Monitoring of riverbed stability and morphology by regional councils in New Zealand: part 2

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Contents

Summary

Project and Client

Tasman District Council requested Landcare Research to complete a review of the range of techniques used by four regional councils (Otago Regional Council, Southland Regional Council, Greater Wellington Regional Council, Horizons MW) to monitor changes in riverbed levels, river stability and morphology, and to help manage gravel extraction with a view to determining future data collection needs.

Objectives

The objectives were to review:

- the techniques used for bed level monitoring and subsequent analysis
- the frequency of monitoring, and whether it accounts for both long-term trends and short-term fluctuations in bed level
- whether the method(s) and frequency of monitoring are considered optimal by Regional Councils
- what range of river types are monitored and what are typical cross-section distances, when cross-section survey techniques are used
- what other methods have been used, or are being considered, to optimise riverbed stability monitoring
- approaches to assessing gravel supply and sustainable gravel extraction rates

Methods

Information was obtained by accessing published information from libraries and regional council Web sites and directly requesting information from Council staff.

Results

- River cross-section surveys are the primary tool used by the four regional councils to monitor riverbed levels and calculate gravel volume changes. These are used with gravel extraction volumes from contractor's returns to calculate gravel load on a conservation of volume basis.
- Aerial photos are used to supplement the information from cross sections and monitor shifts in channel position, changes in channel morphology, and to identify areas with gravel beaches. Site visits are also commonly used to supplement the information from cross-sections.
- The trends in bed levels, stored gravel volumes and gravel extraction volumes are used to set gravel extraction limits.
- The river cross-section survey networks of the four councils have been established for flood risk management but they consider the design is adequate for gravel management purposes.
- The frequency of surveys has been highly variable in the past, but has tended to become more frequent. For rivers with high extraction pressure, surveys are now typically carried out every 1 to 3 years.
- Cross-section spacing is highly variable, ranging from 100 m to several km and is primarily dependent on river size. There does not appear to have been a clear rationale

for cross-section spacing but it is clearly related to river width. In many larger rivers cross sections were initially spaced at ½ mile (0.8 km) intervals.

- Councils that have used RICODA in the past for analysing the bed level data, are now using Hilltop Software for calculating mean bed levels and gravel volumes using the end area method. Others have continued to use X-sect.
- None of the councils are currently considering using LIDAR as it is too expensive and cannot be used in the wetted channel.
- Horizons and Greater Wellington Regional Council have used bedload transport formulae to calculate gravel load.
- Three of the four councils still use in-channel extraction of gravel but most of the gravel in Southland rivers now comes from floodplain sources and gravel extraction has been used for restoration of river habitat and biodiversity enhancement.

Conclusions

- Cross-section surveys are the primary tool used for monitoring bed level changes by the 4 councils, but they are supplemented by aerial photo interpretation and site visits.
- All the councils have inherited cross-section networks established between the 1940s and 1970s. They were established for flood management purposes and have a cross-section spacing that was developed for this purpose; however, they are regarded as suitable for managing gravel extraction.
- The frequency of survey is highly variable but has tended to become more frequent in recent years. A number of the councils adopt a two-tiered approach of regular surveys supplemented by surveys after significant flood events.
- Gravel extraction is estimated from returns provided by contractors, generally on a monthly to 6-monthly basis.
- The cross-section data and gravel extraction returns are used as the basis for estimating gravel transport using the morphological budgeting approach. GWRC and Horizons MW also use transport formulae to provide an independent estimate of gravel transport rate.

Recommendations

- TDC adopt a two-tiered approach to bed level data collection, with rolling programmes of regular surveys (every 4–5 years as at present) supplemented by surveys after significant flood events.
- Sustainable management of the gravel resource requires the systematic collection of measurements of the trends in bed levels, gravel deposition and excavation rate data over time to be able to set and adjust extraction levels according to gravel supply.
- Because the rivers of Tasman District do not have large natural deposition zones there is a need to assess the proportion of gravel supply that can be sustainably harvested without having significant in-stream and downstream effects.
- An alternative to the regular cross-section surveys would be to better establish gravel flux through short-term investigations involving a combination of field measurement (using digital photogrammetry and GPS, and possibly LIDAR in the future) and modelling of gravel transport. Such investigations could help establish an average sustainable gravel supply rate which could be adjusted following large flood events.
- TDC should review the Environment Southland experience of moving away from a reliance on active channel gravel sources to using floodplain sources that provide biodiversity enhancement opportunities.

1. Introduction

River cross-section surveys are the primary tool used by most regional councils, including Tasman District Council (TDC), to monitor river bed levels and to help set gravel extraction limits. While river cross-section surveys provide direct data on trends in mean bed levels, they do have limitations for calculating changes in gravel storage in the river, gravel transport rate and relating these parameters to gravel extraction rates (Basher 2006).

In 2006 Landcare Research reviewed the range of techniques used by several regional councils (Hawke's Bay, Gisborne District Council, Marlborough District Council, Environment Bay of Plenty) to monitor river bed levels, to estimate sustainable gravel supply, and to set gravel extraction limits (Basher 2006). One of the recommendations in that report was that TDC complete the review by summarising how the remaining regional councils deal with this issue. This report presents results of a survey of methods used by Otago Regional Council, Greater Wellington Regional Council, Southland Regional Council and Horizons MW to manage and monitor gravel extraction rates.

2. Objectives

The objectives were the same as for the earlier review, that is to review:

- techniques used for bed-level monitoring and subsequent analysis,
- the frequency of monitoring, and whether it accounts for both long-term trends and short-term fluctuations in bed level,
- whether the method(s) and frequency of monitoring are considered optimal and if not, what would be considered a good balance between cost and data usefulness,
- what range of river types (width, gradient, nature of bed sediments, etc.) and consequently what typical distances are they spread apart (either in terms of a multiple of the cross-section length, and/or active channel bank-to-bank distance), should cross-section survey techniques be used,
- what other methods are employed or being considered to optimise riverbed stability monitoring,
- approaches to assessing gravel supply and sustainable gravel extraction rates.

3. Methods

Information was obtained by accessing published information from libraries and regional council Web sites and by directly requesting information from Council staff.

4. Results

4.1 Environment Southland

Cross-section surveys, supplemented by aerial photograph analysis, are the primary tools for river bed level monitoring by Environment Southland (ES). In many rivers historical cross-section data is restricted to bridge sites and bench mark positions (Southland Regional Council 1994). The latter were established for flood protection design and were not located to monitor gravel movement. The primary aim of bed level monitoring by ES is to determine long-term trends. The spacing of cross-sections varies from very close spacing at bridge sites to 1–3 km through reaches of consistent form. There has recently been a move to establish cross-sections on beaches for monitoring before and after extraction, and for surveys of the volume of gravel on beaches above water level (Southland Regional Council 1992, 1994). Bed levels and volume changes have been calculated using the end-area method in RICODA (Southland Regional Council 1992). The frequency of bed-level monitoring currently averages about 5 years, or more frequently after channel forming flood events, and records extend back 30 years for some rivers.

Historically, most gravel was extracted from Southland rivers primarily by skimming of gravel beaches and bars, although there was some in-stream excavation. Most (>90%) of the gravel was sourced from the Aparima, Oreti and Mataura Rivers (Hudson 2000a, Leddington 2007). Consents require reporting of gravel extraction volumes, although the details are often sketchy (Southland Regional Council 1994). In 1996 Environment Southland (ES) undertook a review of the state of knowledge of gravel extraction management and an assessment of knowledge gaps for sustainable management (Hudson 1996). The review identified a lack of knowledge in a number of areas, including gravel supply, sustainability of current gravel extraction, and the effects of extraction on reach hydraulics, channel stability and habitat.

Hudson et al. (1997a) suggest that mountainous headwaters are a major source of gravel for the Mataura River, but that in the Aparima and Oreti most of the gravel is derived from the bed and banks in the middle reaches of these rivers. No quantitative estimates of gravel supply were given. Similarly, quantifying levels of gravel extraction was difficult before the mid-1990s when detailed returns began to be compiled.

Hudson et al. (1997a, 1998) provided a synthesis of the available bed level data for the Aparima, Mataura and Oreti Rivers, used the data to calculate bed-level changes, assess bed-level trends, and related the trends to gravel extraction. On the Aparima River only bridge survey and stream flow gauging surveys were available. On the lower Mataura River cross-section surveys over the lower 53 km of the river were undertaken in 1972 and 1992 (46 cross-sections, of which 24 were resurveyed in 1992), and on the middle Mataura River surveys were undertaken in 1974 and 1997 (52 cross-sections in 1974, 96 in 1997). In addition there were cross-sections at 6 bridges and 4 gauging sites. On the Oreti River there were long profiles of the river taken at a number of dates, limited cross-section surveys, bridge surveys and stream flow gauging surveys. Hudson et al. (1997a) also identified a number of issues related to archiving and interpreting the survey data. Channel volume losses were calculated using the end-area method with individual cross-section changes extrapolated to a “representative river reach” (determined from channel patterns), rather than uniformly extrapolating from each cross-section. Hudson et al. (1998) noted how changing the representative length can greatly modify the volume change. They suggested:

- current rates of extraction on the Aparima River are sustainable (based on very limited data from bridge surveys and stream gauging records),
- rates of extraction on the Mataura River have been excessive because the river has degraded to bedrock for much of its length and bridge foundations have been exposed (the data showed an average decline of bed levels >0.5 m, and up to 3 m at individual cross-sections),
- parts of the Oreti River have aggraded while others, where there has been high gravel extraction, have degraded with bed levels fluctuating by several metres (see Hudson 2000b).

Following these investigations, which suggested current gravel extraction exceeded supply rates, and a gravel workshop, ES implemented a River Aggregate Management Strategy to move away from a reliance on beach skimming (Hudson 1997b). The objectives (Leddington 2007) were to:

- avoid, mitigate or remedy the adverse effects of bar skimming as the exclusive source of aggregate,
- use river corridor extraction to increase river habitat diversity,
- protect or enhance infrastructure integrity through environmentally sensitive river engineering.
- For the last 10 years ES has extracted the bulk (90%) of gravel away from active channels (i.e. on the floodplain) and in the process restored oxbow lakes, floodway ponds and backwaters for biodiversity enhancement. However, the costs of obtaining gravel have risen significantly and as a result ES are now considering the need to better understand the gravel resource, including requirements for bed-level monitoring and estimating sustainable gravel supply (Hudson 2000a). Two issues remain unresolved, namely are river gravel bars re-built following major floods and what is the aggradation/degradation status in the main gravel supplying rivers (Aparaima, Mataura, Oreti, Upukerora). Hudson (2000a) recommends cross-section surveys of key river reaches to try and resolve these issues.

4.2 Otago Regional Council

Until quite recently Otago Regional Council (ORC) had undertaken very little monitoring and there was little information on the volume of gravel available in Otago rivers although gravel extraction is widespread throughout the Otago region (Fig. 1). However, monitoring has now increased and ORC produce 3 or 4 river reports each year that summarise gravel inputs and outputs, indicate sustainable extraction rates, and recommend future extraction levels (e.g., ORC 2001, 2005, 2006). The reports take a broad geomorphological approach, looking at how gravel gets into rivers, land use and land-use change, hydrology, historical extraction, engineering works and structures, and how all these impact on the gravel resource.

ORC use a variety of approaches for managing gravel extraction, including repeat cross-section surveying of rivers used for gravel extraction, grain-size assessment, 1-D sediment

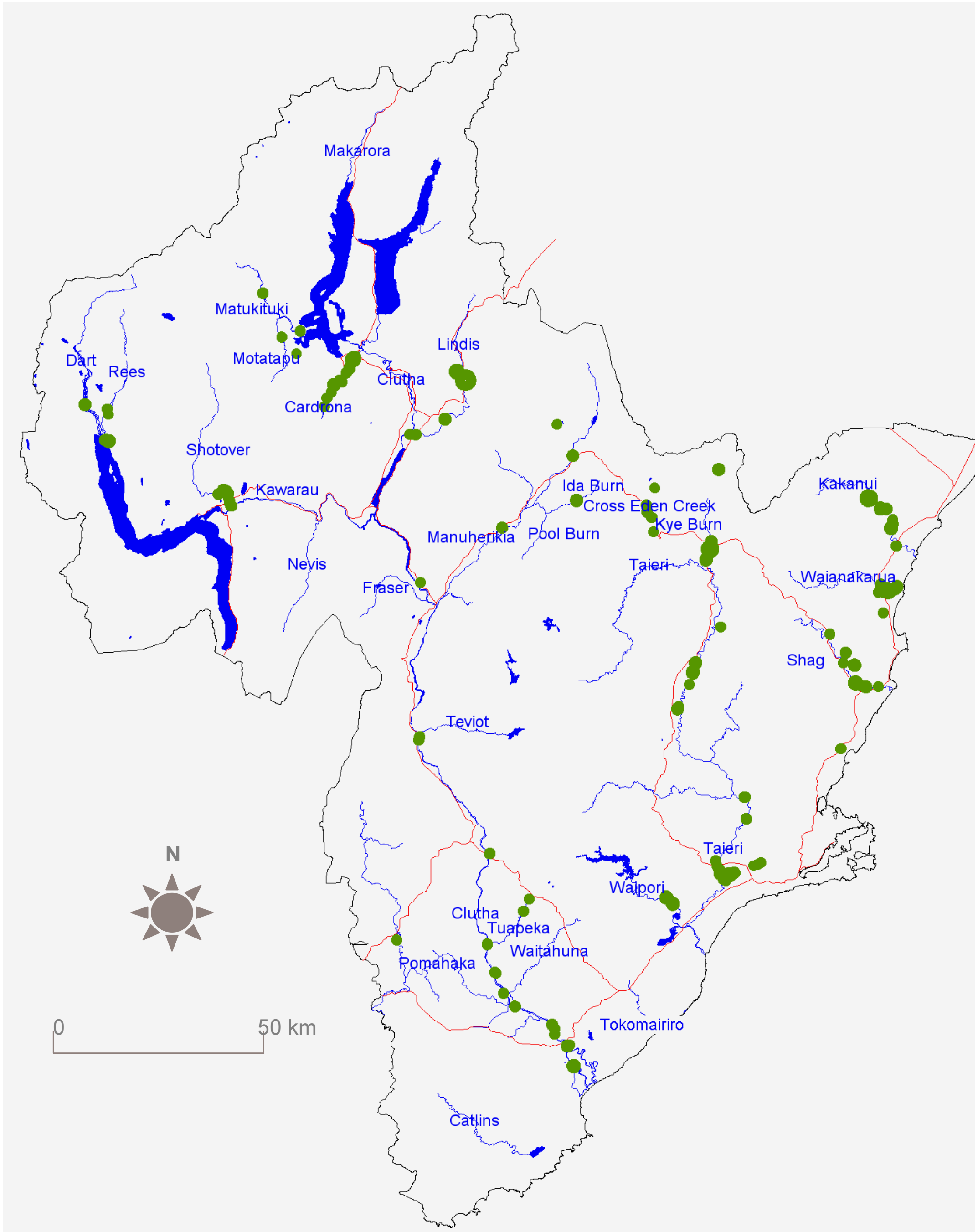

Fig. 1 Sites (green dots) where gravel extraction has taken place in Otago rivers over the period 1994–2004.

transport modelling, gravel extraction volume monitoring, and river reach sediment budget assessment. Aerial photos are available for every river but are flown infrequently (>5 yrs) and are used to help monitor river behaviour and set gravel extraction levels.

The frequency of bed level monitoring varies from once every two years to once every 10 years, depending on the activity of the river and the extraction pressure (Table 1). Currently most rivers are being surveyed at 5-yearly intervals, with more frequent monitoring on the Kawarau, Heriot and Cardrona rivers. Historically surveys were often at much greater intervals, and not all cross-sections on a river were surveyed. Both long-term trends and short-term trends are identified, where the data are available to allow it. For example, ORC (2006) list (partial) surveys for the Manuherikia River in 1904, 1948, 1967, 1970, 1979, 1985, 1995 (twice), 1996, 1997, 2000, 2001, 2005. ORC also use old bridge surveys and railway line traverses to obtain very old cross-section data and this has proved very useful in separating land-use change effects from gravel extraction effects (Jessica Bell pers. comm. June 2007). The oldest cross-section survey is on the Clutha River (1875).

Table 1 Summary of bed level surveys in Otago rivers.

River	Number of cross-sections	Current Frequency	Last Survey	Next Survey
Arrow	10	5 years	2006/07	2011/12
Cardrona	34	4 years	2003/04	2007/08
Dart	5	5 years	2004/05	2009/10
Rees	12	5 years	2002/03	2007/08
Heriot	16	3 years	2004/05	2007/08
Kakanui	21	5 years	2005/06	2010/11
Kauru	9	5 years	2005/06	2010/11
Shag	22	5 years	2003/04	2008/09
Kawarau				
at Shotover Confluence	4	2 years	2006/07	2008/09
Chards to Lake Wakatipu	10	2 years	2006/07	2008/09
Shotover	17	2 years	2006/07	2008/09
Manuherikia	18	5 years	2005/06	2010/11
Galloway flood protection works	5	5 years	2005/06	2010/11
Pomahaka	12	5 years*	2002/03	2007/08
Clutha				
at Beaumont	4	5 years	2002/03	2007/08
Koau, Matau and Main Branch to Tuapeka Mouth	54	5 years	2002/03	2007/08
Upper Taieri				
upstream of Patearoa Waipiata Road	25	5 years	2004/05	2009/10
why is there a space here?				
Upper Taieri				
downstream of Patearoa Maniototo Road	6	5 years	2004/05	2009/10
near Outram	6	5 years	2002/03	2007/08
Taieri				
upstream of Allanton	27	5 years	2002/03	2007/08
downstream of Allanton	26	5 years	2002/03	2007/08
Waianakarua	9	5 years	2003/04	2008/09

* ORC (2005) lists previous surveys in 1988, 1990, 2001, 2002, 2005

Cross-section spacing is largely a function of historical investigations. In flood defence schemes and in highly active gravel extraction areas the frequency of cross-sections is higher – one every several hundred metres. In low-activity gravel extraction areas, particularly in long single-thread rivers (e.g., the Clutha) the spatial frequency is lower – one every few km. There can be a mix of cross-section spacing in one river, depending on gravel extraction activity.

Most cross-section surveys use a mix of GPS, depth sounder traverses and total station, with GPS the predominant technology on dry land. Multipath SONAR has been used for some 3D surveys of the Clutha River delta, because it was needed for modelling. It is not generally used elsewhere because of cost and practicality issues. X-sect software is used to determine minimum (thalweg) and mean bed levels. Reporting of bed-level trends uses both mean bed levels (e.g., ORC 2006) and thalweg (the line of maximum depth along a river channel) bed levels where surveys have different lateral extents (e.g., ORC 2005). The cross-section network is considered to be the most feasible option for monitoring bed level trends and assessing sustainable gravel extraction volumes in the Otago Region (Jessica Bell pers. comm. June 2007).

Within a year of a cross-section survey being carried out on a given river, a gravel management report is written (e.g., ORC 2005, 2006) which outlines:
changes to the river bed since the last assessment was done,
the overall degradation or aggradation status of the river bed,
any recommendations for future gravel extraction such as location of excess amounts of gravel that should have high priority for extraction or zones where gravel extraction should no longer be allowed.
Site visits are used to confirm these interpretations.

All gravel extraction in Otago requires a resource consent, and conditions of the consent are to notify ORC before any extraction works and provide a gravel return after extraction. The returns are usually made every 6 months (before the end of April and the end of October) and consist of the monthly volume of gravel extracted (m^3). For any river in which extraction occurs, a file of all gravel returns can be sourced from an electronic database. Many rivers have gravel management plans that prescribe the amount of gravel to be extracted, and conditions attached to extraction.

The objective of gravel management in Otago is usually sustainable gravel extraction, rather than flood protection, with the exception of rivers such as the Manuherikia where there are issues of increased sedimentation and flooding caused by backwater effects from sedimentation in dams (Johnstone 2001). If cross-section monitoring or interpretation of the river morphology indicates a riverbed is degrading and/or the river banks are eroding, gravel extraction is reduced or halted until future analysis demonstrates that further extraction is sustainable. In catchments on the northeast coast of Otago, gravel extraction volumes are small because the rates of gravel production and transport are too low to contribute much bed material to the river. However, in many catchments of western Otago there can be large volumes of gravel input to the channel during major flood events and extraction volumes may be increased following flood events. In a few western Otago rivers (e.g., Rees, Shotover, Dart) the volume of gravel delivered from the catchment is greater than is extracted from the river; however, these sites are generally too isolated to become major sources of construction gravel for the Otago Region.

To determine whether gravel extraction is sustainable requires monitoring of gravel extraction rates (as outlined above), changes in the gravel budget of rivers from which gravel is taken, and assessment of impacts of gravel extraction on river and riparian habitat. ORC accepts that measuring all the terms in a river gravel budget directly is not practicable (Jessica Bell pers. comm. June 2007) and, as a proxy ORC uses the changes that take place over time in the mean bed level in the active channel and the thalweg. Short-term (shorter than decades) changes in riverbed and banks are determined by repeat cross-section surveying to indicate whether the river has aggraded or degraded its bed and whether net bank erosion is taking place. However, they recognise that cross-section surveys reveal only gross changes that have taken place between surveys and that there may be short-term changes in river morphology in the intervening period. The interpretation of cross-sections is supplemented by site visits made to each cross-section around the time of surveying to broadly assess upstream and downstream changes. The morphology of the riverbed, banks and floodplain may indicate whether sufficient gravel is available to sustain gravel extraction. The vertical abandonment of structures such as bridges or fords is used to indicate degradation of the riverbed. Bank retreat is deduced from the outflanking of river margin trees and the exposure of their root systems by fluvial erosion. Information may also be obtained from a series of aerial or oblique photographs taken over several years. The grain size of sediments at extraction sites is used to indicate the effects of gravel extraction that selects only a particular cohort of grain sizes. In these cases, a trained river engineer or fluvial geomorphologist is used to interpret the information. In rivers such as the Clutha, where it is practically difficult to survey cross-sections of the channel, or where changes are taking place over an extremely long period of time, it may be necessary to assess the rate of gravel transport in the river directly. A variety of methods are used to do this, including direct particle monitoring and modelling of sediment transport.

Monitoring the direct impact of gravel extraction on river biota has not taken place in any river in Otago to date, although such studies are planned for the Kauru River (Jessica Bell pers. comm. June 2007). When the Department of Conservation and/or Fish and Game councils make recommendations on restricting the months in which gravel may be extracted for the protection of biota, these are usually included as conditions in the consent. The main areas of concern for the impact of gravel extraction on biota are: trout spawning, native fish spawning and migration, nesting birds, and weed control.

4.3 Greater Wellington Regional Council

Cross-section surveys are the primary tool used by Greater Wellington Regional Council (GWRC) for bed level monitoring. Three main rivers are monitored – the Hutt, Otaki and Waikanae Rivers – with limited surveying on other rivers. These three rivers are steep alluvial rivers draining from the Tararua Ranges and carrying relatively high gravel loads.

On the Hutt River there are 319 cross-sections over a river length of 33.5 km, with an average spacing of 105 m. On the Otaki River there are 118 cross-sections over a river length of 13.7 km, with an average spacing of 116 m. On the Waikanae River there are 51 cross-sections over a river length of 6.8 km, with an average spacing of 133 m. On all three rivers the primary driver for the surveys is management of flood risk, with gravel extraction used to manage bed levels within defined limits to maintain flood conveyance capacity.

The Hutt River has a very extensive cross-section survey record. Cross-section surveys of the Hutt river are now carried out every 5 years, or following a major flood event (>20 year return period), as part of the Hutt River Floodplain Management Plan (HRFMP). Complete surveys were done in 1987, 1993, 1998, and 2004. A partial survey was completed in 2005,

following the January 2005 flood event. Before the HRFMP, cross-section data was obtained on an irregular basis including:
minor surveys between the mouth and Melling bridge in 1871, 1900, 1903, 1908, 1914, 1926, and 1931,
extensive surveys after a large flood in 1939,
minor surveys in 1952, 1954–56, 1960, 1964, 1967–69, and 1971–74.
In 1977 the Wellington Regional Water Board established 64 permanent cross-sections at approximately 400-m intervals extending from the mouth to Te Marua. These were surveyed in 1977, 1981 and 1984, and partial surveys were carried out in 1978–80, 1982–83 and 1985. Between 1987 and 1989 the first full survey of the Hutt River was undertaken using the complete 319 cross-sections.

The Otaki River also has a very extensive cross-section survey record. Cross-section surveys of the Otaki river are now done every 5 years, or following a major flood event (>20 year return period), as part of the Otaki River Floodplain Management Plan. Complete surveys were done in 1991, 1996, 2001, and 2006. Previously the Manawatu Catchment Board had completed many cross-section surveys of the Otaki river, including full or partial surveys in 1947, 1952, 1956, 1967, 1974, 1983, 1985, and 1988 (Brougham & McLennan 1983). Similarly, the Waikanae River has a recent cross-section survey record with surveys carried out every 5 years, or following a major flood event (>20-year return period), as part of the Waikanae River Floodplain Management Plan. Surveys were carried out in 1991, 1995, 1999, and 2004.

RICODA was previously used for analysing the data but Hilltop Software is now used to calculate mean bed levels and calculate gravel volume changes (using the end-area method). Comprehensive reports compiling the survey data and detailing the results of bed level and gravel volume calculations are produced (e.g., Borrer 2005; Khanam & Campbell 2006; Campbell & Khanam 2006). The inflow of gravel into the monitored reaches is inferred from the volumetric change of bed levels, the volume of lateral erosion and extraction quantities using the morphological budgeting approach based on conservation of volume (Basher 2006). Gravel extraction is monitored from operator's returns.

The three main rivers have a rolling programme of surveys scheduled every 5 years to monitor long-term trends. Short-term fluctuations are monitored following significant flood events. A meeting is held between Consents Management and Operations (river engineers) each year to determine which rivers to survey based on:
the extent of gravel extraction (if large volumes are being extracted then surveys would be undertaken every year),
the sensitivity of the reach (if bed levels are degrading then surveys would be undertaken every year),
the presence of sensitive infrastructure (e.g., bridges, water intakes).
On other lower priority rivers, a revolving programme results in surveys every 2 to 8 years. GWRC believes the full 5-yearly cross-section surveys, with limited resurvey following major flood events, provides an optimal level of monitoring (J. Cox, pers. comm. March 2007) by identifying the problem areas in the rivers.

In addition, the three main rivers are flown biennially allowing limited monitoring of river morphology, such as changes in the meander pattern and the number of pools and riffles. LIDAR has been considered as an alternative to cross-section surveys but is not considered appropriate at present because of cost and inability to use it within the wetted channel (J. Cox, pers. comm. March 2007).

4.4 Horizons MW

Horizons MW use cross-section surveys as their primary tool for bed level monitoring and managing gravel extraction. Many of the rivers in the Manawatu region carry and deposit large gravel loads and the primary reason for managing gravel extraction is to maintain flood conveyance capacity in aggrading river beds (A. Beveridge, pers. comm. April 2007), particularly in the south-east Ruahine streams, lower Rangitikei, Pohangina and Kawhatau Rivers. Extraction is directed to those areas where gravel deposition is affecting flood control structures. However, there are also parts of rivers where demand for gravel is greater than supply and tight restrictions on gravel extraction have been imposed (lower Manawatu, Oroua, Mangatainoka, Ohau, middle Rangitikei).

There are cross-section networks on all the larger rivers that have flood control schemes (lower and upper Manawatu, Rangitikei, upper Whanganui, Pohangina, Ohau, Mangatainoka, streams draining the south-east Ruahines). The lower Manawatu has 96 cross-sections over a 39 km reach (average spacing c. 400 m), the Rangitikei River has 117 cross-sections between the sea and Rewa (c. 63 km, spaced at 400–800 m), and the Upper Whanganui has 56 cross-sections at semi-regular intervals over a 14-km length (c. 250 m spacing). Cross-sections on most rivers are spaced at 500–1000 m (A. Beveridge, pers. comm. April 2007).

The frequency of surveys and length of record is highly variable. The lower Manawatu was first surveyed in the 1940s but most comprehensively surveyed in 1991, 1993, 1996, 1999, 2000, 2004 and 2005; 1997 was the only year that all cross sections were surveyed (Webby et al. 2006). On most rivers the cross-section survey data extends back to the 1970s. The Rangitikei River was surveyed in 1975/76, 1976/77, 1978/79, 1983/84, 1988–91. The Upper Whanganui was surveyed in 1971, 1991 and 2000. Currently most surveys are in response to flood control scheme reviews and are usually every 10 years on major rivers and 10–20 years on minor rivers (A. Beveridge, pers. comm. April 2007). Surveys are carried out more frequently in response to significant flood events (>10-year recurrence interval).

RICODA used to be used to calculate bed levels and volume changes (e.g., Horizons MW 2000a), but currently Hilltop Software is used for this purpose (e.g., Webby et al. 2006). Gravel transport is estimated using morphological budgeting based on bed level trends and gravel extraction, and sometimes incorporating abrasion losses (Webby et al. 2006). Gravel extraction is estimated from contractor’s returns, which in the past are believed to have underestimated extracted volumes. At present monthly gravel extraction returns are required as part of the resource consents for extraction. Abrasion losses from bed material transport have been estimated by modelling sediment transport rate using a number of different transport formulae and then applying an abrasion coefficient for greywacke (Horizons MW 2000b; Webby et al. 2006).

Bedload transport formulae have also been used to estimate gravel transport rate and provide an independent estimate of the likely limits to transport rate. For example, the Meyer-Peter and Muller, Engelund and Hansen, and Einstein and Brown formulae were used in the upper Manawatu to provide estimates of gravel transport rate (Horizons MW 2000b). Some reports provide estimates of long-term gravel supply but it is not clear how they are derived (e.g., Horizons MW 2000a).

In addition, Horizons staff use aerial photos to interpret shifts in channel position and changes in channel morphology, and to identify areas with gravel beaches.

Horizons staff are confident that the current monitoring, along with local knowledge of the rivers by staff, is sufficiently robust to manage adequately both gravel resource and flood management problems (A. Beveridge, pers. comm. April 2007). They are not considering any major changes to the cross-section network, and envisage continuing use of cross-section based analysis as the primary tool for managing gravel extraction, supported by air photo interpretation and GPS surveys of key sites.

5. Conclusions

All four regional councils use river cross-section surveys as the chief tool for monitoring bed level changes in their rivers. Cross-section data are supplemented by aerial photo interpretation and site visits to assess channel behaviour. All the councils have inherited cross-section networks established from the 1940s to 1970s. These networks were established for flood management purposes and have a cross-section spacing that was developed for this purpose; however they are regarded as suitable for managing gravel extraction. The frequency of survey is highly variable but has tended to become both more frequent in recent years and to be better adjusted to extraction pressure in any river. A number of the councils adopt a two-tiered approach of having regular surveys supplemented by surveys after significant flood events that contribute large volumes of gravel. Gravel extraction is estimated from returns provided by contractors, generally on a monthly to 6-monthly basis.

The cross-section data and gravel extraction returns are used as the basis for estimating gravel transport using the morphological budgeting approach. GWRC and Horizons MW also use sediment transport formulae to provide an independent estimate of gravel transport rate.

Most councils are using beach skimming from the active channel as the primary source of gravel, but ES have moved away from a reliance on sources within the active channel to using floodplain sources that also provide biodiversity enhancement opportunities.

6. Recommendations

- Sustainable management of the gravel resource requires the systematic collection of measurements of the trends in bed levels, gravel deposition and excavation-rate data over time. These data can be used to set and adjust extraction levels according to gravel supply. In the rivers of Tasman District that typically do not have large natural deposition zones there is a need to assess the proportion of gravel supply that can be sustainably harvested without having significant in-stream and downstream effects.

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- For Tasman District a two-tiered approach to bed level data collection may be appropriate, with rolling programmes of regular surveys (every 4–5 years, as at present) supplemented by surveys after significant flood events.
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- An alternative to the regular cross-section surveys would be to better establish gravel flux through short-term investigations involving a combination of field measurement and modelling of gravel transport. Presently digital photogrammetry or GPS are the most cost-effective options for obtaining such data. There is a clear need to consider LIDAR in the future as the cost decreases and combined terrestrial and bathymetric LIDAR becomes available. Such investigations could help establish an average sustainable gravel supply that might be adjusted following large flood events.
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- TDC should review the ES experience, by moving away from a reliance on active channel gravel sources to using floodplain sources that provide biodiversity enhancement opportunities.

7. Acknowledgements

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