Management of gravel extraction by Nelson City Council

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Contents

Summary

Project and Client

Nelson City Council (NCC) requested Landcare Research to provide advice on how to assess the gravel yield from Nelson rivers, and how to monitor the effects of gravel abstraction.

Objectives

- Review currently held data and estimate gravel yield of Nelson Rivers
- Recommend appropriate (low cost) future monitoring to improve knowledge of the gravel resource and to detect significant changes resulting from over-extraction
- Recommend how gravel extraction issues (specifically volume of extraction) might be dealt with in the Nelson Resource Management Plan

Methods

- Relevant written documents and electronic files were provided by NCC
- A literature search focused on analysis of recent approaches to estimation of sustainable gravel yields, and gravel management by other councils
- Gravel yield from the main NCC catchments was estimated as a proportion of suspended sediment yield
- A brief visit was made to the Wakapuaka and Whangamoa Rivers.

Results

- Much of the current gravel extraction is small scale (volumes up to several hundred cubic metres) for flood control and stormwater structure management purposes. Larger scale commercial extraction is limited to the Wakapuaka and Whangamoa Rivers. The amount of gravel extraction undertaken each year appears to be poorly known and the ability of Council staff to source such information is poor because there is no system for consistently recording and retrieving this information. As a result it is difficult for council officers dealing with resource consents to exercise discretion in relation to the cumulative volume that has been extracted from any river. Most consents have a condition relating to the permitted gravel extraction level, normally set relative to water level. There is no systematic data collection to assess bed-level trends.
- Gravel supply rates for Nelson rivers were estimated as a proportion of suspended sediment yield. Assuming a gravel yield of 25% of the suspended sediment yield gave supply rates to the coast of about 1000, 1500, 400, and 150 m^3 for the Wakapuaka, Whangamoa, Maitai Rivers and Brook Stream respectively. These figures appear to be of a similar magnitude to consented extractions, and there appears to be no demonstrable evidence of over-extraction (e.g., undermining of bridges or stopbanks) suggesting that current extraction rates are probably not excessively high.
- Bedload transport formulae and a morphological method (based primarily on cross-section surveys) have been used by regional councils in New Zealand to help determine gravel supply rates and set gravel extraction limits. In addition, some Councils use either aerial photography or ground-based inspections to enable visual evaluations of gravel accumulations. Visual assessments are the lowest cost method for evaluating gravel accumulation (although of less value for determining gravel loss, unless there is a clear

baseline against which to assess channel change), and assessing riverbed response to extraction.

- To improve the current knowledge of the gravel resource in Nelson, the NCC should consider a number of options (listed in order of probable decreasing cost): establishment of a small cross-section network in the key reaches where gravel is repetitively extracted; aerial photography of key reaches where gravel is repetitively extracted; regular visual inspection of key sites, with compilation of notes regarding the morphology of the riverbed and banks, and ground-based photographs.
- In addition, establishment of a system for tracking extraction volumes on (at least) an annual volume is critical. These measures will only have value if the data are regularly analysed.
- Resource consents should have a standard set of conditions relating to excavation levels, method of extraction, entry of machinery to the water, stockpiling of gravel, timing of extraction, returns of extracted volumes, and mitigation of adverse effects.

Conclusions

- The amount of gravel extraction undertaken each year in Nelson City is poorly known, and the ability of Council staff to source this information is poor because there is no system for consistently recording and retrieving this information.
- Annual gravel supply rates for Nelson rivers were estimated as about 1000, 1500, 400, and 150 m^3 for the Wakapuaka, Whangamoa, Maitai Rivers and Brook Stream respectively and appear to be of a similar magnitude to consented extractions. There appears to be no demonstrable evidence of over-extraction, suggesting current extraction rates are probably not excessively high.
- The effective regulation and monitoring of gravel excavation activities requires the systematic collection of measurements of the trends in bed levels, gravel deposition and excavation rate data over time to set maximum and minimum excavation rates. Cross-section surveys are the most commonly used tool for establishing trends in bed levels. However, regular visual inspection of key sites in Nelson Rivers (permanently located by GPS), with compilation of notes regarding the morphology of the riverbed and banks, and ground-based photographs would provide a lower cost alternative.

Recommendations

- NCC should establish a system for archiving and retrieving gravel extraction returns and compile annual estimates of gravel extraction from each river
- NCC should establish a system for investigating bed-level trends either using cross-section surveys or regular visual inspection of key sites (permanently located by GPS), with compilation of notes regarding the morphology of the riverbed and banks, and ground-based photographs
- Monitoring of bed-level trends would allow gravel extraction to be matched with supply rates/availability, and also allow adjustment of an excavation threshold if bed-level trends indicate aggradation or degradation. It does, however, require Council staff to become familiar with assessing variation in rates of supply and regularly visiting the rivers.

1. Introduction

Nelson City Council (NCC), like many regional councils in New Zealand, controls the amounts of gravel extracted from local rivers. Extraction of gravel from riverbeds is used both to improve the flood-carrying capacity of rivers by reducing the build up of gravel within the flood channel, and to source aggregate. However, over-extraction can destabilise channels and banks, and/or affect the ecologic functioning of rivers, particularly if undertaken at the wrong time, the wrong place, or in a way that damages the river bed or margins. For these reasons councils exercise controls on the amounts, and the process of extraction to avoid or reduce adverse effects.

Nelson City Council (NCC) has requested Landcare Research to provide advice on how best to assess the amount of gravel yielded from Nelson rivers and how to monitor the effects of gravel abstraction. NCC are concerned that resource consents are issued for gravel extraction without a full understanding of the available gravel resource, or of the potential impacts of over-extraction either on bank and bed stability or river ecology. In addition, there is uncertainty about the amounts of gravel being extracted.

2. Background

The potential impacts of gravel (over)extraction are well known (e.g. Kelly et al. 2005; Rinaldi et al. 2005) and include: bed degradation and consequent effects on channel and bank stability, increased sediment loads, decreased water clarity and sedimentation, changes in channel morphology and disturbance of ecologically important roughness elements in the river bed, ecological effects on bird nesting, fish migration, angling, etc., modification of the riparian zone including bank erosion, direct destruction from heavy equipment operation, discharges from equipment and refuelling, reduction in groundwater elevations, impacts on structures and access, bio security and pest risks, impacts on coastal processes.

What is less well known in Nelson is the available gravel resource, and the extent to which it is being over, or under, utilised. There have been no previous estimates of gravel yield from Nelson rivers, nor has there been any analysis of current extraction volumes. The only previous work has been the brief description by Stocker (2002) of: the sources of gravel moving in to the Wakapuaka, Whangamoa and Maitai Rivers, current gravel mining practices, and mapping of the beaches suitable for gravel mining. Stocker (2002) also recommended gravel extraction be permitted on the basis of availability rather than an annual volume.

3. Objectives

The specific objectives agreed to by NCC and Landcare Research were to: review currently held data, including regional predictive models, and make a preliminary assessment of gravel yield of Nelson Rivers recommend appropriate (low cost) future monitoring to improve knowledge of the gravel resource and to detect significant changes resulting from over extraction recommend how gravel extraction issues might be dealt with in the Nelson Resource Management Plan.

4. Methods

Information was derived from the following sources:

- Written documents and electronic files provided by NCC, including information on gravel extraction from the NCC consents database a previous River Control report (Stocker 2002), which had a brief analysis of gravel extraction issues extracts from the NCC Freshwater Plan.
- A literature search including analysis of recent approaches to estimation of sustainable gravel yields and gravel management by other councils, including Environment Canterbury, Environment Bay of Plenty, and Marlborough District Council Gravel yield from the main NCC catchments estimated as a proportion of suspended sediment yield.
- A brief visit to the Wakapuaka and Whangamoa Rivers, including discussion with one long-term gravel extractor.

5. Results

5.1 The Nelson rivers

The Nelson rivers include the larger catchments of the Wakapuaka (114 km^2), Whangamoa (113 km^2), Maitai (95 km^2), Brook Stream (27 km^2) and Roding River that drain the Bryant Range, the smaller steams around the city, namely Jenkins Creek, Arapiki Stream, Poormans Valley Stream, Oldham Creek, York Stream, Orchard Creek, and Orphanage Creek. They tend to be short, steep catchments with limited areas of gravel deposition in floodplains and terraces. In the upper reaches these rivers are incised in narrow bedrock channels and in the middle reaches they tend to flow within deeply incised alluvial channels. In the lower reaches the channels are less incised and water regularly flows out of the channel and on to broad floodplains (Keith Anderson, pers. comm. June 2006). The depositional areas near the coast are confined to narrow valleys with no large fan or delta development. The Wakapuaka River does not transport gravel to the coast with a natural deposition zone for gravel in the lowermost c.5 km of the river. It is likely that this also applies to the Whangamoa River.

5.2 Gravel extraction sites and amounts

Historically, gravel has been extracted from both the larger rivers (Maitai River, Brook Stream, Wakapuaka River, Whangamoa River, Roding River), and the smaller streams around the city (Jenkins Creek, Arapiki Stream, Poormans Valley Stream, Oldham Creek, York Stream, Orchard Creek, and Orphanage Creek). Table 1 (from the NCC Resource Management Plan) summarises many of the sites from which gravel is extracted in these rivers and gives typical volumes that may be extracted after flood events. At the sites listed in Table 1 the extraction is for flood control purposes or to clear gravel from intake structures for the Nelson city stormwater system, and the volumes extracted after flood events are typically several hundred cubic metres.

At other sites in the Wakapuaka and Whangamoa Rivers (Table 2) gravel extraction consents have been issued for flood control purposes, and to access gravel for farm tracks and commercial use. At some of these sites the volumes extracted are larger (1000–5000 m^3), although it is unclear in some cases whether the volumes extracted are the total volume or an annual volume (Table 2). Some consents appear to have no limit placed on volumes extracted (e.g., consent number 930358 that operated in the Wakapuaka River between 1993 and 1998), although there is a requirement that if individual extractions are greater than a minimum volume then the consent holder must notify NCC to allow an opportunity for a river inspection prior to gravel being removed.

The actual amount of gravel extraction undertaken each year appears to be poorly known, and the ability of Council staff to source such information seems poor. Table 2 summarises the information held in the consents database for the large-scale extraction sites in the Wakapuaka and Whangamoa Rivers. Many of these resource consents contain a clause requiring returns on gravel extraction:
"The resource consent holder shall keep an accurate record of the quantity of gravel and other material removed from the ……. stream. Such records shall be forwarded to the Councils Resource Consent Monitoring Officer" either at the conclusion of the consent, 3 monthly or annually. It is unclear whether this condition has always been enforced, but some Council paper files do contain gravel returns with the appropriate resource consent file. However, it appears these returns are not stored electronically and are therefore difficult to retrieve and summarise. Consequently, it is not possible to give annual totals of gravel extracted from any of the rivers. This information may exist in Council paper files but it is not currently readily accessible. Similarly for the sites listed in Table 1 council staff identify the volume of gravel to be extracted for flood control and storm water management purposes, but the actual volume extracted is not recorded.

5.3 Existing rules for gravel extraction

Gravel extraction for flood control purposes is a permitted activity at the sites listed in Table 1, so long as conditions relating to disturbance of the river bed, provision of a schedule of extraction to interested parties (iwi, Department of Conservation, Fish & Game), and total extracted quantities (as listed in Table 1) are met. In other cases gravel extraction is a restricted discretionary or discretionary activity. Discretion is exercised in relation to the cumulative volume that has been extracted from the river, the volume of gravel available, the location at which extraction is to occur, the duration of extraction, the timing of extraction, the method of extraction, and the avoidance, remediation or mitigation of any adverse effects. Consents have a range of conditions relating to the level to which gravel may be extracted including:

- above mean water level
- above water level at the time of extraction
- or some other condition relating to the line and profile from which gravel may be extracted (e.g., 400 mm above median river level).

Setting an excavation level seems to be the main criterion used to evaluate the volume of gravel available and to assess the cumulative volume available for extraction. It assumes all gravel above a certain height above mean water level at any site is available for extraction, and that if this condition is met then over-extraction will not occur. However, this may not be the case where mean bed-level is degrading and water level is lowering through channel deepening.

Many of the consents listed in Table 2 also have conditions relating to compliance monitoring:

- inspection of the river by a Council officer (variously the Resource Consent Monitoring Officer, Inspections Supervisor Planning and Consents, a registered engineer or experienced hydrologist) if the proposed extraction exceeds a minimum volume
- returns of volumes of gravel extracted
- inspection of the river following extraction (by a registered engineer or experienced hydrologist) to check that consent conditions have been complied with.

It is not clear to what extent these conditions are implemented but it appears lack of staff means they are rarely enforced (Paul Sheldon, pers. comm. June 2006), so that no NCC staff have a good personal knowledge of the sites from which gravel is being extracted, or of the river systems in general.

At the sites where gravel extraction is regularly undertaken by NCC for flood control and stormwater management purposes (under the Freshwater Plan as a permitted activity – Table 1) there is no requirement for returns of the actual volume extracted. Consequently it is difficult to determine the cumulative volume that has been extracted from each river. However, these sites are regularly visited by council staff who inspect the flood control and stormwater structures to determine the volume of gravel to be extracted. As a result NCC stormwater engineering staff do have a good knowledge of the behaviour of the rivers and the need to extract gravel to maintain the integrity of the flood control and stormwater management system.

Table 1 NCC aggregate extraction sites where it is a permitted activity (from Appendix 28.1, Nelson Resource Management Plan)

River	Location	Activity
Maitai River	Concrete ford by golf club 20 m upstream and 20 m downstream of ford	Up to 300 m³ after each high flood event#.
	Almond Tree flats ford For a distance of 75 m above and 50 m below the ford	Up to 800 m³ after each high flood event#. Note:100 m³ of extracted aggregate redeposited on downstream side of ford each year.
	Black Hole for a distance of 100 m downstream	Up to 600 m³ after each high flood event#
Brook Stream	By OK Corral for a distance of 50 m upstream	Up to 500 m³ after each high flood event#.
	Behind reserve at 26 Brook St for a distance of 50 m, also a grit chamber at end of concrete channel	Up to 500 m³ after each high flood event#
	Manuka Street ford for a distance of 20 m above ford and 50 m below the ford.	Up to 100 m³ after each high flood event#
	Downstream of Nile St culvert there is a grit chamber plus a distance of 20 m downstream	Up to 600 m³ after each high flood event#
	At Brook Street/Maitai river confluence for a distance of 100 m upstream of Dommet St bridge	Up to 500 m³ after each high flood event#
Wakapuaka River	Maori Pa Road bridge For a distance of 60 m above bridge	As per Resource Consent 985158 and associated Environment Court ruling, up to 600 m³ after each high flood event#.
Poorman Stream	Open channel Up to 75 m upstream of SH6 culvert and 20 m downstream of SH6.	Up to 500 m³ after each high flood event#
Orphanage Creek	Detention pond above Main Rd Stoke culvert and for a distance of 100 m above pond.	Up to 800 m³ every 2 years#
Jenkins Stream	Two grit traps. (1) by SH6 at end of concrete culvert and (2) below the bridge over SH6	Catch pit structures, up to 400 m³ after each high flood event#
	Upstream of Annesbrook Drive for a distance of 100 m	Up to 200 m³ after each high flood event#
Arapiki Stream	In ditch upstream of SH6 culvert for a distance of 50 m	Up to 60 m³ after each high flood event#
All intake structures	Council stormwater reticulation system intake structures	Volumes and situations vary as required.

At all these sites excavation is below river level and requires excavator in river bed.

Table 2 Current and past aggregate extraction sites from the NCC resource consents database (Paul Sheldon, pers. comm. February 2006). Excludes sites from Table 1.

Year	Expiry date	Consent number.	River	Location	Quantity	Purpose	Comments
1993	1998	930358	Wakapuaka	NZMS O27: 452018, 453016, 454016, 450008, 453013	Unspecified (unlimited)	flood control	includes river training & bank protection
1995	1997	950492	Wakapuaka	150m upstream of Harvey's ford (O27: 449005)	Unspecified (unlimited)	unspecified	
1997		975075	Wakapuaka	O27: 445003		flood control (prevent flooding of ford)	file not found
1998	2003	985174	Wakapuaka	O27: 438997	Unspecified (unlimited)	unspecified	
1998	2008	985366	Wakapuaka	O27: 455027, 455030	100 m^3 total p.a.	unspecified	
2000	2005	005173	Wakapuaka	O27: 455027, 452019	200 m^3 p.a.	road repair	
2001	2006	015119	Wakapuaka	Paremata flats, about O27: 455028	Unspecified (unlimited)	flood control, bank protection	redistribution to flats
2001	2006	015159	Wakapuaka	11 sites between O27: 447005 and Maori Pa Bridge	100 m^3 total p.a.	farm roads, flood control	
2005	2015	RM55409	Wakapuaka		Only limited by location and height above normal water level	farm tracks	
1993	1998	930105	Whangamoa	Mt Albert (McFarlanes) O27: 555098	Unspecified (unlimited)	flood control	
1993	1994	930009	Whangamoa	4 sites between estuary and SH6: O27: 556101, 554098, 555090, 554088	1500 m^3	flood control	includes groyne construction – relocate gravel to bank
2001	2006	015237	Whangamoa	2 sites lwr Whangamoa O27: 555089 & 553082	5000 m^3	unspecified	not specified if quantity is annual or total
2005	Not yet issued	RM55409	Whanagamoa	Mid Stem	5000 m^3	contracting	
2005	Not yet issued	RM055682	Whangamoa		750 m^3	farm tracks	

5.4 Estimating gravel yield in Nelson rivers

The amount of sediment entering a river system depends on factors such as:

- topography
- catchment size
- geology (rock type and structure, tectonics, geological history including a history of glaciation)
- climate (particularly rainfall) and flooding
- vegetation cover
- land use.

The most important controls on sediment yield in New Zealand are rainfall and rock type (Hicks et al. 1996).

Nelson catchments tend to be very stable by New Zealand standards, with moderate rainfall and very stable rock types, and typically have low suspended sediment yields. Hicks et al. (2004) quote specific suspended sediment yields of several larger Nelson Rivers (Aorere, Motueka, Wairoa, Pelorus) in the range c. 140–340 t/km^2/yr, compared with >1000 t/km^2/yr for east coast South Island rivers of similar size. It is generally assumed that gravel (or bedload) yields reflect the suspended sediment yield, suggesting gravel yields from Nelson rivers will also be low.

The sources of gravel are either primary (i.e. hillslope erosion by landslides, gullies, debris flows, etc.) or secondary sources (reworking of gravel that has been previously deposited in terraces, fans and floodplains). Nelson catchments tend to have a relatively low incidence of primary erosion, and even the larger catchments (Wakapuaka, Whangamoa, Maitai, Brook Stream and Roding River) have relatively small areas of terraces, fans and floodplain suggesting rates of gravel supply have been low in the long-term. Stocker (2002) describes some of the sources of gravel in the Wakapuaka and Whangamoa catchments and suggests disturbance associated with forestry operations may be a significant source of gravel.

There are no published data on gravel yield for rivers in the Nelson region. In fact, there is little published data on gravel yield of New Zealand rivers in general, largely because of the difficulty of measuring the bedload component of sediment yield in larger rivers (Hicks et al. 2004). In the absence of any direct measurements of bedload, indirect methods have been used to provide estimates of gravel yield.

Three approaches have commonly been used to estimate gravel load in New Zealand:
application of bedload formulae (see Carson & Griffiths 1989; Hicks et al. 2004; Balley 2006)
a morphological method based on repetitive measurements of river bed topography (either along cross-sections, or using GPS, LIDAR, or digital photogrammetry) to calculate gravel volume changes between surveys (see Griffiths 1979; Noell 1992; Pak 2003; Sriboonlue & Basher 2003; Environment Canterbury 2006)
as a proportion of suspended sediment yield (e.g., Environment Canterbury 2006).

By default gravel supply rates are often estimated as a proportion of suspended sediment yield (SSY), as the cheapest and most practical option. Recent analysis of New Zealand-wide information on SSY (Hicks et al. 1996; Hicks & Shankar 2003a, b) has provided reliable estimates of SSY throughout New Zealand. Gravel supply rates can either be calculated from published estimates of SSY (e.g., Hicks & Griffiths 1992; Hicks & Shankar 2003a; Hicks et al. 2004) from similar rivers (based on characteristics such as location, area, underlying geology, rainfall, channel slope, flow regime), or from a national coverage of spatially distributed SSY. This national GIS coverage enables reconnaissance-scale estimates of SSY from New Zealand's rivers and streams. It was developed by NIWA in collaboration with Landcare Research using a model relating sediment yield per unit area to mean annual rainfall and to an 'erosion terrain' classification (broadening the Hicks et al. 1996 analysis to a national scale). The erosion terrains were defined on the basis of slope, rock type, soils, dominant erosion processes, and expert knowledge. The resulting map of sediment delivery to rivers and streams has been adjusted over gauged catchments so that the sediment yield predicted by the empirical model matches the gauged yields measured at over 200 river stations(see ftp://ftp.niwa.co.nz/ResourceManagementTools/Sedmap/). Catchment SSY can be derived by integrating the raster coverage of SSY over the catchment area. The layer can be used to estimate suspended-sediment delivery to rivers and streams from within any defined catchment boundary. Having estimated SSY, gravel yield can be estimated as a proportion of SSY. Hicks and Griffiths (1992) suggest that in larger rivers bedload is <25% of suspended load, while Griffiths and Glasby (1985) estimate that the bedload delivered to the coast is 3–10% of suspended load.

Since there have been no bed-level surveys of Nelson rivers, estimates of gravel yield can only be derived as a proportion of SSY. The national coverage of SSY was used to calculate the catchment SSY for the larger Nelson catchments (Table 3). The amount of gravel was calculated as a proportion of SSY, using a range of 3 to 25% to provide estimates on the limits to likely bedload yield. A higher proportion (50%) has also been used to provide a likely upper limit on bedload yield. Because the Nelson catchments are small and steep it is likely that gravel yield lies between 10 and 25% of SSY. These estimates are for the time-averaged transport rate to the coast (or catchment outlet in the case of the Brook Stream). However, it is also worth noting that gravel is not transported continuously. Rather it is characterised by episodic and discontinuous movement controlled by floods that can mobilise bed material, and by the movement of "slugs" or waves of bed material that result from the impact of landslides, large storms or changes in land use (Hicks et al. 2004). Thus the supply rate (and volume available for extraction) is not constant through time.Comparing these values with the consented extractions listed in Table 1 and 2 suggests they are of a similar magnitude. In addition there appears to be no demonstrable evidence of over-extraction (e.g., undermining of bridges or stopbanks), suggesting current extraction rates are probably not excessively high in relation to supply rates.

Table 3 Estimates of gravel yield as a proportion of suspended sediment yield for the main Nelson rivers

Catchment	Area	Sediment yield	Specific sediment yield	Gravel yield (m^3/year)			
		(t/yr)	(t/km^2/yr)	3%#	10%	25%	50%
Wakapuaka	114	10 630	93	123	409	1022	2044
Whangamoa	113	16 630	147	192	639	1599	3198
Maitai	75*	3980	53	46	153	383	765
Brook Stream	27	1570	58	18	60	151	302

* excludes the area above the Maitai dam # proportion of SSY

5.5 Monitoring methods for determining gravel supply rates and impacts of gravel extraction

Measurement of bedload transport in gravel bed streams is notoriously difficult and expensive, and has been undertaken in very few rivers. The approaches used include (after Hicks & Gomez 2003):

- bedload sampling. Because bedload transport rates are highly variable spatially and temporally, it is very difficult and time-consuming to use direct sampling to get an unbiased estimate of time-averaged transport rate
- bedload traps. These provide reliable data on bedload yield, but are difficult and expensive to install particularly in larger rivers
- bedload tracers. These can provide reliable data so long as the tracer can be recovered, and the relationship between transport rate, entrainment and displacement length, and the velocity of the sediment is known
- bedload transport formulae. There are numerous bedload transport formulae - see Reid and Dunne (1996) and Hicks and Gomez (2003) for brief summaries of the use of bedload transport formulae. They are relatively difficult to apply, requiring information on the depth, width, and gradient of the channel, and on sediment characteristics, and are best suited for time-averaged transport rates. A range of approaches are used that relate bedload transport rate to water discharge (e.g., Shulits 1934), shear stress (e.g., Meyer-Peter & Mueller 1948), or stream power (Bagnold 1980). This approach has been applied to the Waimakariri River (Carson & Griffiths 1989; Meyer-Peter and Muller formula) and two Bay of Plenty rivers (Balley 2006; Meyer-Peter and Muller, Engelund and Hansen, and Einstein and Brown formulae)
- a morphological method based on bed-level cross-section surveys, photogrammetry, GPS and LIDAR surveys. The morphological method has mostly been based on cross-section surveys (e.g., Griffiths 1979; Noell 1992; Sriboonlue & Basher 2003), or more recently on digital photogrammetry and LIDAR (Lane et al. 2003). The method requires long-term data sets to give reliable time-averaged transport rates, and typically only give minimum estimates of transport rates particularly when derived from relatively infrequent cross-section surveys (Fuller et al. 2003).

For rivers where bed-level monitoring has been undertaken and gravel extraction volumes are known, gravel load can be calculated on a conservation of volume basis over the surveyed river reach. Gravel entering the reach either leaves or remains in the reach. So, for a given reach:

$$\frac{\Delta V_g}{\Delta t} = Q_{gravelinput} - Q_{gravelout} - Q_{gravelextraction}$$

where: ΔVg = change in volume of gravel (m^3) calculated from riverbed surveys
Δt = years between surveys
$Q_{gravel\ input}$ = volume of gravel entering the reach from upstream (m^3/yr) generally only able to be estimated from catchment erosion rates
$Q_{gravel\ extraction}$ = volume of gravel extracted from the river reach (m^3/yr) derived from gravel extraction returns
$Q_{gravel\ out}$ = export of gravel out of the river reach by downstream transport (m^3/yr); this is the unknown in the equation and can be solved for.

This approach provides a minimum estimate of gravel load, with the accuracy of the estimate depending on the frequency of cross-section surveys and the spacing of cross-sections. It also

requires an estimate of gravel entering the reach, which is often only poorly known. Bed-level surveys do, however, provide reliable data on trends in bed-level.
In addition, some Councils use either aerial photography or ground-based inspections to enable visual evaluations of gravel accumulations. This is the lowest cost method for evaluating gravel accumulation (although of less value for determining gravel loss, unless there is a clear baseline against which to assess channel change), and assessing riverbed response to extraction.

The most commonly used method of quantitatively monitoring bed-level trends and setting gravel extraction limits is based on bed-level cross-section surveys. Many Councils in New Zealand have used this approach over the last 40 to 50 years. The reason for establishment of the cross-section networks has often been flood-risk management, and the design of networks is not necessarily ideal for gravel management purposes (Environment Canterbury 2006).While they do provide a good long-term understanding of bed-level trends, they have limitations for estimating gravel transport rates (relating to the spatial variation in river bed topography, temporal fluctuations in bed material transport and frequency of surveys). Use of GPS or LIDAR surveys addresses some of these limitations, but are currently relatively expensive to implement.

These surveys only have value if matched by information on gravel extraction rates so that the gravel volume changes in the river bed can be compared with extraction volumes. Realistically, gravel extraction rates can only be determined by reliable returns from consent holders. Consent compliance monitoring, including tracking of consented volumes and extraction returns, is essential to improved management of the gravel resource.

In order to improve the current knowledge of the gravel resource in Nelson, NCC should consider a number of options (listed in order of probable decreasing cost):
- establishment of a small cross-section network in the key reaches where gravel is repetitively extracted
- aerial photography of key reaches where gravel is repetitively extracted
- regular visual inspection of key sites and compilation of notes regarding the morphology of the riverbed and banks and ground-based photographs at sites that can be relocated and rephotographed (e.g., location and direction from GPS).
- In addition, establishment of a system for tracking extraction volumes on (at least) an annual basis is critical. These measures will only have value if the data are regularly analysed.

5.6 Managing gravel extraction

The principles that might govern management of gravel extraction are:
- Identify zones of gravel accumulation that provide a long-term supply that can be sustainably harvested. Many Councils take advantage of natural accumulation zones to harvest gravel that is not being transported to the coast (e.g., on the Waimakariri and Wairau rivers). The lower reaches of the Wakapuaka and Whangamoa Rivers should be investigated to determine if they are zones of long-term gravel accumulation suitable for gravel mining
- Where there are no natural accumulation zones, assess the proportion of gravel transport rate that can be sustainably harvested without having significant downstream effects

- The effective regulation and monitoring of gravel excavation activities requires the systematic collection of measurements of bed-levels to establish whether there are trends in bed-levels. These data can be used to set and adjust extraction levels according to gravel supply
- Consider whether there are alternatives, such as suitable sites for land-based extraction
- Establish and enforce the requirement for gravel extraction returns, and analyse these data to establish extraction levels and their relationship with bed-level trends
- Establish a standard consistent wording of consent requirements for extraction levels, gravel extraction returns and other conditions relating to the timing of extraction, the method of extraction, and the avoidance, remediation or mitigation of any adverse effects, etc. Other Councils have operational guidelines for gravel extraction that impose a standard procedure before, during and after gravel excavation and NCC should consider preparing these for local contractors.

In assessing the suitability of sites for gravel extraction the following key criteria need to be considered:

- Sensitivity of the reach. This takes account of trends in the riverbed shown by existing bed-level monitoring data and/or assessments of natural sediment supply. A sensitive reach is one where bed levels and volumes appear to be degrading rapidly or falling below design levels, or where a lack of aggradation is evident. This may be due to natural processes or over-extraction of gravel
- Extraction pressure. This takes account of past, present and projected rates of gravel extraction. Close attention should be paid to reaches where large volumes of material have or are being extracted, or where demand is increasing rapidly
- Flood risk. This takes account of the level of flood risk posed within the reach and how gravel extraction can contribute to managing this
- Presence of infrastructure. Identify the presence of all sensitive infrastructure such as bridges, water intakes, pylons etc. and how they might be affected by aggradation or degradation
- Bed and bank stability. This takes account of existing problems associated with bed and/or bank stability, and potential problems that may arise through flow path changes consequent upon extraction activities
- Ecological sensitivity. Identify any ecological sensitivities such as native fish or salmonid spawning sites, bird nesting areas, significant indigenous fauna and habitat.

Stocker (2002) recommended that the level of gravel extraction should be set by availability, rather than on an average annual basis. This is essentially the basis of the permitted extractions listed in Table 1 for flood control and structure maintenance. This system appears to work well in those generally small rivers, and the rationale for the permitted extractions is clear. The volumes of gravel are generally small and consistent with likely supply rates. It is also the basis of extractions from the Wakapuaka River by some operators (K. Anderson, pers. comm. June 2006) who repetitively remove gravel from some beaches to alleviate the flooding problems posed by continuing aggradation.

In the larger rivers where consented extractions are occurring there are two important issues:

- defining allowable excavation levels
- monitoring to assess bed-level trends and to compare total extraction volumes with supply rates.

Stocker (2002) suggested defining available gravel as any gravel higher than a threshold height above the adjacent water level (e.g., 400 mm above adjacent water level), close monitoring of bed-level trends and adjustment of the threshold if bed-level trends indicate aggradation or degradation. This would also allow gravel extraction to be better matched with supply rates/availability and acknowledge that the supply rate is not constant through time. It does, however, require Council staff to become familiar with assessing variation in rates of supply.

The rivers where extraction occurs tend to be relatively small, and have a very simple morphology. While surveyed cross-sections would be easy to establish on these rivers, the cost may be more than NCC can currently justify. An alternative would be to establish permanently located sites where regular (at least annual) visual inspection was made with compilation of notes regarding the morphology of the riverbed and banks (including bank height, sediment character, beach size) and ground-based photographs at sites that can be relocated and rephotographed (with location and direction determined from GPS). It may even be feasible for such simple monitoring to be undertaken by consent holders to provide a permanent long-term record of river behaviour and impacts of extraction.

In addition, there is a clear need for extraction volumes to be reported and for NCC to establish a computer-based system to record, retrieve and analyse this information. This system should include information on location of extraction, extraction volumes, and reason for extraction.

6. Conclusions

The amount of gravel extraction undertaken each year in Nelson City is poorly known, and the ability of Council staff to source this information is poor because there is no system for consistently recording, retrieving and analysing this information.

The effective regulation and monitoring of gravel excavation activities requires the systematic collection of measurements of the trends in bed levels, gravel deposition and excavation rate data over time to set maximum and minimum excavation rates. Cross-section surveys are the primary method used by regional councils in New Zealand to help determine gravel supply rates and set gravel extraction limits. Some Councils use either aerial photography or ground-based inspections to enable visual evaluations of gravel accumulations. To improve the current knowledge of the gravel resource in Nelson, NCC should consider a number of options (listed in order of probable decreasing cost): establishment of a small cross-section network in the key reaches where gravel is repetitively extracted; aerial photography of key reaches where gravel is repetitively extracted; regular visual inspection of key sites, with compilation of notes regarding the morphology of the riverbed and banks, and ground-based photographs.

Annual gravel supply rates for Nelson rivers were estimated as about 1000, 1500, 400, and 150 m^3 for the Wakapuaka, Whangamoa, Maitai Rivers and Brook Stream, respectively. These figures appear to be of a similar magnitude to consented extractions, and there appears to be no demonstrable evidence of over-extraction, suggesting current extraction rates are probably not excessively high.

7. Recommendations

NCC should:

- establish a system for investigating bed-level trends. Given the small amount of current gravel extraction, a visual inspection of key sites (with compilation of notes regarding the morphology of the riverbed and banks, and ground-based photographs) may be the most practical and affordable system for NCC. This will only have value if the data are regularly analysed
- establish a system for archiving gravel extraction returns and compiling annual estimates of gravel extraction volumes.

Monitoring of bed-level trends would allow gravel extraction to be matched with supply rates/availability, and allow adjustment of an excavation threshold if bed-level trends indicate aggradation or degradation. It does, however, require Council staff to become familiar with assessing variation in rates of supply and to visit the rivers regularly.

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