66	-0.05
Molesworth (4)	Bed Material	1.25	0.59	0.22
Trawool (5)	Armour Layer	-4.47 to -5.37	0.43 to 0.79	0.34 to -0.05
	Substrate	-2.53 to -3.29	1.99 to 2.45	0.28 to 0.47
	Lee-Side Shadow Deposit	-1.37	2.55	-0.68
	Bedload	1.30	1.85	-0.42
Seymour Gauging Station (6)	Armour Layer	-6.80 to -6.83	0.79 to 0.83	0.04 to 0.15
	Extraction Platform	-4.72	1.01	-0.16
	Lee-Side Shadow Deposit	-2.25 to -3.10	0.98 to 1.52	0.36 to -0.02
Seymour Hume Freeway Bridge (7)	Armour Layer	-4.63 to -4.72	0.58 to 0.59	0.08 to 0.14
	Substrate	-2.45 to -3.44	1.44 to 1.97	0.28 to 0.56
	Bar Tail	-2.83	1.99	0.66

Table 1 Grain size statistics for the various sediment types at each sample site on the Mid-Goulburn River. For location of sample sites, see Figure 2.

[1] - After Folk and Ward (1957)

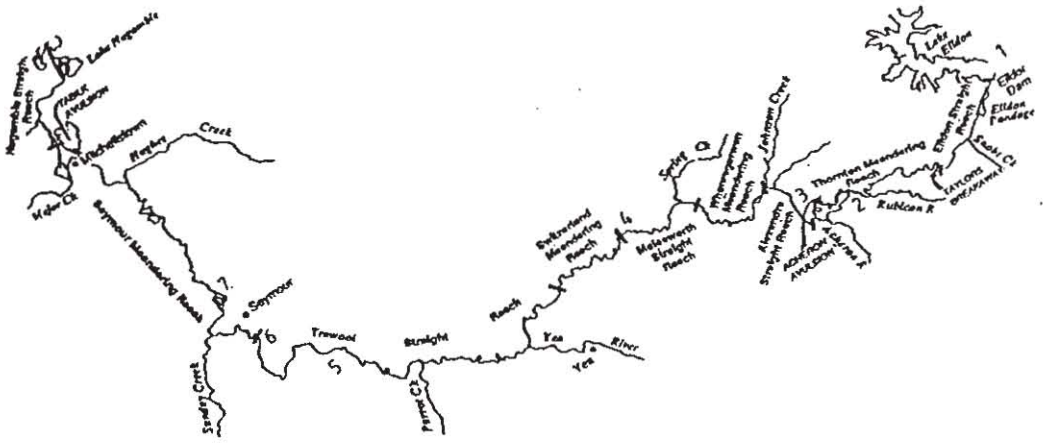

Figure 2 - Index Locality Plan of Gauging Stations.

The frequency of mobilisation of the armour layer at the Eildon, Trawool and Seymour gauging stations was determined by applying Meyer-Peter and Müller's (1948) threshold of motion criterion. Maximum irrigation flows (say 10 000 ML/d or 115.7 m^3/s) are incompetent to mobilise the armour layer at all sites (Table 2). The reason for the very high discharge to mobilise the armour layer at Seymour is that the channel impinges against bedrock resulting in the localised input of coarse gravel.

Flows well in excess of bankfull stage are clearly required to mobilise the armour layer which is a static or immobile feature on the Mid-Goulburn River.

Two extraction sites were investigated to determine whether armour layers reform following disturbance and, if they do, whether their grain size characteristics are the same as natural armour layers.

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The armour layer developed on an abandoned extraction platform at Seymour and on mid channel bars at the Hume Freeway bridge was sampled (Table.1). While the two adjacent to the Hume Freeway have grain size characteristics indistinguishable from natural armour layers, the extraction platform is significantly different. This platform had been abandoned about two months before sampling and further regulated flows will rapidly modify the surficial sediment. Given sufficient time, armour layers essentially identical to natural features will be produced.

GAUGING STATION	THRESHOLD DISCHARGE FOR INITIAL MOTION (m^3/s)	FLOW DURATION[1] (%)
	Meyer-Peter and Müller - Q_{bf}	Q_{bf}
Eildon	697.0	<0.01
Trawool	373.7	0.2
Seymour	>1201	<0.01

Table 2. Discharges required for threshold of motion of the armour layer at each gauging station and their associated flow duration.
1 - for the period 1 January 1984 to 1 January 1994.

2.4 Sediment Transport Rates and Sediment Yields

The purpose of this section is to try to estimate the bedload yield of the River to determine what is a "safe" extraction rate. To achieve this aim, sediment transport measurements were carried out at the Eildon, Trawool and Seymour gauging stations during the winter low flow period (22 and 24 July 1994) and during the summer irrigation releases (20, 21 and 22 December 1994). Suspended sediment was sampled with the USDH 48 depth integrated sampler and bedload was sampled with the Helley-Smith pressure difference sampler (Helley and Smith, 1971). Suspended sediment concentrations were determined by membrane filtration. Bedload was collected and bagged in the field, transported to the laboratory, dried at 105°C and then weighed. One bedload sample was also combusted in a muffle furnace at 550°C to determine how much of the sample was organic matter. The results of the field measurements are shown in Table 3.

The bedload measurements at Eildon and Trawool demonstrate that irrigation flows do not transport large amounts of bedload. Furthermore, the bedload flux at Eildon for a discharge of 34.9 m^3/s is misleading. This bedload gauging was completed soon after discharge had been increased abruptly from 470 ML/d (5.44 m^3/s) to 3014 ML/d (34.9 m^3/s). During the gauging we observed rafts of macrophytes being transported following their detachment from the bed. Therefore, the bedload sample was combusted to determine its organic matter content. Only 18.2% (0.024 t/d) was clastic sediment with the remaining 81.8% (0.106 t/d) being organic matter, in particular, various parts of macrophytes.

The particle size distributions of the bedload samples collected in December 1994 demonstrate that the bedload sediment at discharges of 102.8 to 109.6 m^3/s is much finer than the substrate and other mobile sediment types (Table 1). This indicates that the measured bedload is a non-capacity load which has been entrained either from local deposits on the bed or by bank erosion.

It is often assumed that the particle size distribution of bedload is the same as the bed material. While this can be the case on some armoured gravel bed rivers it is not the case where there is selective transport of finer grain sizes. Lisle (1995) found that selective transport of fine sediment temporarily stored on the bed in patches occurs in rivers which commonly retain immobile armour layers until discharges greatly exceed bankfull. This is the situation on the Mid-Goulburn River.

Threshold of motion calculations demonstrate that bankfull flows, and usually sub-bankfull flows can transport fine gravels of 6-8 mm. Therefore, irrigation flows are certainly competent to transport small amounts of sand and fine gravel. Field measurements and calculations using the Meyer-Peter and Müller (1948) equation indicate that fluxes will not exceed 2 t/d. While bedload equations are notoriously unreliable (Hean and Nanson, 1987; Erskine et al., 1985), the checking of theoretical fluxes against measured values in the present case lends support to the results.

Based on the duration of competent irrigation flows at each gauging station and the measured and calculated bedload fluxes transported by these flows, only about 58 to 102 t/yr are transported by regulated flows on the Mid-Goulburn River.

Allowing for the duration of flood flows each year and the fact that they do not usually mobilise the armour layer, mean annual bedload yields do not exceed 300 t/yr

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

GAUGING STATION	DISCHARGE (m^3/s)	FLOW DURATION[1] (%)	BEDLOAD DISCHARGE (t/d)	SUSPENDED SEDIMENT CONCENTRATION (mg/L)	SUSPENDED LOAD DISCHARGE (t/d)
Goulburn River at Eildon	34.9	52.1	0.13	8	24.1
	102.8	15.0	0.84	3	26.7
Goulburn River at Trawool	21.8	87	0	6	11.3
	109.6	20.8	1.64	3	28.4
Goulburn River at Seymour	21.8	88	nd	5	9.42
	103.3	25.5	nd	3	26.8

Table 3 Results of the sediment sampling at the three gauging stations on the Mid-Goulburn River. For location of stations, see Figure 2.
nd - not determined 1 - for the period 1 January 1984 to 1 January 1994.

2.5 Extraction induced Channel Changes

Five extraction sites were resurveyed to determine channel changes caused by mining. The results showed that while there was spatially discontinuous minor erosion and deposition at most sites, little replenishment of sand and gravel had occurred since the completion of mining. The mining itself had greatly enlarged the channel. The survey results support the bed load measurements that there is little contemporary replenishment.

3. IMPLICATIONS FOR MANAGEMENT

From the investigation it is shown that the current rates of extraction is greater than the replenishment rate. Furthermore, extraction is usually removing a gravel armour layer which is important for maintaining a stable channel. If river management aims to maintain a stable channel, the disturbance of all armoured bars and riffles should be prevented. The bed load measurements and the resurvey of extraction sites demonstrate that extraction from the Mid-Goulburn River should be limited. Removal of sand and gravel at rates greater than 300t/yr will exceed the replenishment rate. The replenishment rate is so small as to raise doubt about the viability of commercial extraction. Sand and gravel mining is currently being conducted on a non sustainable basis and there are no obvious sites where extraction will benefit the river ecosystem.

4. GUIDELINES FOR EXTRACTION

In order to assist the licensing authority and extractors, guidelines for assessment of sand and gravel extraction applications have been prepared.

4.1 Site Analysis and Assessment

In the analysis and assessment of proposed extraction sites, mining should be permitted only when all the following conditions are met:

- the extraction must benefit the stream (ie. major alignment instabilities can be corrected by extraction; public and private assets can be protected; the development of channel avulsions can be delayed or prevented; heavy deposition is removed; and habitat values are maintained or increased;
- it can be demonstrated that no long term irreversable impact on the river will occur;
- the extraction is within available replenishment rates; and
- extraction must be undertaken according to approved guidelines.

4.2 Monitoring and Control of Resource Extraction

Monitoring of stream reaches subject to extraction is extremely important in influencing management of extraction operations (NSW Department of Water Resources, 1992). This can be achieved by stream surveys before and after extraction and at regular intervals to monitor changes in the stream. Monitoring creates greater awareness of stream changes. Monitoring and reporting, (NSW Department of Water Resources, 1992) will serve a number of important objectives:

- development of baseline information on the condition of the streams and inventory of the sand and gravel availability;
- identification of trends in stream condition.; and
- evaluation of the performance of management agencies and management strategies using the survey information.

5. CONCLUSIONS

Since 1982 an estimated 200,000m^3 of material has been removed from the Goulburn River and in reaches of tributary streams adjacent to the river. This represents an average of 14,000m^3/yr of material removed. The current rate at which

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stream deposits are extracted from the Mid-Goulburn River cannot be sustained. The replenishment rate is too small to allow continued commercial extraction. An adverse impact on stream conditions is likely should extraction rates continue at the present rate.

Conclusions drawn from these investigations are:

- that active sand and gravel resources available for extraction in the study area are limited;
- sediment yield in the Goulburn River is extremely low and;
- extraction operations which impact on the armour layer of the stream should be restricted.

Existing extraction rates on the Mid Goulburn River is not sustainable without the river system responding to over extraction. The rate of mining is exceeding the replenishment rate of material which will result in geomorphic and environmental impacts.

Extraction of sand and gravel from streams should only be undertaken with extreme care and only approved where all of the following can be demonstrated:

- extraction will assist in meeting stream management objectives for the reach;
- extraction rates are within sustainable yields; and
- guidelines and permit conditions for the operations will be enforced.

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