Environment Canterbury

Waihao River Report
Status of Gravel Resources and Management Implications

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1. Introduction

As part of Environment Canterbury's wider "Regional Gravel Management Investigation" MWH have been commissioned to prepare reports on the Status of Gravel Resources and Management Implications for ten "Priority One" rivers within the Canterbury Region.

The Waihao River in South Canterbury is one of the ten "Priority One" rivers. Investigation of the Waihao River's gravel resources is important because:

- River gravels are used extensively throughout Canterbury (including from the Waihao River) as a construction material for roads, buildings and other infrastructure.
- Gravel aggradation in the Waihao River is a crucial aspect of flood management. Allowing gravel to accumulate in the channel has the effect of reducing the channel capacity and increases the likelihood of a flood escaping the main channel.
- Extracting too much gravel risks damage to infrastructure such as stopbank collapse and bridge pier undermining. These types of events are hazardous to life and property.

This report provides an initial overview of the Waihao River before reviewing its changing bed profile and gravel extraction records to assess the available gravel supply. On the basis of the assessed available gravel supply recommendations are made as to the river's future gravel resource management.

2. Waihao River Description

The Waihao River runs for around 95km from its headwaters in the Hunters Hills, where it drains the valleys bounded by Mt Nimrod (1,525m), Mt Airini (1,373m), Mt Aitken (1,063m), Mt Blyth (1,006m), Tara (908m), Mt Studholme (1,085m) and Elephant Hill (510m). The catchment area of the Waihao River is estimated to be 580km^2.

For the 70km of the river (north branch) above the Waihao Forks the river drains hill country formed predominantly by dark greywacke and black argillite (Hunter Hills).

Below Waihao Forks the river flows a further 26km to the sea across glacial outwash fans and river terrace gravels (predominantly greywacke and schist).

The Waihao River catchment does not include any towns. Habitation is limited to isolated dwellings. State Highway 1 and the main trunk railway cross the Waihao River within 1km of the sea.

3. River Processes

3.1 Flooding

The Waihao River has a flood control scheme on it below State Highway One. This scheme was constructed in the early 1970's and provided protection from floods including stopbanks that were designed for 25,000 cusecs or 708m^3/s with 300mm freeboard. This was the estimated 50 year return period flood however since the 1960's when the scheme was designed, the return period for this discharge has been revised to about a 15 year return period. During the interim, the largest flood was in 1986 and estimated to be 1250m^3/s.

In 1988 the stopbanks were raised in several areas over a total length of about 3km. This followed analysis of the August 1986 flood which showed that these stopbanks were low by about 0.75m relative to the remainder of the stopbanks. This raising required about 10,000m^3 gravel extraction from the river fairway.

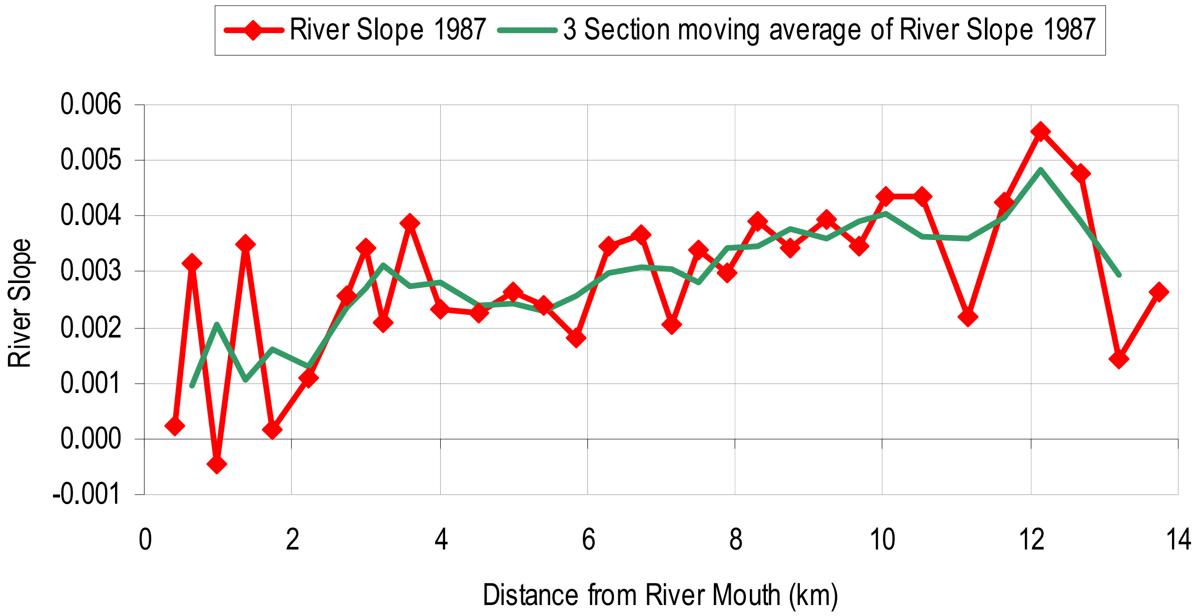
The scheme stopbank capacity is to be reviewed very shortly and this will provide the best areas for gravel extraction and the budget in Section 6 shows that there is a net influx of gravel into the lower reaches of this river.

The river control scheme required several cuts through river bars that were quite large, as the thalweg channel was very meandering prior to the scheme. This means that many of the cross-sections had fairway positions that were high relative to the low flow channel. This is especially so between meterages 3,500 and 5,000 where bed levels of the river have dropped between 0.5 and 0.9m. The large drop in bed levels from 1966 to 1983 in the reach from 2,500 to 8,000m reflects this situation which has occurred on many other rivers in South Canterbury and also reflects the gravel extraction to build the stopbanks. Since 1983 the bed levels in this reach from 2.5 to 8.0km have steadily risen with a large increase in the 1983 to 1987 period (0.06m) reflecting the very large 1986 flood events.

3.2 Bed Profile

The river bed slope derived from the 1987 mean bed levels is shown in figure 3.1 below.

Figure 3.1: Waihao River Bed Slopes 1987 (m/m)



This shows that the river drops off in slope from about 0.0035m/m at km 13, to close to 0.001m/m at the mouth. There is a large drop off in slope from 2 to 4km that corresponds to the river changing from its gravel phase to its silt phase. This drop in slope means that there is potential for extraction in this area which is confirmed by the gravel budget prepared in section 6 below.

A very approximate analysis (Connell 1992) using Yalin's formula (Henderson (1966) p444) and calibrated using the aggradation on the North Branch Ashburton River, indicates that a maximum of over 35,000m^{3}/yr could be deposited in this reach below per year as a result of this drop in slope. The model assumes that the sediment is moved by a 50% of mean annual flood discharge flowing for 0.5% of the year over about 50% of the fairway width. However, as the river catchment is in reasonably good condition, the river is probably not transporting its potential bed load and therefore actual figure will be much less than this as indicated by the gravel budget which gives a figure of about 25% of this.

Studies (McSaveney and Whitehouse, 1989) of the catchment erosion indicate that about 150t/km^{2}/yr is eroded from the catchment area (the hill area which is about 330km^{2}) which gives a total load (both suspended and bed load) of about 25,000m^{3}/yr (assuming 2t/m^{3}). The bed load, Hicks and Griffiths (1992), is between 3% to 25% of this total or between 750 and 6,250m^{3}/yr.

To be able to give an accurate figure would require a much larger study than has been undertaken here and the best guide available with the present information is the gravel budget prepared in section 6 below. It is possible that the gravel budget may be high, as there have been two very large floods

4. Gravel Extraction

Environment Canterbury monitor gravel extraction from the Waihao River by requiring extractors to submit returns indicating how much, when and where gravel is taken. The Waihao River gravel returns for the period from 1990 to June 2003 have been made available to us.

Our analysis of the returns data has been to determine the patterns of where and when gravel has been extracted from the Waihao River over the 13.5 years of record. Table 4.1 extends the record to 14 years (by extending the 2003 returns out to a full year).

Table 4.1: Gravel Returns by Year for the Waihao River

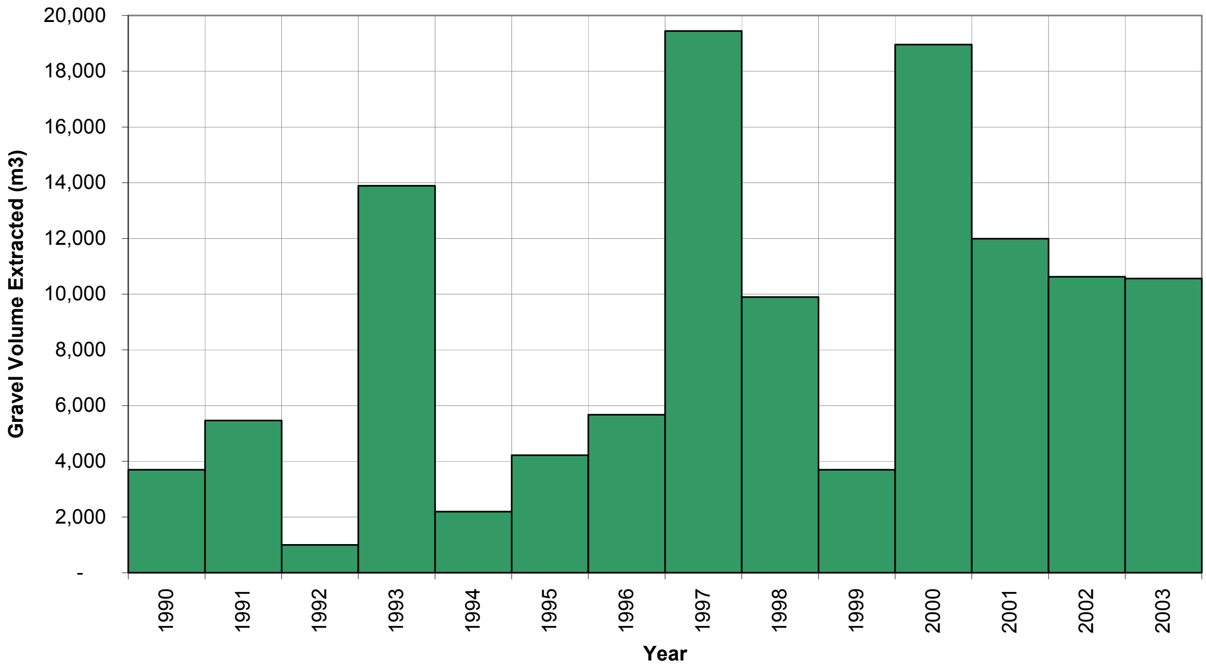
Year	Waihao
1990	3,697
1991	5,468
1992	997
1993	13,890
1994	2,192
1995	4,217
1996	5,672
1997	19,446
1998	9,898
1999	3,697
2000	18,957
2001	11,992
2002	10,625
2003[1]	10,560
Total	**121,308**

1. Returns for year 2003 to June have been doubled to estimate full year extractions

For the Waihao River the total volume of gravel extracted over the period of record was 121,300m^3, at an average rate of 8,660m^3/yr.

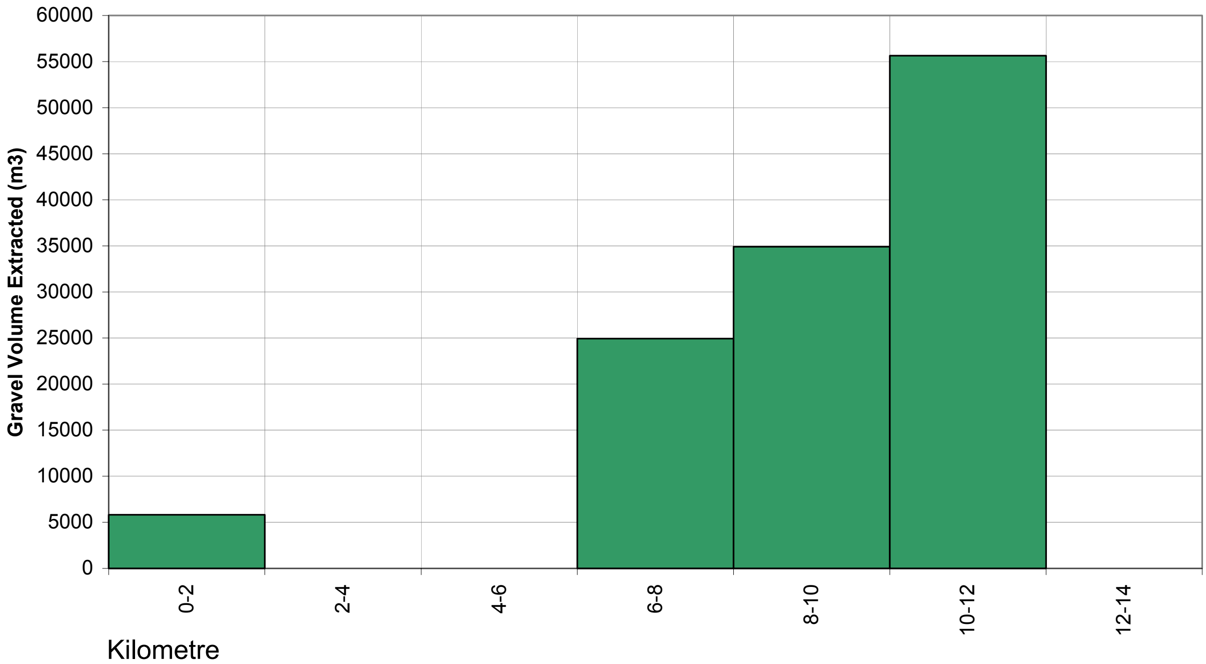
The temporal distribution of the extractions has not been even over the 14 years of return records. Figure 4.1 contains a chart that shows particularly high rates of extraction in 1997 and 2000. The general trend appears to be for the volume of gravel extracted to be increasing.

Figure 4.1: Waihao River Gravel Extraction by Year



The spatial distribution of the gravel extraction shows most of the gravel is removed between 6 and 12km from the river mouth (between Lundy's Ford and Wains Crossing Road). This part of the river includes the State Highway 1 and Main South Railway bridges.

Figure 4.2: Waihao River Gravel Extraction by River Distance (1990-2003)



4.1 River Bed Changes

Environment Canterbury monitors the Waihao River channel by surveying cross-sections on a regular basis. The reduced data from the cross-section monitoring has been made available to us. Table 5.1 contains the cross-section data.

Table 5.1: Cross-sectional Data

River Section	River Distances (km)	Number of Cross-Sections	Number of Surveys and Survey Dates
Waihao River[1]	0 to 14.05	35	6 –1965/66, 1977, 1983/84, 1987, 1989/90, 2001

Notes to table:
1. Environment Canterbury data file: *Waihao Mean Bed Levels.xls*

Environment Canterbury cross-section data used in our analysis is:

- The cross-section locations measured from the Waihao River mouth.
- The cross-section fairway widths calculated as the difference between the left and right channel offsets.
- The cross-section fairway mean bed levels (MBL).

Our analysis includes estimating the gravel volumes (above MSL) by integrating between adjacent cross-sections assuming linear variations of channel width and MBL along the channel between the cross-sections.

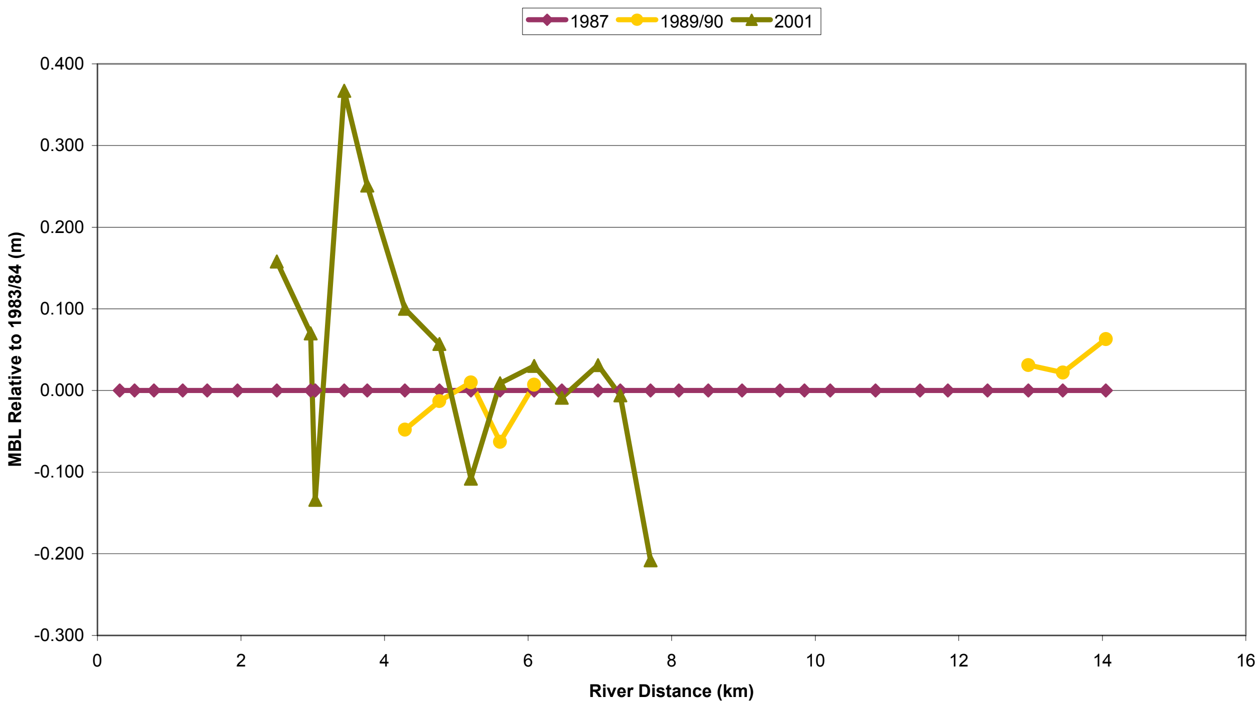
4.2 Mean Bed Level Changes

The change in the Waihao River's fairway mean bed level (MBL) over the period from 1983/84 to 2001 is shown in Figure 5.1. The chart shows the MBLs relative to the MBLs of the 1983/84 survey.

The 1965/66 data set is not included in the chart because of the lack of a relationship between benchmarks used in 1965/66 and later years (as noted in the Environment Canterbury notes attached to the data set). The 1977 data is not included because of the limited number (six) of cross-sections actually surveyed in that year. The 1984 data is not included in the analysis because of very large differences between it and the 1987 survey (which can be sensibly used with the later surveys).

The charts show a general raising of the bed level with the indicative average MBL increasing by around 40mm 1987 to 2001.

Figure 5.1: Waihao River MBL Relative to 1987 Levels

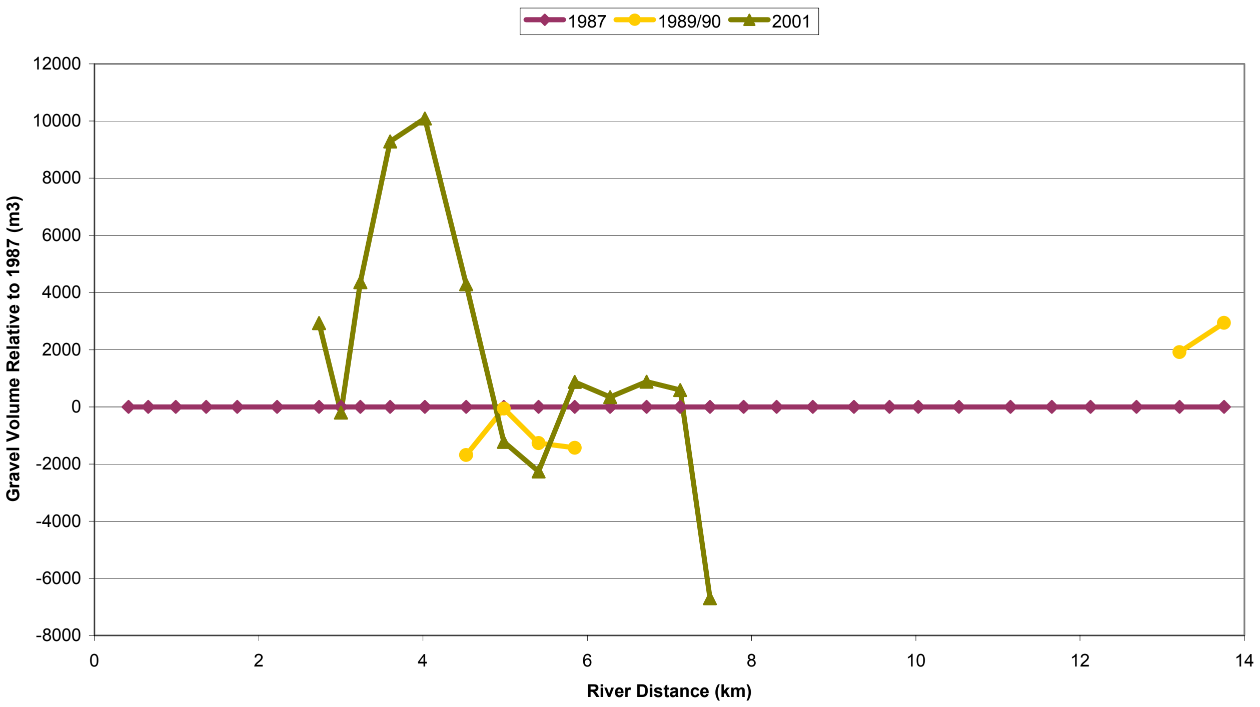


4.3 Gravel Volume Changes

The change in the Waihao River's fairway gravel volumes over the period from 1987 to 2001 is shown in Figure 5.2.

The chart describes a similar pattern to that discussed in Section 4.2 with an increase in gravel volumes.

Figure 5.2: Waihao River Fairway Only Gravel Volumes Relative to 1987 Survey



The changing volume of gravel in the Waihao River in terms of absolute volumes and rate of gain for is shown in Table 5.2. The figures in Table 5.2 are derived by calculating the gravel volume change where possible (between 2.5km and 7.7km) and pro-rating that figure to reflect the entire reach between the most upstream (14.05km) and downstream (0.31km) cross-sections.

Table 5.2: Waihao River Gravel Volume Change

Period	Gravel Volume Change (m^3)	Rate of Change (m^3/year)
1987 to 2001	+61,300	+4,380

5. Gravel Supply

Using the available data the gravel supply in the Waihao River can be best estimated using a conservation of volume approach over the river reach. Put simply, gravel entering either leaves or remains in the reach. In mathematical terms for a given reach of river (refer also to accompanying schematic below):

$$\frac{\Delta V_g}{\Delta t} = Q_{g.in} - Q_{g.out} \qquad \text{(Eqn. 1)}$$

where:

ΔV_g	=	change in volume of gravel (m^3)
Δt	=	time elapsed (y)
$Q_{g.in}$	=	total volume rate of gravel into river reach (m^3/y)
$Q_{g.out}$	=	total volume rate of gravel out of river reach (m^3/y)

Gravel leaves the reach either by extraction or by being transported down-river. Gravel enters the reach either from upstream, side tributaries or bank erosion. Building this into Equation. 1 gives us Equation 2.

$$\frac{\Delta V_g}{\Delta t} = Q_{g.river.in} - Q_{g.river.out} - Q_{g.extraction} \qquad \text{(Eqn. 2)}$$

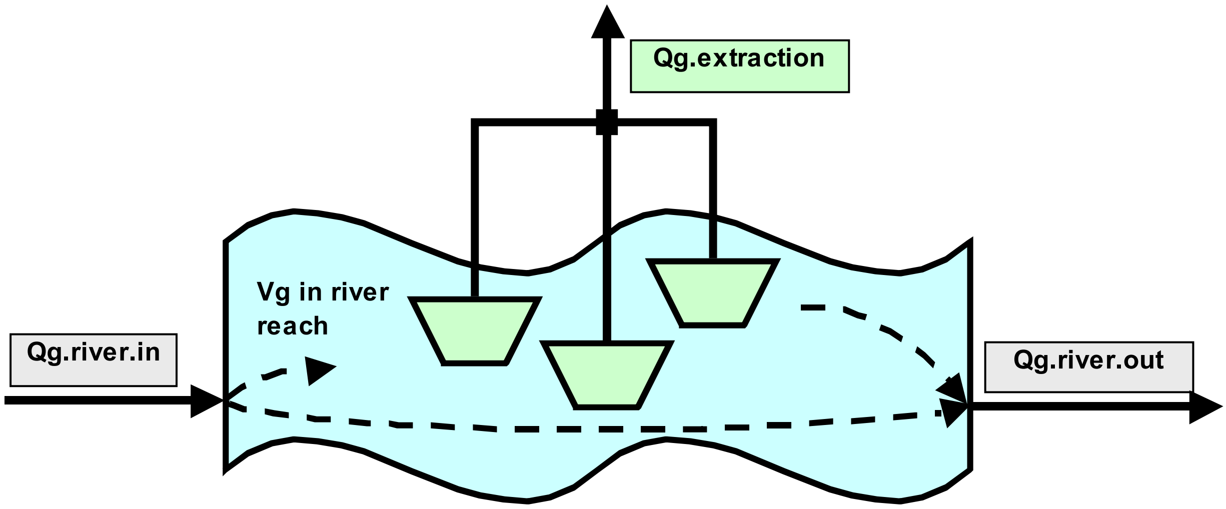
where:

$Q_{g.river.in}$	=	volume flow rate of gravel into river reach from upstream, side tributaries or bank erosion (m^3/y).
$Q_{g.river.out}$	=	volume flow rate of gravel out of river reach by downstream transport (m^3/y)
$Q_{g.extraction}$	=	volume flow rate of gravel extracted from river reach (m^3/y)

Equation 2 can be solved for $Q_{g.river.net}$ (the difference between $Q_{g.river.in}$ and $Q_{g.river.out}$) from the recorded extraction rates and bed level surveys. To estimate the absolute values of $Q_{g.river.in}$ and $Q_{g.river.out}$ we use catchment erosion rate estimates to assess $Q_{g.river.in}$ and then solve for $Q_{g.river.out}$ as the remaining unknown.

The schematic contained in Figure 6.1 shows the gravel volume flows and changes.

Figure 6.1: Schematic Representation of Change in Gravel Volumes



Gravel extraction data is available from 1990 to 2003. The useful MBL surveys extend from 1983/84 to 2001. The following analysis is based on the average observed rates of extraction and gravel volume change.

To estimate the gravel inflow we use the reported bed load figures from the Opihi and Orari River Catchment erosion studies by Cuff, (1974, 1981) and sediment ratings, de Joux, 1981) which are 20 to about $80m^3/km^2/yr$ using the total catchment area. These figures are based on gravel trapped behind shingle traps on the Opihi River and using the erosion rating for those catchments to derive a figure for the whole catchment from the erosion rating of all the other subcatchments. They also include abrasion as discussed in erosion study on the Orari (Cuff, 1981) which estimated it at about 40% but it depends upon the ratio of greywacke and argilite.

Extrapolating the lower range of figures to the Waihao River with a catchment area of $520km^2$ gives a corresponding bed load input from the catchment of between 10,000 and $20,000m^3/yr$ depending upon the actual erosion in the catchment.

As the river turns to its silt phase about 2km from the mouth (slope of about 0.001m/m), it is unlikely that any shingle reaches the coast. This means that the total input is about $13,000m^3/yr$. This figure would include any shingle added from bank erosion and degradation of the bed therefore the erosion in the catchment is likely to be much less than the $13,000m^3/yr$.

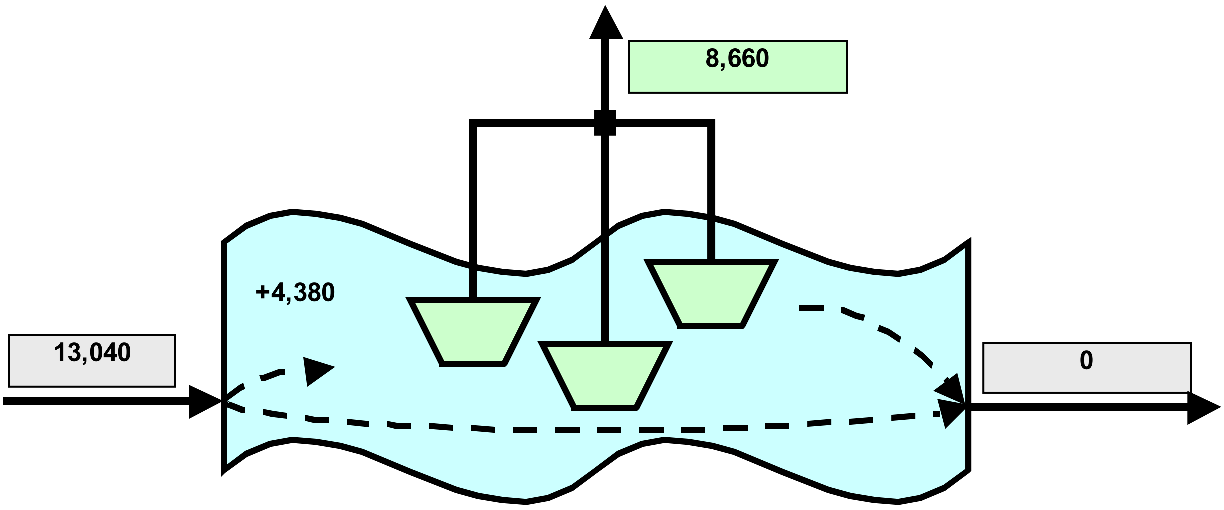
Thus for the Waihao River the following observed and derived quantities are used in Eqn. 2.

$\Delta V_g / \Delta t$	$4,380m^3/yr$	(averaged over 1987 to 2001)
$Q_{g.extraction}$	$8,660m^3/yr$	(refer Section 4)
$Q_{g.river.in}$	$13,040m^3/yr$	(as above)
to yield $Q_{g.river.out}$ =	$0m^3/yr$.	

The figures indicate that the river is aggrading.

The estimated annual average gravel volume flows, extractions and volume changes (all in m^3/yr) are shown in Figure 6.2. The grey coloured boxes show the river bedloads, the light green box shows the gravel extraction and the pale blue box shows the rate of gravel volume change in the river reach.

Figure 6.2: Waihao River - Schematic Representation of Change in Gravel Volumes



6. Discussion and Recommendations

The gravel budget shows that there is a sustainable gravel supply of around 13,000m^3/yr in the Waihao River. Some caution is required with this figure because it was derived from observed gravel volume changes over a limited reach of the river.

The proxy design bed level indicated to us by Environment Canterbury is the 1987 bed level.

The latest Waihao River survey (2001) shows around:

- 30,000m^3 of "above design bed level" gravel between 3 and 5km
- 2,500m^3 of "above design bed level" gravel between 6 and 7.5km.

In addition to those areas listed above other parts of the Waihao River not surveyed in 2001 could also have excess gravel.

Future extractions could target the sustainable 13,000m^3/yr extraction plus some additional extraction to remove the excess material in the listed areas.

Cross-section monitoring of the Waihao River should be recommenced to produce a full set of cross-sections for comparison with the 1987 survey.

7. References

Cuff, J.R.I., (1974), Erosion in the Upper Opihi Catchment, South Canterbury Catchment and Regional Water Board, 66p.

Cuff. J.R.I. (1981), Erosion in the Upper Orari Catchment. Publication No. 19, South Canterbury Catchment Board and Regional Water Board,. Timaru. 152p.

de Joux, R. T. (1981), The water resources of the Orari River. Publication No. 24, South Canterbury Catchment Board and Regional Water Board, Timaru, 115p.

Griffiths, G.A. And Hicks, D. M,. (1992), Sediment Load, in Mosley M.P., Waters of New Zealand, New Zealand Hydrological Society, Wellington.

Henderson, F.M., (1966), Open Channel Flow, MacMillan, New York. 22 p.

McSaveney, M.J. And Whitehouse, Ian E., (1989), Antropic Erosion of Mountain Land in Canterbury, New Zealand Journal of Ecology, (Vol 12, p 151-163.