Opihi and Tengawai rivers:

Status of gravel resources and management implications

Report U05/31

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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 the Opihi River and Tengawai River, Canterbury. Major findings/recommendations include:

- It is likely there is significant under-reporting of recent gravel extraction. As well, some corrections in the gravel returns data base are required; and historic records should be incorporated.
- The Opihi and Tengawai River beds are degrading as the result of a combination of factors, notably:
  - ⇒ coastline retreat causing lower Opihi River re-grading;
  - ⇒ uplift causing upper plains incision;
  - ⇒ reduction in gravel supplies from scheme works; and
  - ⇒ gravel extraction.
- Large floods in 1986, 1994 and 1997 scoured the bed, or were locally neutral in effect, and transported large quantities of bed material to the sea (e.g. Opuha Dam breach).
- Gravel is not being replenished at the rate of extraction and security of supply is uncertain – alternative supplies should be evaluated (e.g. off channel, land based and coastal zone).
- The effects of gravel extraction exceeding rates of replenishment are not quantified, but could be significant and should be evaluated.
- Historically large quantities of gravel were probably delivered to the coast from channel degradation (>80,000 m^3/y from the surveyed reaches). Gravel delivery to the coast has probably decreased because gravel extraction is under-reported.
- In the Lower Opihi gravel extraction has probably increased fairway capacity to more than the 50 year design flow, but this should be more rigorously evaluated to identify possible bottlenecks and to target gravel extraction.
- Extraction of ~2 million m^3 of gravel would provide 100 year event fairway capacity, but may cause channel instability, and alternative approaches to gravel extraction should be evaluated.
- Bed levels in the bridge reaches may be approaching critical limits, and management plans may be 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 Opihi and Tengawai rivers in South Canterbury.

Careful management of the gravel resources of the Opihi and Tengawai rivers 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 Opihi River floodplain management (SCCB 1985).

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 (i.e. locations for and constraints on excavation).

2 River character

The Opihi is a gravel bed river that flows in a generally south easterly direction about 80 km from the Rollesby Range and Two Thumb Range of the foothills to the Pacific Ocean near Temuka (Fig. 1). The Opihi has three major tributaries: the Temuka River to the north (confluence km 4; with its major tributaries the Hae Hae Te Moana, Kakahu and Waihi rivers[2]); the Tengawai River (confluence km 18) to the south; and the Opuha River (confluence km 32.5) [3]. The combined area of these catchments is 2,400 km^2 (Fig. 1; Table 1).

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[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."

[2] The Waihi-Temuka gravel budget is evaluated in a separate report.

[3] Distances are expressed in kilometres (km) from the river mouth, based on the Environment Canterbury cross section location plans (Opihi 2001; Tengawai 1999); with extensions or interpolation based on triangulation of waypoints from TopoMap/ortho photographs.

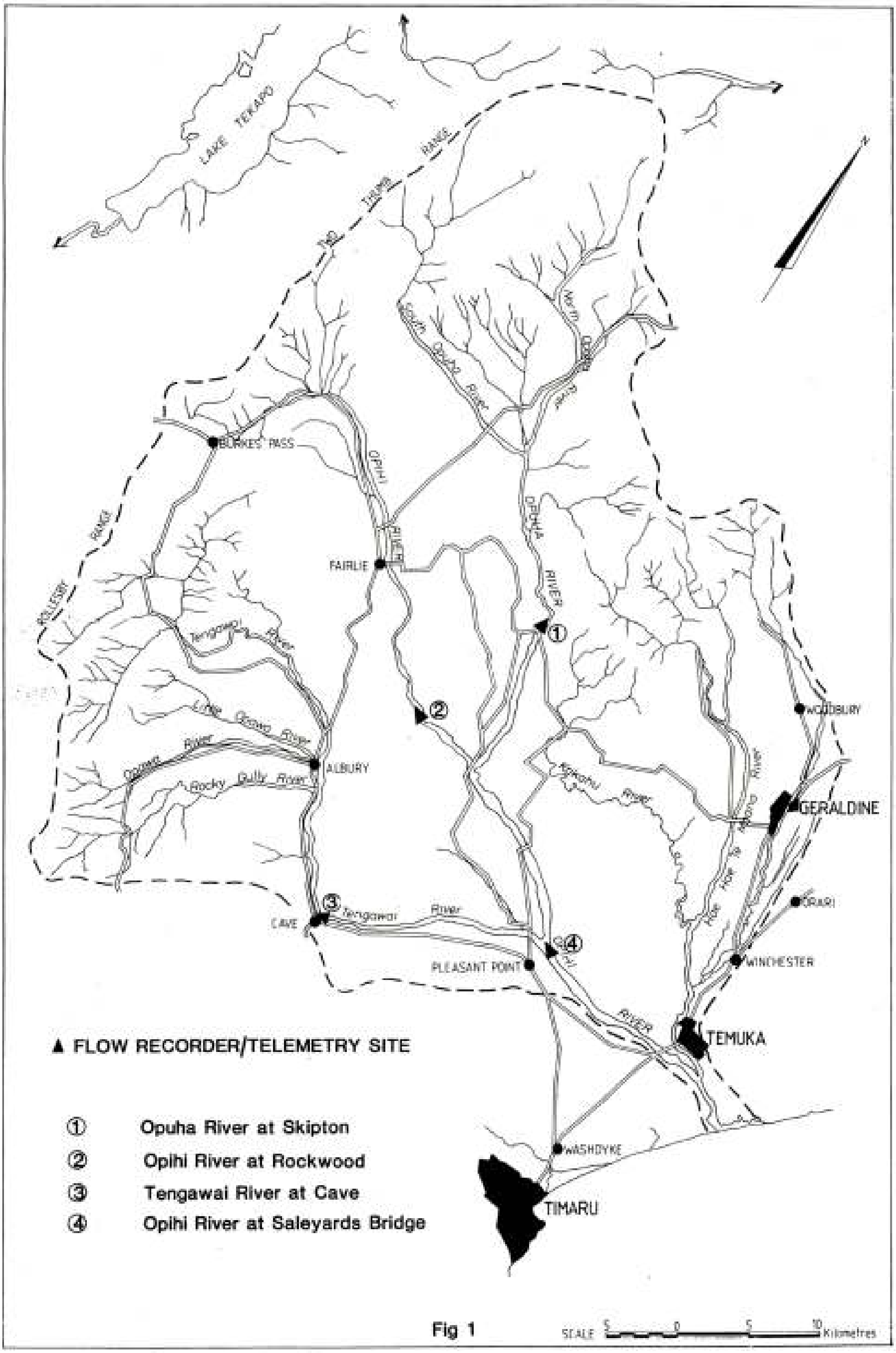


Fig. 1 Opihi catchment (Scarf et al. 1984)

Table 1 Summary of catchment and flow statistics

River	Area (km²)	River Km	Flow Estimates					Channel Capacity
			MALF	Mean	MAF	10 year	50 year	
Opihi								
Rockford	406	33.0	1.3	5.5	170	331		1500
Saleyards	(1650)	17.4			(600)	(1600)	(2820)	2200
Mouth	(2,400)	0			(735)	(2,000)	(3,500)	3000
Tengawai								
Picnic Res[1].	489	14.7; 32.6*		4.1	241 (196)	574 (665)	(1120)	
Mouth	(640)	0; 17.9*						
Opuhu								
Skipton	458	11.3; 43.8*	0.56	9.5	214	401		
Mouth		0; 32.5*						300
Temuka					[144]	[664]	[1166]	
Mouth	[625]	0; 4.0*	{2.35}	{8.86}				

* Distance upstream from mouth of Opihi; [1] Connell & Miller (1992) at Cave. Sources: Flow estimates ECan website (May 2005); Figures in ( ) from Connell & Miller (1992); [ ] from Connell *et al.* 1993; and {} from de Joux (1981). Channel capacity from Lees & Thomson (2003); River distances from this study based on ECan gauge coordinates and cross section locations.

De Joux (1981) divides the Opihi catchment into four distinct regions:

- **Canterbury Foothills:** The headwaters of the Opuha and upper Opihi are typified by moderately steep ranges with alpine vegetation, bare rock and scree above 1200m. Elevation ranges from 180-2200 m with an annual precipitation of approximately 990 mm.
- **Waitaki:** The headwaters of the Tengawai River are mainly steep ranges up to 1800m with snowgrass and tussock cover. Average precipitation (largely snowfall) is approximately 610mm.
- **Timaru Downlands:** Within the catchment, this region extends from the Opihi River mouth to above Fairlie (460 m) and is typified by flat plains and rolling hill country used for pasture and cropping. Average annual precipitation is approximately 660mm.
- **Canterbury Plains:** The main tributaries of the Temuka River arise from flat coalescing alluvial fans with a cover of short tussock grasses and intensive land use pattern. Rainfall averages approximately 740mm per year.

Temuka is the largest township in the Opihi catchment with a population of 4,000 in 2001 (Statistics New Zealand) (Fig. 1). Other centres include Geraldine (2,200); Pleasant Point (1,200) and Fairlie (700).

3 Flooding and flood management

Flood management has focused on the lower reaches of the Opihi catchment where the rivers flow over coalescing floodplains and older alluvial fan surfaces of the Canterbury Plains. Upstream of the Rockford Bridge (km 33) the Opihi River flows through a narrow bedrock gorge (km 37-45.5).

In the upper plains below the Opihi Gorge the river flows in a progressively shallowing trench; with a natural braided pattern that has been confined with bank protection and now flows in a sinuous, generally single thread pattern (Fig. 2). The river bed elevation is ~160 m and the adjacent terraces are ~40 m higher at km 36. At km 26, immediately before the valley widens onto the expansive plains, the south bank terrace is ~13 m higher than the river bed. Downstream of km 26 stopbanks have been constructed on both banks. This upper reach equates to the upper entrenched reach described by Lechie (1994) in his analysis of Canterbury Plains rivers.

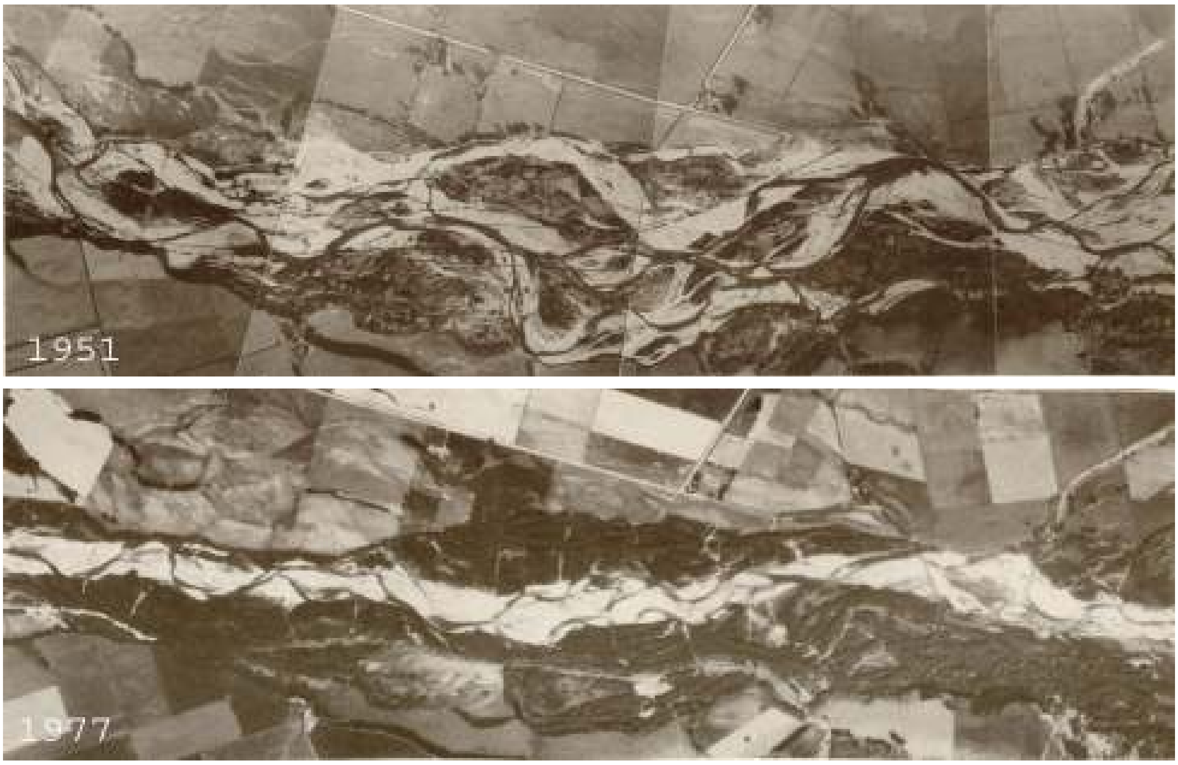


Fig. 2 Opihi River km 22.5 to 26.7 (based on SCCB 1985)

Further downstream the rivers are weakly incised or flow on the fan surfaces with low or non-existent banks over much of the reach to the sea (Lynn *et al.* 1997). This reach equates to the "zone of minimum erosion" described by Lechie (1994) as a feature of Canterbury Plains rivers. However, there is no apparent zone of entrenchment (Lynn *et al.* 1997) resulting from coastal retreat of ~1.0 -1.6 m/y (citations in Lechie 1994). Topographic maps suggest the bed may be perched (i.e. higher than the surrounding floodplain); but more detailed floodplain topographical surveys are required to provide certainty.

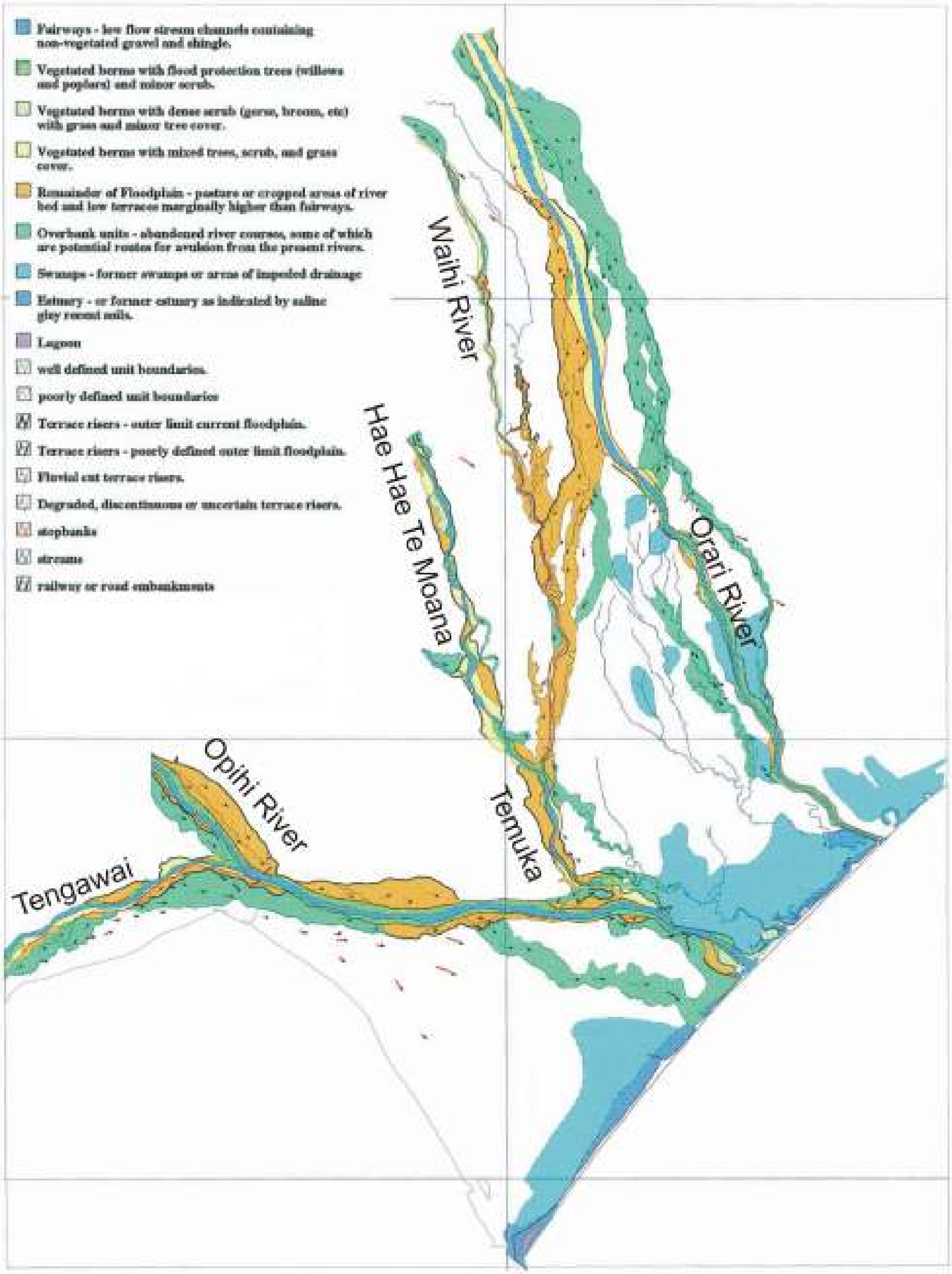


Fig. 3 Geomorphic map of fluvial features (based on Lynn et al. 1997)

As expected from a reach with minimal incision into the floodplain, or in reaches that appear perched above the surrounding floodplain, frequent bank overtopping and channel shifts occur. The floodplain is a mosaic of old channels. When overbank flow occurs there are preferential flow paths along existing troughs. Water that spills over the banks initially carries little or no bedload, therefore is aggressive and will scour along its route. As material builds up in the main channels, more water is forced overbank and there is a strong tendency for avulsion into other, often somewhat lower, parts of the floodplain (e.g. Fahnestock 1963; Carson 1984). Without containment (e.g. bank protection) this process is repeated.

Repeated channel shifts are clearly evident in the floodplain map (Fig. 3) and underlie the need for river control. For example, prior to 1852 when it cut its own course to the sea, the Orari River (752 km^2) flowed into the Temuka River (Williams 1968). The Orari-Waihi-Temuka Catchment Control Scheme noted that during high floods the Orari River "… regularly over-flowed its banks and a sizeable portion of the total flood discharge followed the old historic course into the Opihi-Temuka-Waihi River system, leaving a trail of devastation and wreckage in its path. This was one of the primary reasons for an OWT control scheme." (Stringer & Rowell 1978). Breakouts were reported in 1868, 1871, 1902 and 1945 (Lynn *et al.* 1997).

River works affecting the Opihi River catchment can be described as having several objectives (Herd & Powell 1964; Williams 1968; Stringer & Rowell1978; SCCB 1985; Connell & Miller 1992):

1. Prevent erosion of infrastructure, particularly the bridges, with localized works starting in the 1880s.
2. Contain the active channel to a particular course (e.g. miscellaneous works, such as embankments, in the Opihi prior to the first control scheme in 1951; stopbanks to prevent Orari flow into the Opihi were initiated in 1954; and stopbanks to contain a 50 year flood were constructed in the Opihi in the 1970s).
3. Straighten and constrict the channel to concentrate flow and scour gravel during floods and transport gravel to the sea (miscellaneous tree planting and rock works in the lower reaches are evident in 1934 aerial photographs; with extensive works in the 1970s) (Fig. 4; Fig. 5).
4. Clear the fairway of vegetation to increase hydraulic efficiency and to reduce sediment trapping.
5. Decrease the supply of bed material with extensive tree planting and rock works along the main rivers and tributaries; and with gully planting, drop structures and gravel traps to control erosion and reduce supply to the lower river system (in the 1970s).
6. Encourage gravel extraction to increase fairway capacity; or at least limit a reduction in fairway capacity; and to reduce bar formation with associated bank erosion.

Opihi design discharges (50 year return period flood) are 1,529 m^3/s above Pleasant Point (km 18); 2,407 m^3/s from Pleasant Point to Temuka (km 4); and 3,129 m^3/s over the lower 4 km to the sea (SCCB 1985) (Table 1).

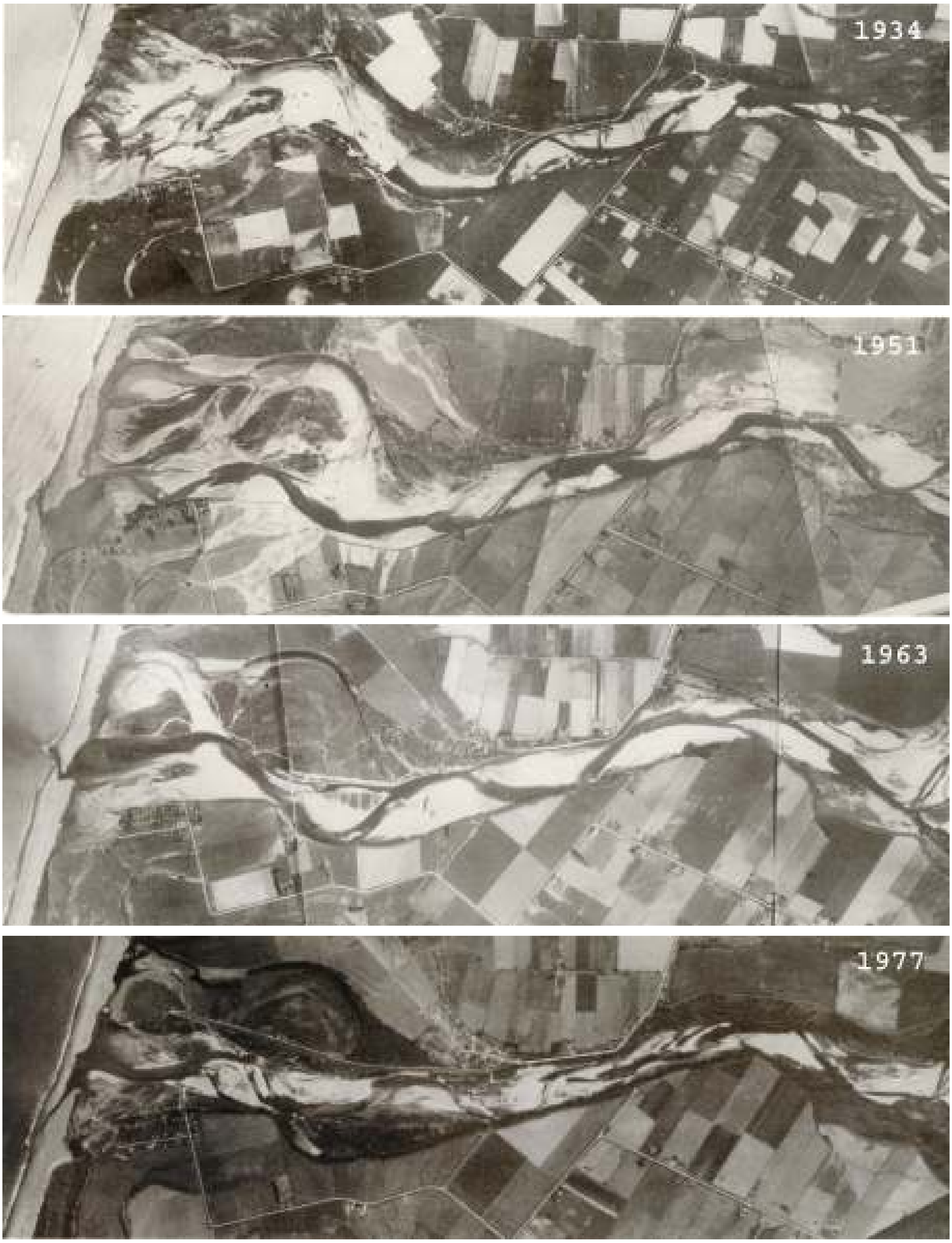


Fig. 4 Opihi River mouth to km 4.25 (based on SCCB 1985)

Plans in SCCB (1985) show design widths of 120 to 300 m in the lower 4 km; 165-280 m upstream to the Tengawai confluence (km 18); and 150 to 180 m from km 18 to 26.5. Contemporary widths (1998-99 ortho photographs) range from 125-340 m (average of 215 m); 155-330 m (average of 225 m); and 115-285 m (average of 205 m), respectively.

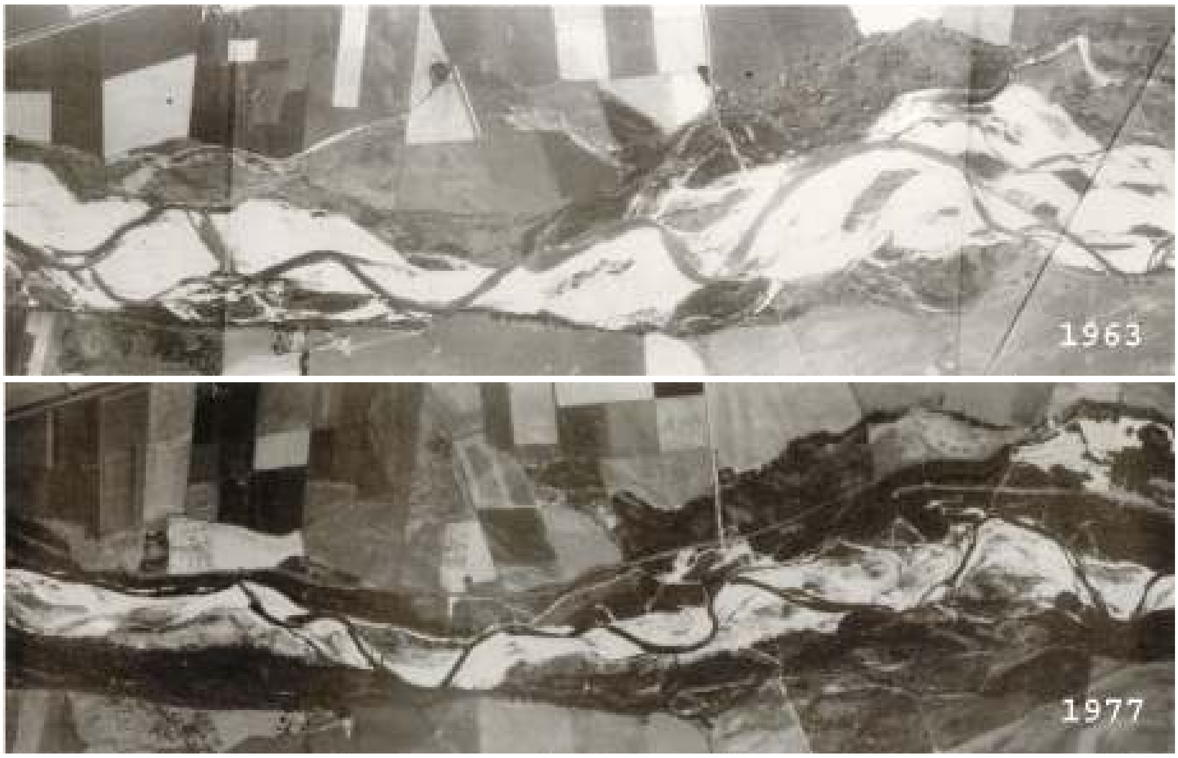


Fig. 5 Opihi River km 8.1 to 12.5 (based on SCCB 1985)

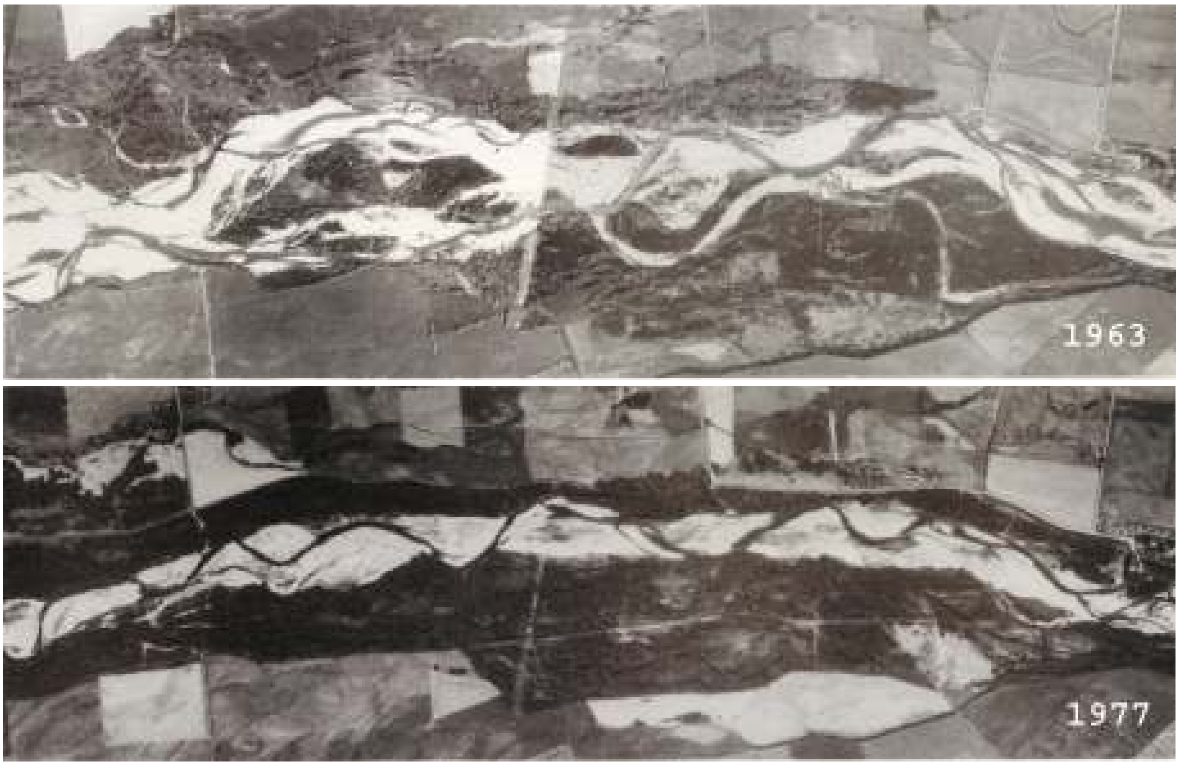


Fig. 6 Opihi River km 12 to 16.5 (based on SCCB 1985)

Above the Opihi Gorge the river flows through an extensive glacial outwash gravel, till and fluvial plain from km 46 to km 62.7. The river had a wide wandering/braided habit (Carson 1984) prior to extensive berm planting, but now the river tends toward a confined single thread channel (average width 100 m; range 45-170 m to km 57) (Fig. 7).

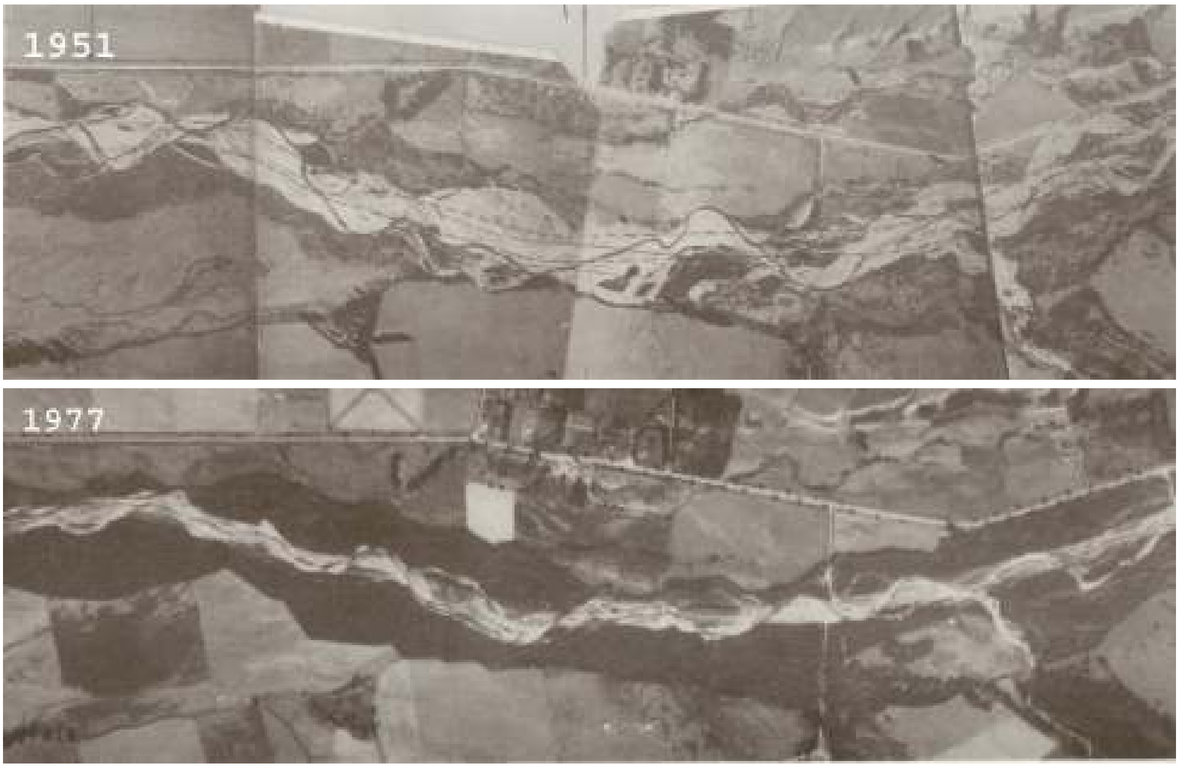


Fig. 7 Opihi River km 59.3 to km 62.7 (based on SCCB 1985)

The Tengawai River extends upstream 66 km from the Opihi confluence (km 18). River distances for the cross sections refer to the distance to the mouth of the Opihi, not the Tengawai-Opihi confluence (i.e. the first Tengawai cross section is referred to as 18,580 m not 0 m).

The river and tributaries flow through highly dissected glacial outwash gravels, till and fluvial plains upstream of Cave (km 35), bordered by the foothills for 15 km (to km 50). Above km 78 the river is confined by the foothills and ranges with an alluvial bed over greywacke and argillite bedrock on the left bank and limestone, siltstone and mudstone on the right bank.

River control objectives for the Tengawai included channel and catchment works (e.g. tributary stabilization and sediment control). The design discharge is the 50 year return period flood of 878 m^3/s (SCCB 1985). This presumably applies to the works area downstream of Cave (~river km 17; cross section 34710). Contemporary river channel widths are considerably narrower and the Tengawai River is straighter since the river works in the 1970s (Fig. 8; & Fig. 9). In the foothills reach above Cave widths range from ~50 to 250 m. In the upper plains the river has a narrow cleared fairway (~100 m) and extensive berm planting.

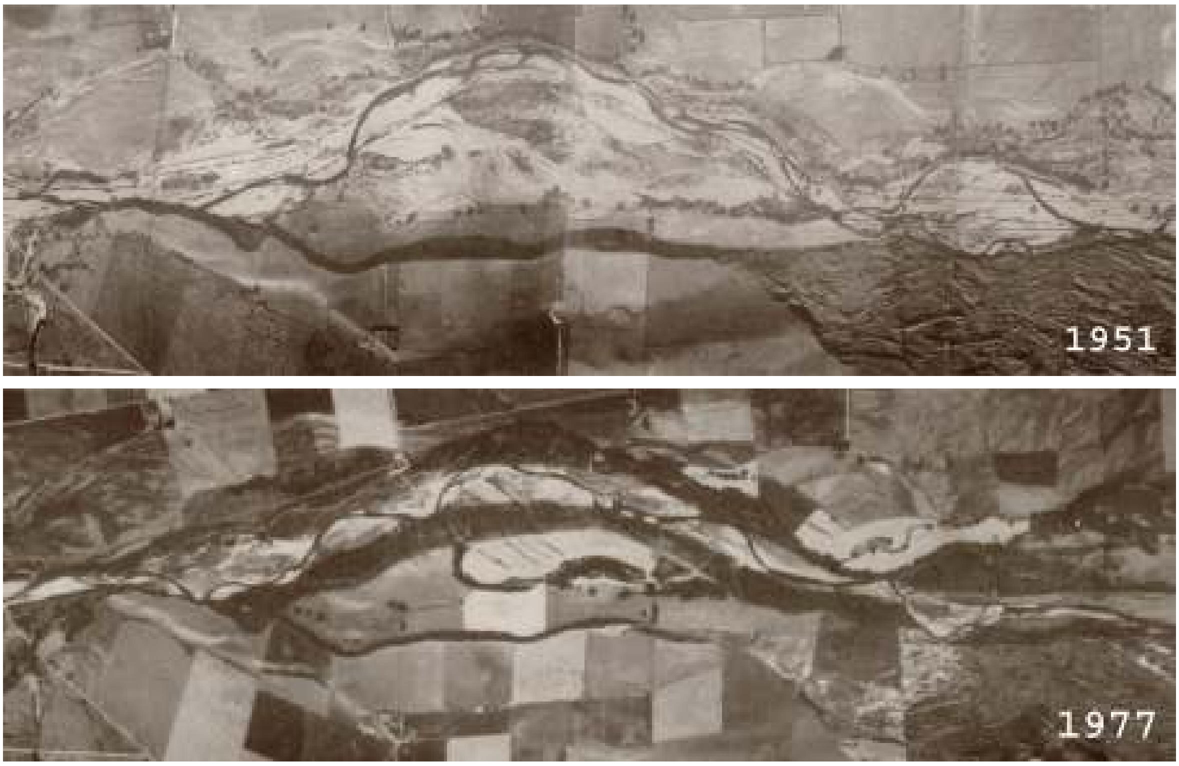


Fig. 8 Tengawai River cross section km 20.3 to 24.8 (based on SCCB 1985)

Fig. 9 Tengawai River cross section km 29 to 33.5 (based on SCCB 1985)

4 Gravel supply to the lower river

Indirect estimates of bedload inputs were made by Cuff (1974) based on a catchment erosion rating. He estimated 16,000 m^3/y for the Opihi and 24,000 m^3/y for the Opuha at the Opihi confluence. Adams (1980), using a bedload equation, arrived at similar figures (16,000 m^3/y and 22,000 m^3/y, respectively). Griffiths & Glasby (1985) took bedload as a proportion of the estimated suspended sediment and calculated a load of 39,000 m^3/y at the mouth of the Opihi, which is similar to Adams (1980) estimate for the Opihi mouth of 37,000 m^3/y.

Connell & Miller (1992) attempted to calculate bedload transport from cross section data but reported there was little change in the previous ten years. They note "Analysis of old bed level surveys indicates the present gravel extraction rates of 60,000 m^3/y only match the inflow into the Lower Opihi River."

It is likely that the extensive soil conservation measures in the catchment reduced erosion and delivery of sediment to the river system. Also, it is likely that the extensive river bank protection measures and berm planting has reduced the availability of gravel from the river itself.

SCCB (1985: 12) noted "The single thread concept was though to be the most efficient channel to transport gravel. Even this concept is in doubt today with the latest research on bed load transport (Williams (1970)… indicating that a deeper channel is less efficient at transporting gravel than a shallow channel."

Other studies confirm the importance of bank scour along braids as a major mechanism of gravel transport (Carson & Griffiths 1989; Hicks *et al.* 2000). Elimination of sinuous braids suppress bed load transport and straightening of braided rivers, narrowing and conversion to single thread decreases bedload transport rates. Channel narrowing has not flushed out gravel, but probably 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) which are cost prohibitive (SCCB 1985).

Extreme events may change sediment delivery and transport. The 1986 flood on the Tengawai had an estimated return period of 100 years; and was an extreme event on the Opihi (Connell & Miller 1992) (Tengawai at Cave 1,438 m^3/s; Opihi at Rockford 1,020 m^3/s)[4]. Lee & Thomson (2003) state the 1986 flood was the biggest recorded flood in the Opuha River in recent times (600 m^3/s; nominal 50 year return period). A large flood also occurred in 1994 (Opihi at Rockford 748 m^3/s; Tengawai at Cave 800 m^3/s; Opuha at Skipton 767 m^3/s).[4]

In February 1997 the partially constructed Opuha Dam overtopped and breached following heavy rainfall, sending a flood wave 23.5 km down the Opuha River into the Opihi River. Lees & Thomson (2003) estimate the peak discharge downstream of the dam at 1,800-2,000 m^3/s, which was in the range of a probable maximum flood (1,500-2,000 m^3/s).

[4] Tony Gray, ECan, written comm.

A large input of sediment was derived from the dam breach itself (consisting of silty outwash gravels, river gravels, and rockfill from the dam foundations; Coleman *et al.* 2004) and from erosion of the river channel downstream (Fig. 10). The contribution of sediment from the breached embankment is probably modest (~250,000 m^3 based on a topographic map in Coleman *et al.* 2004). Contributions from the river channel have not been quantified, but could be substantial.

Lee & Thomson (2003) state "The flood carried all before it, sweeping the riverbanks clear of vegetation and soil … Shingle to a depth of 11 m was dumped over the turbine in the powerhouse. Two days after the failure, a concrete-mixer truck from the dam site was found buried in shingle about 500 m downstream of the dam."

Fig. 10 Opuha Gorge, 5 km downstream of Opuha Dam, February 1997 (Lees & Thomson 2003)

5 Rates and location of gravel extraction in the lower river

Gravel extraction information prior to 1990 was not available[5], but for the Opihi River Williman & Smart (1987) report "Sand and gravel extraction is currently 50 000 m^3/year (historically similar)…. Annual replenishment is unknown." Connell & Miller (1992) report extraction of 60,000 m^3/y as matching the inflow of gravel into the Lower Opihi. Similar information was not reported for the Tengawai River.

In the period 1990-2002[6] the average annual extraction from the Opihi was 106,700 m^3/y, while the Tengawai provided about one tenth as much (10,600 m^3/y) (Fig. 11). Recent gravel extraction is probably significantly under-reported, possibly by a factor of 2 or more.[7]

In the Opihi River the volume and location of extraction varies in time and space (Fig. 12). Average annual rates of extraction varied: 1990-1994 68,460 m^3/y; 1995-1999 131,085 m^3/y; and 2000-2002 129,891 m^3/y. Overall there appears to be an increase in extraction from 1990 to 1996-1997, but this may have reached a plateau.

[5] Gravel extraction data was provided by Matthew Surman, ECan, from the consents database.
[6] Data for 2003 is incomplete, so is not included in the average.
[7] Bruce Scarlett, Ecan, Timaru, pers. comm.

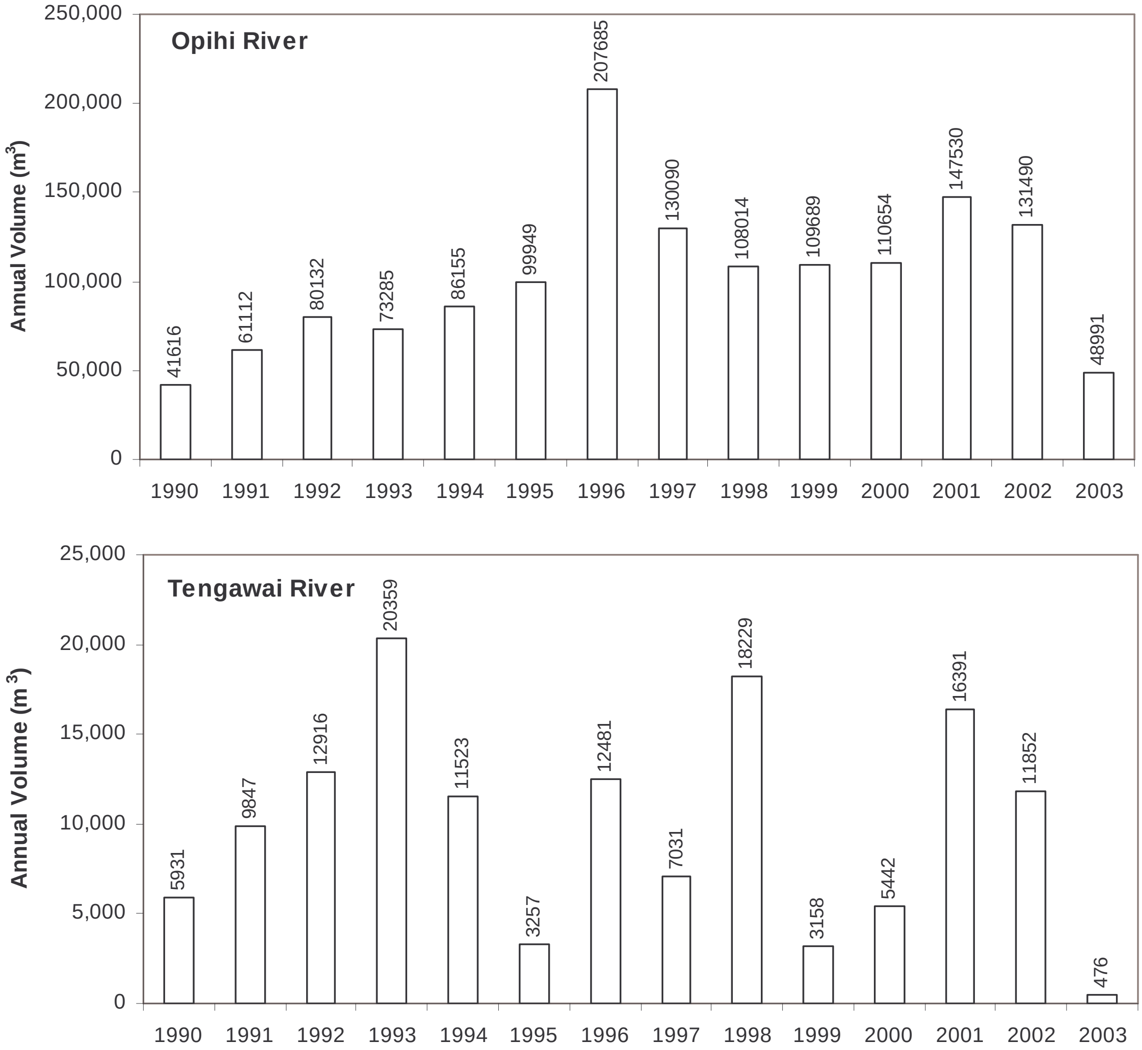
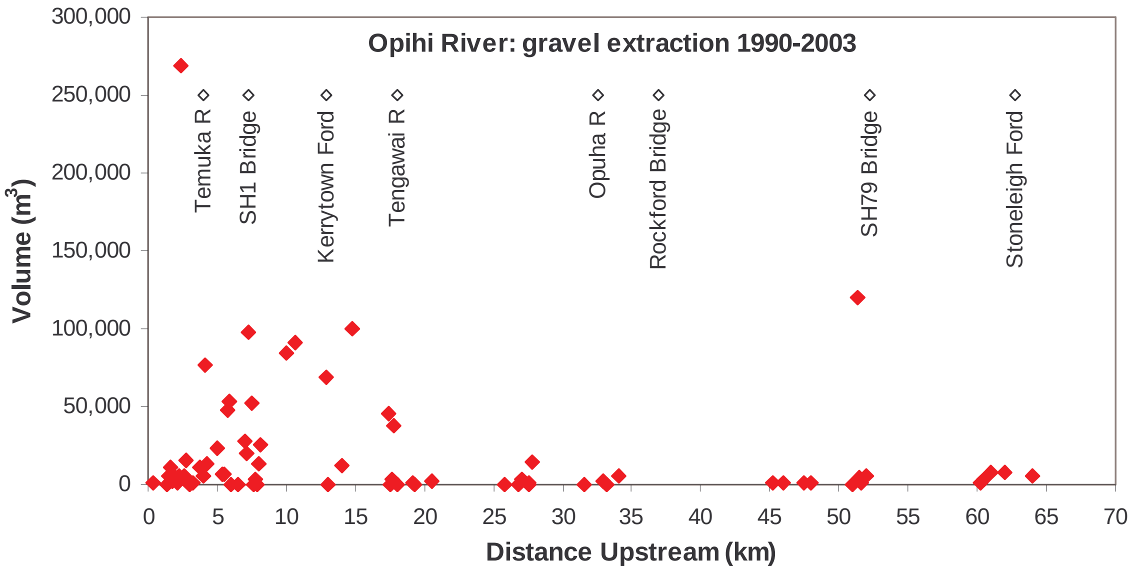


Fig. 11 Volume of gravel extracted 1990-2003 Opihi and Tengawai rivers

There appears to be a shift in extraction to the Temuka-Tengawai reach of the Opihi. In the first five years of record (1990-1994) 342,300 m^3 was extracted with more than 70% taken from the sea to Temuka confluence (km 0-4; ~48,000 m^3/y); with most of the remainder equally from km 4-18 and >km 35 (~10,000 m^3/y in each reach). From 1995-1999 655,427 m^3 was extracted, with 11% from km 0-4 and 77% from km 4-18. In the three years 2000-2002, when 389,674 m^3 was extracted, 5% was from the lower 4 km, 80% was from km 4-18, and 13% above km 35.

Extraction from the Tengawai River is concentrated in the lower 12 km (cross section km 18-30) [8] averaging ~7,000 m^3/y (66% of the total) with ~3,650 m^3/y taken from cross section km 30 to km 56 (Fig. 12).[9] The proportion is relatively constant over periods of several years.

[8] Volumes and mean bed levels in the Tengawai River are referenced in terms of cross section distances (i.e. from the mouth of the Opihi, not the Tengawai-Opihi confluence). Some inconsistencies in the consents data base have been resolved in consultation with Kevin McFall.
[9] 4,932 was extracted from Mawaro Creek (km 39 on the Tengawai).



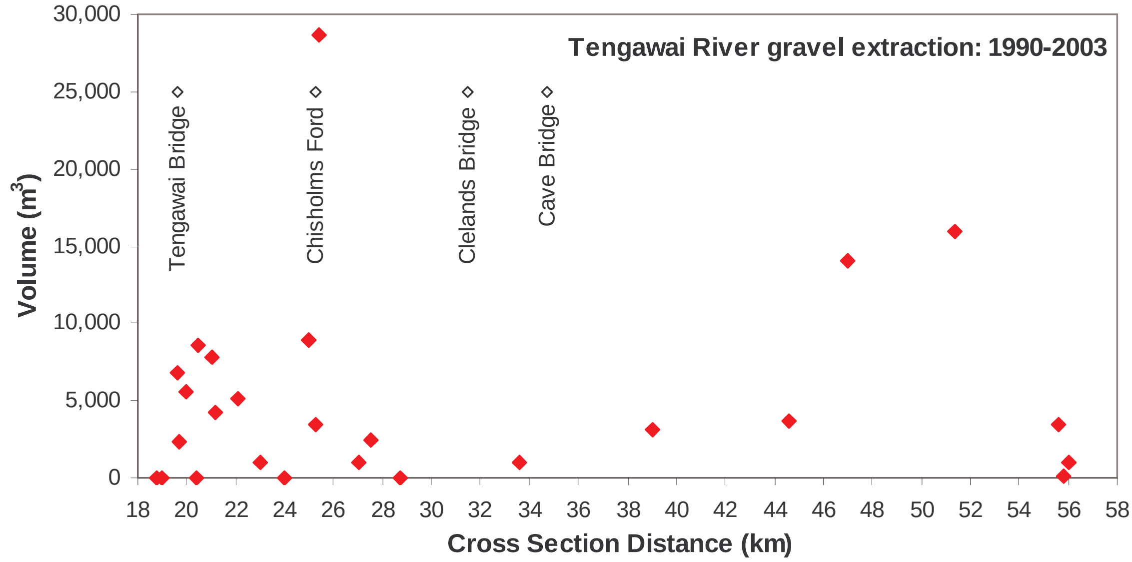


Fig. 12 Location of gravel extraction Opihi and Tengawai rivers

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. Survey locations described in Appendix 1.

6.1 General bed levels

In the Lower Opihi there has been a fairly progressive decline in mean bed level (MBL) from 1953 to 2004 over the lower reaches (Fig. 13). Bed levels over the lower 12.65 km decreased on average 76 cm since 1966; 48 cm since 1974; 37 cm since 1982 (with little change from 1982-1987 as reported by Connell & Miller, 1992); and 28 cm since 1994. From ~km 14 to the mouth of the Tengawai (cross section 17.885) change has been more erratic. Mean bed levels in 1966 were up to 52 cm higher than 2004, but averaged 32 cm over the reach. Again, there was little change in average bed levels in the period 1982-1987, but bed levels since decreased on average by 29 cm.

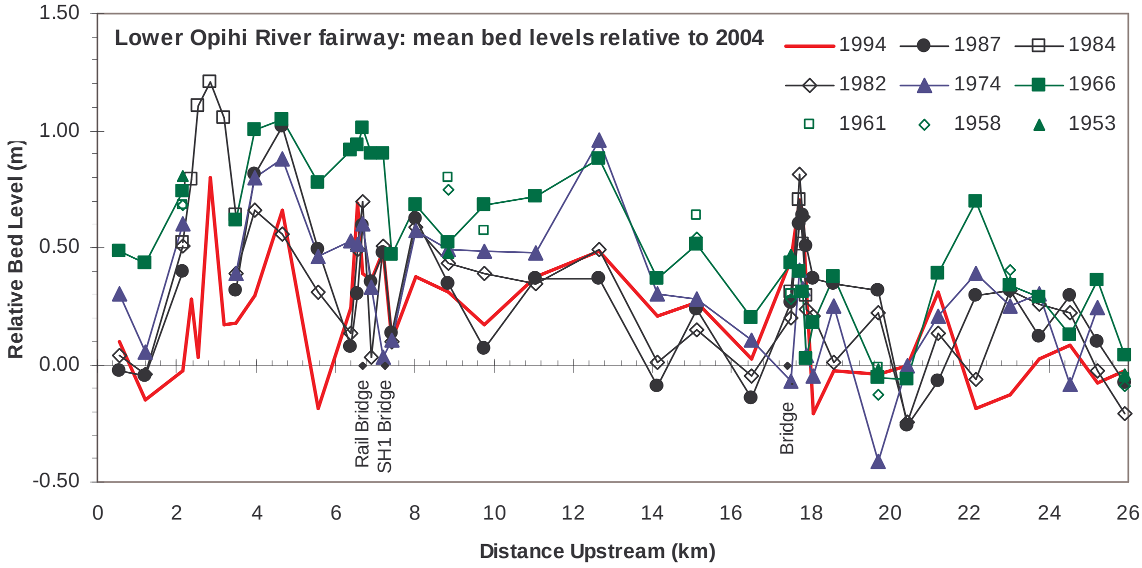


Fig. 13 Lower Opihi River MBLs relative to 2004

Above the Tengawai confluence, Opihi bed levels were higher in the past: 1966 average MBLs were 24 cm higher than in 2004; 11 cm higher in 1974, and 8 cm higher in 1982 (Fig. 14). From 1982 to 1987 the bed generally built up (~8 cm), with degradation averaging 19 cm by 1994, with minor rebuilding to 2004 (3 cm).

In the upper reaches of the Opihi limited data suggest the cross sections immediately above the gorge are aggrading (Fig. 14). Further upstream, from km 52 to 65, the reach is progressively degrading (71 cm since 1952; 67 cm since 1962; 33 cm since 1984; and 27 cm since 1987).

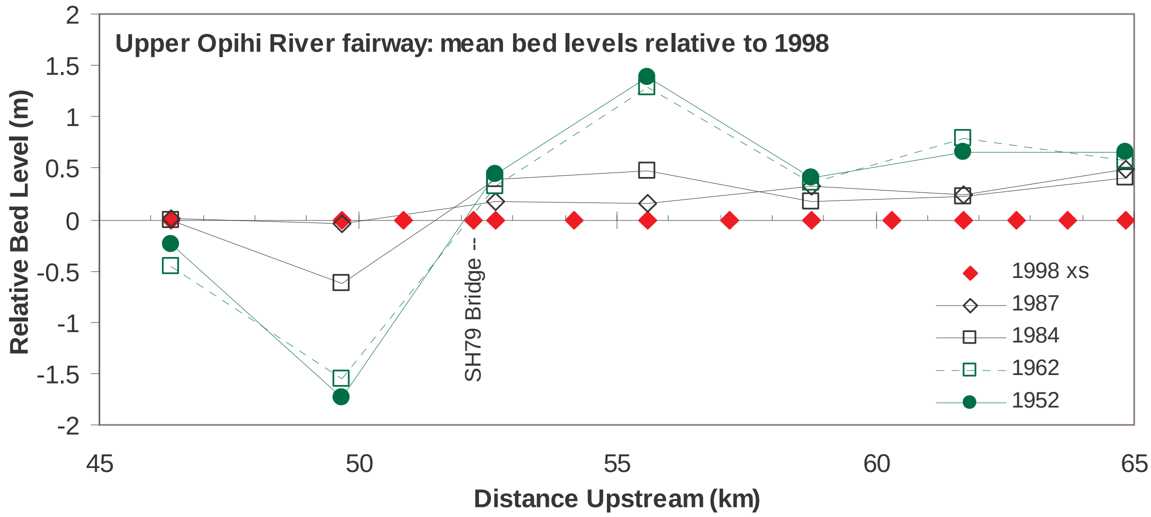


Fig. 14 Upper Opihi River MBLs relative to 1998

Mean bed levels on the Tengawai River from the mouth (km 18) upstream about 9 km (to km 26.3) were higher in the past than in 1997 (an average of 47 cm higher in 1962; and around 30 cm higher in 1974, 1982 and 1987), but there is little difference over the period 1994-1997 (Fig. 15). Around km 27-30 bed levels are more erratic, with some large local bed levels increases. The upper reach mean bed levels are tending to progressively decrease.

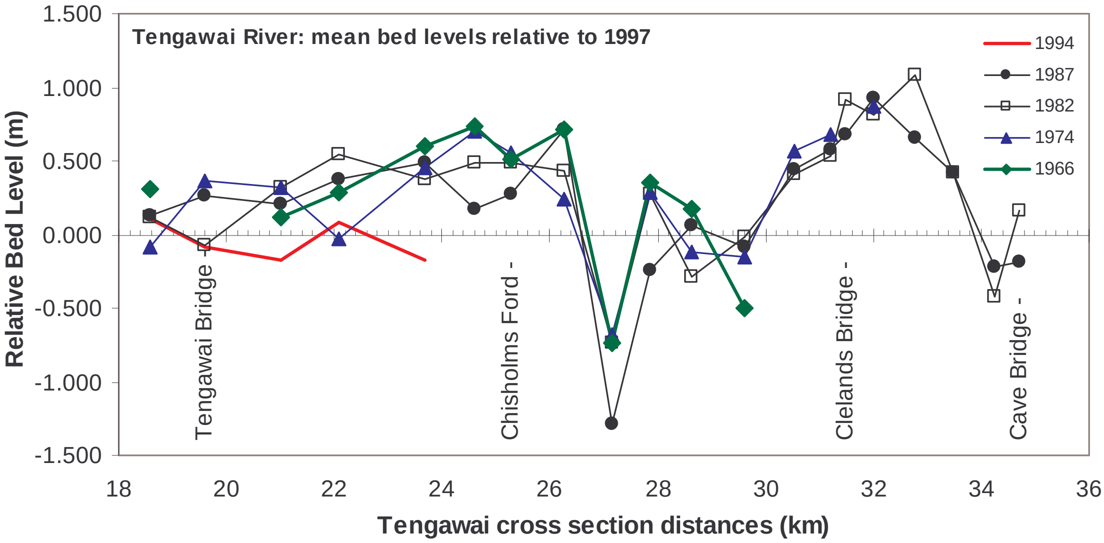


Fig. 15 Tengawai River mean bed levels relative to 1997 (river km 0-18; cross section km 18-36)

6.2 Bridge reach bed levels

Around the State Highway 1 and rail bridges over the Opihi, the river reach tends to follow the general declining bed level trend. For the 6.58 to 7.44 km reach, MBLs were on average 85 cm higher in 1966 than 2004 (range 47-101 cm) (Fig. 16). Present levels are equal or lower than 1970 and 1980 surveys by ~30-40 cm on average over the reach.

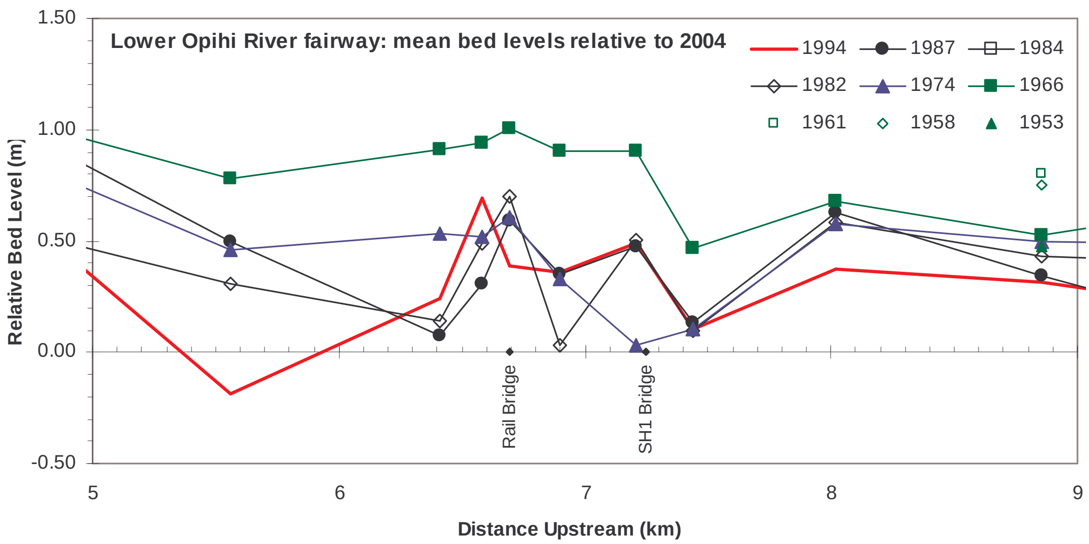


Fig. 16 Opihi River SH1 Bridge reach mean bed levels

Immediately above the SH79 Bridge, upper Opihi bed levels have been erratic since the 1950s, with a tendency to degrade (Fig. 17). Bed levels in 1953 were comparable to 1966. Over the 15.13-17.885 km reach, 2004 bed levels are ~20 (1974) to ~50 cm (1984) lower.

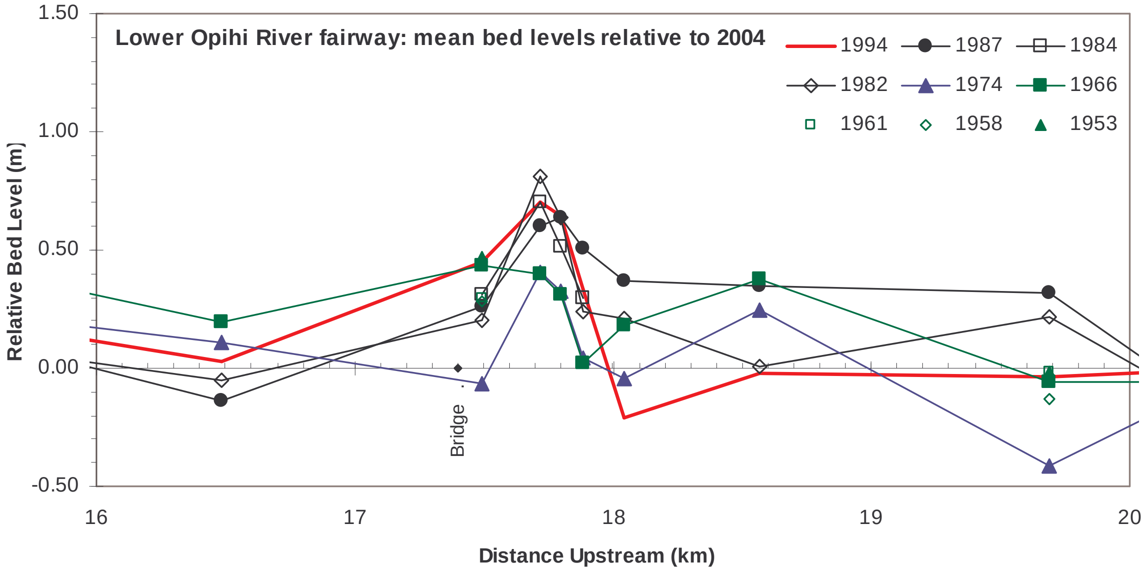


Fig. 17 Opihi River SH79 Bridge reach mean bed levels

Historic bed levels in the Tengawai River bridge reach are variable: 1966, 1974 and 1987 levels are ~20 cm higher than 1997, with a lower bed in 1982 (+12 cm) and a decline to -5 cm in 1994 (Fig. 15). In the Clelands Bridge reach the bed was about 75 cm higher in the 1970s and 1980s than 1997. There is no intermediate survey data. Near Cave Bridge the levels varied, but the three nearest cross sections suggest a decline in bed levels since the 1980s (~30 cm).

6.3 Flood levels

Opihi design discharges (50 year return period flood) are 1,529 m^3/s above Pleasant Point (km 18); 2,407 m^3/s from Pleasant Point to Temuka (km 4); and 3,129 m^3/s over the lower 4 km to the sea (SCCB 1985). The Tengawai design discharge is 878 m^3/s.

Connell & Miller (1992) reported that gravel extraction could eliminate the necessity to raise stopbanks. They proposed extraction on all areas of major stopbanking except the new stopbank above Pleasant Point (Opihi km 18). They calculated bed levels of the river fairway would need to be lowered 45 cm on the Opihi and 75 cm on the Tengawai to achieve 100 year flood capacity (based on 1987 cross section surveys, 1986 flood observations and hydraulic modelling). [10]

[10] There is a 64% chance of overtopping with a 50 year return period flood in the next 50 years; and a 33% chance in the next 20 years. Designing for a 100 year return period flood would decrease the risk of overtopping to 18% in the next 20 years.

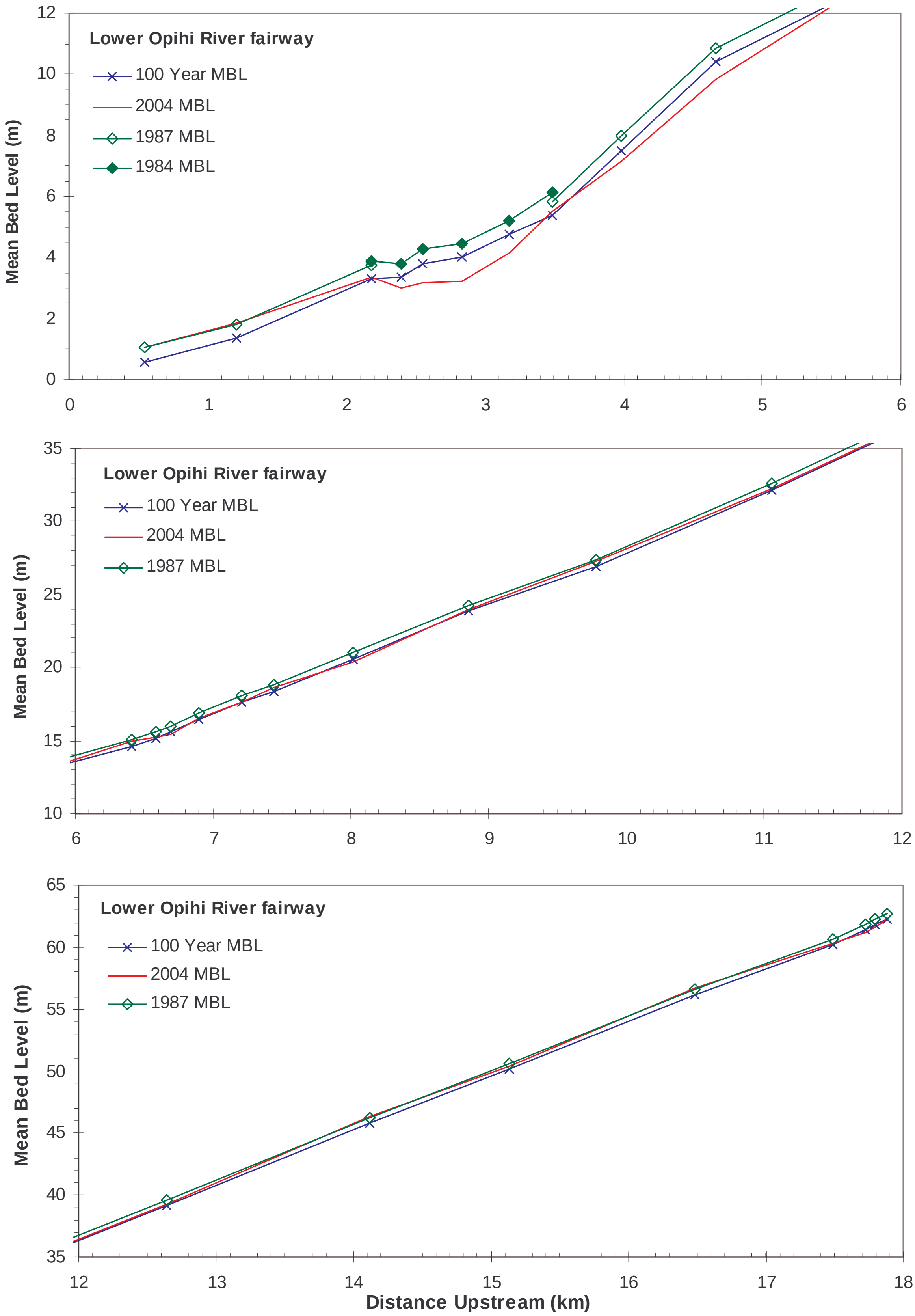


Fig. 18 Lower Opihi River 1984/1987, 2004, and 100 year flood mean bed levels

When the Opihi 2004 mean bed levels are compared with the bed levels required for passage of a 100 year flood (1987 MBL -0.45 m), two major bottlenecks are apparent (Fig. 18).[11] Over the lower ~2 km 2004 mean bed levels are ~50 cm higher than the 100 year flood MBLs. From km ~7.5 to 17.5 the 2004 MBLs are on average 23 cm higher than the 100 year flood MBL.

Applying a similar analysis to the Tengawai, but with a 0.75 m average reduction from the 1987 MBLs, shows that with a few local exceptions the whole bed has impeded 100 year fairway capacity. From 18-25.3 km the average 1997 bed level is 26 to 57 cm above the proposed flood MBL. There is greater variability upstream. The average 1997 bed level is 56 cm above the flood MBL, but the range is large (-18 cm to 2 m).

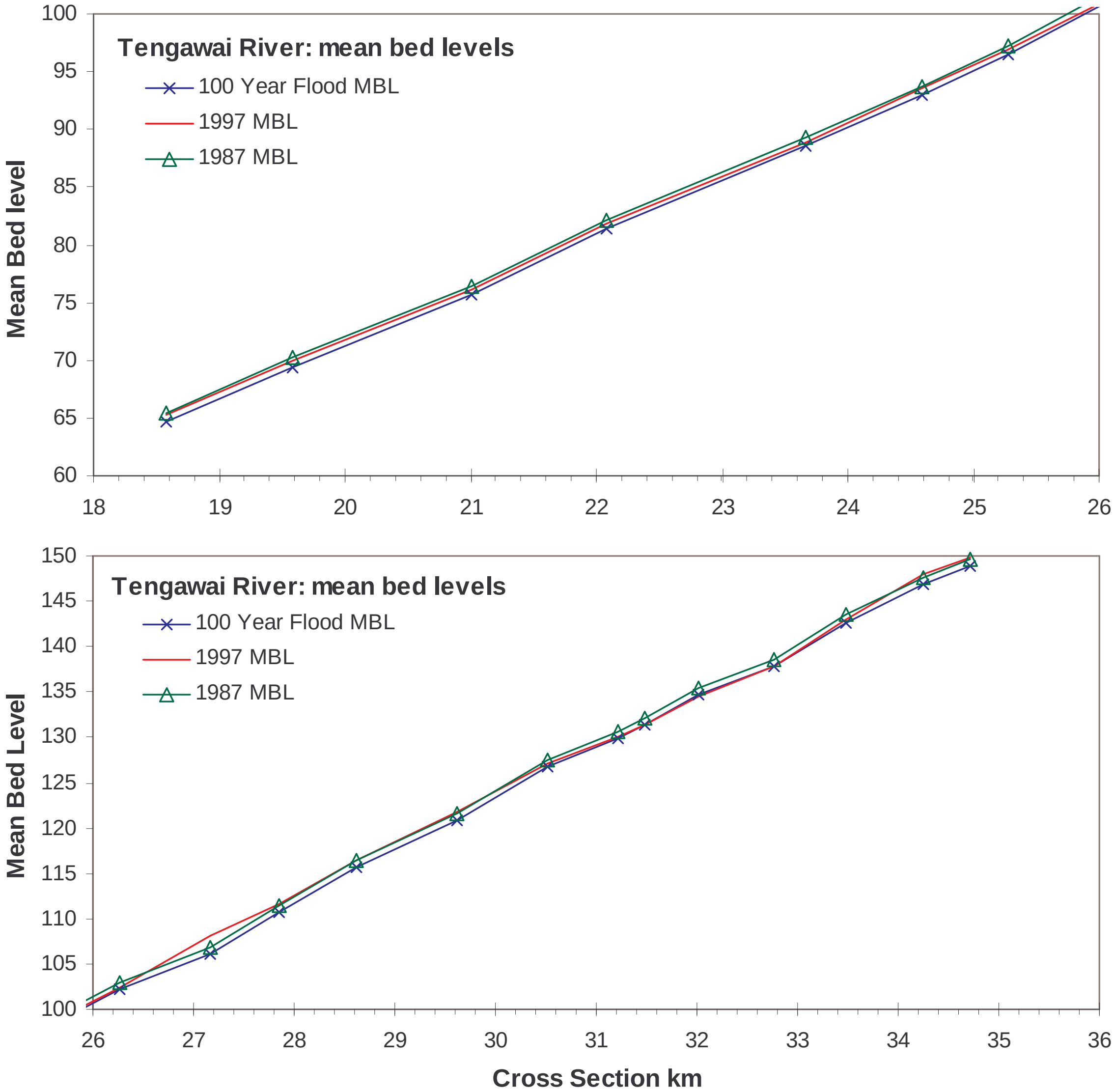


Fig. 19 Tengawai River 1987, 1997 and 100 year flood mean bed levels

[11] If the hydraulic data from Connell & Miller (1992) were available, then a cross section by cross section comparison could be made (e.g. Hudson 2005 – Waimakariri River).

SCCB (1985) noted: “Gravel extraction will continue to manage to assist with scheme performance. Where appropriate, extractors will be directed to areas of aggradation, or excessive bar formation to improve the hydraulic character of the river.”

The volumes of gravel extraction required to achieve 100 year flood bed levels will require substantial gravel removal, but not as large a volume as calculated from the 1984-1987 surveys (1,900,000 m^3 on the Opihi for 100 year capacity; Connell & Miller 1992).

6.4 Gravel transport and storage

Changes in bed material storage in the fairway are calculated from 1966, 1972, 1982, 1987, 1994 and 2004 surveys using the prismoidal formula to interpolate the volume of the riverbed (specifically the fairway) between cross sections over time. The river is split into zones for this analysis.

6.4.1 Lower Opihi River below the Tengawai

A feature of Canterbury Bight rivers is degradation near the coast due to coastline retreat (Lechie 1994). Degradation may be accelerated by gravel extraction (e.g. Ashburton River – Hudson 2000; 2005). As noted in section 3, Lynn *et al.* (1997) indicate there is no apparent zone of entrenchment in the lower Opihi River, but this observation is contrary to bed level trends.

Most of the extraction (86% in the period 1990-2002) takes place in the lower Opihi below the Tengawai confluence (km 0-18) (Fig. 12). In the period 1966-2004 the Opihi fairway degraded by ~4,000,000 m^3 over the lower 18 km (~108,000 m^3/). Gravel extraction accounts for ~2,630,000 m^3 (64%). This estimate is based on historic extraction of 60,000 m^3/y (Connell & Miller 1992), assuming similar locations of extraction to the recent record; and 1990-2003 extraction records.[12]

If coastline retreat/river re-grading was not occurring, 130,000 m^3/year of gravel extraction would be required to account for the change in bed volume in the lower Opihi in the period 1966-2004. This rate of gravel extraction is unlikely historically, but is in the range of recent reported extraction.

Major departures from the long term rates of degradation (~110,000 m^3/y) occur in three periods:

- 1982-1987: Degradation averaging 12,000 m^3/y occurred, with ~52,000 m^3/y extraction from the reach. Hence the minimum average reach input is 40,000 m^3/y (with an unknown amount of gravel by-passing to the sea). The effects of the 1986 extreme flood (section 4) are unknown. Scenarios include:
  - ⇒ Limited material was brought downstream in the flood;
  - ⇒ Any extra material brought downstream was transported through to the sea with little deposition in the lower river;
  - ⇒ General scour removed material from previous deposition.

[12] The 2003 half year reported extraction was doubled; and the extraction to mid 2004 was taken as half the reported average annual extraction for the reach in the period 1990-2002. If the historic rate of extraction was 50,000 m^3/y (Williman & Smart 1987), degradation attributable to gravel extraction would decrease to 59%.

- 1987-1994: Degradation averaging 194,000 m^3/y occurred (Fig. 12); of which 56,000 m^3/y (~30%) is from gravel extraction.
  - ⇒ This must be largely due to general scour, probably because of the 1994 floods.
  - ⇒ There may be an element of under-reporting of gravel extraction, but this is unlikely to account for much of the change.
- 1994-2004: Degradation averaging 114,300 m^3/y occurred, which was matched by gravel extraction. This suggests there was little gravel input to the reach, but this is improbable given the Opuha dam breach and general flooding in 1997 (section 4). The most probable scenarios are:
  - ⇒ Recent gravel extraction is under-reported and much of the material deposited in the reach as the result of large floods was removed by extraction and scour.
  - ⇒ Large quantities of material brought downstream were transported through to the sea with little deposition in the lower river.

If the river bed were lowered to provide 100 year flood protection (section 6.3), a limited "surplus" volume of material would be available from the lower 2 km (270,000 m^3), and there is about the same size "deficit" from km 2 to 5.56 (-295,000 m^3) (Fig. 20). Further upstream ~720,000 m^3 is surplus from km 6.41 to 18.72; and ~520,000 m^3 is surplus from km 18.04 to 25.905 (total gross surplus of ~1,500,000 m^3).

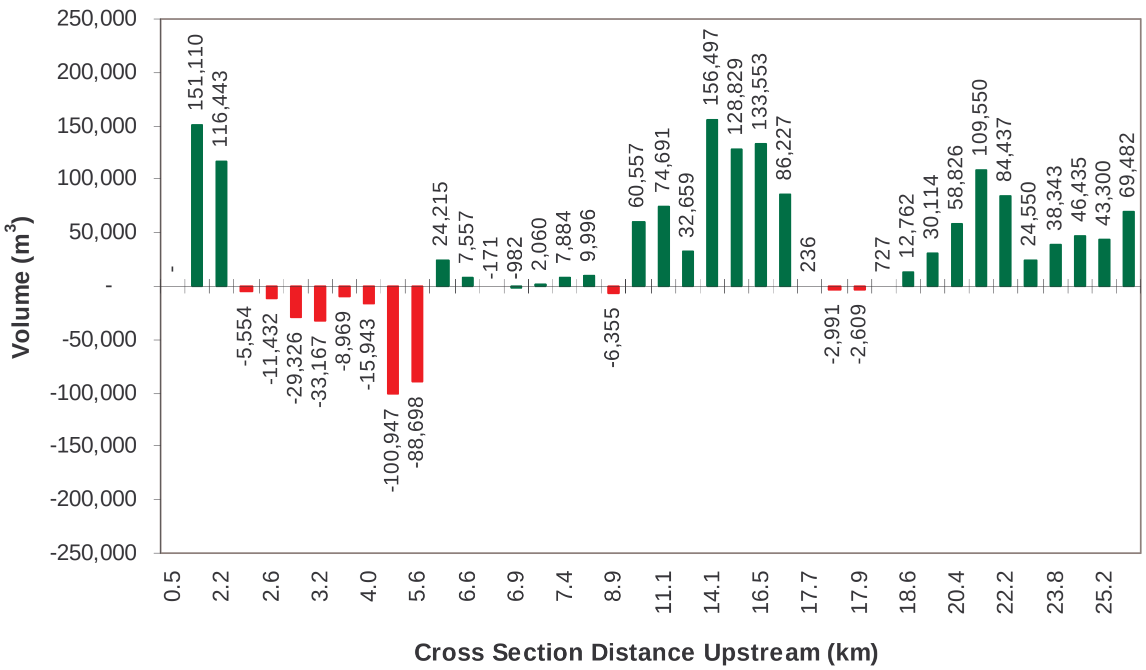


Fig. 20 Opihi River sediment storage in 2004 relative to a 100 year flood design bed level

6.4.2 Opihi River from the Tengawai to Opuha confluences

Limited gravel extraction occurs in the reach from the Tengawai confluence (km 18) to the Opuha confluence (km 32.5) (3,882 m^3, or 0.3% of the total in the period 1990-2002) (Fig. 12). However, the 7.34 km surveyed reach (cross section 18565 to 25905) degraded ~490,000 m^3 since 1966 (~13,000 m^3/y on average) (Fig. 13).

Major departures from the long term rates of degradation occur in three periods:

- 1982-1987: Aggradation of 149,000 m^3 occurred (~30,000 m^3/y). This is probably due to major inputs from the 1986 extreme flood.
- 1987-1994: Degradation of 337,000 m^3 occurred (~48,000 m^3/y), with virtually no gravel extraction (~330 m^3/y). This must be due to general scour, including scour of the lower river reaches to the sea (section 6.4.1).
- 1994-2004: There was little change (aggradation of 3,229 m^3; ~330 m^3/y). Large quantities of material from the Opuha dam breach, and from Opuha channel scour, must have passed through the system without significant deposition.

6.4.3 Upper Opihi River

Upper Opihi River cross sections begin above the gorge (km 46) and extend upstream through the upper alluvial plains to ~km 65. Eleven percent of the total extraction from the Opihi River occurs in this reach. A small volume of extraction (~300 m^3/y) occurs between the gorge (km 45.5) and the lower cross section (km 46.397).

Historic survey cross sections are quite far apart (~3 km on average) (Fig. 14), so earlier data was interpolated to match the 1998 surveys. The mean bed levels for intermediate points were pro-rated by the distance between cross sections. The average spacing of the interpolated sections is 1.42 km, which is still far apart given the narrow channel (~100 m). The few available cross sections suggest bed levels have similar behaviour, so the results are considered to be indicative.

Below SH79 Bridge there was little change from 1952 to 1962, but there are large differences in later periods:

- From 1962 to 1984 the bed aggraded 230,000 m^3. Gravel extraction was insignificant (2,000 m^3), hence the net rate of bed material input was ~10,500 m^3/y.
- From 1984 to 1987 the bed aggraded 70,000 m^3, with extraction of 350 m^3, hence the net rate of bedload input over the three years was ~23,000 m^3/y, which may be explained by large inputs with the extreme flood of 1986.
- From 1987-1998 there was little change (Fig. 14); despite large floods in 1994 and 1997.

Above SH79 Bridge there was little change from 1952 to 1962, but the limited data suggest a degradational trend since then:

- From 1962 to 1984 the bed degraded 350,000 m^3, with gravel extraction of ~150,000 m^3.
- From 1984 to 1987 the bed degraded 200,000 m^3, with gravel extraction of 26,500 m^3.
- From 1987-1998 the bed degraded 540,000 m^3, with gravel extraction of 120,000 m^3.

Net contributions of bed material from the upper Opihi were minimal:

- In the period 1962-1984 the net contribution from upper reach degradation (~200,000 m^3) basically was cancelled out with the aggradation in the reach below the bridge (230,000 m^3). The difference could be local sources of material (e.g. Strathconan Creek and Coal Stream), but is probably in the order of the error of analysis given the cross section spacing.
- From 1984 to 1987 the net contribution from the upper reach (~175,00 m^3) is far in excess of local aggradation (~70,000 m^3), hence ~100,000 m^3 must have been transported downstream (i.e. ~30,000 m^3/y).
- From 1987 to 1998 the upper reach contributed 420,000 m^3; with little change in the reach below SH79; hence the catchment above the gorge contribution on average a minimum of ~40,000 m^3/y to the system.

Large floods in 1986, 1994 and 1997 scoured the bed, or were locally neutral in effect, and transported large quantities of bed material downstream to the gorge and through the lower reaches of the Opihi to the sea.

6.4.4 Tengawai River

To estimate volume changes and sediment transport, historic gravel extraction had to be estimated because detailed gravel extraction records prior to 1990 were not available. Several assumptions were made:

- That the historic rate of extraction on the Tengawai is 56% of the recent (1990-2002) extraction (based on reports of Opihi extraction).
- That the locations of extraction are similar over time (as noted earlier the proportion extracted from particular reaches was relatively constant).
- The gravel take for particular reaches of the Tengawai can be estimated by pro-rating the average extraction for the period of record by the proportion taken from that particular reach.

Over the lower several km, the Tengawai River generally degraded since surveys began in 1966 (Fig. 15). Over the period 1966-1997 the bed degraded 295,000 m^3, with extraction estimated at 140,000 m^3 (~50% of the loss). Within this there were periods of aggradation and degradation:

- Minor degradation occurred in the period 1966 to 1974 (50,000 m^3); which may be largely due to gravel extraction (~34,000 m^3).

- From 1987 to 1997 the reach degraded by 250,000 m^3, of which 62,000 m^3 (about 25%) was due to gravel extraction.
- Minor aggradation occurred in the period 1974-1982 (17,000 m^3); requiring a net bedload input of ~6,000 m^3/y.
- From 1982 to1987 the lower cross sections aggraded ~15,000 m^3; with material derived from the immediate upstream cross sections (12,500 m^3), with large losses further upstream.

In the 27.16 to 29.62 km reach the bed has periods of aggradation and degradation, but the volumes are small (-7,300 m^3/y from 1982-1987; to +8,700 m^3/y from 1987 to 1997). Gravel extraction is inconsequential (110-500 m^3/y, depending on the period). Erosion upstream exceeds the net deposition downstream.

Above ~km 30 limited surveys show the bed degraded (7,000 m^3 from 1982-1987; and 126,000 m^3 from 1987-1997). Gravel extraction for these periods totalled 250 and 550 m^3, respectively. The annual rates of change are small: ~1,400 m^3/y and 12,600 m^3/y, respectively.

Based on 1997 v. 1987 bed levels, lowering the Tengawai River fairway to provide for 100 year flood protection (section 6.3) would provide ~900,000 m^3 of bed material, mainly from the lower 12 km (Fig. 21). However, since the 1997 survey about 60,000 m^3 would probably be extracted and about 200,000 m^3 would probably be lost to general degradation.

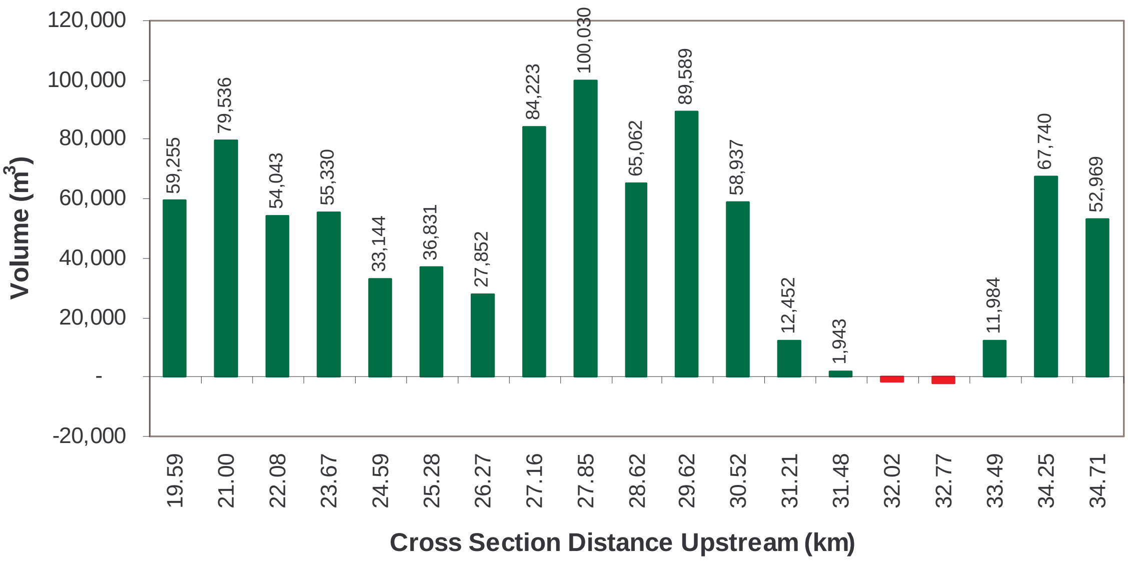


Fig. 21 Tengawai River sediment storage in 1997 relative to a 100 year flood design bed level

In summary, major losses in the lower reaches of the Tengawai River are only partially compensated from upstream degradation, and partially explained by gravel extraction. The largest change, net degradation of ~190,000 m^3 in the period 1987-1997, coincides with major degradation in the Opihi River below the Tengawai confluence. Big floods in the system did not cause major aggradation – they were locally neutral in net effect or scoured the bed. Excavation to increase fairway capacity to a 100 year event would provide about 640,000 m^3 of gravel.

7 Discussion and recommendations

Gravel extraction may be significantly under-reported and there are inconsistencies in the reported locations of gravel extraction in the ECan gravel returns data base.

Sustainable management relies on accurate data, so appropriate procedures must be implemented to obtain accurate extraction information (±10%); locations of extraction should be specified in terms of the ECan river distance/cross section maps; and 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 of historic gravel extraction. This information is important in determining changes over time.

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

Throughout the river where gravel extraction is occurring the bed is degrading. In part this is attributable to natural processes, particularly coastline retreat causing river re-grading in the lower reaches; and uplift causing river incision in the upper plains (Lechie 1994). Rates of degradation in these reaches and general degradation throughout the river are accelerated by Opihi Catchment Scheme controls on gravel supplies in the catchment, tributaries and mainstem, and by gravel extraction.

In the period 1990-2002 the average annual extraction from the Opihi was 106,700 m^3/y, while the Tengawai provided about one tenth as much (10,600 m^3/y). More than 86% of Opihi extraction occurs below the Tengawai confluence (km 18). Historically rates of 50-60,000 m^3/y were reported from the system as being sustainable, but the river degraded. Over the lower 18 km in the period 1982-1987 degradation averaged 12,000 m^3/y, with ~52,000 m^3/y of extraction, hence the minimum average reach net input is 40,000 m^3/y. (The system is open ended with an unknown amount of gravel by-passing to the sea). In other periods degradation exceeds extraction so a budget can not be calculated. Large floods in 1986, 1994 and 1997 scoured the bed, or were locally neutral in effect, and transported large quantities of bed material to the sea (e.g. Opuha Dam breach).

Gravel is not being replenished at the rate of extraction and security of supply (given other constraints or unknowns) is uncertain.

An evaluation of alternative gravel supply sources is required (e.g. off channel habitat creation – Hudson 1997; land mining; coastal mining).

A critical issue not addressed here is what are the affects of gravel extraction exceeding the rate of replenishment? 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).

An evaluation of the affects of gravel extraction is required in the Opihi system to determine if there are significant changes in physical habitat (e.g. the size, frequency and quality of gravel bars as habitat; access to tributaries) and if these changes have adverse effects (e.g. on fish spawning success; invertebrate productivity).

A positive consequence of large scale gravel extraction is that fairway capacity probably exceeds the 50 year design throughout the lower Opihi; and in places probably exceeds the 100 year fairway capacity. However, this assessment is based on reach average conditions in 1987, not an analysis by individual cross sections. A draft report on the Lower Opihi (CNFM 2004) and unpublished report on the Upper Opihi (Oliver 2002) could be used to undertake a section by section analysis.

A rigorous evaluation of fairway capacity is required to identify if there are bottlenecks in the systems and to target gravel extraction (e.g. Waimakariri River: MW 2000; Hudson 2005).

Removal of gravel to provide a 100 year event fairway capacity would yield 1,500,000 m^3 from the Opihi below km 26; and 640,000 m^3 from the lower Tengawai River. While this was considered as an alternative to raising stopbanks (Connell & Miller 1992), it was recognised that "lowered bed levels will increase the bank erosion attack to the river berms and would require additional bank protection work. Bank erosion can be severe on this river so this problem needs to be seriously considered." Natural degradation is also occurring.

An evaluation of channel and bank stability with continuing natural channel degradation and gravel extraction is required. This should include evaluating approaches to extraction (e.g. removal or lowering of point bars to reduce bank erosion: SCCB 1985; excavating channels rather than removing a veneer of gravel over a large area).

Mean bed levels around the bridges are up to a metre lower as the result of channel degradation and gravel extraction over the last 40 or 50 years. This is similar to the current situation on the Ashburton and Waimakariri rivers where the bridges are built on shallow piles and bridge stability is dependent on maintaining bed levels. Bed levels in the bridge reaches, particularly the lower Opihi, are probably highly sensitive to local gravel extraction.

Trigger levels (mean bed levels and minimum bed levels in a cross section) and guidelines for extraction near the bridges are required (e.g. Waimakariri River: Boyle 1996).

While it is clear that the coastline is rapidly retreating (e.g. Kirk 1991); it is less clear as to the effect of gravel extraction on these processes. There appears to be little net deposition of bed material in the rivers in extreme floods; which may mitigate effects of river gravel extraction.

As well, over the period of record river degradation is providing large inputs of gravel to the coast (e.g. ~50,000 m^3/y net from Opihi below the gorge; 14,500 m^3/y net from the Upper Opihi; 16,200 m^3 net from the lower Tengawai; and an unknown, but probably large quantity from the

Opuha River). Under-reporting of gravel extraction must reduce these values, but by an unknown amount.

As part of an assessment of alternative gravel supplies, particularly the extraction of gravel from the coastal zone, the role of river contributions to the coastal budget should be more fully investigated (e.g. Hicks 1998 did not consider inputs from channel degradation).

8 Acknowledgements

Environment Canterbury (Bill Meccia) provided the river cross section data; location maps (Norm Daniels); gravel returns (Matt Surman; Jamie Glass); supporting documents (Belinda van Eyndhoven; John Gebler; Robert Apple); and photographs (Philip Lees). Kevin McFall of ECan provided revised distances for the Tengawai gravel data. This assistance is gratefully acknowledged.

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11 Appendix

	Lower Opihi River Summary of Survey Dates									
Dist (m)	1953	1958	1961	1966	1974	1982	1984	1987	1994	2004
545				Feb-66	Mar-74	Jul-82		Apr-87	Nov-93	Jul-04
1205				Feb-66	Mar-74	Jul-82		Apr-87	Nov-93	Jun-04
2180	Mar-53	May-58	Nov-61	Feb-66	Mar-74	Jul-82		Apr-87	Nov-93	Jun-04
2395							Apr-84		Aug-94	Jun-04
2550							May-84		Aug-94	Jun-04
2835							Apr-84		Aug-94	Jun-04
3180							Apr-84		Aug-94	Jun-04
3485				Feb-66	Mar-74	Jul-82	Apr-84	Apr-87	Nov-93	Jun-04
3985									Jul-94	Jun-04
4665				Feb-66	Feb-74	Jul-82		Apr-87	Nov-93	Jun-04
5560				Feb-66	Feb-74	Jul-82		Apr-87	Nov-93	Jun-04
6410				Feb-66	Feb-74	Jul-82		Apr-87	Nov-93	Jun-04
6580				Feb-66	Feb-74	Jul-82		Apr-87	Nov-93	Jun-04
6695				Mar-66	Feb-74	Jul-82		Apr-87	Nov-93	Jun-04
6900				Mar-66	Feb-74	Jul-82		Apr-87	Nov-93	Jun-04
7205				Mar-66	Feb-74	Jul-82		Apr-87	Nov-93	Jun-04
7440				Mar-66	Feb-74	Jul-82		Apr-87	Nov-93	Jun-04
8015				Mar-66	Feb-74	Jul-82		Apr-87	Nov-93	Jun-04
8855	Mar-53	May-58	Dec-61	Mar-66	Feb-74	Jul-82		Jun-87	Jan-94	Jun-04
9780			Nov-61	Mar-66	Feb-74	Jul-82		Jun-87	Feb-94	Jun-04
11055				Mar-66	Feb-74	Jul-82		Jun-87	Feb-94	Jun-04
12645				Mar-66	Feb-74	Jul-82		Jun-87	Feb-94	Jun-04
14115				Mar-66	Feb-74	Jul-82		Jul-87	Feb-94	Jun-04
15130	Mar-53	Jun-58	Dec-61	Mar-66	Feb-74	Jul-82		Jul-87	Feb-94	Jun-04
16485				Mar-66	Dec-73	Jul-82		Jul-87	Feb-94	Jul-04
17490	Mar-53	Jun-58	Dec-61	Mar-66	Dec-73	Jul-82	May-84	Jul-87	Feb-94	Jun-04
17720				Mar-66	Dec-73	Jul-82	May-84	Jul-87	Feb-94	Jun-04
17795							May-84		Feb-94	Jul-04
17885				Mar-66	Dec-73	Jul-82	May-84	Jul-87	Sep-94	Jul-04
18040				Mar-66		Jul-82		Jul-87	Sep-94	Jun-04
18565				Mar-66	Dec-73	Jul-82		Jul-87	Sep-94	Jun-04
19685	Mar-53	Jun-58	Feb-62	Mar-66	Dec-73	Jul-82		Jul-87	Jun-94	Jul-04
20435				Mar-66	Dec-73	Jul-82		Jul-87	Jun-94	Jul-04
21225				Mar-66	Dec-73	Jul-82		Jul-87	Jun-94	Jul-04
22170				Mar-66	Dec-73	Jul-82		Jul-87	Aug-94	Jul-04
23000	Mar-53	Jul-58	Feb-62	Mar-66	Apr-74	Jul-82		Jul-87	Aug-94	Jul-04
23775				Mar-66	Apr-74	Jul-82		Aug-87	Aug-94	Jul-04
24520				Mar-66	Apr-74	Jul-82		Aug-87	Aug-94	Jul-04
25220				Mar-66	Apr-74	Jul-82		Aug-87	Aug-94	Jul-04
25905	Mar-53	Jul-58	Feb-62	Mar-66		Jul-82		Aug-87	Sep-94	Jul-04

XS No	Distance	Width	Upper Opihi River Mean Bed Level (m) 1952	1962	1984	1987	1998
15	46397	108.90	254.524	254.307	254.745	254.769	*254.757*
16	49677	55.50	276.661	276.852	277.769	278.359	278.398
16B	50860	101.30	*287.771*	*287.843*	*288.415*	*288.101*	287.419
16A Bridge	52240	102.50	*300.732*	*300.663*	*300.834*	299.465	299.181
17	52649	134.10	304.573	304.463	304.515	304.311	304.133
17A	54170	85.40	*319.941*	*319.837*	*319.444*	*319.180*	318.455
18	55590	61.00	334.289	334.191	333.382	333.061	332.911
18A	57190	55.60	*350.821*	*350.744*	*350.254*	*350.169*	350.127
19	58747	109.50	366.908	366.853	366.673	366.818	366.499
19A	60315	99.20	*383.851*	*383.892*	*383.509*	*383.583*	382.500
20	61702	120.60	398.839	398.965	398.402	398.412	398.176
20A	62735	88.40	*410.904*	*410.963*	*410.531*	*410.562*	410.104
20B	63710	87.30	*422.292*	*422.288*	*421.979*	*422.030*	421.762
21	64826	73.90	435.326	435.250	435.082	435.157	434.671

Values in red are interpolated.

Tengawai River

XS No	File Name	Revised Km	1966	1974	1982	1987	1994	1997
1	TIXS18580	**18.580**	166	174	182	187	194	197
2	TIXS19590	**19.590**		174	182	187	194	197
3	TIXS21000	**21.000**	166	174	182	187	194	197
4	TIXS22080	**22.080**	166	174	182	187	194	197
5	TIXS23670	**23.670**	166	174	182	187	194	197
6	TIXS24590	**24.590**	166	174	182	187		197
7	TIXS25280	**25.280**	166	174	182	187		197
8	TIXS26270	**26.270**	166	174	182	187		197
9	TIXS27160	**27.160**	166	174	182	187		197
10	TIXS27850	**27.850**	166	174	182	187		197
11	TIXS28620	**28.620**	166	174	182	187		197
12	TIXS29620	**29.620**	166	174	182	187		197
13	TIXS30520	**30.520**		174	183	187		197
14	TIXS31210	**31.210**		174	183	187		197
14A	TIXS31480	**31.480**			183	187		197
15	TIXS32020	**32.020**		174	183	187		197
16	TIXS32770	**32.770**			183	187		197
17	TIXS33490	**33.490**			183	187		197
18	TIXS34250	**34.250**			183	187		197
19	TIXS34710	**34.710**			183	187		197