Waimakariri River: Status of gravel resources and management implications

Report R05/15

ISBN # 1-86937-569-6

Prepared by

Dr Henry R. Hudson
Environmental Management
Associates Limited, Christchurch

June 2005

58 Kilmore Street
P O Box 345
CHRISTCHURCH
Phone: (03) 365 3828
Fax: (03) 365 3194

Environment Canterbury
Your regional council

75 Church Street
P O Box 550
TIMARU
Phone: (03) 688 9069
Fax: (03) 688 9067

Website: www.ecan.govt.nz
Customer Services 0800 324 636

Citation: Hudson, H.R. 2005. Waimakariri River: Status of gravel resources and management implications. Environment Canterbury Report R05/15, Christchurch. 25 pages.

Summary

Environmental Management Associates (EMA) were commissioned by Environment Canterbury (ECan) to evaluate the status of the river gravel resources and management implications on the Waimakariri River, Canterbury.

Attention is focused on the sustainable volume of aggregate available, the locations where excavation is appropriate, and constraints on excavation. Major findings/recommendations include:

- Limit extraction to 100,000 m^3/y in the reach from the motorway bridge (km 5.63) downstream
- Continue with the trigger levels and guidelines for extraction to protect the bridges
- Assess if high bed levels still occur (post 2000 survey) downstream of the highway bridges and redirect gravel extraction if required to reestablish fairway capacity
- The sustainable rate of excavation for the reach below km 8.45 (to the sea) exceeds 220,000 m^3/y over the long term
- High bed levels upstream of km 10.06 have reduced channel capacity, particularly around km 12
- Recent rates of extraction (270,000 m^3/y from 1995 to 2001) in the gravel bed reach downstream of km 8.45 appears to be inducing headward retreat into the problem reach immediately upstream
- Cross sections (including km 8.45 to 15.59) should be resurveyed and evaluated to determine if headward retreat continues to lower bed levels/flood risk around km 12
- If high bed levels persist, alternative approaches and locations of gravel extraction should be evaluated (without extensive flow diversion, excavation from the south bank is probably precluded from km 10-13 km)
- Upstream of Crossbank (km 17.81) limited gravel extraction occurs - bed levels are decreasing because of erosion and the zone of entrenchment is migrating downstream over the very long term
- Once the 2004 survey data is processed, bed levels trends and flood levels in the upper reaches should be evaluated to determine the flood risk at the hinge point.

Table of Contents

List of Figures

1 Introduction

Environmental Management Associates (EMA) were commissioned by Environment Canterbury (ECan) to evaluate the status of the gravel[1] resources and management implications for gravel extraction on the Waimakariri River. Careful management of gravel resources is required:

1. River gravels are a preferred source of building materials and sustainable supply is critical.
2. Over exploitation can lead to infrastructure problems, such as undermining of bridges (Boyle 1996), with major financial implications and potential liabilities to Environment Canterbury.
3. Over exploitation can have significant environmental effects (Hudson 1997; Day & Hudson 2001; Kelly *et al.* 2005).
4. Gravel extraction is an essential component of Waimakariri River floodplain management (Griffiths 1991; Montgomery Watson 2000).

This evaluation provides a brief overview of river character and aspects of the flooding problem before evaluating:

- Gravel supply to the lower river
- Rates and location of gravel extraction in the lower river
- Affects on the river bed
- Recommendations for future extraction:
    - ⇒ Locations where excavation is appropriate
    - ⇒ Constraints on excavation (e.g. trigger levels).

2 River character

The Waimakariri is a large, steep, braided, gravel bed river that flows in a south easterly direction about 140 km from the Southern Alps to the Pacific Ocean (Fig. 1). The catchment area is 3,564 km^2, of which 2,460 km^2 is above the Lower Gorge (Griffiths 1979).

Above the Old Highway Bridge gauge (river km 5.23)[2] the catchment area is 3,210 km^2 with a mean flow of 120 m^3/s, mean annual flood of 1,520 m^3/s, maximum recorded flow of 3,990 m^3/s, suspended sediment load of 3.1 Mt/yr (Hicks 1998), and bedload of approximately 260,000 ± 10,000 m^3/yr (Griffiths 1991)[3].

---

[1] Technically the term “gravel” refers to a specific size range of rock fragments (2-64 mm). In keeping with the terms of reference, “gravel” in this report refers to riverbed material, largely consisting of sand and gravel sized material, but ranging from very fine material (silt and clay) to cobbles and boulders.

[2] Distances are expressed in kilometres (km) from the river mouth, based on the plans “Environment Canterbury cross section locations Waimakariri River 1997.”

[3] In the lower gravel reach; gravel does not move through to the coast.

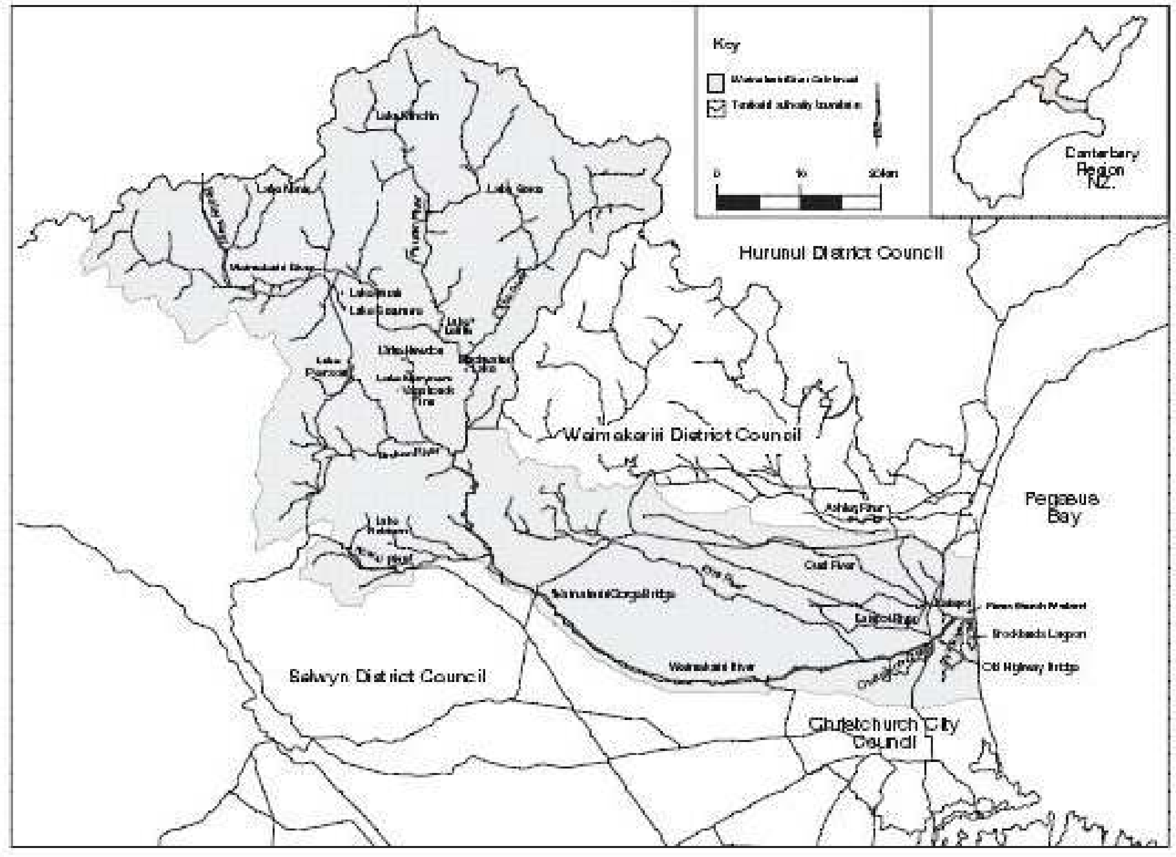


Fig. 1 Map of the Waimakariri River and catchment (ECan 2004)

Altitudes range from 2,408 (Mt Murchison) on the Main Divide of the Southern Alps to ~300 m where the river emerges to flow across the Canterbury Plains at Woodstock (river km 71.3) to the sea.

Mountain-foothill landscapes in the Waimakariri catchment reflect extensive glacial and post glacial activity. The upper northern area is covered in beech forest. Elsewhere, apart from isolated patches of forest; tussock grasslands, scrub, bare rock, and extensive deposits of rockfall and fans predominate.

From the Lower Gorge the Waimakariri flows over an extensive braidplain to the Pacific Ocean. The braidplain is composed of coarse-grained fluvial sediments derived from erosion of the Southern Alps and foothills. The braidplain was formed in several phases of progradation during glacial episodes, with subsequent incision (entrenchment) and terrace development during deglacial and interglacial periods in the upper plains, and progradation downstream (Leckie 1994; Browne & Naish 2003) (Fig. 2, Fig. 3). The plains were not glaciated except perhaps for minor valley glacier advances extending a few kilometers past the gorge (Gage 1958). Most of the plains are farmland except near the sea which is largely urbanized (City of Christchurch; and Kaiapoi).

Fig. 2 View upstream to the Gorge Bridge (ECan 1995)

Fig. 3 View upstream from river km 6 during a small freshet (after Hicks et al. 2000)

3 Flooding and flood management

Flood management has been an ongoing problem because of the natural tendency of the Waimakariri River to flow in multiple courses over a broad alluvial fan extending over a 50 km front from Lake Ellesmere northwards.[4] There are no major tributaries inputs into the Waimakariri below the Gorge Bridge, apart from the Eyre River (which was diverted into the Waimakariri in 1929), and streams entering near the coast (e.g. Kaiapoi River, Styx River) (Fig. 2, Fig. 3).

The plains section of the Waimakariri in its natural state can be divided into four segments:[5]

1. An entrenched upper plains reach where the river has incised into the plains (Fig. 2)
2. A mid fan transport reach where the riverbed intersects the highest surface of the plains.
3. An aggrading lower fan anastomosing channel reach with large islands.
4. A prograding sand bed based, tidal channel and lagoon.

At the edge of the foothills at Woodstock (river km 71.3) the terraces are ~80 m high and the river flows in a progressively shallowing trench with a braided bed (Fig. 2). At the Lower Gorge (river km 59.9), where the river is locally constricted, the bed elevation is ~250 m and the surrounding terraces are more than 50 m above the riverbed. Downstream the terraces are ~30 m high at Browns Rock (river km 54.2) to km 50; ~20 m at km 45; with no confining south bank terrace and less than a 10 m north bank terrace by river km 35.

Historically overflows from the Waimakariri River occurred in the reach from km 35 to km 25 (Fig. 4) because river bed levels intersect the floodplain and the alignment of the channel (the river begins slowly changing direction from south east flowing to east flowing; Fig. 1).

Numerous attempts were made to control the overflow towards Christchurch by constructing embankments in the old river channels in the Halkett-Crossbank reach (Fig. 4).[6] Ultimately these were successful in preventing overflows reaching Christchurch. No more overflows to the Avon were reported after 1868 (Griffiths 1979).

---

[4] Soils evidence indicates that the most recent of these overflows, which went through the Christchurch city area, linked with the Heathcote River about 900 years ago and the Halswell River in the past 300 years (Cox & Mead (1963). Several breakouts of the Waimakariri to the Avon were reported in the period 1845 to 1868, but not since then (Griffiths 1979; Logan 1987).

[5] These segments vary from those proposed by Lechie (1994) who defined an upper entrenched reach downstream to km 21; a zone of minimal or negligible erosion (km 21-11); and a zone of progradation (km 11 to the sea). Griffiths (1979) places the end of the entrenched zone at km 18; but does not segment the reach below Crossbank (km 18) to the sea. Between 1929/32 and 1954/57 Griffiths (1979) reported general aggradation in the gravel reach below river km 18; with more recent bed lowering attributable to gravel extraction.

[6] The first recorded protective works (1859) was embankment in an old channel near Halkett.

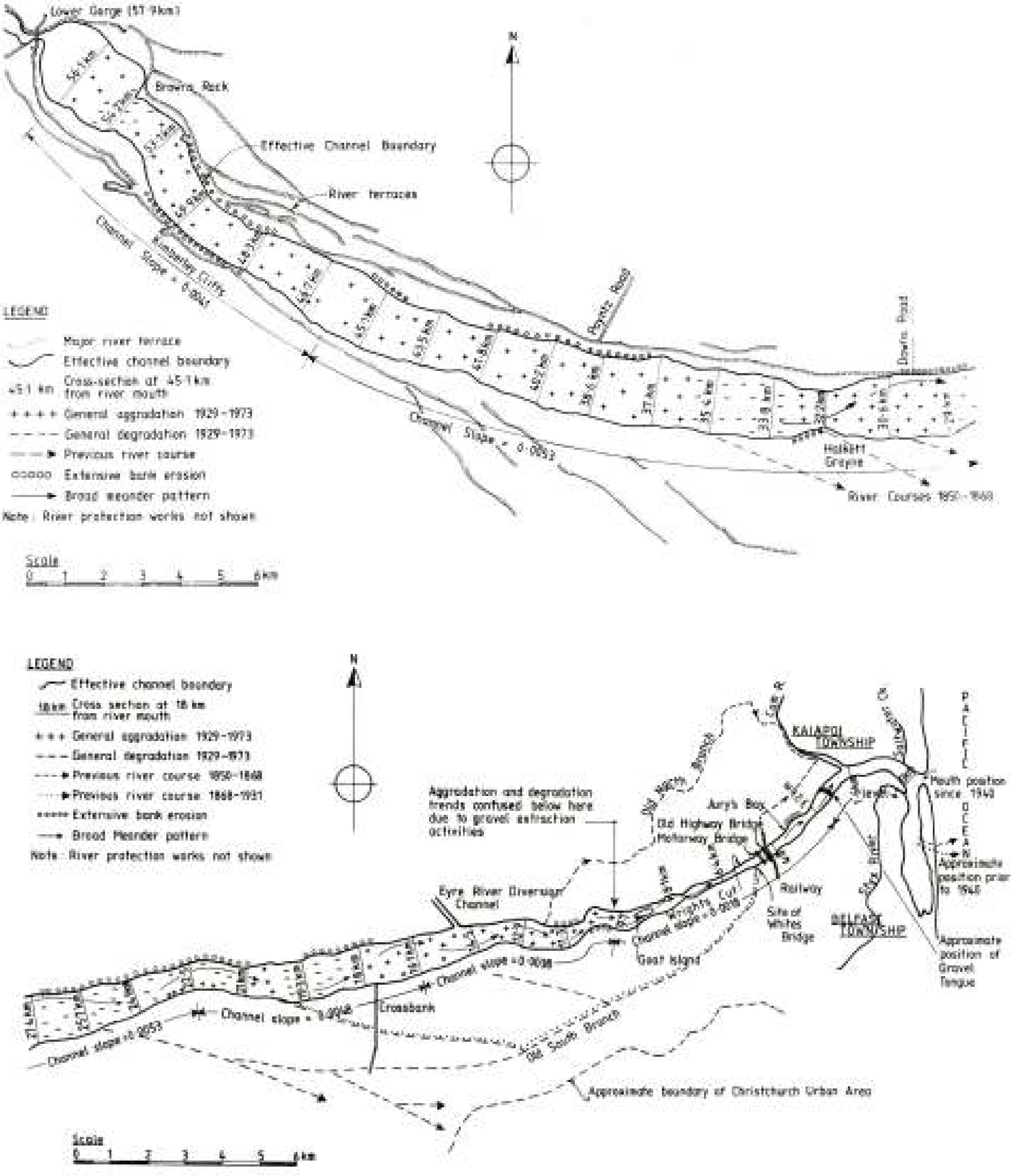


Fig. 4 Schematics of the Waimakariri River below the Lower Gorge (after Griffiths 1979)

Further bank protection works were undertaken in the Halkett-Crossbank reach and along the north bank from km 16 to 23 in the period to 1928; with the Hay’s No. 2 scheme constructing a continuous embankment from Halkett to Harewood, and closing off of the South Branch of the Waimakariri at Crossbank in the early 1930s (Logan 1987).

The lower fan anastomosing reach of the Waimakariri caused persistent flooding of the large farmed islands and the settlement of Kaiapoi. [7] In 1867 there was a partial diversion of the North Branch into a flourmill waterway that enlarged and captured the total flow and divided Kaiapoi Island (Logan 1987). The remnant North Branch was cut off from the Waimakariri and is now called the Kaiapoi River.

Under Hay's Scheme in the 1930s the river was straightened with Wrights Cut above the newly built Main North Road Bridge (~km 5.6 – 7.0) and Stewarts Gully channel was widened and captured the entire flow (~km 3-5). The river was confined to a comparatively narrow course with the construction of Crossbank blocking the South Branch; and with various other groynes and embankments (Fig. 4). As well, to alleviate flooding in Kaiapoi, and to assist drainage of the Ohoka-Rangiora swamp, the Eyre River was diverted from the Old North Bank Channel (the present Kaiapoi River) into the Waimakariri at km 14.5 in 1929. While Hay's Scheme failed in its attempt to by pass gravel to the sea, it did contain floodwaters to the vicinity of the river (Griffiths 1979).

The floods of 1940, 1950 and 1957 (probably the largest flood since c. 1848) "… demonstrated unequivocally that Hays No. 2 Scheme no longer met it objectives, mainly owing to the effects of gravel deposition in the river channel. Accordingly, a review was undertaken which resulted in the adoption of the Waimakariri River Improvement Scheme1960." (Griffiths 1979). The 1960 Schemes major objectives were to raise, extend and strengthen the existing stopbanks to pass a 167,000 cusec flood (4730 m^3/s; 100 year return period) without overflows, and to control gravel inputs in the catchment and in the river up to the gorge. The scheme, which was implemented in 1963 and completed in 1989, has contained flood flows but has not bypassed gravel to the sea (Griffiths 1979).

Over the last 6500 years sea level has been relatively stable and river gravel has prograded (built up and seaward) approximately 14 km over the coastal sand deposits (Griffiths 1991; Browne & Naish 2003). Presently the gravel tongue is about 2.5 km upstream from the coast. It is uncertain if large scale gravel extraction has halted the downstream movement of the gravel into the lower sand bed channel and lagoon.[8]

Flooding in the reach is not reported as an issue, but to alleviate upstream flooding and to facilitate gravel flushing, Hay's Scheme unsuccessfully attempted to create a new river mouth bypassing the lagoon. A more direct route to the sea was naturally formed in the 1940 flood (Logan 1987).

---

[7] Nelson's (1928) map (in Griffiths 1995) showed the lower Waimakariri was very wide with several large islands (e.g. McLeans, Coutts, Templars, Bailes, and Kaiapoi islands). For example, at km 10 (The Groynes) the channel was ~2500 m in 1928 and 450 m in 1997; at km 15 the channel was ~4250 m in 1928 and 1030 m in 1997.

[8] Griffiths (1979; and citations therein) reported the position of the gravel sand transition at 2.5 km upstream; with braid bars 3 km from the coast in 1979; at 3km from the coast in 1960; and 300 m downstream of the Old Highway Bridge (i.e. km 4.9) in 1930; and 800 m downstream of Wrights Bridge in 1927 (i.e. km 5.5) in 1927. Blakely & Mosley (1987) suggest from soil maps that the toe of the gravel fan was probably 8-12 km from the sea before Polynesian settlement.

A comparison of 1960 and 1999 predicted flood levels shows aggradation has significantly reduced fairway channel capacity in sections of the river (MW 2000). Targeted gravel extraction is required to alleviate this situation (Sections 6 & 7).

4 Gravel supply to the lower river

Detailed assessments of gravel supplies to the lower river were undertaken by Griffiths (1979); Carson & Griffiths (1989) and others. Estimates are quite accurate because the Waimakariri is a closed system (gravel is not flushed to the sea); the trapped silt component is a small proportion of the trapped bed material in the active channel; there are good records of gravel extraction; and cross section surveys repeated on a five year cycle (locations are shown in Fig. 3).

Annual bedload yield past Crossbank (km 18) is variable (Griffiths 1979; Carson & Griffiths 1989):

- 217,000 m^3/y in the period 1929-1954
- 223,400 m^3/y in the period 1929-1973
- 275,000 m^3/y for the period 1955-1983
- 187,000 m^3/y for the period 1967/68-1972/73
- 285,000 m^3/y for the period 1972/73-1977/78
- 269,000 m^3/y for the period 1977/78-1982/83.

Over shorter time frames bedload yields are highly freshet/flood dependent. Based on morphological measurements of sequential aerial photographs above Crossbank (from km 22 to 27) data in Carson & Griffiths (1989) shows bedload transport varying from ~5,000 m^3/month to more than 40,000 m^3/month.

As well as temporal variations in bedload transport, Carson & Griffiths (1989) document longitudinal variation in transport within these survey periods. These spatial differences are attributed to the bedload waves moving downstream (Griffiths 1993).

At a larger scale, an idealised model of the fluvial system has been proposed as part of the River Environment Classification (Snelder *et al.* 1999). In this regard, Mosley & Schumm (2000) describe a runoff and sediment production zone from the mountains and foothills; a transfer zone; and a deposition zone in the silt phase/tidal phase of the river.

In contrast, Griffiths (1979) found that at least 65% of the material causing aggradation problems in the lower reaches was derived locally from the channel bed and banks below the Lower Gorge and not from the upper catchment.[9] This proportion would increase if the ~12 km upper plains reach between Woodstock and the Lower Gorge (Fig. 2) was included. Deposition occurs before the silt phase/tidal phase of the river. About 3.5 km from the coast annual bedload yield is ~65,000 m^3 (Griffiths 1979); and the gravel bed finishes at km 2.5 (see [8]).

---

[9] Griffiths (1988) (cited in Griffiths 1991) calculated the volume of post-glacial entrenchment of the river into the Plains between Staircase Gorge (Woodstock) and about Halkett; and estimated annual transport over the past 16,000 years of 300,000 ± 140,000 m^3/y. He calculated the proportion of gravel coming from bank erosion below Lower Gorge was 70% ±11%.

The decrease in bedload yield downstream is attributable to a change in channel gradient (Fig. 4) and to recent changes in river form and processes. In brief, upstream of Crossbank down to km 14, the active channel width of the braided channel is usually more than 1,000 m. Below river km 14 the stopbanks converge and braiding decreases until about river km 10 where the river is essentially single-thread alternating bar morphology with an active width of ~400 m. The river continues to narrow over the last several km.

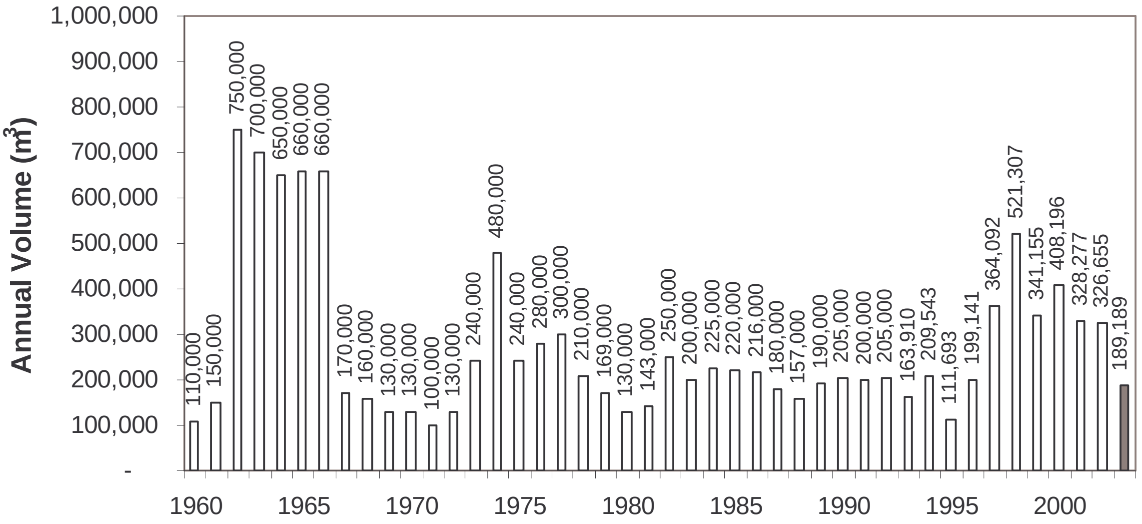
Carson & Griffiths (1989) suggested that the major mechanism of gravel transport appears to be bank scour along braids.[10] Thus, the elimination of sinuous braids would suppress the major mechanism of bed load transport and straightening of braided rivers, narrowing and conversion to single thread would decrease bedload transport rates not increase them as proposed in the Waimakariri Scheme.

Channel narrowing has not flushed out gravel in the Waimakariri River. On the contrary, it probably has accelerated aggradation (e.g. North Branch Ashburton River – Hudson 2000). To flush out gravel requires very constricted channel widths (e.g. the gorges); which would require extreme bank protection in a gravel bed river (Carson 1997).

5 Rates and location of gravel extraction in the lower river

Limited volumes of gravel were extracted from the Waimakariri River in the period up to 1960. Griffiths (1979) reports 380,000 m^3 total in the period 1929-1954 (~15,000 m^3/y). Ecan records [11] show an annual extraction of 110,000 m^3/y in the period from 1955-1961. Recent annual returns are summarized in Fig. 5 (with partial records for 2003).

Fig. 5 Annual gravel returns 1960-2003 (ECan data)



---

[10] This observation is supported by detailed time-lapse photography at Crossbank: Hicks *et al.* (2000).

[11] ECan hand written records tally the gravel returns from 1960 to 1992; and the consents electronic data base has more recent gravel returns. Data was also summarized in "Table II Total shingle movement between surveys." (Data ending 1981).

A major increase in gravel extraction occurred with the construction of the northern motorway. In the period 1962-1966 inclusive 3,742,000 m^3 of aggregate (mainly gravel and sand) was extracted (Table 1). Since then gravel returns show an average extraction of 228,000 m^3/y, but there is a wide range in any given year (100,000 – 520,000 m^3/y) (Fig. 5).

Almost all of the gravel is extracted in the lower reaches below Crossbank. In the period 1960-2003 inclusive 11,700,000 m^3 was removed from below Crossbank and 400,000 m^3 from above Crossbank. Most of the latter (300,000 m^3) was taken in 1974 for the Southern Motorway construction. In the period 1993-2003 almost 95% of the 3,200,000 m^3 extracted was from below Crossbank (km 17.5); particularly between the Old Highway Bridge (km 5.23) and km 11 (2,930,000 m^3) (Fig. 6).

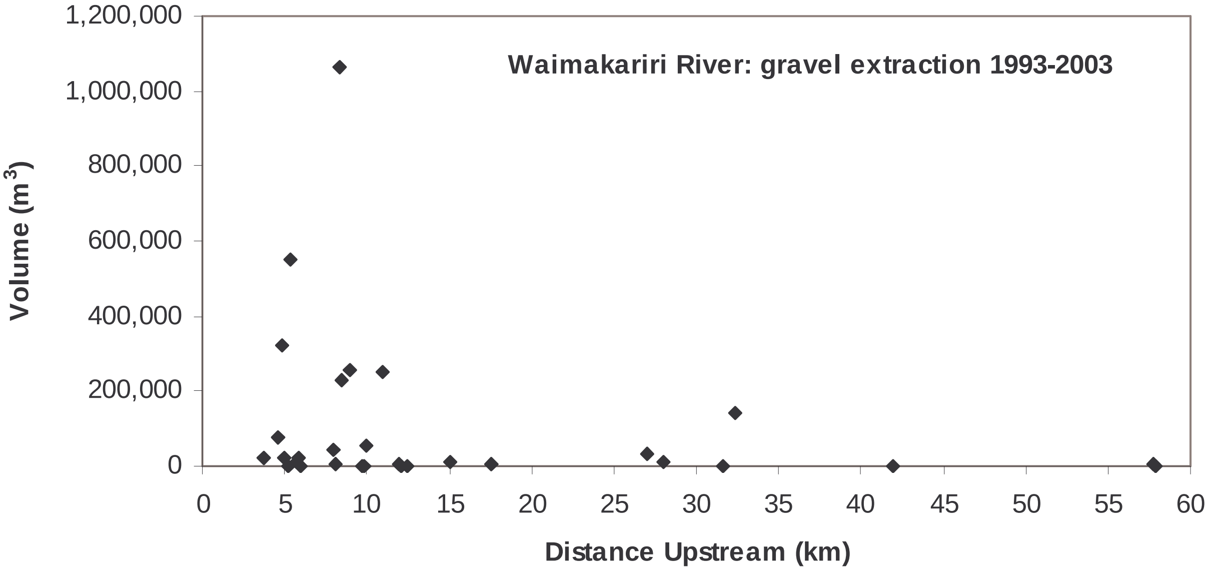


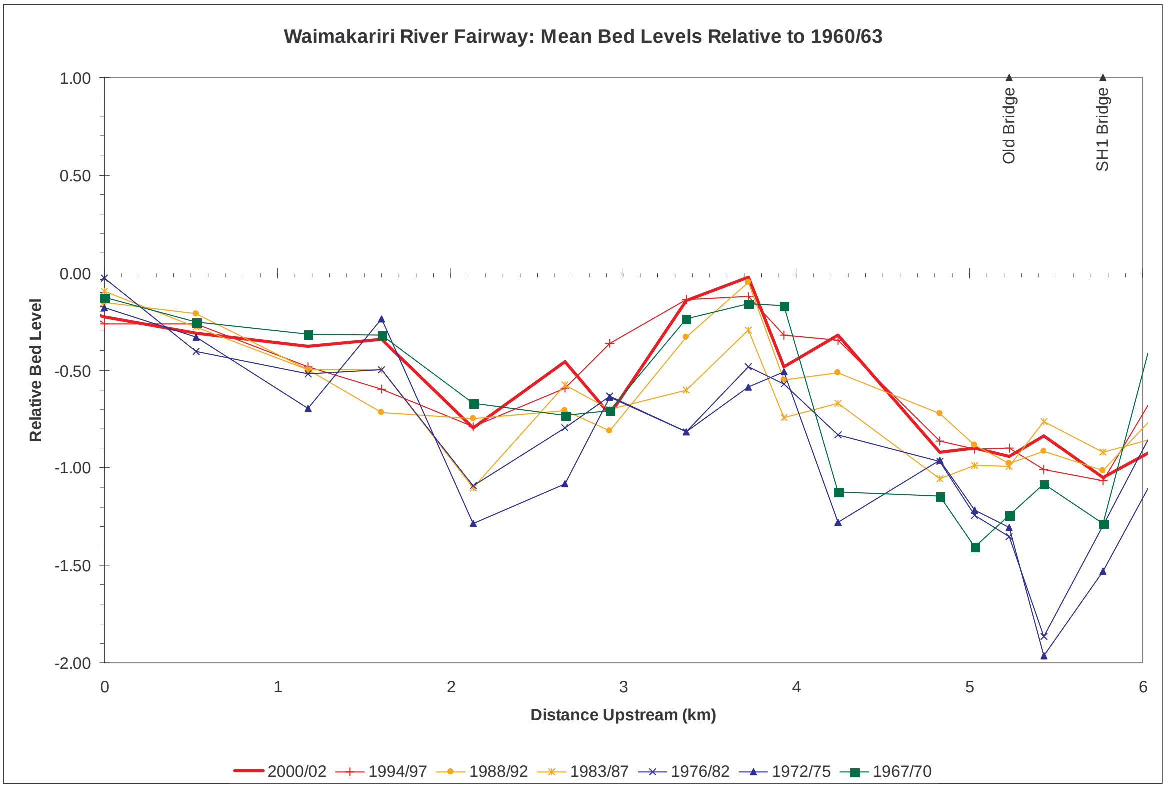
Fig. 6 Location of gravel extraction 1993-2003

6 Effects of gravel extraction

Following the approach of Griffiths (1979) the focus is on gravel and mean bed levels in the active river channel rather than overbank areas which experience significant silt deposition. Data was provided by Environment Canterbury. Survey locations are shown in Fig. 4 and the cross sections are described in Appendix 1.

6.1 Bed levels

In the lower reaches below Crossbank mean bed levels increased, and gravel storage increased 2,400,000 m^3 from the earliest surveys in 1929/32 to 1954/57 (Griffiths 1979). This increase continued to the 1960/63 survey; but there was a major decrease in bed levels with the northern motorway excavations in the vicinity of the bridges (~4-6 km from the mouth) upstream to km 11 in the 1967/68 survey (Fig. 7). The greatest change was in the single thread gravel bed reach upstream to km 10.86 (-0.72 m average); with up to a 1.4 m decrease around the bridges. On average there was little change further upstream.



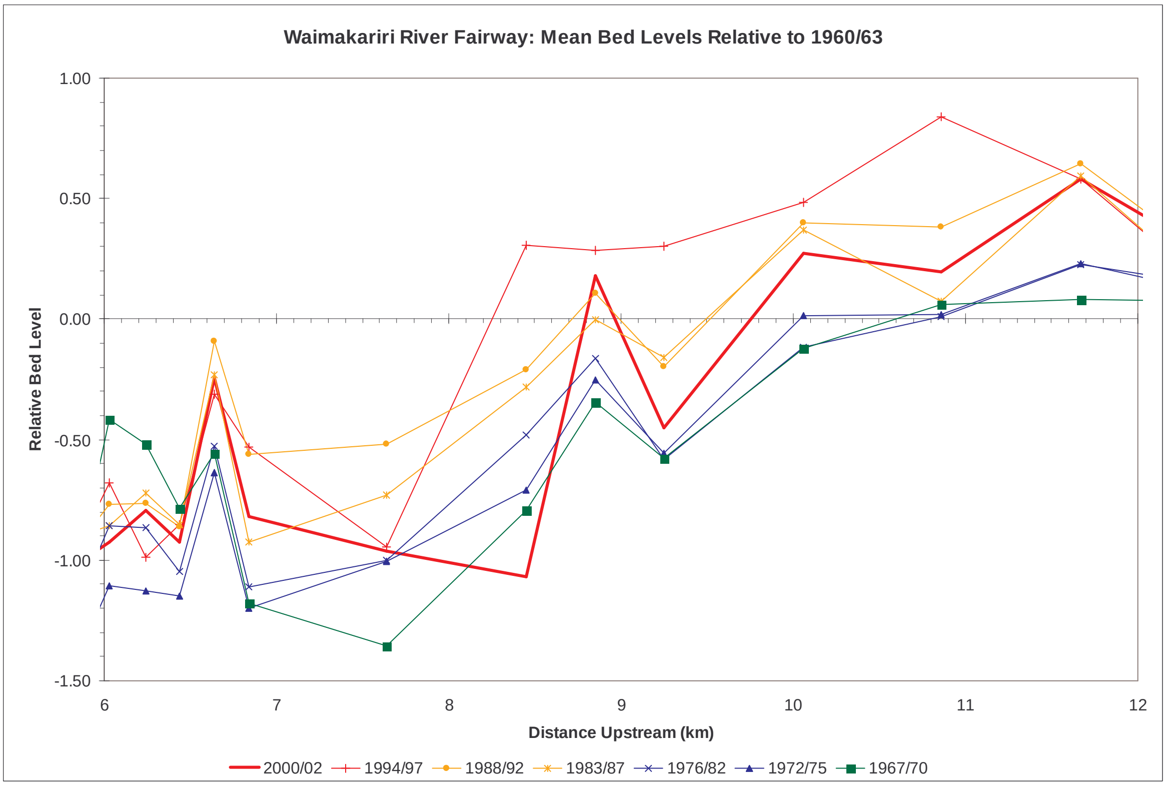


Fig. 7 Recent mean bed levels relative to 1960/63 bed levels (km 0-12)

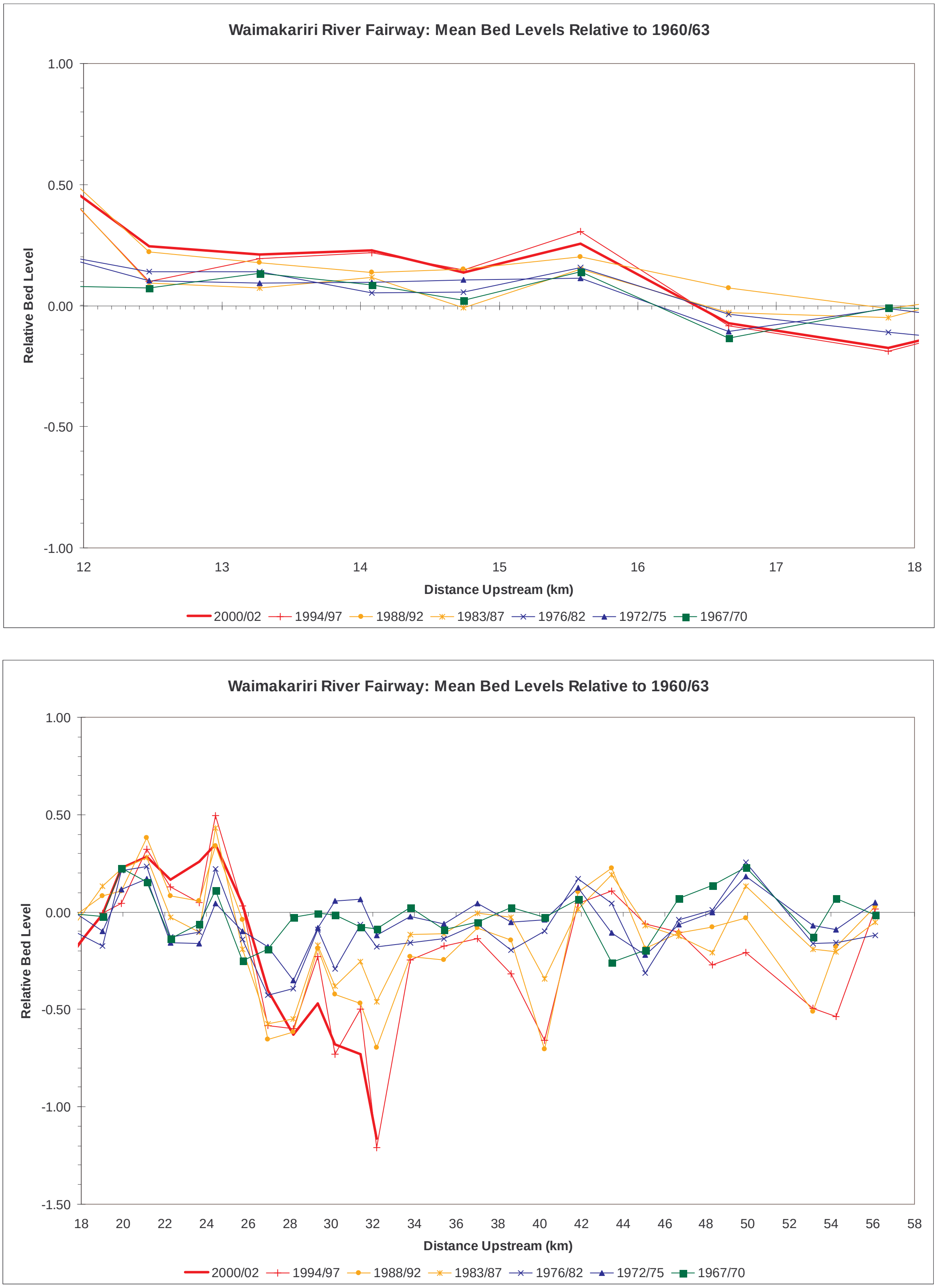


Fig. 8 Recent mean bed levels relative to 1960/63 bed levels (km 12-56)

For each survey period to 2001 the average bed level in the single thread gravel bed reach (to km 10.86) was lower than 1960 (from -0.40 m in 1995 to -0.89 m 1972). However, above km 10 to 16 mean bed levels have been consistently higher than the 1960 levels; with a tendency to increase with time (Fig. 7).

There may be some headward retreat as a consequence of gravel excavation focused between km 7.5 and 8.5. There was no extraction in 1995 and 860,000 m^3 until mid 2001. In this period mean bed levels decreased upstream to km 10.86 (average of -0.48 m) (Fig. 7). There is little difference in mean bed levels upstream to km 16 in the 1995 to 2001 period (average of -0.02 m), but mean bed levels are on average 0.17 m higher in 2001 than 1960 (Fig. 7, Fig. 8).

Relative to 1960, mean bed levels are variable with local recent degradation (~km 17-19) and aggradation (km 20-26 ~0.30 m higher) above Crossbank (Fig. 7, Fig. 8). There is evidence of sediment waves (Griffiths 1979) but overall there is a strong tendency for progressive degradation above km 25.

6.2 Flood levels

Flood levels from the 1960 flood investigations were compared with flood levels predicted with the same assumptions, but with recent cross section surveys (Montgomery Watson 2000). They found that aggradation has significantly reduced fairway channel capacity in sections of the river.

Predicted water levels from the MW (2000) study were plotted as deviations from the 1960 water levels; and the most recent bed level surveys have been likewise compared with the 1960 mean bed levels (Fig. 9). Surveys in the study reach were undertaken in 1994/95, not 1994/99, which is important because of subsequent changes.

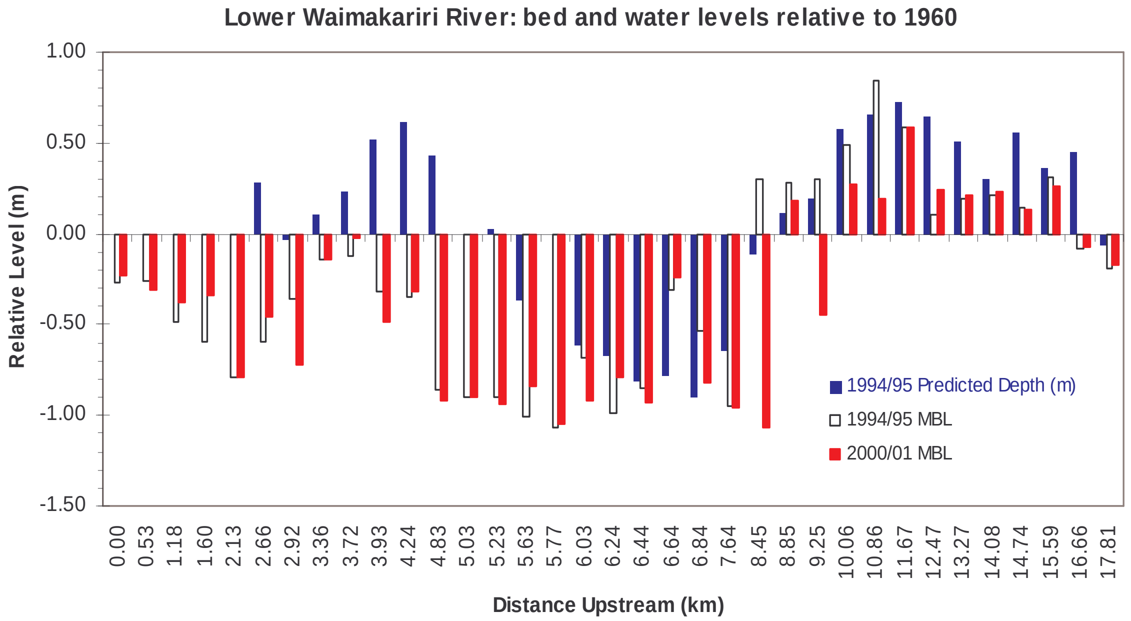


Fig. 9 Predicted water levels and mean bed levels relative to 1960 design conditions (data from MW 2000; ECan)

Effects of the motorway gravel extraction are clearly evident in the bed levels of the lower river: predicted water levels above the bridges to km 8.85 are on average 0.55 m lower than the design water levels (Fig. 9). Montgomery Watson (2000) attributes higher water levels both downstream and upstream of the bridges to aggradation. This is only partly correct (Fig. 9):

- Raised water levels below the bridges are not associated with increased bed levels – the bed is lower than 1960
- Upstream of the constricted single thread channel reach (~km 9) aggradation has decreased channel capacity.

The greatest increase in water levels was 0.72 m (km 11.67), with an average increase of 0.53 m from km 10-16. The reach above Crossbank was not evaluated in the 1960 flood investigations.[12]

As a consequence of aggradation in the period 1960-1994/95 fairway capacity has decreased from the design flow of 4730 m^3/s to as low as 1770 m^3/s. The reach average capacity of the upper segment from km 8.85-16.66 is 2980 m^3/s.

Subsequent channel changes have modified this situation. As noted earlier, bed levels are lower in 2000/01 than the modelled scenario (1994/95 surveys) in the critical reach around km 8-11. This lowering is probably due to gravel extraction immediately downstream. Never the less, a serious under-capacity situation still exists. Targeted gravel extraction is required to alleviate this situation, with large volumes of gravel removal to achieve the design capacity.

6.3 Gravel transport and storage

In the period 1967/68 to 1995 the sand bed reach to the mouth degraded 102,048 m^3 (3,650 m^3/y); but the gravel bed river reach upstream to Crossbank aggraded by 2,136,355 m^3 (~76,300 m^3/s) in 28 years. From mid 1967 to mid 1995 (28 years) gravel extraction totalled 5,604,300 from the plains below the gorge; of which 402,250 m^3 was from above Crossbank. Thus, the bedload passing Crossbank was ~262,000 m^3/y, which is consistent with estimates for other periods (Griffiths 1979; Carson & Griffiths 1989).

From mid 1995 to mid 2001 (survey years) 1,866,455 m^3 of gravel was removed from the gravel reach below Crossbank (~310,000 m^3/y); but the gravel input past Crossbank was relatively low (1,036,079 m^3; ~173,000 m^3/y). In the six year period the sand bed reach aggraded ~42,640 m^3; the bridge reach (km 2.66-5.63) degraded 18,374 m^3; and the reach from the bridges to km 10.86 degraded ~740,777 m^3. Thus, the total net losses for the single thread channel gravel bed reach downstream of km 10.86 averaged ~145,000 m^3/y.

---

[12] Williman & Low (1988) (cited in Griffiths 1991) computed flood levels from Halkett (km 35.4) to the mouth. They reported no loss of capacity. However, when the 1982/83 bed levels are compared with the 1994/95 bed levels used by MW (2000) the expectation would be that the floodway in 1982/83 was under capacity for some of the lower river cross sections (km 2.66, 3.36-4.83); possibly around km 11-17 & 20-26; and probably for km 10.86 & 12.47.

This loss of bed volume strongly suggests that present rates of gravel extraction (>300,000 m^3/y) in the lower reaches are not sustainable under current conditions of low bedload input (Section 4).[13] However, there appears to be a positive effect on reducing bed levels immediately upstream where fairway capacity is impaired by high bed levels.

The reach from km 11.67 to Crossbank (km 17.81) aggraded 784,815 m^3 from 1968 to 1995 (29,000 m^3/y); and degraded (-71,225 m^3) from 1995 to 2001 (~12,000 m^3/y). There was minor gravel extraction in this reach (3,750 m^3/y in the period mid 1995 to mid 2001).

In terms of present stored volumes (2000/02 surveys) relative to the 1960 design fairway condition, the single thread gravel reach below km 10.06 has an overall deficit of 1,401,560 m^3; but from km 10.86 to km 16.66 there is a surplus of 1,189,407 m^3; and a surplus of 2,448,191 m^3 from km 10.86 to km 25.75 (Fig. 10). There is a major deficit relative to 1960 upstream of km 29.96 to km 32.13 (-3,578,438 m^3) in the period 1960-2000/02.[14] Compared to 1960, by 1995 the volume stored in the reach from km 32.13 to km 56.13 decreased by 6,227,340 m^3.

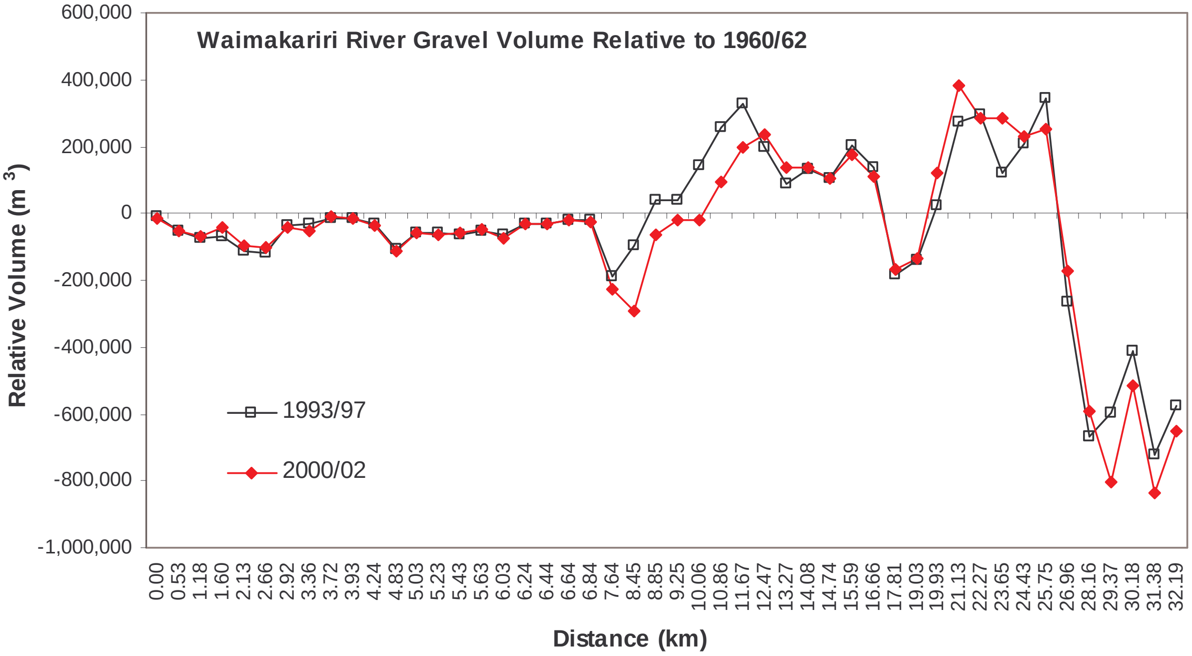


Fig. 10 Volume of stored gravel between cross sections relative to 1960/62

---

[13] This may be a temporary lull in bedload input associated with modest floods in the intervening period.

[14] The surveys further upstream have been completed by ECan (Meccia, pers. comm.) but are not processed.

7 Discussion and recommendations

“Gravel” in this report refers to riverbed material, largely consisting of sand and gravel sized material, but ranging from very fine material (silt and clay) to cobbles and boulders.

There are significant differences in the gravel available along the lower Waimakariri River and particular locations where gravel should or should not be extracted.

> *To ensure that gravel extraction occurs in the correct locations; and to ensure accuracy in reporting gravel returns, all distances should be specified in terms of the ECan river distance/cross section location maps.*

Gravel budgets based on cross sections and mean bed levels refer to the undisturbed material in the riverbed. It is uncertain if the gravel returns are for the volume extracted or loose material. The difference is substantial (often a factor of 1.15 to 1.20 between the undisturbed volume and the loose volume for sand-gravel mixtures).

> *To ensure that gravel budgets can be calculated correctly, and to correctly measure the gravel resource if fees are applied, accurate measures (± 10%) of the weight or loose volume of gravel extraction should be reported.*

Bed levels in the bridge reach (to km 5.63) downstream have been maintained with the rate of gravel extraction from 1995 to 2001.

> *Extraction in the gravel reach from the motorway bridge (km 5.63) downstream should not exceed recent rates (1995-2001: 100,000 m^3/y), unless bed levels increase significantly (i.e. start effecting flood levels), or effects are considered to be significant (e.g. gravel build up in the sand reach is not acceptable).*

Bed levels in the bridge reach (km 4.83-5.63) are probably highly sensitive to local gravel extraction. Fairway capacity is not an issue, but bridge stability is a concern. Guidelines with respect to gravel extraction and monitoring were recommended by Boyle (1996) and appear to be working satisfactorily with maintenance of bed levels in the range of the levels experienced in the 1980s (but well below the 1960 levels). Specification of a minimum bed level at any point in the cross section highlights the variability in bed levels across the channel and danger of localised bridge pier undermining. The minimum allowable bed level is 3.5 m below the mean bed level trigger, which appears realistic. Similarly, the mean bed level trigger reflects the historic minimum mean bed levels following the huge volume of gravel extraction for motorway construction. It would be difficult to justify a lower bed level unless the design specifications of the bridges show the piers are very deep (which is doubtful, particularly for the old road and rail bridges). Conversely, a higher trigger level would be difficult to justify given the historic precedent.

> *Present trigger levels and guidelines for extraction near the bridges (Boyle 1996) should be continued.*

A high point exists in the bed around km 3-4 relative to the 1960 bed level. This has reduced fairway capacity at km 2.66, and km 2.92 - 4.83 to less than the design. It is likely that this situation has prevailed since the 1980s. The flood risk may have changed since the 2000 survey, but this is unknown.

> *The situation should be assessed, based on resurvey of the cross sections and re-evaluation of design flood levels.*
>
> *If high bed levels persist, increasing flood risk, gravel extraction should be directed to the problem reach.*

Bed levels from the motorway bridge (km 5.63) upstream to km 8.45 were substantially reduced to supply gravel for motorway construction in the 1960s. Bed levels up to km 10.4 have been maintained at low levels providing large fairway capacity in a relatively narrow reach. Since 1968 the pit from km 6.64 to km 10.4 has partially infilled. Reach specific figures of extraction are not available for the whole period, but the total extraction for the reach below Crossbank averaged 220,000 m^3/y for the period 1967-2001. (120,000 m^3/y probably occurred from the bridges to km 8.5; with ~100,000 m^3/y from the reach downstream of the bridges).

> *The sustainable rate of excavation for the gravel reach between km 2.5 and km 8.45 exceeds 220,000* m^3*/y over the long term.*

High bed levels upstream of km 10.06 have reduced fairway capacity, particularly around km 12. While it is tempting to direct gravel extraction upstream to this reach, this may not be necessary. Recent rates of extraction (270,000 m^3/y from 1995 to 2001) in the gravel bed reach primarily downstream of km 8.45 appears to be inducing headward retreat into the problem reach.

> *Cross sections (including km 8.45 to 15.59) should be resurveyed and evaluated to determine if headward retreat continues to lower bed levels/flood risk around km 12.*

As well as possibly not being necessary, shifting gravel extraction upstream to the built up reach may not be readily achievable. With the present river alignment and channel pattern, access to the gravel resource is a problem above km 10. There is a deep channel running along the bank protection on the right bank, and the braid bars are low lying and isolated by smaller channels. These bars are frequently flooded. Without extensive flow diversion, excavation from the south bank is probably precluded from km 10-13 km, and there are no major extractors operating from the north bank.

> *The status of bed levels/flood risk in the km 10-16 reach should be evaluated based on more recent survey data before action is contemplated.*
>
> *If high bed levels persist, alternative approaches and locations of gravel extraction should be evaluated.*

Upstream of Crossbank (km 17.81) limited gravel extraction occurs (600,000 m^3 since 1967; with 300,000 m^3 extracted in 1974 for southern motorway construction; 156,000 in 1997-98; and 4 -10,000 m^3/y for the last several years). Bed levels are decreasing because the zone of entrenchment is migrating downstream over the very long term. The present position of the hinge point is reported as km 21 (Lechie 1994) and km 18 (Griffiths 1979), but this is not immediately apparent from the bed level data. While there is some degradation at km 18, the bed is presently higher around km 20-25 than in previous surveys and the 1960 bed level. The bed is progressively lower further upstream (at least to km 32), and is generally much lower than the 1960 bed level.

> *Once the 2004 survey data is processed, bed levels trends should be evaluated to determine the flood risk at the hinge point.*

Different operational rules have been contemplated regarding the width of channel excavation (e.g. full channel width in the lower reaches, and mid channel excavation in the braided reach). The lower excavation reach is narrow (average width ~350 m) with a tendency towards a single channel. The river is about 415 m wide[15] in the reach from river km 9 to 10. The single channel tendency extends upstream to about river km 11. Further upstream the river becomes progressively wider and more braided (~750 m wide from 11.5 to 14 km upstream, and more than 1,000 m at 15 km).

> *The rationale for proposed operational rules should be fully explained.*
>
> *If different operational rules are required, they should be based on channel width and pattern (e.g. full channel downstream of km 11; mid channel upstream km 11).*

An excavation depth of three metres below the natural riverbed prior to excavation may be stipulated as a consent condition. A greater depth of excavation could be justifiably based on the natural minimum bed level (or desired bed level) rather than on an arbitrary depth of excavation from the surface of a point bar. Bed level measurements would be required to establish minimum bed levels; and these values may change over time. This would make excavator operations more complex than a fixed 3 m limit.

> *Design bed levels should be established and signposted at various locations (or written into consent conditions) to identify the maximum permissible depths of excavation.*

Consent conditions often specify measurement of water clarity (e.g. 50 m upstream and 200 m downstream of the excavation point). The upstream reference point is useful, but the 200 m mixing length is arbitrary and inconsistent with 20 times width of the receiving water at the point of discharge proposed by ECan (Main 2003). A conspicuous reduction in visual clarity is sometimes defined in gravel consents as a reduction greater than 20% at the downstream limit of the mixing zone. This is less than what is perceptible to most observers (MFE 1994). A 30% reduction is more realistic (MFE 1994; Norton & Snelder 2003). The black disk method is preferred for accuracy, but for convenience a visual clarity tube could be used (e.g. Kilroy & Biggs 2002).

---

[15] Based on the area of active river bed divided by the reach length (2001 ortho photographs).

If required, specify a zone of reasonable mixing as 20 times the river channel width or 200 m, whichever is greater.

Specify a conspicuous change in visual clarity as a reduction greater than 30 percent at the downstream limit of the mixing zone using a black disk or visual clarity tube.

Smothering of the streambed with fine material was recognised as having a significant impact on aquatic life, but MfE (1994) and ANZECC (2000) do not provide guidelines. Overseas measures of embeddedness are often used because there is a well defined relation between salmonid spawning success and embeddedness (e.g. Bjornn & Reiser 1991; MacDonald *et al.* 1991; Bain 1999); and habitat preferences for native fish and embeddedness (e.g. Jowett & Boustead 2001). If required a consent condition could be specified (Hudson 2005).

Deposition of fine sediment (i.e. < 2mm diameter: sand, silt, and clay) will not increase the embeddedness (Bain & Stevenson 1999) of runs and riffles by more than 10% over a 24-hour period.

8 Acknowledgements

Environment Canterbury (Bill Meccia) provided the river cross section data; location maps (Norm Daniels); gravel returns (Brian McIndoe and Matt Surman); and supporting documents (Belinda van Eyndhoven; Dr. George Griffiths). The constructive review comments of Dr. Murray Hicks (NIWA); Dr. George Griffiths, Tony Boyle and Ian Heslop (Ecan), are greatly appreciated.

9 References

ANZECC 2000. Australian and New Zealand guidelines for fresh and marine water quality. Australia and New Zealand Environment and Conservation Council; Agriculture and Resource Management Council of Australia and New Zealand. www.ea.gov.au/water/quality/nwqms/#quality

Bain, M.B. 1999. Substrate. Pages 95-103 in Bain, M.B.; Stevenson, N.J.; editors. Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, Maryland.

Bain, M.B.; Stevenson, N.J.; editors. 1999. Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, Maryland.

Bjornn, T.C.; Reiser, D.W. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 41-82.

Boyle, A.J. 1996. Waimakariri River bed levels Old Highway Bridge (Christchurch-Kaiapoi). Canterbury Regional Council unpublished report. 6 pages.

Browne, G.H.; Naish, T.R. 2003. Facies development and sequence architecture of a Late Quaternary fluvial-marine transition, Canterbury Plains and shelf, New Zealand: Implications for forced regressive deposits. Sedimentary Geology, 158, p. 57-86

Carson, M.A. 1997. Optimum channel width for gravel bedload transport in channels of given discharge, slope and bed material size. Report U99/70 Canterbury Regional Council, Christchurch. 12 pages.

Carson, M.A.; Griffiths, G.A. 1989. Gravel transport in the braided Waimakariri River: mechanisms, measurements and predictions. Journal of Hydrology 109: 201-220.

CRC. 1995. Proposed Waimakariri regional plan. Canterbury Regional Council Report 95(8).

Day, T.J.; Hudson, H.R. 2001. River management: the recent New Zealand experience. Pages 555-579 in Mosley, M.P.; editor. Gravel-bed rivers V. New Zealand Hydrological Society, Wellington.

ECan. 2004. Waimakariri River Regional Plan. Environment Canterbury Report R04/7. 149 pages.

Gage, M. 1958. Late Pleistocene Glaciations of the Waimakariri Valley, Canterbury. New Zealand Journal of Geology and Geophysics 1: 123-155.

Griffiths, G.A. 1979. Recent sedimentation history of the Waimakariri River, New Zealand. Journal of Hydrology (New Zealand) 18: 6-28.

Griffiths, G.A. 1991. Draft Waimakariri River floodplain management plan. Canterbury Regional Council Report R91(9). 117 pages.

Griffiths, G.A. 1994. Sediment translation waves in braided gravel-bed rivers. Journal of Hydraulic Engineering 119(8): 924-937.

Hicks, D.M. 1998. Sediment budgets for the Canterbury Coast - a review, with particular reference to the importance of river sediment. NIWA Client Report CHC98/2 prepared for Canterbury Regional Council.78 pages.

Hicks, D.M.; Duncan, M.J.; Walsh, J.M.; Westaway, R.M.; Lane, S.N.; Jonas, D.A. 2000. The braided Waimakariri River: new views of form and process from high-density topographic surveys and time-lapse imagery. Gravel bed rivers 2000 CD-ROM. Special publication of the New Zealand Hydrological Society.

Hudson, H.R. 1997. An adaptive management strategy for environmentally sensitive aggregate management in high energy gravel bed rivers in Southland. A report prepared by Environmental Management Associates Ltd, for Southland Regional Council. 82 pages.

Hudson, H.R. 2000. Morphological impacts of river gravel extraction: New Zealand examples. Gravel bed rivers 2000 CD-ROM. Special publication of the New Zealand Hydrological Society.

Hudson HR. 2000. Ashburton River Floodplain Management Strategy: an evaluation of morphological impacts of channel excavations in Blands Reach. Report 2000-02 prepared by Environmental Management Associates Ltd. for Canterbury Regional Council. CRC Report U00/7. 70 pages.

Hudson, H.R. 2003. Ashburton River Floodplain Management Strategy: an evaluation of bedload supply and morphological impacts of gravel extraction for stopbank construction. Environment Canterbury Report U03/15, 52 pages.

Hudson, H.R.; editor. 2005. H20-DSS Hillslopes to Oceans: Decision Support System for sustainable drainage management. New Zealand Water Environment Research Foundation, Wellington, New Zealand. 150 pages

Jowett, I. G.; Boustead, N.C. 2001. Effects of substrate and sedimentation on the abundance of upland bullies (*Gobiomorphus breviceps*). New Zealand Journal of Marine and Freshwater Research 35: 605-613.

Kelly, D.; McKerchar, A.; Hicks, M. 2005. Making concrete: ecological implications of gravel extraction in New Zealand rivers. Water & Atmosphere 13(1): 20-21.

Kilroy, C.; Biggs, B.J.F. 2002. Use of SHMAK clarity tube for measuring water clarity: comparison with the black disk method. New Zealand Journal of Marine and Freshwater Research 36: 519-527.

Leckie, D.A. 1994. Canterbury Plains, New Zealand – implications for sequence strategraphic models. American Association of Petroleum Geologists 78(8): 1240-1256.

Logan, R. Waimakariri. The story of Canterbury's "River of cold rushing water." Logan Publishing, Gisborne. 188 pages.

MacDonald, L.H.; Smart, A.W.; Wissmar, R.C. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. US Environmental Protection Agency and the Centre for Streamside Studies in Forestry, Fisheries and Wildlife, University of Washington. EPA 910/9-91-001. US EPA Seattle. 166 pp.

Main, M.R. 2003. Review of Transitional Regional Plan Rules for Certain Discharges – Incorporating suggestions for amendment in response to public submissions. Environment Canterbury Technical Report No. U03/02 – February.

MfE. 1994. Water quality guidelines no. 2. Guidelines for the management of water colour and clarity. Ministry for the Environment, Wellington. 77 pages.

Mosley, M.P.; Schumm, S.A. 2000. Gravel bed rivers – the view from the hills. Pages 479-501in Gravel-bed rivers V, M.P. Mosley, editor. New Zealand Hydrological Society, Wellington.

MW. 2000. Effects of bed aggradation/degradation on the flood carrying capacity of the Waimakariri River. Montgomery Watson New Zealand Ltd, report for Canterbury Regional Council. 28 pages.

Nelson, G, 1928. Report on the Waimakariri River. A Report to the Waimakariri River Trust, Christchurch. (Cited and map in Griffiths 1991).

Norton, N.; Snelder, T. 2003. Options for numeric water quality objectives and standards for rivers and lakes of Canterbury. Environment Canterbury unpublished report U03/25.

Snelder, T.; Weatherhead, M.; O'Brien, R.; Shankar, U.; Biggs, B.; Mosley, P. 1999. Further development and application of a GIS based river environment classification system. National Institute of Water & Atmospheric Research Ltd Client Report: CHC99/41 for Sustainable Management Fund, Canterbury Regional Council, Environment Waikato.

10 Complementary gravel reports

Hudson, H.R. 2005. Pareora River: Status of gravel resources and management implications. Environment Canterbury Report U05/30.

Hudson, H.R. 2005. Opihi & Tengawai rivers: Status of gravel resources and management implications. Environment Canterbury Report U05/31.

Hudson, H.R. 2005. Waihi River: Status of gravel resources and management implications. Environment Canterbury Report U05/32.

Hudson, H.R. 2005. Orari River: Status of gravel resources and management implications. Environment Canterbury Report U05/33.

Hudson, H.R. 2005. Ashburton River: Status of gravel resources and management implications. Environment Canterbury Report U05/34.

11 Appendix

Dist. (m)	1960/63	1967/70	1972/75	1976/82	1983/87	1988/92	1994/97	2000/02
-470		69/1	72/1	77/1	83/1	88/1	94/1	00/1
0	62/1	68/1	72/1	77/1	82/1	88/1	94/1	00/1
530	62/1	68/1	72/1	77/1	82/1	88/1	94/1	00/1
1180	62/1	68/1	72/1	77/1	82/1	88/1	94/1	00/1
1600	62/1	67/1	72/1	76/1	82/1	88/1	94/1	00/1
2130	62/1	67/1	72/1	76/1	82/1	88/1	94/1	00/1
2660	62/1	67/1	72/1	77/1	82/1	88/1	94/1	00/1
2920	62/1	67/1	72/1	76/1	82/1	88/1	94/1	00/1
3360	62/1	67/1	72/1	76/1	82/1	88/1	94/1	00/1
3720	62/1	68/1	72/1	76/1	82/1	88/1	94/1	00/1
3930	61/1	67/1	72/1	76/1	83/1	88/1	94/1	00/1
4240	61/1	67/1	72/1	76/1	82/1	88/1	94/1	00/1
4830	61/1	67/1	72/1	76/1	83/1	89/1	97/1	01/1
5030	61/1	67/1			87/1	89/1	97/1	01/1
5230			72/1	77/1	83/1	89/1	97/1	01/1
5430	62/1	68/1	72/1	77/1	83/1	89/1	97/1	01/1
5630	60/1	67/1	72/1	77/1	84/1	89/1	97/1	01/1
6030	60/1	67/1	72/1	77/1	84/1	89/1	95/1	01/1
6240	60/1	68/1	72/1	77/1	84/1	89/1	95/1	01/1
6440	60/1	67/1	72/1	77/1	84/1	89/1	95/1	01/1
6640	60/1	67/1	72/1	77/1	84/1	89/1	95/1	01/1
6840	60/1	67/1	72/1	77/1	83/1	89/1	95/1	01/1
7640	60/1	67/1	72/1	77/1	83/1	89/1	95/1	01/1
8450	60/1	68/1	72/1	77/1	83/1	89/1	95/1	01/1
8850	60/1	68/1	72/1	78/1	83/1	89/1	95/1	01/1
9250	60/1	68/1	72/1	78/1	84/1	89/1	95/1	01/1
10060	60/1	68/1	72/1	78/1	84/1	89/1	95/1	01/1
10860	60/1	68/1	73/1	78/1	84/1	89/1	95/1	01/1
11670	60/1	68/1	73/1	78/1	84/1	89/1	95/1	01/1
12470	60/1	68/1	73/1	78/1	84/1	89/1	95/1	01/1
13270	60/1	68/1	73/1	78/1	84/1	89/1	95/1	01/1
14080	60/1	68/1	73/1	78/1	84/1	89/1	95/1	01/1
14740	60/1	68/1	73/1	78/1	84/1	89/1	95/1	01/1
15590	60/1	68/1	73/1	78/1	84/1	89/1	95/1	01/1
16660	60/1	68/1	73/1	78/1	84/1	89/1	95/1	01/1
17810	60/1	68/1	73/1	78/1	84/1	89/1	95/1	01/1
19030	61/1	68/1	73/1	79/1	85/1	91/1	96/1	02/1
19930	60/1	69/1	74/1	79/1	85/1	91/1	96/1	02/1
21130	61/1	69/1	74/1	79/1	85/1	91/1	96/1	02/1
22270	61/1	69/1	73/1	79/1	85/1	91/1	96/1	02/1
23650	61/1	69/1	74/1	80/1	85/1	91/1	96/1	02/1
24430	61/1	69/1	74/1	80/1	85/1	91/1	96/1	02/1
25750	61/1	69/1	74/1	80/1	85/1	91/1	96/1	02/1
26960	61/1	69/1	74/1	80/1	85/1	91/1	96/1	02/1
28160	61/1	69/1	74/1	80/1	85/1	91/1	96/1	02/1
29370	61/1	69/1	74/1	80/1	85/1	91/1	96/1	02/1
30180	61/1	69/1	74/1	80/1	85/1	91/1	96/1	02/1
31380	62/1	69/1	74/1	80/1	84/1	91/1	96/1	02/1

32190	62/1	69/1	74/1	80/1	85/1	91/1	96/1	02/1
33800	62/1	70/1	74/1	80/1	85/1	92/1	97/1	
35410	62/1	70/1	74/1	80/1	85/1	92/1	97/1	
37010	62/1	70/1	74/1	81/1	85/1	92/1	97/1	
38630	62/1	70/1	74/1	81/1	86/1	92/1	97/1	
40230	62/1	70/1	74/1	81/1	86/1	92/1	97/1	
41840	62/1	70/1	74/1	81/1	85/1	92/1	97/1	
43450	62/1	70/1	75/1	81/1	87/1	92/1	97/1	
45060	63/1	70/1	75/1	81/1	86/1	92/1	97/1	
46670	63/1	70/1	75/1	82/1	87/1	92/1	97/1	
48280	63/1	70/1	75/1	81/1	86/1		97/1	
49890	63/1	70/1	75/1	81/1	87/1	92/1		
53110	63/1	70/1	75/1	82/1	87/1		97/1	
54210	63/1	70/1	75/1	82/1	87/1		97/1	
56130	62/1	70/1	75/1	82/1	87/1	92/1	97/1	