

Orari River: Status of gravel resources and management implications

Report U05/33

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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 Orari River, Canterbury. Major findings/recommendations include:

- Some corrections in the gravel returns data base are required; and historic records should be incorporated.
- Survey data from 1949 to 1995/96 was available. Several findings should be confirmed with an analysis of the unprocessed 2004 survey data:
 - ⇒ Gravel extraction is largely from the lower 20 km of the Orari River (88-95% depending on the period).
 - ⇒ Historic rates of gravel extraction have been sustainable (~10,000 m³/y).
 - ⇒ There is uncertainty if recent higher levels of extraction are sustainable. Gravel extraction is increasing (1990 to 1995: 10,450 m³/y; 1995-1999: 23,000 m³/y; 2000-2003: 45,700 m³/y; projected 62,000 m³/y in 2010).
 - ⇒ Over periods of several years bed load inputs vary from 27,200 to 55,600 m³/y on average for the reach from the gorge to the sea.
 - ⇒ Recent increases in gravel extraction have probably increased fairway flood capacity beyond design capacity.
 - ⇒ It is unlikely that bridge stability is an issue.
- Flood statistics should probably be updated.
- Neither the Leckie (1994) model nor the River Environment Classification (Mosley & Schumm 2000) adequately describe downstream morphological changes in the Orari River.
- There is no evidence the Orari River is adjusting to a lower base level by incision near the mouth. It would be prudent to investigate the behaviour of the Orari mouth particularly if gravel extraction from the coastal zone is being considered in the Canterbury Bight.

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1 Introduction

Environmental Management Associates (EMA) were commissioned by Environment Canterbury (ECan) to evaluate the status of the gravel¹ resources and management implications for gravel extraction for several rivers including the Orari River in South Canterbury.

Careful management of the gravel resources of the Orari 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 Orari River floodplain management (Stringer & Rowell 1978).

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 upper Orari River above the gorge is a 520 km² foothills basin flowing from the Ben McLeod Range (with peaks around 1800-1900 m) (Fig. 1). Slopes are predominantly steep, apart from a ~30 km² area of rolling downs-undulating outwash plains in the Mowbary River valley. Many of the other major tributaries (Hewson, Phantom, Mt. Peel Creek and Andrews Stream) have narrow valley flats. At the gorge (river km 40), where the river flows out onto the Canterbury Plains, the elevation of the river bed is ~268 m.

Underlying basement rocks in the upper Orari are principally greywacke/argillites. Andersite and rhyolite are found in Quartz Creek in the north east of the catchment. Extensive deposits of weather rock

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.”

(screens) occur over most of the catchment. The most extensive vegetation cover is snow grass, tussock and grasses (90% of the area); with bare rock over 3% of the area. The major land use is sheep and cattle grazing (Stringer & Rowell 1978).

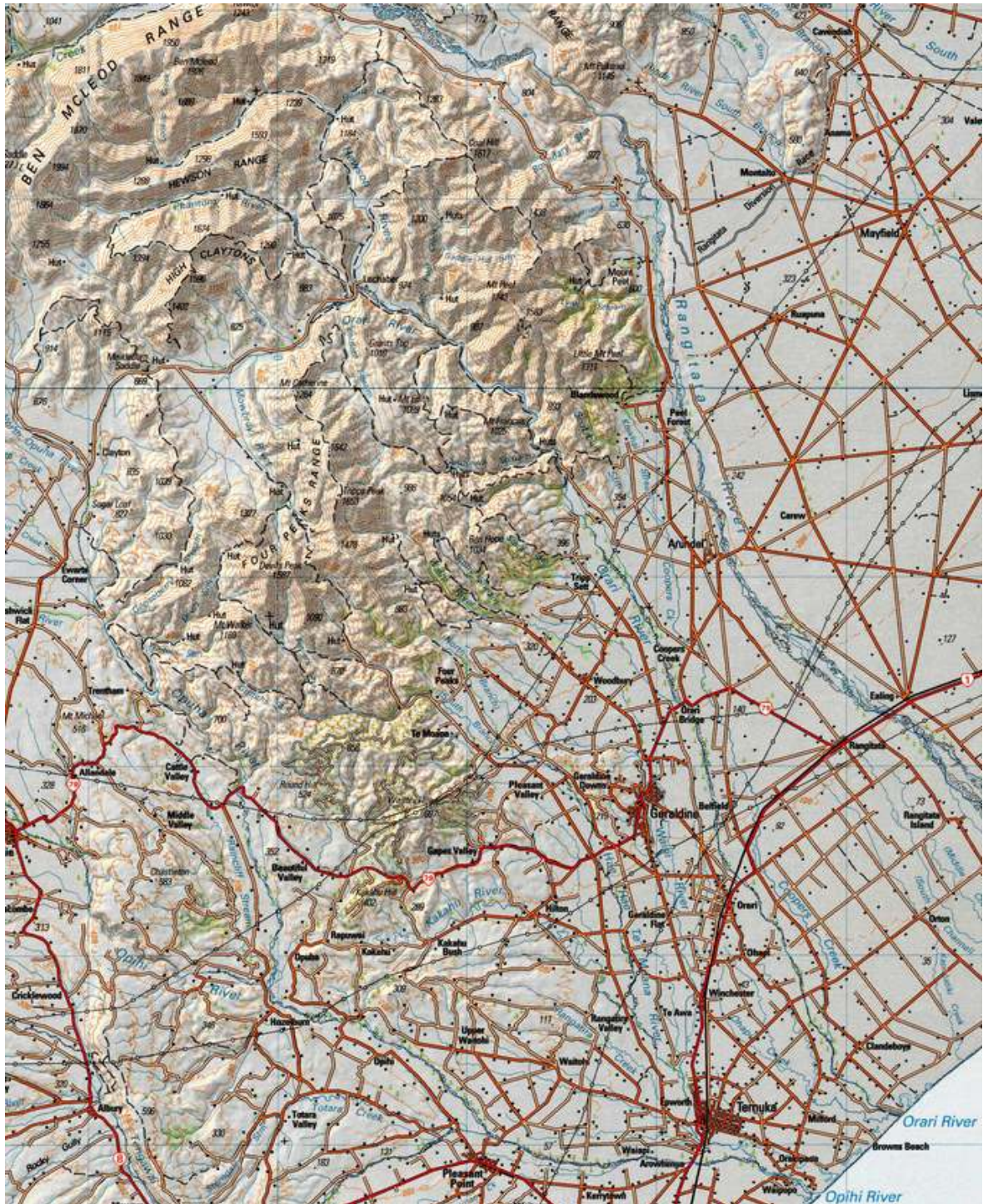


Fig. 1 Map of the Orari catchment (TopoMap)

Below the gorge Orari River outflows produced an extensive glacial outwash fan extending along the present course of Coopers Creek to Clandeboyne in the north and to Temuka in the south. Presently the river is contained to an area of ~238 km², but as recently as about 1852

the Orari joined the Temuka system north-west of the present Winchester Township (Williams 1968) via what is now Dobies Stream (Fig. 1; Fig. 2). The Orari fan coalesced with the much larger and faster growing Rangitata fan to the north and the Waihi fan to the south. Glaciers did not extend onto the upper plains of the Orari fan (McEwan 2002).

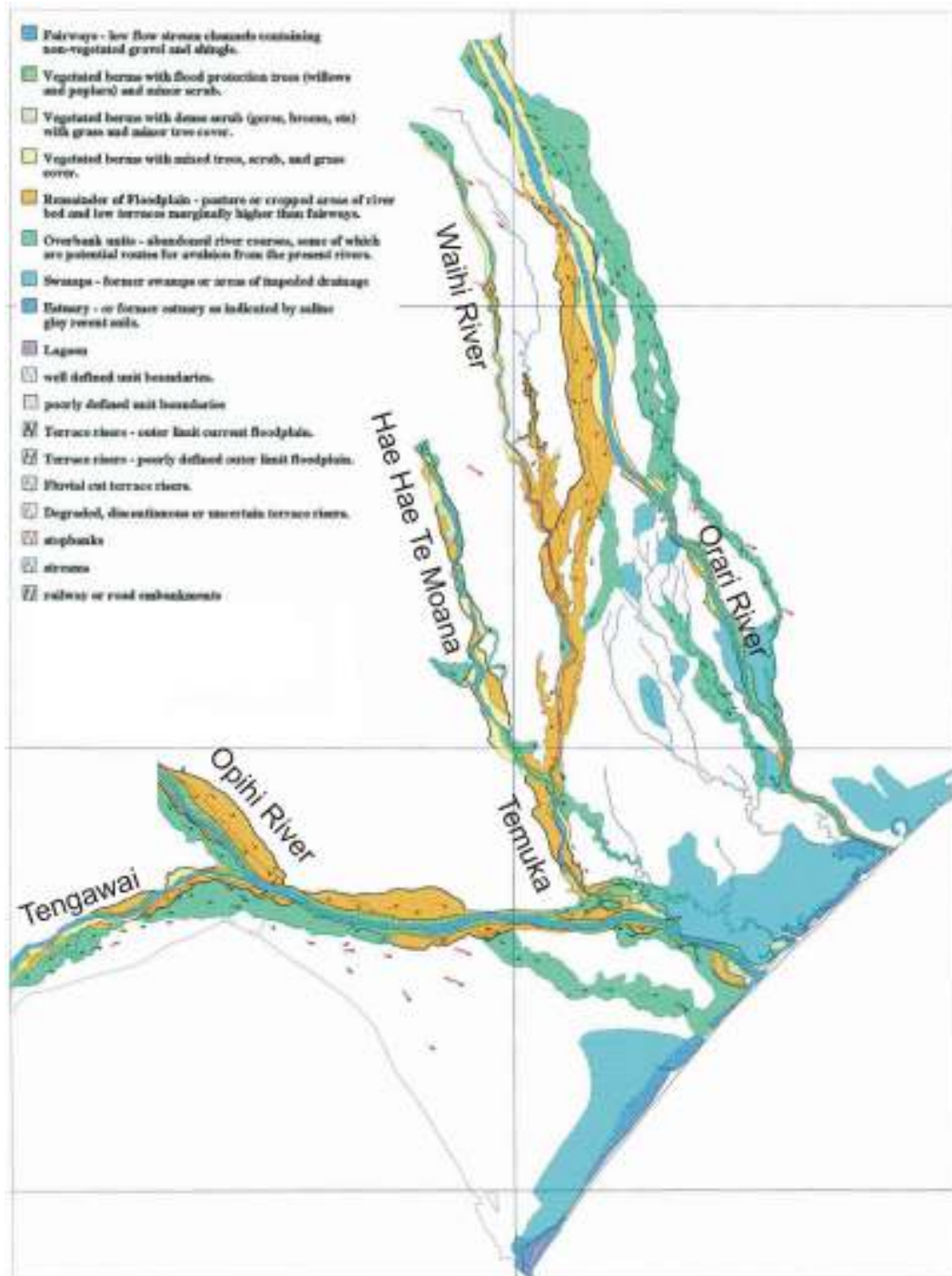


Fig. 2 Geomorphic map of fluvial features (based on Lynn et al. 1997)

The alluvial fans were uplifted and tilted with subsequent incision of rivers into the upper plains surface. At the mouth of the rivers the fans are being eroded by wave action following the post-glacial rise in sea level. Analysis of fan slopes and cliff heights suggest that 4 to 6 km of land have been removed from the plains margin during the last 4,000 to 7,000 years (Kirk 1991). In mid Canterbury, at the mouth of the Orari River, the coastline is retreating ~0.65 m/y (citations in Lechie 1994). As coastlines retreat, rivers adjust to a lower base level by incision near the mouth.

Land use on the plains is intense mixed crop - livestock (sheep, beef and dairy); with high demands for irrigation (McEwan 2002). There are no large communities within the floodplain, but several communities are at risk of flooding in the area, notably Temuka (population of 4,000 in 2001; Statistics New Zealand), Geraldine (2,200) and Winchester (258).

3 Flooding and flood management

Almost all the flood runoff originates from the foothills of the Orari catchment (Connell *et al.* 1993). Floods can occur at any time of year, the largest resulting from easterly rainfalls associated with regions of high pressure to the south of New Zealand and complex low pressure systems passing from west to east near Cook Strait. Easterly storms are usually of short duration, typically 24 to 48 hours (Williams 1968). At the gorge (522 km²) the mean annual low flow is 10.5 m³/s; the mean annual flow is 209 m³/s; and the 10 year return period flood is 485 m³/s (ECan website last updated 2001).

Flood management has focused on the Canterbury Plains reach of the Orari River. Upstream of the Orari Gorge recorder (km 40.12) the river flows through a narrow bedrock gorge. In the upper plains below the 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. 3).

Terraces in the upper plains are ~12-14 m above the river (Fig. 3). The river bed level is ~268 m at the gorge (km 40.12) and the contour along the base of the foothills is 280 m. At km 38 the bed elevation is ~251 m (extrapolated from the cross section mean bed levels) and a trig station on the left bank terrace is 265 m. Terraces on the true right bank are intermittent and lower than the left bank terraces.

A low terrace forms the right bank for ~1 km downstream of km 37.7. The terrace is evident again from km 35 to km 32.5, beginning at the rivers edge but diverging downstream to ~900 m away from the active channel. A stopbank is connected to the upstream end of this terrace and separates the active channel from the floodplain.

Immediately below the gorge a terrace forms the left bank for ~1.2 km. This terrace is continuous from km 40.2 downstream to km 32.5 where the terrace merges with the floodplain surface; where the Rangitata Fan intersects the Orari River (McEwan 2002). Downstream of ~km 37 the left bank the terrace is generally 600 to 900 m away from the river and there a stopbank between the river and the terrace. This upper reach to

the gorge equates to the upper entrenched reach described by Lechie (1994) in his analysis of Canterbury Plains rivers.



Fig. 3 Orari River upper plains view upstream from km 32.5 (October 2004)

Further downstream the river is weakly incised or flows on the fan surface with low or non-existent banks. This reach equates to the “zone of minimum erosion” described by Lechie (1994) as a feature of Canterbury Plains rivers.² Up to 1852 the Orari River discharged into the Waihi River north west of Winchester following the course of the present Dobies Stream (Williams 1968) (Fig. 2). In this reach the natural boundary of the Orari River is a terrace “riser” more than a kilometer west of the Orari River (Lynn *et al.* 1997).

As noted in section 2, a feature of Canterbury Bight rivers is degradation near the coast due to coastline retreat (Lechie 1994). However, entrenchment is not evident in the topography or reported in geomorphological mapping. Prior to major river works the Orari meandered into a lagoon behind the coastal sand dunes, with an extensive area (~7,700 ha) of poor drainage for agriculture (Williams 1968). There is evidence of overflow channels into Ohapi Creek, along the right bank, a few kilometers from the sea (Lynn *et al.* 1997) (Fig. 2).

The essence of the flooding problem is described by Williams (1968): “The Orari River is typical of the shingle bed rivers of Canterbury ... The surrounding land is little higher than the river bed. Shingle causes both instability and rapid filling of river courses. On the shingle fan outfalls, the river persists in the age-old cycle which has formed, and is still forming, the Canterbury Plains. The river gathers shingle from the mountains, and its own banks and bed, at a rate beyond its capacity to transport to the sea. At any positive check or flattening of gradient, the river bed aggrades and fills with shingle. Floodwaters spill over the river banks to pursue less obstructed courses to the sea. The cycle then starts again in the new bed.” This is essentially the process described by Fahnestock (1963) and Carson (1984).

In the Orari-Waihi-Temuka Catchment Control Scheme report it was noted that during large floods the Orari River “... regularly overflowed 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).

A primary objective of the Orari-Waihi-Temuka flood control scheme was to prevent Orari floodwaters entering the Waihi-Temuka system, which it did on a regular basis (Williams 1968). Major flooding was recorded in the early 1850s, 1868, 1902, 1945 and 1986, with lesser flooding in 1951, 1952 and 1957 (Connell *et al.* 1993).

River works in the Orari River catchment can be described as having several objectives (Williams 1968; Stringer & Rowell 1978; Connell *et al.* 1993):

² Lynn (*et al.* 1997) describe “entrenchment” over the lower 7 km of Coopers Creek (an old course of the Orari) to its confluence with the Orari River (km 5.70), but a more apt description may be “weakly incised.”

1. Prevent erosion of infrastructure, particularly the bridges, with localized works starting in the 1880s.
2. Contain the Orari River to the channel it cut directly to the sea in about 1852 (e.g. embankments and stopbanks to contain a 100 year flood and prevent Orari flow into the Opihi were initiated in 1956). The design flow at the gorge is 1,275 m³/s.
3. To divert excess flood waters (255 m³/s) from the Orari River into Coopers Creek along the north bank from ~km 32 and to redirect these flood waters (with additional flow from Sweetwater Creek of 28 m³/s) back into the Orari River near km 6.
4. Straighten and constrict the channel to concentrate flow and scour gravel during floods and transport gravel to the sea.
5. Increase hydraulic efficiency and reduce sediment trapping by removing vegetation from the fairway.
6. 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).
7. 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.

Channel constriction and straightening is evident throughout the Orari River (Fig. 3; Fig. 4). Design fairway widths downstream to State Highway 1 (SH 1; km 15.97) were 600 feet (183 m); downstream of which the fairway gradually narrowed to 330 feet (101 m) through the “badly aggraded reaches.”

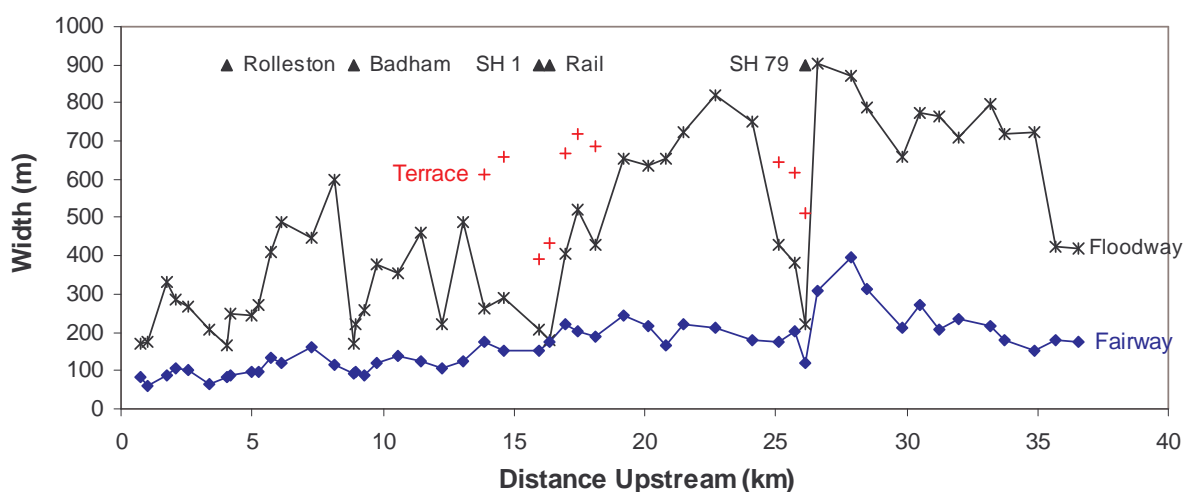


Fig. 4 Orari River channel width based on the cross section surveys and aerial photographs

To by-pass the lagoon area, and to facilitate the transport of gravel to the sea, a straight one mile diversion cut (1.62 km) was made at the mouth, with 7 m high stopbanks that are 183 m apart (Williams 1968). Previously a coastal barrier formed by littoral drift would force the river mouth northward up to 5 km (Lynn *et al.* 1997) during low river flow conditions. A sea wall was constructed at the mouth of the Orari River.

A design discharge of 1,275 m³/s was used for the 100 year flood at the gorge (Williams 1968). This was a reasonable estimate. Connell *et al.* (1993) provide the following estimates (with ECan website estimates to 2001 in brackets):

- Mean annual flow: 253 m³/s (209 m³/s).
- 10 year return period flood: 670 m³/s (485 m³/s).
- 50 year return period flood: 1,083 m³/s.
- 100 year return period flood: 1,252 m³/s.

The last occurrence of major flooding was in 1986 when the Waihi and Temuka (but not the Orari) rivers overflowed their banks. Flood hazard maps, calibrated with observations in the 1986 flood, show by-pass flows down Coopers Creek (as designed – Williams 1968) spreading downstream parallel to the Orari River with significant ponding near the coast. Flows from the Orari down the historic channel (Dobies Creek) past Winchester and into the Opihi River were predicted. Flood flows are also predicted to occur in Ohapi Creek which runs parallel to the Orari River, with some return flow into the Orari, but with the major flow course causing ponding in the coastal area to the south at the mouth of the Opihi.

As noted earlier in this section, excessive sediment inputs and gravel build up in the channel are explicitly recognised as significant problems in the Orari floodplain management scheme (Williams 1968; Stringer & Rowell 1978).

In their flood hazard mapping and evaluation of floodplain management options, Connell *et al.* (1993) made the following statement regarding gravel management: “The South Canterbury Catchment Board took a large number of cross sections surveys on these river systems [Orari-Waihi-Temuka] ... The comparison of levels shows that they have not changed significantly in the study area over recent years.” This proposition is evaluated.

4 Gravel supply to the lower river

Stringer & Rowell (1978) describe large scale inputs of gravel into the major foothill tributaries of the Orari (e.g. Fig. 5). “With a total length of 160 km of gravel bearing streams, a huge amount of debris is feeding from the gravel sources out into the four main rivers and down through the gorge to deposit onto the 13.67 km length of main river between the gorge outlet and the upper Orari bridges... It is essential that control works be carried out in the upper catchment rivers and streams, to reduce the continued high flood damage restoration programmes necessary because of the uncontrolled intrusion of detritus exceeding

the ability of the lower river to handle bed load and suspended sediments in flood times.”

While measures were taken to control excessive inputs of gravel from the foothill tributaries, and the channel was confined in an attempt to reduce bank erosion and flush gravel to the sea, there was no quantification of the volume of gravel delivered to the Orari system in the scheme proposal.



**Fig. 5 Lower Phantom River truncated alluvial fan
(Stringer & Rowell 1978)**

Based on an erosion rating of the catchment, Cuff (1981) estimated bedload of 35,000 m³/y at Orari gorge. de Joux (1980) and Griffiths & Glasby (1985) estimated bed load of 28,400 m³ and 10,730 m³/y, respectively, based on measurements of suspended sediment and an assumed proportion of bedload.

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 reduced the availability of gravel from the river itself.

Contrary to the expectation that a confined single thread channel would efficiently flush gravel to the sea, subsequent studies report 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 (Griffiths & Carson 2000).

5 Rates and location of gravel extraction in the lower river

In the period 1990-2002³ the average annual extraction from the Orari River was 23,112 m³/y (Fig. 6). Average annual rates of extraction varied: 1990-1994 9,692 m³/y; 1995-1999 22,991 m³/y; and 2000-2002 45,681 m³/y. There is a trend of increasing gravel extraction with time with projected extraction of 62,000 m³/y in 2010 and 90,000 m³/y in 2020 ($r^2 = 0.47$); but extraction may have peaked.

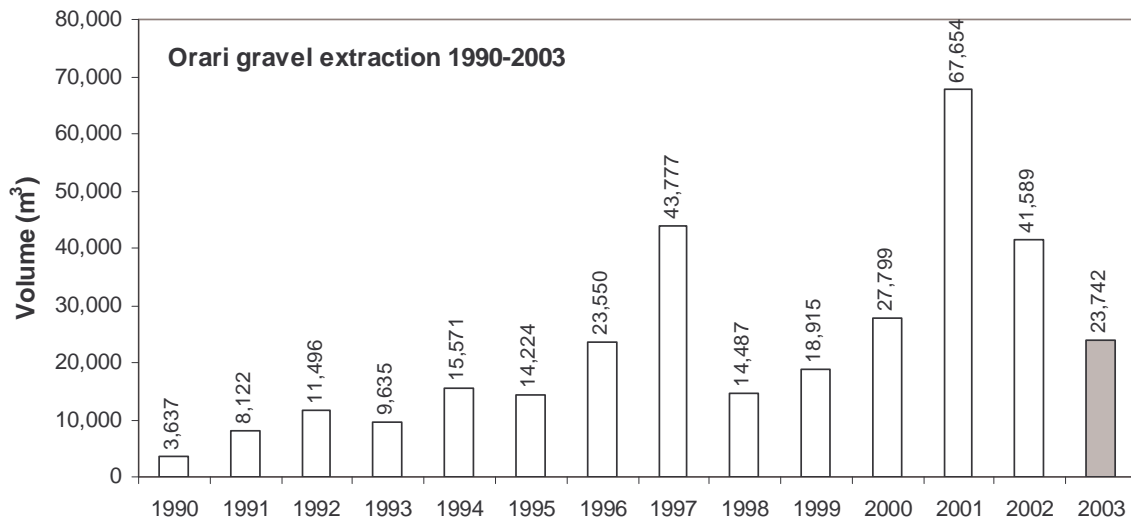


Fig. 6 Orari River: volume of gravel extracted 1990-2003

Extraction from the Orari River is concentrated in the lower ~20 km averaging ~21,600 m³/y (93% of the total) from 1990-2002 (Fig. 7). Per kilometer of river, extraction over the lower ~6 km averages 933 m³/y; 1,221 m³/y from km 6 to 20; 484 m³/y from km 20-36; and 40 m³/y for the upper reaches (km 36 to 59).

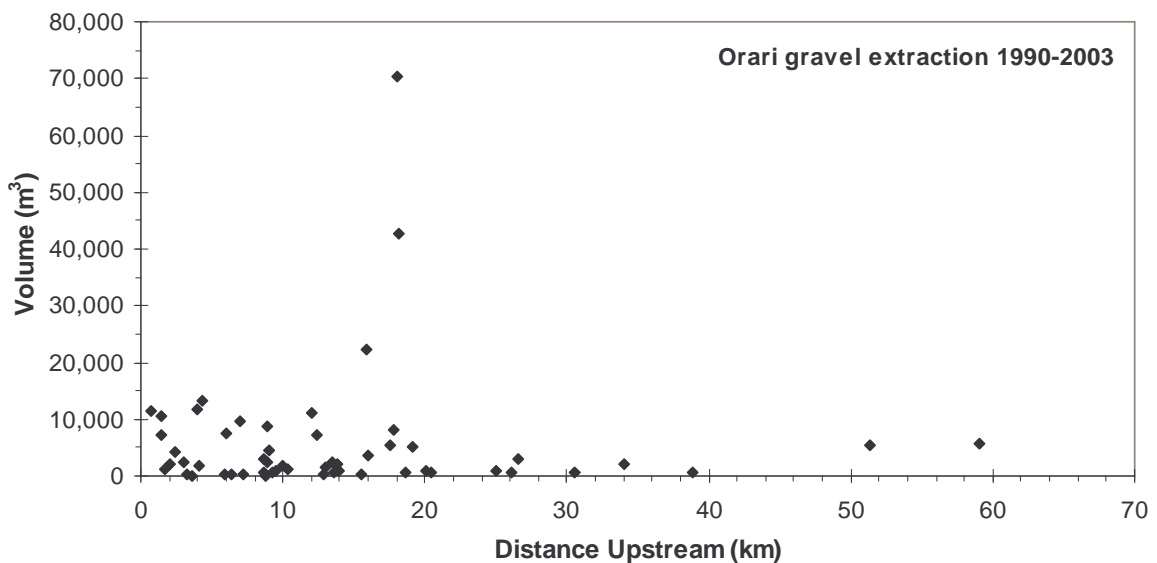


Fig. 7 Location of gravel extraction Orari River

³ Data for 2003 is for six months, so is not included in the average.

When considered in five year periods, the location of extraction has been relatively constant, with 88-95% from the lower ~20 km; 0.3-3% from ~km 20-36; and 1-11% from the upper reaches (>km 36). The lower ~6 km contributed 22-33% of the total; with 57-73% from km 6-19. There is no systematic shift in extraction locations, apart from the proportion taken from the upper reaches declining with time as overall volumes increased. The volume taken from the upper reaches is relatively constant averaging ~900 m³/y (range ~600-1,100 m³/y).

Gravel extraction information prior to 1990 was not available, but for the “Orari- Waihi-Temuka-L. Opihi” rivers, Williman & Smart (1987) report “Sand and gravel extraction is currently 17 000 m³/year. Extraction is controlled to limited sites. Annual replenishment is unknown.” (It is unclear what they mean by “L. Opihi” - elsewhere they report Opihi extraction is 50,000 m³/y; which is consistent with extraction records – Hudson 2005).

Historic gravel extraction from the Orari is estimated from the 17,000 m³/y reported by Williman & Smart (1987), subtracting the Waihi (4,187 m³/y) and Temuka (3,033 m³/y) gravel extraction from 1990-1994. The 9,780 m³/y estimate is consistent with the first five years of record for the Orari (1990-1994: 9,692 m³/y). The latter is used as the estimate of gravel extraction for historic channel changes; with the assumption that the location of historic extraction is the same as in 1990-2002.

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. Survey locations and times are described in Appendix 1. Data to 1995 (to cross section 33) and 1996 (cross sections 35-64) are available. September-October 2004 survey data is not scheduled for processing until July 2005.

Audit notes state that Sections 1 to 33 (to km 16.99) are in true mean sea level; but sections 35 to 62 are in an older datum and could be up to ±100mm off mean sea level. However, the inter survey differences between surveys at each section are correct.

6.1 General bed levels

Prior to major river works, the bed near the mouth aggraded ~27 cm on average from 1949 to 1951 (Fig. 8). There were major reductions in bed levels (~1 m on average) in the lower ~6 km of the Orari River in the period 1951 to 1964, which are attributable to river engineering works. From 1964 to 1995 there was little net change on average over this reach.

For much of the reach from ~km 6 to 15 the bed was higher in 1949/51, with a decrease in bed levels following engineering works. Bed levels were sustained at the post work bed levels through to the 1980s; with a bed build up in places to 1995 (Fig. 8). Upstream of km 15 bed levels

surveys from 1964, 1972, 1981 and 1985 fluctuate around the 1995 bed level (Fig. 8).

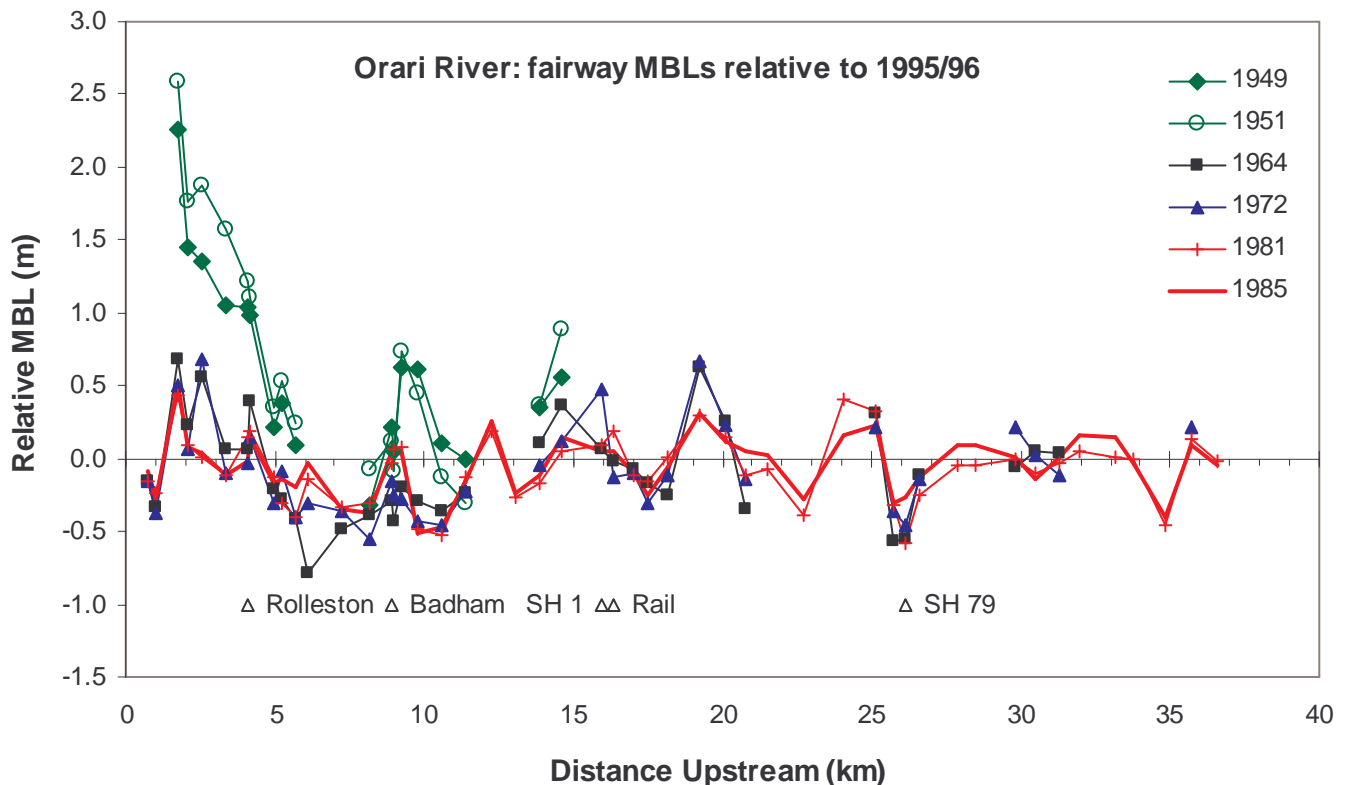


Fig. 8 Orari River MBLs relative to 1995

6.2 Bridge reach bed levels

Bed levels at the lower four bridges decreased as a result of engineering works; but were higher in the most recent survey than in the 1960s and 1970s (Fig. 8). There is little difference in bed levels around these bridges in the period 1985-1995. Around SH 79 (km 26), bed levels are presently higher than in the past (Fig. 8).

6.3 Flood levels

Information is not available with which to quantify fairway capacity, potential bottlenecks, or the role of gravel extraction in maintaining required bed levels. Aggradation is not perceived to be a problem with present rates of gravel extraction (see the closure to section 3, Flooding and flood management). Connell *et al.* (1993) stated "The comparison of levels shows that they have not changed significantly in the study area over recent years." (The study area includes the Waihi and Temuka).

This proposition is vindicated in the bed level analysis of the Orari River discussed in the previous section. However, this is not correct in the Waihi River (Hudson 2005); and bed levels have progressively declined in all surveys in the Temuka River from 1953 to 2001.

6.4 Gravel transport and storage

Changes in bed material storage in the fairway are calculated for segments of the river using 1949, 1951, 1964, 1972, 1981 1985 and 1995/96 surveys.

The prismoidal formula is used to interpolate the volume of the riverbed (specifically the fairway) between cross sections. Only partial comparisons are possible because of data gaps (Appendix 1). Data was interpolated where one section was missing.

6.4.1 Lower Orari River below km 6

Aggradation was cited as a major reason for lower reach channel confinement to flush gravel to the sea (Williams 1968); and this is evident in the 1949 – 1951 surveys where the bed aggraded by 105,400 m³ over the lower 6 km. Gravel extraction from this reach is possibly ~3,000 m³/y; hence the net input of bed material would be ~55,600 m³/y.

Post works, bed levels were relatively stable near the mouth in the period 1964-1972, with minor degradation (~16,000 m³ total) which is probably less than the loss attributable to gravel extraction (~27,000 m³ over the reach).

In the period 1972-1981 total degradation of 27,700 m³ is again accounted for by gravel extraction of 29,800 m³ over the reach; but volumes of gravel extraction are only rough estimates in this period.

The lower ~6 km aggraded by 15,900 m³ from 1981-1985; with gravel extraction estimated to account for 75% of the change. Bed load input into the lower ~6 km would be ~7,000 m³/y; with bed load input into the plains reach below km ~36 of 55,600 m³/y (see below).

From 1985 to 1995 the reach aggraded by ~820 m³/y; with extraction of 3,255 m³/y, requiring a net bedload input ~4,100 m³/y.

These findings are contrary to the proposition that Canterbury Bight rivers are degrading in their lower reaches because of coastline retreat (Lechie 1994; section 2):

- There is no apparent zone of entrenchment in the lower Orari River (section 3).
- The bed is aggrading even with gravel extraction.

It is possible that reported rates of coastline retreat (0.65 m/y; section 2) are mitigated by the sea wall at the Orari mouth. This warrants further investigation because of the longer term implications of coastline retreat and infrastructure integrity.

At a larger scale, an idealised model of the fluvial system has been proposed as part of the River Environment Classification (REC; 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. The silt phase has been eliminated by the river works (section 3), with a channel directly to the sea, and the channel has an aggrading gravel bed.

Confinement of the lower river has proven unsuccessful in preventing aggradation of gravel. Gravel flushing requires very constricted channel widths (e.g. the gorges); which would require extreme bank protection in a gravel bed river (Griffiths & Carson 2000).

6.4.2 Lower Orari River km 6-20

In the reach from cross section 16 to 37 (km 7.25-19.22) sediment budgets can be calculated for 1981, 1985 and 1995, but there are too many missing cross sections in the earlier surveys to calculate meaningful changes.

From 1981 to 1985 there was virtually no net change (+1,151 m³) in the km 6-19 reach; but gravel extraction averaged 5,600 m³ per year in the reach. Net bedload input into the reach would thus be ~-5,800 m³/y.

From 1985 to 1995 aggradation averaged 22,800 m³/y; with gravel extraction averaging 5,770 m³/y. Net bedload input into the reach would thus be ~28,600 m³/y.

This reach encompasses the zone of minimum incision (Lechie 1994), which is a transfer zone (Schumm & Mosley 2000) where substantial aggradation is not expected. However, aggradation occurred even with gravel extraction.

6.4.3 Lower Orari River km 20-36

Cross sections 39 to 64 were surveyed in 1981 (with one section in 1980 and four in 1982); 1985 and 1996. The 1981 data set was treated as though all the sections were surveyed at the same time.

From 1981 to 1985 the bed from ~km 20-36 aggraded 42,760 m³/y; with virtually no gravel extraction (36 m³/y). When totalled with the changes downstream the net bedload input into the lower 36 km of the Orari River was 55,600 m³ in the period 1981-1985.

Conversely, degradation occurred in the upper plains reach from 1985 to 1996 (4,139 m³/y) with virtually no extraction (44 m³/y). When totalled with the changes downstream the net bedload input into the lower 36 km of the Orari River was 27,240 m³/y in the period 1985-1996. The reduced net bedload input may reflect reductions in bedload supplies with catchment control measures (section 3), and reduced sediment transport capacity with a single thread channel (section 4).

Although this reach encompasses the zone of entrenchment (Lechie 1994), there was limited degradation in the 1985-1996 period; and the bed aggraded in the period 1981-1985.

7 Discussion and recommendations

There are inconsistencies in the reported locations of gravel extraction in the recent ECan gravel returns data base involving 4.6% of the total volume. This is not too important in terms of the findings of this report, but it must be emphasised that reliable data underpins management. Also, an attempt should be made to compile historic information to provide a better understanding of sustainable gravel extraction.

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.

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

Gravel extraction is largely from the lower 20 km of the Orari River (88-95% depending on the period). From 1990 to 1995 extraction averaged 10,450 m³/y; increasing to 23,000 m³/y in 1995-1999; and 45,700 m³/y in 2000-2002. Extraction may have peaked, but the trend is for increased extraction (62,000 m³/y in 2010).

Historic rates of gravel extraction have been sustainable (~10,000 m³/y); but there is uncertainty if recent higher levels of extraction are sustainable. Available cross section data only encompasses the period with modest extraction (to 1995).

Over several years bed load inputs calculated from cross section changes are shown to be variable; ranging from 27,200 to 55,600 m³/y for the reach from the gorge to the sea. Indirect estimates of bedload input ranged from 10,700 to 35,000 m³/y. 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 reduced the availability of gravel from the river itself.

It is premature to comment on whether current rates of gravel extraction are sustainable. Surveys from 2004 should be processed (scheduled for July) and this report updated.

The scheme has been successful in terms of containing recent floods, and recent bed levels were not considered to be a constraint (Connell *et al.* 1993). Minor changes since 1985 probably do not effect fairway flood capacity to the point where targeted gravel extraction is warranted. Recent increases in gravel extraction have probably increased fairway flood capacity, but this should be confirmed with an analysis of the unprocessed 2004 survey data. Also, given the number of recent large floods, and longer period of record, the flood statistics should probably be updated (e.g. Waihi revisions – Hudson 2005).

The flood statistics should probably be updated.

It is unlikely that bridge stability is an issue, at least to 1995. Subsequent higher rates of extraction may have changed this situation.

Two models have been proposed to explain or describe changes in river channel characteristics downstream:

- Leckie (1994) described three main river segments in Canterbury Bight rivers: a degrading upper plains, a zone of minimal incision, and a degrading lower segment.
- As part of the River Environment Classification (Snelder *et al.* 1999), 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.

Neither model adequately describes the Orari. Although the upper reaches have incised into the floodplain, as proposed by Leckie (1994), recent surveys show bed levels are in quasi-equilibrium, not substantially degrading. More recent surveys will show if this situation continues or if the upper plains reach is a major source of sediment in its

own right (e.g. Waimakariri – Griffiths 1979; Hudson 2005) rather than just a transfer zone (Mosley & Schumm 2000).

There is an extensive zone of minimum incision, where the river is at or near the floodplain surface. A major priority of the Orari flood control scheme was to contain the flows in this reach and to focus flows in a direct path to the sea. Gravel extraction has been an essential component of the scheme in maintaining bed levels. However, the expectation that a confined single thread channel would efficiently flush gravel to the sea is unfounded. Channel narrowing has not flushed out gravel, but probably accelerated aggradation by reducing transport capacity and confining the area of deposition. Clearly the reach is not a transfer zone as proposed by Mosley & Schumm (2000).

While general coastline erosion is reported for the Orari area and the Canterbury Bight coastline in general (Kirk 1991; Lechie 1994), there is no evidence of the Orari adjusting to a lower base level by incision near the mouth, though the river has been cut directly to the coast. The bed is aggrading even with gravel extraction.

It would be prudent to investigate the behaviour of the Orari mouth particularly if gravel extraction from the coastal zone is being considered in the Canterbury Bight.

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10 Complementary gravel reports

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

Location			Orari River Fairway Surveys						
XS	XS ID	Km	1949	1951	1964	1972	1981	1985	1995/96
1	OIXS00717	0.72			1964	1972	1981	1985	1995
2	OIXS01000	1.00			1964	1972	1981	1985	1995
4	OIXS01767	1.77	1949	1951	1964	1972	1982	1985	1995
5	OIXS02100	2.10	1949	1951	1964	1972	1982	1985	1995
6	OIXS02533	2.53	1949	1951	1964	1972	1981	1985	1995
8	OIXS03338	3.34	1949	1951	1964	1972	1981	1985	1995
9	OIXS04054	4.05			1964	1972	1981	1985	1995
10	OIXS04150	4.15	1949	1951	1964	1972	1981	1985	1995
11	OIXS04966	4.97	1949	1951	1964	1972	1981	1985	1995
12	OIXS05220	5.22			1964	1972	1981	1985	1995
13	OIXS05725	5.73	1949	1951	1964	1972	1981	1985	1995
14	OIXS06096	6.10			1964	1972	1981	1985	1995
16	OIXS07250	7.25					1981	1985	1995
18	OIXS08158	8.16	1949	1951	1964	1972	1981	1985	1995
19	OIXS08888	8.89			1964	1972	1981	1985	1995
20	OIXS08963	8.96	1949	1951	1964	1972	1982	1985	1995
21	OIXS09271	9.27	1949	1951	1964	1972	1981	1985	1995
22	OIXS09750	9.75	1949	1951	1964	1972	1982	1985	1995
23	OIXS10579	10.58			1964	1972	1981	1985	1995
24	OIXS11421	11.42	1949	1951	1964	1972	1982	1985	1995
25	OIXS12242	12.24						1985	1995
26	OIXS13042	13.04					1981	1985	1995
27	OIXS13864	13.86	1949	1951	1964	1972	1981	1985	1995
28	OIXS14629	14.63	1949	1951	1964	1972	1981	1985	1995
31	OIXS15971	15.97				1972	1981	1985	1995
32	OIXS16362	16.36			1964	1972	1981	1985	1995
33	OIXS16988	16.99			1964	1972	1981	1985	1995
34	OIXS17466	17.47			1964	1972	1981	1985	1995
35	OIXS18127	18.13			1964	1972	1981	1985	1995
37	OIXS19221	19.22					1981	1985	1996
39	OIXS20118	20.12			1964	1973	1981	1985	1996
40	OIXS20792	20.79			1964	1972	1981	1985	1996
41	OIXS21479	21.48					1981	1985	1996
43	OIXS22700	22.70					1982	1985	1996
45	OIXS24080	24.08					1982	1985	1996
47	OIXS25150	25.15			1964	1972	1981	1985	1996
48	OIXS25729	25.73			1964	1972	1981	1985	1996
49	OIXS26130	26.13			1964	1972	1980	1985	1996
50	OIXS26619	26.62			1964	1973		1985	1996
52	OIXS27857	27.86					1981	1985	1996
53	OIXS28492	28.49					1981	1985	1996
55	OIXS29826	29.83			1964	1973	1981	1985	1996
56	OIXS30483	30.48			1964	1973	1982	1985	1996
57	OIXS31271	31.27			1964	1973	1982	1985	1996
58	OIXS31992	31.99					1981	1985	1996
60	OIXS33184	33.18					1981	1985	1996
61	OIXS33771	33.77					1981	1985	1996
62	OIXS34856	34.86					1981	1985	1996
63	OIXS35696	35.70				1973	1980	1985	
64	OIXS36574	36.57					1981	1985	1996