Pareora River:

Status of gravel resources and management implications

Report U05/30

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Summary

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

Major findings/recommendations include:

- Some corrections in the gravel returns data base are required; and historic records should be incorporated.
- Gravel extraction is cyclical with reported annual rates over the last 30 years varying from nil to 38,000 m^3/y; with an average of ~12,000 m^3/y historically; ~18,000 m^3/y for 1990-1999; with increased extraction since then (~40,000 m^3/y). More than 95% of extraction occurs in the lower 15 km; with a shift from the lower few km to the middle section from 1990 to 2003.
- Degradation increased from ~4,800 m^3/y (1949-1967) to ~25,000 m^3/y since then. In the first period extraction greatly exceeded degradation (a factor of 2.5). In the 1967-1986/87 period extraction accounted for ~40% of degradation; and recently (1986/87-1999) extraction accounted for ~90% of degradation.
- Increased degradation is attributed to a combination of factors; including probable declines in sediment supply as the river was confined to about half its original width by treed berms, and as the river lost its braided habit and was forced to flow more as a single thread channel with less transport capacity. The gorge water supply dam initially trapped bedload, but does not appear to impede transport at present.
- Contrary to conventional wisdom, recent river re-grading due to coastline retreat is probably a small component of the lower river degradation (~500 m^3/y); because the rate of coastline retreat is small (1938-1984: 0.32 m/y; 1977-2000: 0.04 m/y). The volume attributable to coastal retreat is probably less than the error in gravel returns.
- Bed levels have declined by ~50 cm since 1949, with a few exceptions where bed levels increased locally. Gravel is not being replenished at the rate of extraction and supply is unsustainable.
  - ⇒ Extraction should be limited to local small scale uses.
  - ⇒ Alternative supplies should be evaluated (e.g. off channel; land based; and coastal zone).
- If large scale extraction continues significant bed lowering will result with potential adverse effects on channel bed and bank

stability, bridges, pipelines, and stream habitat. If large scale gravel extraction continues:

⇒ An assessment of effects on channel and bank stability, and infrastructure, is required.

⇒ Bed levels in the bridge reaches may be approaching critical levels, and a management plan may be required.

⇒ Effects on physical habitat and aquatic life should be evaluated.

- A positive consequence of large scale gravel extraction and channel degradation is that floodway capacity exceeds the scheme design capacity. However, with revised streamflow estimates, the design flow is about a 10 year return period flood.
- To provide 1:25 year flood protection with 30 cm freeboard, removal of about 100,000 m^3 from the fairway is required based on 1999 bed levels. This has probably already occurred, but some small scale targeted gravel extraction may be required.

⇒ A re-survey of selected cross sections is required.

⇒ Flood capacity should be re-assessed based on the re-surveyed bed levels.

⇒ Gravel should be removed to establish flood capacity, or for river control purposes, if required.

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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 for several rivers including the Pareora River in South Canterbury (Fig. 1).

Careful management of the gravel resources of the Pareora River 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, with major financial implications and potential liabilities to Environment Canterbury.
3. Over exploitation can have significant environmental effects in the rivers themselves (Hudson 1997; Day & Hudson 2001; Kelly *et al.* 2005) and on the coastal zone (e.g. reduced aggregate supplies accelerating coastal erosion – Kirk 1991).
4. Gravel extractions, and control of gravel supplies, are essential components of floodplain management in the Pareora River (ECan *et al.* 2003).

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

- Gravel supplies.
- Rates and location of gravel extraction.
- Affects on the river bed.
- Discussion and recommendations.

2 River character

The Pareora is a rainfall fed gravel bed river flowing from the north-west to south-east trending Hunters Hills to the coast south of Timaru (Fig. 1). The 58 km long river initially flows along a fault in a northerly direction through steep greywacke-argillite hill country before flowing through downlands (rolling topography) where the flow is easterly then south-easterly. The downlands of the Cannington Flat are underlain by gravel with a thick mantle of loess (fine textured wind blown sediment) (Waugh 1987). The upper and lower catchments are separated by a short gorge section (~km 20-22) formed in Mount Horrible basalts and limestone. Elevation ranges from ~100 m at the gorge to 1,591 m (Te Huruhuru).

Major tributaries include Burnett Stream, draining from the north; and White Rock River, Motukaika Stream and the South Branch Pareora

[1] "Gravel" is a specific size range of rock fragments (2-64 mm); but is also commonly used to describe riverbed material, largely consisting of sand and gravel sized material, but ranging from very fine material (silt and clay) to cobbles and boulders. Also called "shingle."

River draining from the Hunter Hills in the south-west. These tributaries join the upper Pareora above km 16.9 (Fig. 1). At Pareora Huts (km 16; 424 km^2) the mean annual flood is 239 m^3/s and the 10 year return period flood is 568 m^3/s (ECan website).

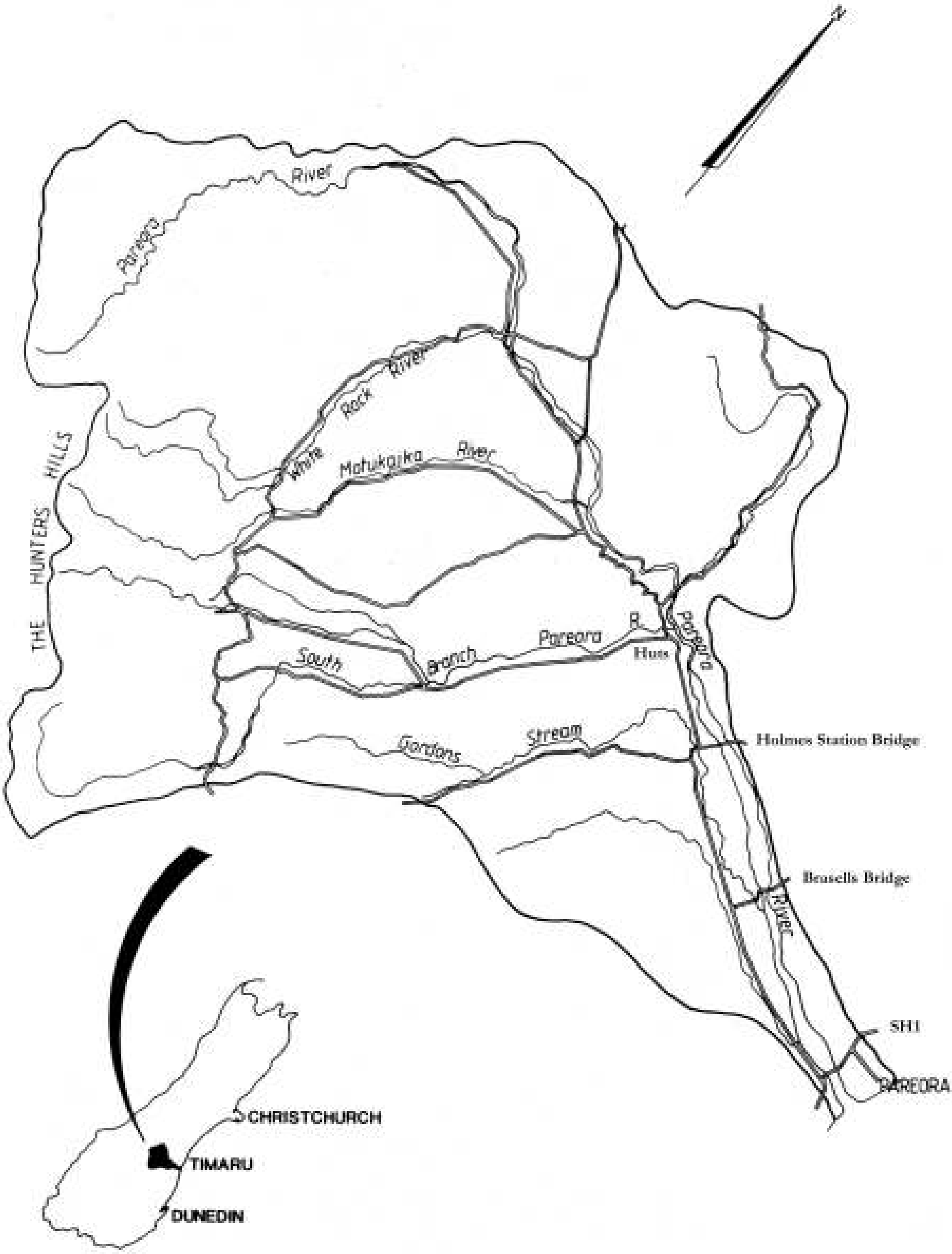

Fig. 1 Pareora River catchment geography (based on Waugh 1987)

In the Lower Pareora River below the gorge the plains are composed of alluvium ranging from stony gravels and boulders to silt. The floodplain is ~2km wide on the southern side of the river. The northern side of the river is bounded by high terraces which extend along the north bank from the gorge to the coast. Near the gorge the terraces are close to the river, but over the lower ~8 km the terraces are up to 1.5 km north of the present river. The floodplain, which lies between the higher elevation north bank terrace and downlands to the south, is low elevation with contour lines suggesting the river is weakly incised.

Gordons Valley Stream and several spring fed streams enter the lower river. These streams are often dry in the summer (Hayward *et al.* 2003). The Pareora itself has a mean flow of 3.7 m^3/s at the gorge (ECan website), but the lower ~13 km may cease to flow in dry years (Waugh 1987). The catchment area at the coast is about 540 km^2 (Waugh 1987).

Land use in the upper catchment is generally low to moderately intense sheep and cattle grazing, with some cropping, and native forest in the upper valley and tributaries. The downlands and plains have intensive farming with land uses on the floodplain including sheep, beef, and dairy farming (ECan *et al.* 2003).

The largest centre in the catchment is Pareora township with a population of 462 in 2001 (Statistics New Zealand); and the major industrial activity is the Pareora freezing works on the margin of the lower floodplain near the sea. There is a small holiday house settlement adjacent to the river at Pareora Huts.

3 Flooding and flood management

Easterly and southerly airflows provide the bulk of the precipitation which varies from more than 1000 mm along the Hunter Hills to 600 mm at the coast. In winter there may be a small snow pack at elevations greater than 1200 m, which produces higher base flows in the spring (Waugh 1987).

Annual flood peaks range from 22.5 m^3/s (1982) to an estimated peak flow of 1,450 m^3/s in 1986 (an estimated return period of 150 years; ECan *et al.* 2003). This was an extreme event in much of South Canterbury and was more than twice the size of Pareora floods in 1951 and 1961. In each decade since 1930 the Pareora River has at least one flood of about 600-700 m3/s, with occasional larger events, such as in 1932 and 1986 (Waugh 1987).

After a history of flooding the Lower Pareora River Control Scheme was initiated by a report to the Soil Conservation and River Control Council in 1958 (Jones 1958; cited in SCCB 1981). Objectives of the scheme included (SCCB 1981; Waugh 1987):

- Protection of the Pareora township.[2]
- Initial provision of 25 year flood protection in main stem and lower river tributary streams with a 300 mm freeboard (using

[2] Pareora township is located on the north bank terrace and is higher than the estimated 500 year flood level (Fig. 2 in ECan *et al.* 2003).

channel straightening, gorse and broom clearance, berm planting and stopbanking).

- Bring about the entrenchment of the main flood channel, heightening of berms and confinement of all except extreme floods below berm levels.
- Ultimately developing, by natural channel evolution of a single thread channel, a main river floodway with a stable width of 160m and fairway of 76 m containing a 100 year flood.
- Upstream of the gorge isolated works include stopbanking, bank protection and gravel control structures.

Stopbanks were constructed along much of both banks from the gorge to the sea, apart from where there were relatively high terraces. It was conceded that the 1958 scheme objectives would not be met unless considerable live planting and selective heavy bank protection work was undertaken (SCCB 1981). Fig. 2 to Fig. 4 illustrate the extent of river confinement pre-scheme (1951), at the time of the scheme review (1981) and in 2004. At the survey cross sections the average width in 1951 was 309 m (range 66-812 m); compared with 155 m in 2004 (range 108-220 m).

Waugh (1987) described the design flow of the river as 400 m^3/s at the gorge and 500 m^3/s at State Highway 1 (km 1.43) with 300 mm freeboard; with a maximum carrying capacity of the stopbanks of 600-700 m^3/s – a return period of 15 years. CHFM (2004) provide similar values for the scheme capacity: (493 m^3/s from cross sections 1-6; 467.5 m^3/s from 7-13; 433 m^3/s from 14-20; and 397 m^3/s from 21-27).

Recently the scheme objectives have been revised (ECan *et al.* 2003): “To maintain the Lower Pareora River Control Scheme to minimise erosion, flooding and aggradation and to contain a flood flow of 500 m^3/s (cumecs) downstream of the Pareora Huts". With a longer period of record, a 500 m^3/s design flow is now equivalent to approximately the 10 year return period (10% Annual Exceedance Probability) event.

A major flood in 1961 caused widespread flooding and damage to scheme works, but the scheme did minimise flooding over the next 25 years. The March 1986 flood (1,450 m3/s; 150 year return period), probably the largest since 1868, “…completely overwhelmed the scheme works with several kilometres of stopbanks overtopped and large overflows onto the floodplain. The first major breakout was at Pareora Huts, where the stopbank was overtopped by 700 mm and subsequently breached causing major devastation to the Huts area. Several huts were washed away and floodwaters entered a further 35 (approximately) huts/baches. It was estimated that approximately 500 m^3/s (cumecs) spilled onto the floodplain.” (ECan *et al.* 2003).

There is an apparent contradiction between the design capacity and the frequency of flooding that has occurred. The reason is that the bed has degraded by about 40 cm since 1967 which has provided greater flood capacity (CHFM 2004).

Gravel management is an important component of the Pareora River floodplain management strategy. SCCB (1981) identified aggradation and berm-terrace erosion at km 4.7. Elsewhere degradation and bed scour combined with meandering carved out berms leaving high banks and undermining pole planting.

ECan *et al.* (2003) reported that potentially aggradation could be a problem, but commercial gravel extraction of ~20,000 m^3/y on average maintained bed levels in the period 1986-1999. “Gravel extraction – to help maintain channel capacity, extraction by contractors has and should continue to be encouraged in areas where there is some aggradation.” Continuation of the ten year bed resurvey was recommended with additional surveys if required.

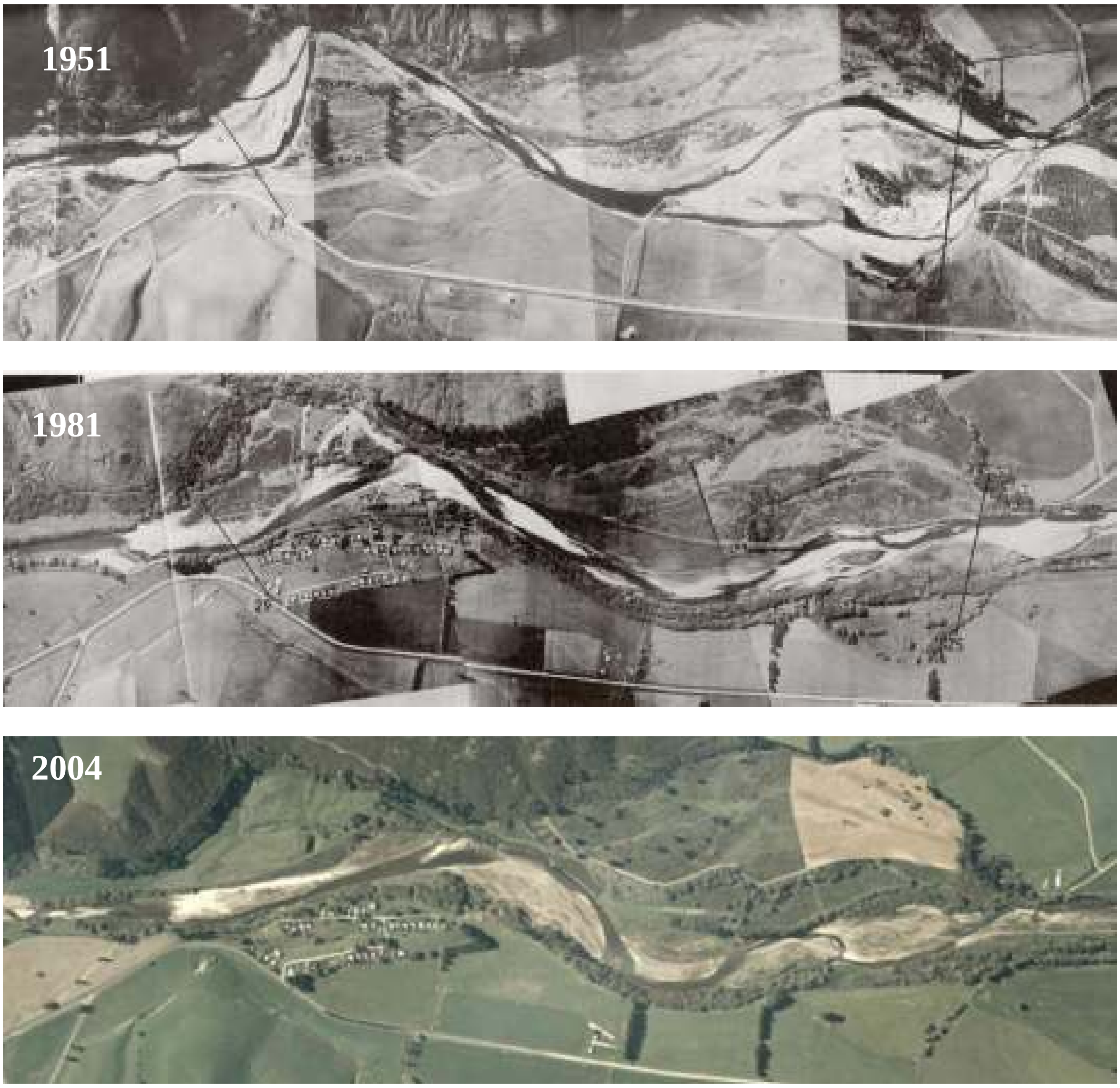

Fig. 2 Pareora River at Pareora Huts 1951, 1981 and 2004 (SCCB 1981 and LINZ aerial photographs)

Fig. 3 Pareora River at Brasell's Bridge 1951, 1981 and 2004 (SCCB 1981 and LINZ aerial photographs)

Fig. 4 Pareora River mouth 1951, 1981 and 2004 (SCCB 1981 and LINZ aerial photographs)

4 Gravel supply

Gravel is derived from most of the upper catchment tributary streams and from the Pareora River itself. Most of the gravel, consisting mainly of greywacke, is from bed and bank erosion. Tributaries to the lower river (below the gorge) carry very little gravel and several were straightened, cleared, and constructed into grassed waterways (SCCB 1981).

With confinement into a single thread channel, suppression of gorse and broom growth in the fairway and promotion of berm vegetation, the river is likely to have lower gravel inputs. However, contrary to SCCB (1981), the river probably has a reduced transport capacity because braided rivers are more efficient at transporting gravel than single thread channel (see discussion in Hudson 2005 – Waimakariri River).

There are two dams, one at the lower end of the gorge (km 20.8); and a dam and intake at km 42.7 in the upper valley. The gorge dam was constructed for the Timaru water supply, but SCCB (1981) note that "…due to aggradation and other reasons the dam is no longer in use. However, the dam still remains and it is possible the dam and the gorge have had some effect on the degradation of the river downs as far as cross section 26." (Km 15.34).

Timaru District Council draws water from the Pareora at the gorge dam although it is largely infilled with gravel.[3] Extensive gravel deposits are evident upstream, but it is unlikely the dam impedes gravel transport in floods. The upper valley dam is not evident in aerial photographs, which suggests it may be buried and does not impede gravel transport downstream.

5 Rates and location of gravel extraction in the lower river

Gravel extraction in the lower river varied from zero to 35,498 m^3 per year in the period 1971 to 1980 (average 12,277 m^3) (SCCB 1981). Williman & Smart (1987) report historic rates of sand and gravel extraction of 11,000 m^3/y.

Consent records show that in the period 1990-2002 a total of 254,200 m^3 was extracted (~19,550 m^3/y over the 13 years) from the Pareora River. In the first six months of 2003 almost 24,000 m^3 was extracted, so the projected volume for the year is ~48,000 m^3 (Fig. 5).

Gravel extraction appears to be cyclical with major surges of extraction (e.g. 1974: 35,498 m^3; 1975: 27,989 m^3; 1979: 23,305) with recent reported highs of ~38,000 m^3 (Fig. 5). There is no trend of statistical significance.

The location of extraction also varies (Fig. 6).[4] In the first five years of record where locations are specified (1990-1994) 74,000 m^3 was extracted with 53% from the lower 3 km; 42% from km 3-14; and 5%

[3] Judy Blakemore, Timaru District Council, pers. comm.

[4] Some of the locations are incorrectly specified, or not specified (involving 5% of the total extracted). These were corrected based on the history of extraction by contractors.

from the upper catchment (>km 20). From 1995-1999 123,000 m^3 was extracted, with 54% from the lower 3 km; 44% from km 3-14; and 2% from the upper catchment. In the three years 2000-2002, when 57,200 m^3 was extracted, 21% was from the lower 3 km; 72% from km 3-14; and 7% from the upper catchment. The km 14-21 reach had a total extraction of 634 m^3 (0.25%).

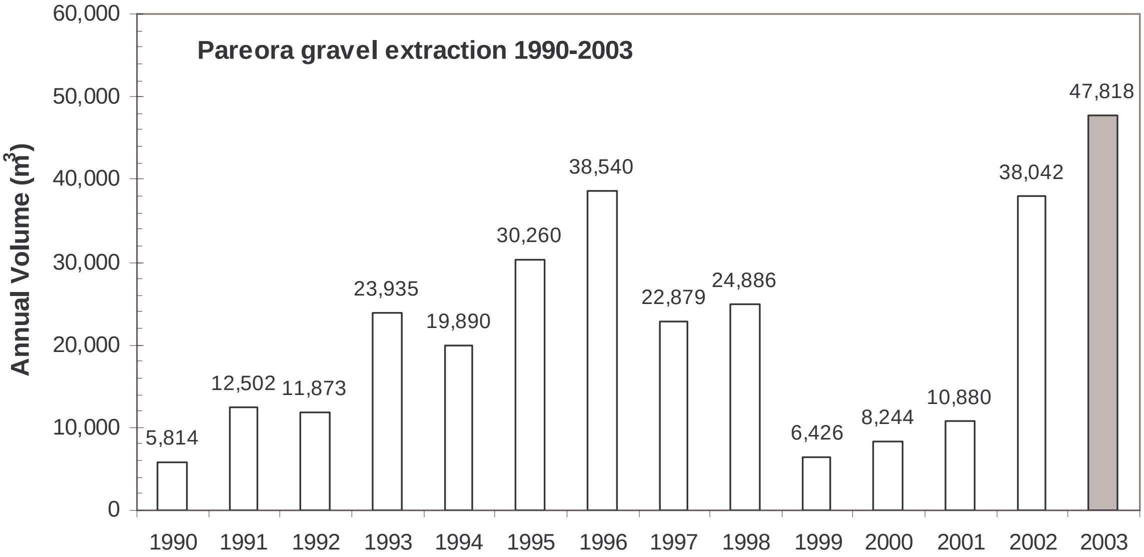

Fig. 5 Volume of gravel extracted 1990-2003

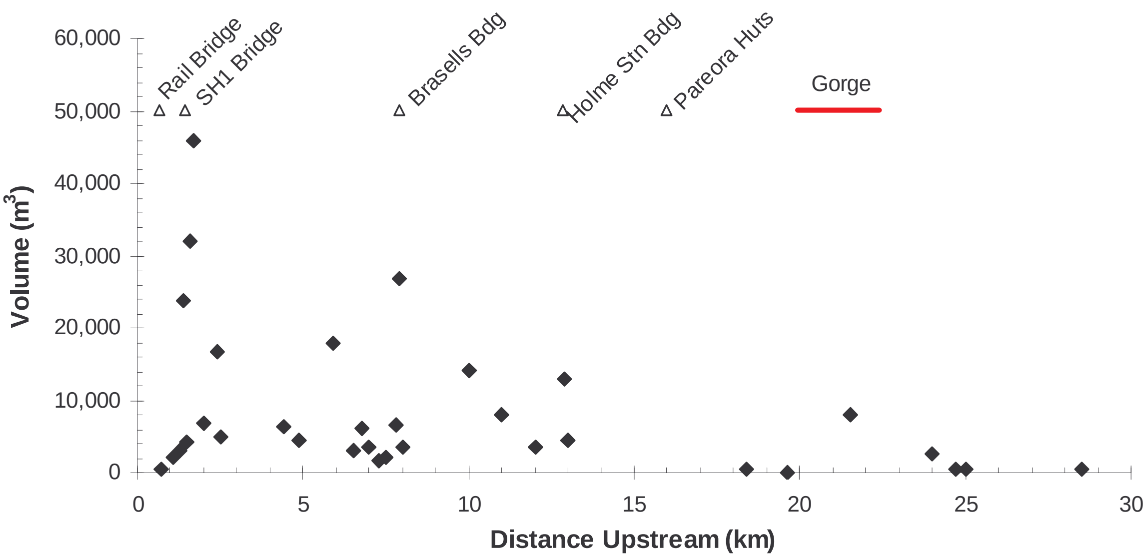

Fig. 6 Location of gravel extraction

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 (the fairway) rather than overbank (berm) areas which experience significant silt deposition. Data was provided by Environment Canterbury with an explanation of the survey offsets and other auditing information in the database. Surveys are described in Appendix 1.

January 2000 audit notes state: “Comparisons from 1967 to 1999 are valid as the Fairway position remained relatively constant during this period. The Fairway position in 1949 was distinctly different on most sections!”

6.1 General bed levels

Bed levels have declined progressively since 1949, with a few exceptions where bed levels increased locally (Fig. 7). On average mean bed levels decreased 51 cm from 1949 to 1999 (range -33 to -119 cm).

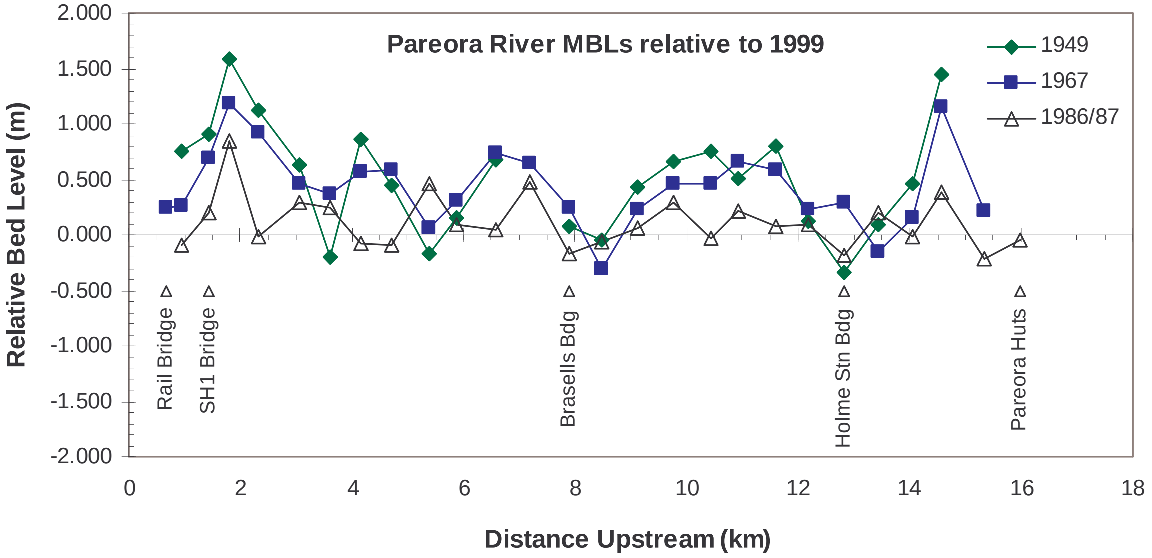

Fig. 7 Pareora River mean bed levels (MBLs) relative to MBLs in 1999

Greatest decreases in bed level occur near the mouth. In the period 1949-1999 the bed level decreased on average by 100 cm (range 62-160 cm). This is probably attributable to various factors (section 6.4) including:

- Reduced sediment supplies and transport capacity.
- Gravel extraction in the lower reaches.
- Re-grading of the river because of coastline retreat.

Immediately below the gorge, the Pareora Huts reach may have degraded as the result of the gorge dam (section 4). The concept is that dams trap sediment and clear water scour occurs downstream (the concept of “hungry water” - Kondolf 1997).

6.2 Bridge – pipeline bed levels

In the upper plains reach there is a partially exposed concrete capped water supply pipeline near Pareora Huts. SCCB (1981) note that about half the structure was visible and that care was required to ensure no further scouring occurred. Timaru District Council staff confirm that the pipeline is partially exposed, but do not consider it under threat.[3] Exposure is not unexpected given that bed degraded up to 150 cm in this reach between 1949 and 1999. However, there appears to be a bed level recovery since the survey in 1986/87 (Fig. 7). The pipeline is not evident in 2004 aerial photographs (from enlargements of Fig. 2).

Bridges were not considered to be under threat by SCCB (1981). Bed levels at State Highway 1 experienced the greatest change: 22 cm drop from 1949 to 1967; with a further drop of ~50 cm from 1967 to 1986/87. Since then bed levels at the bridge dropped a further 20 cm (Fig. 7). The Rail Bridge experienced progressive but lesser degradation (24 cm in the period 1967-1999). Bed levels at Brasells and Holme Station bridges have been erratic. Net changes in the period 1949 to 1999 are -8 cm and +33 cm, respectively.

6.3 Flood levels

As noted in section 3, the flood management scheme capacity varies from ~400 m^3/s in the upper plains below the gorge to ~500 m^3/s in the lower reaches to the sea. This scenario was modelled (~10 year return period), along with a flow 300 m^3/s greater than the original design discharges to assess 25 year return period flood requirements. This flow far exceeds the revised scheme objective to contain a 500 m^3/s flood flow downstream of Pareora Huts (ECan *et al.* 2003). Flood and stopbank levels are plotted against the 1999 bed levels to identify where overflows may occur and to target gravel extraction (Fig. 8).

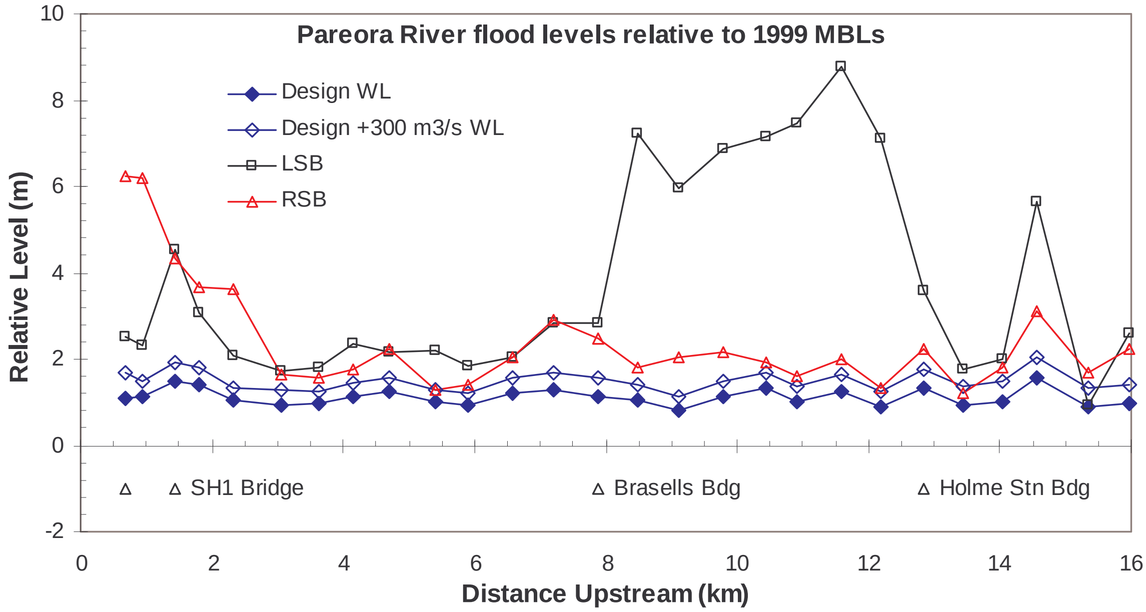

Fig. 8 Pareora River 10 & 25 year flood and stopbank levels relative to 1999 MBL (data from CHFM 2004)

CFHM (2004) proposed that a more uniform flood protection standard be adopted by allowing the bed in areas with large freeboards to raise by 50 cm above 1999 levels, and to excavate high points in the system, specifically cross sections 10, 11, 18, 19 and 21 (km 5.39, 5.89, 10.45, 10.92 and 12.18, respectively). As well, it was proposed to lower the bed at cross section 15 and 23 to the 1967 level.

6.4 Gravel transport and storage

Changes in bed material storage in the fairway are calculated from 1949, 1967, 1986/87, and 1999 surveys and design bed levels (CFHM 2004), using the prismoidal formula to interpolate the volume of the riverbed (specifically the fairway) between cross sections over time.

In the period 1949-1967 the lower ~16 km of the Pareora River experienced net degradation of ~86,000 m^3 (~4,800 m^3/y). This estimate is tentative because it is based on the bed levels over the present fairway, which is not necessarily coincident with the channel position in 1949. Gravel extraction estimates are speculative for the 1949-1967 period, but applying recent rates of extraction (1990-1999) (Fig. 5) and pro-rating by where recent gravel extraction occurred (Fig. 6); tentative sediment budgets are calculated.

If gravel extraction in the lower ~16 km reach was ~11,800 m^3/y; then gravel extraction exceeded net degradation by a factor of ~2.5; requiring a net bedload input of ~7,000 m^3/y. If extraction was around 5,000 m^3/y, extraction would match degradation requiring no net bedload input. (This system is open ended - there is an unknown quantity of bed material passing through the lower reach to the sea without net deposition).

Following channelisation there was a dramatic increase in degradation in the period 1967-1986/87 over the lower ~16 km (~600,000 m^3; ~31,000 m^3/y). The increased rate of degradation over the period 1949-1967 is attributable to several factors; but these can not be rigorously quantified:

- 1949 surveys are not exactly replicated, but they appear to provide realistic mean bed levels.
- Reduced sediment supplies to the lower reaches with berm planting and channel confinement.
- Possible increased rates of gravel extraction.
- Sediment trapping in the water supply dam, before it infilled and allowed bedload by-passing.
- Large floods in 1986 may have scoured the bed with little net deposition (as was the case in the Opihi – Hudson 2005).

From 1986/87 to 1999 (the latest survey) the lower 15.97 km of the Pareora River (the uppermost cross section) degraded ~237,000 m^3 (~19,000 m^3/y). Gravel extraction records are considered reliable for this period (Fig. 5 & Fig. 6). Extraction accounts for ~90% of the net degradation in the lower reaches. The deficit in bed storage volume (~1,900 m^3/y) is possibly due to under-reporting of gravel returns with some degradation attributable to river re-grading with coastline retreat.

When degradation is broken down by reach, gravel extraction from km 14.05 to the upper cross section (km 15.97) is equal to the average annual degradation (~600 m^3/y) in the period 1986/87 to 1999. The reach from km 3.63 to 13.44 degraded 156,000 m^3 and gravel extraction accounted for about half of this loss (81,000 m^3). The slug of bed material from the channel degradation moved into the lower 3.06 km to compensate for large scale extraction in that reach. The lower 3.06 km degraded by 73,400 m^3 in the period 1986/87-1999, but 149,000 m^3 was extracted from the reach. Taking the upstream inputs into account, about 5,600 m^3 was contribution to the coast in the period 1986/87-1999 (~500 m^3/y). More material from upstream was probably transported through the Lower Pareora River without a net contribution to bed material storage (i.e. it passed through the system).

This is contrary to conventional wisdom. As pointed out by Hicks *et al.* (2003), it is often assumed that coastal erosion rates have increased since the damming of the Waitaki River[5] in 1935 due to the reduction in both the volume and grain size of the material available to the coastal budget; and that coastal erosion has been accelerated by irrigation affects on cliff stability. Also, based on coastal cell travel times from Neale (1987), Hicks *et al.* (2003) suggest any deficit in gravel supply from the Waitaki due to hydro-control commencing in the mid 1930's might be expected to have reached Timaru by about 1980 (unless it was buffered by coastal cliff erosion).

A detailed discussion of coastline erosion and erosion protection measures near the mouth of the Pareora River is provided by Waugh (1987). Rates of retreat of the low loess cliffs to the south of the river and the unconfined beach to the north of the seawall [6] are 0.3 m/y and 0.25 m/y, respectively. Hicks *et al.* (2003) append data showing rates of erosion at Pareora from 1938-1984 of 0.32 m/y; and 0.04 m/y from 1977-2000. With limited coastal retreat some lower reach degradation with river re-grading in response to coastline retreat would be expected. However, the volume (~500 m^3/y) is less than the error expected from gravel returns.

Fairway flood capacity is far less than envisioned in the Lower Pareora River Control Scheme (SCCB 1981). CFHM (2004) proposed new design bed levels (design flow plus 300 m^3/s to provide 25 year flood protection; with 30 cm of freeboard). When these design bed levels and bed storage volumes are compared with 1999, there is little available for extraction:

- There is a deficit of 65,000 m^3 over the lower ~3 km
- There is a surplus of 91,300 m^3 from km 3.62-13.44
- There is a surplus of 7,600 m^3 from km 14.05 to the gorge.

Gross volumes of gravel extraction required to provide 1:25 year flood protection have probably already been extracted.

- Lower ~3 km: 24,000 m^3 to 2003, and 30,000 m^3 to mid 2005;

[5] The Waitaki River is ~50 km south of the Pareora.
[6] The seawall was built in 1952 and extends about 1 km north of the mouth.

- Km 3.62-13.44: 76,800 m^3 to 2003, 97,000 m^3 to mid 2005.[7]

A critical issue is whether the extraction occurred in the required places. Considering the recent location of extraction (Fig. 6) and high points in the river bed (Fig. 8):

- Extraction is excessive in the lower ~3 km.
- Targeted extraction may be required around km 5-6; but nearby extraction may have induced headward retreat or downstream erosion with sediment starvation.
- Small scale extraction (~7,600 m^3) may be required above km 13 where little gravel extraction occurs.

A resurvey of the river, which is not due until 2009, would confirm the necessity for targeted gravel extraction. There is unlikely to be a large quantity of material to be removed from these bottlenecks (i.e. more than the average annual extraction).

7 Discussion and recommendations

There are inconsistencies in the reported locations of gravel extraction in the ECan gravel returns data base.

Gravel extraction sites and gravel returns should be specified in terms of the ECan river distance/cross section location maps. A few inconsistent gravel returns should be corrected in the data base.

There is a lack of historic data in the digital gravel returns data base, but there is often knowledge of historic gravel extraction, or paper records or reports of gravel extraction (e.g. SCCB 1981). This information is important in determining changes over time.

Historic gravel extraction information should be compiled and incorporated into the consents data base.

Gravel extraction is cyclical with annual rates over the last 30 years varying from nil to 38,000 m^3/y. Most of the extraction (96%) occurs in the lower 15 km of the Pareora River. In the period 1949-1967 it is tentatively estimated that net degradation of ~86,000 m^3 (~4,800 m^3/y) occurred. Gravel extraction possibly exceeded net degradation by a factor of ~2.5; requiring a net bedload input of ~7,000 m^3/y.

Degradation increased to ~25,000 m^3/y from 1967-1988/89 which is over twice the rate of gravel extraction. (In these instances bedload input can not be calculated because the system is open-ended). Increased degradation is attributed to a combination of factors including probable declines in sediment supply as the river was confined to about half its original width by treed berms; and a loss in transport capacity as the river lost its braided habit and was forced to flow more as a single thread channel. The gorge water supply dam initially trapped bedload, but does not appear to impede transport at present.

[7] Gravel extraction estimates: 2003 – double volumes from the first 6 months of 2003; 2004 & 2005: based on 1990-2002; pro-rated by location (1990-2002 & 2000-2002, respectively).

In the period 1988/89 to 1999 extraction accounts for more than 80% of the net degradation of ~22,500 m^3/y. The deficit in bed storage volume of ~4,500 m^3/y is probably due to river re-grading with a small amount of coastline retreat.

Bed levels have declined by ~50 cm since 1949, with a few exceptions where bed levels increased locally. Gravel is not being replenished at the rate of extraction and supply is unsustainable.

In channel gravel extraction should be limited to small scale local uses (NRRP Chapter 6; fact sheet 6).

Alternative sources of gravel are required (e.g. off channel habitat creation – Hudson 1997; land mining).

A positive consequence of large scale gravel extraction and channel degradation is that floodway capacity exceeds the scheme design capacity. However, with revised streamflow estimates, the design flow is about a 10 year return period flood. CHFM (2004) evaluated the flood capacity and recommended a new design bed level to accommodate the original design flows (~400 m^3/s at the gorge increasing to ~500 m^3/s in the lower river), with additional capacity (300 m^3/s) to provide 1:25 year flood protection with 30 cm freeboard. However, when these design bed levels and bed storage volumes are compared with 1999, there was little available for extraction (there is a deficit of 65,000 m^3 over the lower ~3 km; and a surplus of ~100,000 m^3 to the gorge). By mid-2005 it is estimated that 30,000 m^3 would be extracted from the lower 3 km and 97,000 m^3 from the river to the gorge.

A re-survey of selected cross sections and hydraulic analysis is required to establish if there are weak points in the flood protection scheme.

Small scale gravel extraction may be required to maintain or establish flood capacity or for river control purposes.

There is a high demand for river aggregate in the Lower Pareora River, with recent rates of extraction in the 40,000 m^3 range. Presently there does not appear to be a problem with bridge stability and partial exposure of the water supply pipeline has been a feature for decades (SCCB 1981). However, if large scale extraction continues significant bed lowering will result with potential adverse effects on channel bed and bank stability, bridges, pipelines, and stream habitat. Other studies have shown effects may be significant (Day & Hudson 2001; Kelly *et al.* 2005), necessitating a moratorium on gravel extraction from the active river channel (e.g. Mataura River, Southland - Hudson 1997).

If large scale gravel extraction continues, then an assessment of affects on channel and bank stability, and infrastructure, is required.

In addition, the effects on physical habitat (e.g.the size, frequency and quality of gravel bars as habitat; access to tributaries) and aquatic life (e.g. fish spawning success; invertebrate productivity), should be evaluated.

8 Acknowledgements

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11 Appendix: Pareora river cross sections

Old Cross Section No	Km	1999	1986/87	1967	1949
1	0.67	1999		1967	
2	0.95	1999	1987	1967	1949
3	1.43	1999	1987	1967	1949
4	1.81	1999	1987	1967	1949
5	2.33	1999	1987	1967	1949
6	3.06	1999	1987	1967	1949
7	3.62	1999	1987	1967	1949
8	4.15	1999	1986	1967	1949
9	4.71	1999	1986	1967	1949
10	5.39	1999	1986	1967	1949
11	5.89	1999	1986	1967	1949
12	6.59	1999	1986	1967	1949
13	7.2	1999	1987	1967	
14	7.89	1999	1986	1967	1949
15	8.48	1999	1986	1967	1949
16	9.11	1999	1986	1967	1949
17	9.78	1999	1986	1967	1949
18	10.45	1999	1986	1967	1949
19	10.92	1999	1986	1967	1949
20	11.59	1999	1986	1967	1949
21	12.18	1999	1986	1967	1949
22	12.83	1999	1987	1967	1949
23	13.44	1999	1986	1967	1949
24	14.05	1999	1986	1967	1949
25	14.57	1999	1986	1967	1949
26	15.34	1999	1986	1967	
27	15.97	1999	1986		