Assessing the effects of river-gravel extraction on coastal erosion

Prepared for West Coast Regional Council

August 2017

Prepared by:
D M Hicks

For any information regarding this report please contact:

Murray Hicks
Principal Scientist, River & Coastal Geomorphology
Sediment Processes
+64-3-343 7872
m.hicks@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
PO Box 8602
Riccarton
Christchurch 8011

Phone +64 3 348 8987

NIWA CLIENT REPORT No: 2017206CH
Report date: August 2017
NIWA Project: ELF17503

Quality Assurance Statement		
	Reviewed by:	Richard Measures
	Formatting checked by:	Fenella Falconer
	Approved for release by:	Jo Hoyle

Contents

Executive summary

This report provides advice and guidance to West Coast Regional Council (WCRC) around assessing the potential effects of river gravel extraction on coastal erosion. The advice is aimed at giving WCRC greater certainty about how to manage gravel extraction in rivers so that the benefits from using the West Coast gravel resource can continue to be obtained in appropriate forms and locations and at a rate which ensures that adverse effects on coastal hazard risks are appropriately managed. It is anticipated that the advice will be reflected in WCRC's RMA planning documents or by other action as needed, and will also be used in resource consent processing.

The work scope included providing a generic overview of the potential effects of river gravel extraction on coastal erosion, including how the effects can develop, and guidance on what information or investigations would help to assess if these effects will be significant. This was developed largely from existing knowledge, but also addressed questions posed by WCRC planners, engineers, and consents staff during a video-conference.

In overview, West Coast beaches are typically formed of sand and gravel, and while the gravel may only form part of a beach it is usually concentrated on the upper foreshore where it serves a very useful role protecting against storm waves – thus depleting a beach gravel stock is a recipe for shore retreat and backshore flooding.

The sources of gravel to West Coast beaches include rivers and erosion of coastal outcrops by waves and slope failure processes. It is considered that gravel supplies to the West Coast rivers are cyclic over several-century time scales, driven by large earthquakes on the Alpine Fault. The coast is currently towards the lower end of this gravel delivery cycle, hence stocks of beach gravel along some segments of the coast are in a relatively diminished state and these coasts are eroding. For this reason, the current supply of river gravel to the coast may be 'precious' in regard to replenishing beach stocks continually reduced by abrasion and longshore transport and so maintaining the natural protective functions of the shore. Another good reason for preserving beach sediment stocks (and their sources) as much as possible is to mitigate the effects of rising sea level. The rate of sea level rise is expected to accelerate in the coming decades, and most shores are expected to erode as a consequence.

The extent and timing of the effect of a river gravel extraction operation on gravel delivery to the coast depends on the extent that the extraction site is 'connected' to the coast and how far upstream it is. Only connected gravel pathways will induce coastal effects, and these effects will be more delayed and diffused over time the further upstream the extraction site is. However, extraction at a site tens of kilometres upstream from the coast can still have a significant coastal impact, even if its signal is delayed and diffused. If the site is close to the coast, even a short phase of extraction may cause a substantial albeit temporary reduction in the gravel delivery to an adjacent beach, increasing the risk that the beach backshore may experience erosion and/or flooding.

When assessing the potential effects of any particular river gravel extraction proposal on coastal stability, the fundamental consideration is the impact of the extraction on the sediment budget of the coast adjacent to the river mouth. This can be broken down into estimating: (i) the impact on the river gravel load delivered to the mouth, then (ii) the river load contribution to the beach sediment budget.

Assessing the impact on the gravel load delivered to the river mouth should consider: the delivery of the load from the extraction site to the river mouth; the proportion of the load passing the extraction site that is intercepted by the extraction; the term of the extraction; the distance from the coast; and the cumulative effects of multiple extractions on the same river, whether current or past. Assessing whether the river gravel load makes a significant contribution to the beach sediment budget is straight-forward where information on the coastal gravel budget estimates exists, however, this is rarely the case and so geomorphic evidence is required. The last step is assessing the coastal hazard associated with any increased risk of coastal erosion due to the river gravel extraction. Elevated scrutiny should automatically be given to cases where rivers discharge gravel to existing Coastal Hazard Areas.

Guidelines and “rules-of-thumb” are provided for each step of these assessments, and a decision-tree is provided for deciding if impacts are likely to be significant.

Beyond the guidance provided in this report, there does not appear to be any national scale guidance directed at assessing coastal effects of river gravel extraction. Information on the topic appears to be limited to case examples where river gravel extraction (or at least reduced gravel load) has been considered a contributing factor to coastal erosion.

1 Introduction

1.1 Background

West Coast Regional Council (WCRC) manage gravel extraction from the West Coast's rivers. A potential effect of such extraction, particularly when taken from the lower (near coast) reaches, is on erosion of the adjacent coast.

Currently, WCRC staff who issue consents for river gravel extraction generally do so by comparing the scale of the gravel take with an appreciation of the gravel load of the river (consent is generally granted if this ratio is small). While this pays implicit regard to the impact on coastal gravel delivery, there is currently no explicit mechanism to determine if there is likely to be an effect of riverbed gravel extraction on coastal erosion.

The Department of Conservation (DOC 2016) has submitted on WCRC's Proposed Regional Policy Statement (WCRC 2015) and Proposed Regional Coastal Plan (WCRC 2016), seeking policy modifications to manage potential effects of gravel extraction in the lower reaches of rivers on coastal erosion.

WCRC are therefore considering whether this is an issue that requires further policy direction and/or can be managed through existing processes with improved guidelines, and have sought technical advice from NIWA to inform on these questions.

1.2 Aims and anticipated uptake pathway

The advice is aimed at giving WCRC greater certainty about how to manage gravel extraction in coastal reaches of rivers so that the benefits from using the West Coast gravel resource can continue to be obtained in appropriate forms and locations and at a rate which ensures that adverse effects on coastal hazard risks are appropriately managed.

It is anticipated that the advice provided will be reflected in WCRC's RMA planning documents or by other action as needed. Guidance on how to determine if a riverbed gravel take will affect coastal erosion will be used in resource consent processing. When applying the guidance, if this indicates that there is no, or a low, risk of coastal erosion from riverbed gravel extraction, the activity can continue to be enabled in the appropriate planning documents. If the guidance shows there is a risk of gravel extraction contributing to coastal erosion, WCRC can then decide what action needs to be taken to avoid or reduce the risk of the activity contributing to coastal erosion.

1.3 Work scope and program

The advice sought by WCRC includes:

- A generic overview of the potential effects of river gravel extraction on coastal erosion on the West Coast, including how the effects can develop, and guidance on what information/investigations would help to assess if these effects will be significant.
- Answers to specific questions posed by WCRC planners, engineers, and consents staff.

The work was desktop-based and included a teleconference with WCRC staff, held on 10 April 2017.

1.4 Acknowledgements

The work was funded by an Envirolink Small Advice Grant (Contract 1758-WCRC159). Lillie Sadler coordinated the project for WCRC. We also thank WCRC staff Sarah Jones, Paulette Birchfield, Brendon Ross, Oliver Varley, Gerald McCormack, Rachel Clark, Sandra Cox, Tony Ridge, and Wayne O'Keefe for contributing to the videoconference.

2 What are the potential effects of river gravel extraction on coastal erosion on the West Coast?

West Coast beaches are typically formed of sand and gravel, and the gravel usually concentrates on the upper foreshore – either mixed with coarse sand or separated in the form of a shingle ridge[1] - while the lower beach and nearshore is typically flatter and sandy. Gravel also makes beaches steeper and more wave-reflective, and so gravel ridges provide a good natural protective barrier to storm waves at high tide. Thus, while it may only form part of a beach, gravel serves a very useful purpose, and depleting the beach gravel stock is a recipe for shore retreat and backshore flooding.

The sources of beach gravel include rivers and shore erosion. On the West Coast, the erosion of sea cliffs formed from outcrops of Pleistocene moraine or alluvial deposits delivers 'ready-made', rounded gravel, but erosion of other rock-types (e.g., landslides off limestone or granite cliffs) also contributes gravel-grade material. Rivers certainly provide the main supply of gravel on the long spans of low-lying coast (where there is no cliff erosion). On the coast, the gravel is generally moved alongshore northward by the prevailing westerly swell, and in the process is worn down by abrasion.

The supply rate of river gravel to the coast is influenced by catchment size, steepness, rainfall, rock-type, and tectonic and geomorphic history. Gravel generation in the steep, mountainous headwaters is strongly influenced by earthquake-triggered landslides, while its evacuation from the mountains is driven by flood runoff from heavy rain. Gravel delivery to the coast may fluctuate at 100-1000 year time scales from cycles of aggradation and down-cutting on alluvial fans at the toes of the mountains and along the valleys connecting to the coast. It is currently considered that gravel delivery to the West Coast is towards the lower end of the delivery cycle, since it has been some 300 years since the last major earthquake on the Alpine Fault. In that context, stocks of beach gravel along some segments of the coast (e.g., Rapahoe-Punakaiki, Granity-Hector) are in a relatively diminished state and these coasts are eroding as a consequence (e.g., Hicks 2014, Allis 2016).

In such situations, the current supply of river gravel to the coast may be 'precious' in regard to replenishing beach stocks continually reduced by abrasion and longshore transport and so maintaining the natural protective functions of the shore.

Another good reason for preserving beach sediment stocks (and their sources) as much as possible is to mitigate the effects of rising sea level. The rate of sea level rise is expected to accelerate in the coming decades, and most shores are expected to erode as a consequence.

As detailed in the following section, the extent, timing, and 'shape' of the effect of a river gravel extraction operation on gravel delivery to the coast depends on the extent that the site is 'connected' to the coast and how far upstream it is. Only connected gravel pathways will induce coastal effects, and these effects will be more delayed and diffused over time the further upstream the extraction site is. To understand the mechanism behind this, consider that extraction off a gravel bar (over, say, a few months) will create a 'hole' which will be filled by gravel brought from upstream by subsequent floods. While this restocking is occurring, the bar will supply less gravel downstream, and so the 'hole' will diffuse downstream to the next bar and so on. As this happens the 'hole' also spreads out over a longer reach. If the extraction site is many kilometres upstream from the coast, then the effect on the coastal gravel delivery will be delayed and buffered over time, but if the site is close to the coast (e.g., upstream of the SH6 bridge over the Fox River), it may mean a temporary but

[1] Gravel is "combed" up on the foreshore by the asymmetry of waves – which produces a shorter but more intense up-wash.

substantial reduction in the gravel delivery to an adjacent beach – which will increase the risk that the beach backshore may experience erosion and/or flooding.

It should be noted that while the effects of reduced river sediment loads on shore erosion are typically expected to be downdrift[2] from river mouths, they can also be felt updrift. A good example is at the Mokihinui River mouth, where the river has built a wave-dominated delta. The delta acts as a "soft groyne" that traps sand and controls the width of beach on the southern (updrift) side of the river (just like Gentle Annie Headland further north acts as a "hard groyne" that traps sediment moving off downdrift from the Mokihinui River mouth). NIWA investigations of the proposed Mokihinui HEP dam (Hicks et al. 2007) predicted that the Mokihinui delta would retreat after the dam intercepted most of the river's supply of sand and gravel, and in consequence the beach shoreline on its southern flank would also retreat.

It is also of note that where a river's bed is aggrading, gravel extraction can have the beneficial effect of mitigating the aggradation and reducing flooding hazards. In such cases, potential negative effects of extraction on coastal erosion may require balancing against positive local effects in-river.

Figure 2-1: Mokihinui River mouth. The wave-dominated delta at the Mokihinui River mouth traps littoral drift sand moving alongshore from the south, stocking the beach south of the river mouth. Yellow line indicates extent of shoreline extension by river delta. Reducing the river's sand and gravel load will 'flatten' the delta and cause the beach to the south to be trimmed back (potentially to yellow line).

[2] Downdrift refers to the net direction of wave-driven littoral (or longshore) drift along a coast. A beach downdrift from a river will receive sediment from the river. A beach updrift from a river may have sediment passing along it that passes the river. On the West Coast, the net longshore transport direction is south to north, so the downdrift shore is to the north of a river mouth.

3 Factors to consider when assessing the potential effects of river gravel extraction on coastal erosion

This section outlines what information/investigations can help to assess if the effects of a river gravel extraction operation will be significant. Fundamentally, the effect to consider is the impact of the river gravel extraction on the sediment budget of the coast adjacent to the river mouth. This can be broken down into estimating: (i) the impact on the load delivered to the mouth, then (ii) the river load contribution to the beach sediment budget.

3.1 Impact on the gravel load delivered to the river mouth

This should consider several things:

- the delivery of the load from the extraction site to the river mouth
- the proportion of the load passing the extraction site that is intercepted by the extraction
- the term of the extraction
- the distance from the coast, and
- cumulative effects of multiple extractions.

3.1.1 Gravel delivery from extraction site to river mouth – Geomorphic setting

The gravel load transported by a river out of the mountains may not be the same as what it delivers to the coast, indeed, often the coastal delivery is less. This is because of gravel deposition at places where the transport capacity wanes, typically at slope breaks and/or coming out of valley-confinement (e.g., alluvial fans – e.g., Waiho fan) or the intersection of alluvial fans with coastal plains (where there may be a gravel/sand transition – e.g., Waimakariri River). The gravel load is also reduced downstream by abrasion (which is sensitive to rock-type). In some instances, the load can increase towards the coast (e.g., lower Ashburton River, which drops its gravel load on the upper Canterbury Plains but it recovers gravel by incising into the lower plains because its slope has been increased by coastal retreat).

Therefore, it is important that the geomorphic setting of the river span between the extraction site and the coast is appreciated. Resources for doing this include Google Earth, Maptoaster (or other digital topographic maps), cross-section surveys, and field knowledge. Typical questions to ask around this span of river are:

- Is the extraction reach aggrading (e.g., is it on an alluvial fan that is accumulating at the slope break between the mountains and the coastal plain – such as the Waiho River at Franz Josef)? If so, then the river's gravel load will be reducing downstream, and the impact of the extraction on the coastal gravel delivery will be proportional, not absolute. Are there cross-section surveys or is there field evidence that quantifies this?
- Is there a gravel/sand transition upstream of the mouth (typically marked by an abrupt slope reduction and a change from braided to narrow, meandering planform)? If so, then there will be no gravel connection with the coast.

- Does it stay braided (or at least semi braided) to the coast, and/or is its slope at least around 1 m/km? If so, then full delivery of the gravel load can be assumed.
- Does the river steepen, is it incised through old alluvial terraces, and does it emerge onto a retreating coast? If so, the load likely increases downstream, and extraction from upstream of the slope change likely has less proportional impact on the supply to the coast.
- Does the river deposit its gravelly bedload in a large estuary, with little if any being delivered to the coast (at least over 'planning' time scales)? If so, then the rivers gravel load does not connect with the coast.

3.1.2 Extraction rates compared with gravel load passing the extraction site

A crude estimate of the mean gravel load passing the extraction site can be made assuming that this equates to a small percentage (e.g., 10 per cent) of the mean annual suspended load passing the site. The mean annual suspended load can be estimated from empirical models, for example that of Hicks et al. (2011), which was calibrated for the West Coast Region using data from West Coast rivers[3]. This model can be accessed from NIWA's Rivermaps tool at https://shiny.niwa.co.nz/nzrivermaps.[4]

The river gravel mass load (t/yr) can be converted to a bulk-volumetric load (to equate with extraction volumes) by assuming a bulk gravel density of 1.8 t/m^3. For example, for the Hokitika River past Hokitika, the estimated suspended load is ~ 6.2 million t/yr, thus the gravel bedload ~ 6.2x10^6 x 0.1 / 1.8 = 340,000 m^3/yr.

If the proposed extraction exceeds, say, 10 per cent of the estimated mean annual bedload, then the downstream effects should be considered[5].

Sometimes only part of the river's bedload is targeted for extraction. For example, WCRC staff commented that extraction their rivers generally focussed on material finer than 250 mm unless specifically taken for crushing. This raises the question of possible side-effect of size-selective extraction on bed-material supply and mobility. River bedloads (and the supply to the coast) are dominated by the finer fractions of the material found in the bed. Targeting only the finer fractions may leave an overly coarse armour layer, which may hinder gravel resupply from within the bed – which would be important in a situation where the river secures a significant part of its bedload from its own bed (e.g., Ashburton River on Canterbury coast). Conversely, taking too much of the armour may "loosen-up" the bed and actually increase the gravel load – at least for a short time. The effects of size-selective extraction should be considered on a case-by-case basis.

3.1.3 Term of extraction, distance from coast, and extraction holidays

The term of the intended extraction should be considered along with the volumetric extraction rate. For example, taking the equivalent of the mean annual gravel bedload for just one year may be assumed to cause similar effect to the time-averaged budget downstream as taking 10 per cent over

[3] Note that the Hicks et al. (2011) estimator only estimates the long-term average suspended load. It does not predict temporal variability in load due to transient events such as landslides triggered by earthquakes or extreme rainstorms.

[4] In Rivermaps: select West Coast region; select National Estimates tab; select sediment load from the Select variable type tab. The load is given in t/yr at any selected reach.

[5] The 10% threshold provided here is partly arbitrary in that it is not supported by any particular case studies. Nonetheless, it is set conservatively low in allowance that the estimate of the gravel bedload could be in error by up to a factor of around 4 (due, for example, to a x2 uncertainty in the suspended load estimate compounded by another x2 uncertainty in the gravel load / suspended load ratio). In such a case, the extraction could potentially amount to 40% of the actual gravel load even if estimated to be only 10%. WCRC may care to raise this threshold if they wish, but the risk of a 'false negative' impact will increase.

10 years. This allows that the annual sediment load of a river typically ranges by up to about a factor of 10 year by year[6] (simply as a consequence of hydrological variability), and thus the effect of a single year's extraction should cause no more short-term impact than typical annual variability does, while the long-term impact will be dampened.

Pursuing this further, consider a river that has a mean annual gravel load of 40,000 m^3/yr. If 40,000 m^3 is taken from a short reach in one year, then that will leave a "hole" to be filled by gravel brought from upstream by subsequent floods. One large flood may quickly fill the hole, but during a dry spell with no large floods it may take several years to fill the hole. In the interim, though, the gravel supply to the reach downstream (and the coast) would not cease because the lower margin of the extraction hole would diffuse downstream, restoring at least a partial gravel supply.

An important factor is the distance of the extraction site from the coast. The above example assumes an adequate span of river downstream of the extraction site to buffer delivery to the coast. However, if the extraction site is close to the coast (e.g., upstream of the SH6 bridge over the Fox River), then there will be minimal buffering. In that case, the effect of the extraction hole could propagate along shore from the river mouth – depleting beach gravel stocks and potentially exacerbating an erosion phase. Thus large, short term takes should be avoided for sites close to the coast – even if the impact on the long-term budget is small.

A reasonable "rule of thumb" to balance term and take (at least for sites more than several km upstream from the coast) would be to consider the gravel take insignificant if the average annual extraction rate over 10 years does not exceed 10 per cent of the estimated mean annual bedload. For example, if 20 per cent of the load was taken every year over five years, then the river would need to be given a holiday for another five years to meet the 10-year average criteria and recoup its gravel stocks.

Similar logic should be applied when setting consent durations. On the New Zealand east coast, where there is a high demand for gravel and there are concerns around coastal gravel supply and stability (e.g., southern Hawkes Bay), then ten years would be regarded as a long consent period and shorter consents are common. On the West Coast, the maximum term should scale inversely with the potential effects but should still be restricted to a maximum of ten years. This will be long enough to provide surety of supply but will also allow flexibility to deal with factors such as accelerated coastal erosion due to rising sea level.

3.1.4 Cumulative effects of multiple extractions

The effect of individual extractions should be considered in the context of (i) other concurrent extractions elsewhere along the same river and (ii) the history of extraction. The effects of multiple gravel takes will have a spatially cumulative impact on the coastal gravel delivery, while deficits in gravel supply to the coast can accumulate over time. So, for example, it would not be a good idea to consent any extraction from a river that has recently been over-extracted. Thus, when assessing potential effects, extraction should be accumulated (and averaged) over space (multiple sites) and time (to account for legacy effects from past extractions).

[6] For example, Hicks (2016) found that the annual sediment load of the Arawhata River ranged over a factor of 7.7.

3.1.5 Monitoring

Monitoring datasets can also inform on the potential downstream effects of gravel extraction. River extraction effects monitoring is best done near the source, i.e., by monitoring river bed levels around the extraction site. Unless extraction continues over decadal time scales, chasing an extraction signal downstream and along the coast will likely be difficult because of spatial diffusion and time lags in the gravel supply deficit against background "noise" from floods and coastal storm events. If extraction produces no significant change in mean bed levels at the extraction site (say more than 0.2 m degradation), then it is unlikely that it will have a significant impact on gravel exports. Clearly, an extensive, regularly-surveyed network of cross-sections set up to help manage river bed levels and flood capacity (e.g., as monitored by Environment Canterbury on the Waimakariri River) would be ideal, but the reality is that such networks are expensive to maintain and are rare on the West Coast.

3.2 The importance of the river load to the coastal sediment budget

If the analysis outlined in Section 3.1 suggests that the river's gravel load connects with the coast and the take will cause a significant (say 10 per cent) reduction in the time-averaged gravel delivery to the coast (or a reduction of the order of the annual load in any single year – as per the Fox example), then the next step is to evaluate the potential impact on the coast. The things to be considered are:

- the coastal beach gravel budget
- the configuration, character and stability of the coast up- and down-drift from the river mouth, and
- the assets and infrastructure potentially at risk from shore erosion.

3.2.1 Coastal beach gravel budget

Coastal sediment budgets are useful for establishing if spans of beach shore are stable, accreting, or eroding. The budget accounts for sediment sources (rivers, wave-driven littoral drift from alongshore, rocky backshore erosion, shells) and losses (littoral drift away from the beach, wind-blow inland, abrasion, offshore transport). As discussed in Section 2, while gravel may only form part of a beach, by being concentrated on the upper foreshore it serves a very useful purpose in protecting the shore against storm waves, and thus depleting the beach gravel stock is a recipe for shore retreat and backshore flooding.

Where gravel budget estimates exist, then the relative contribution of the river to the total gravel supply should be assessed. If the river is a significant source (e.g., supplies more than, say, 20 per cent), then any significant reduction in the river's gravel load due to extraction should be of concern. Unfortunately, there are few locations on the West Coast where gravel budgets have even been estimated, let along established reliably[7]. Thus geomorphic evidence is required to assess the relative importance of a particular river's gravel load to the adjacent coast. Again, a key resource for geomorphic assessment of the coastal setting is aerial or satellite imagery (e.g., from Google Earth), but field knowledge and coastal profile or shoreline surveys are also important.

[7] One example where a gravel budget has been estimated is for the Hokitika River. Hicks (2003) estimated that the coarse sand and gravel supply from the Hokitika River to the beach fronting Hokitika township was ~ 190,000-390,000 m^3/yr, while Gibb (1987) estimated that 230,000-250,000 m^3/yr of gravel and coarse sand was transported northward alongshore past Hokitika above the MLWS level – which suggests that the Hokitika River is the dominant source of foreshore sediment at Hokitika.

3.2.2 Coastal configuration, character and stability

The first consideration is the coastal configuration and character at the river mouth. Questions to ask include:

- On a long span of beached coast or in a long embayment, does the shoreline trend bulge seaward at the river mouth (showing a wave-dominated delta planform)? If so, then the river likely contributes a significant beach sediment supply to the local beach sediment budget, and reducing its sediment load may lead to erosion both downdrift and updrift of the river mouth (e.g., Hokitika River, Mokihinui River – see Figure 2-1).

- Is the river mouth in an embayment bound by relatively short headlands, is there a reasonably well-stocked beach updrift from the river mouth, and/or is there a spit across the river mouth (probably from the south side)? If so, then the river is likely a subordinate source of beach sediment compared with the littoral drift supply (e.g., Pororari River and Punakaiki River – see Figure 3-1).

- Is the river mouth in the downdrift shelter of a large rocky headland and has a beach immediately north of it? If so, then the location is unlikely to be nourished by littoral drift from the south (in such situations, littoral drift is likely to bypass the river mouth on the inner shelf) and the river is likely the dominant source of beach sediment (e.g., Mahitahi River and Fox River – see Figure 3-2). If there is no beach north of the river mouth then it is not a significant beach sediment source.

- Is there any evidence that the shore adjacent to the river mouth is eroding - such as evident from historical aerial/satellite imagery (e.g., Google Earth historical imagery), photogrammetry-based shoreline mapping, beach profiles, geomorphic features such as erosion scarps, anecdotal knowledge? If so, then any reduction in river beach sediment delivery is likely to exacerbate the erosion.

3.2.3 Coastal assets

The consequences of any shore erosion/flooding exacerbated by river gravel extraction will depend on what assets (e.g., buildings) or infrastructure (e.g., roads, utilities such as sewage, power, or water lines) lie in the coastal hazard zone.

Areas on the West Coast with assets already considered at some risk from coastal hazards have been mapped into Coastal Hazard Areas (NIWA 2012, WCRC 2016 Schedule 3C, Table 3-1), thus any extraction from rivers within or adjacent to a Coastal Hazard Area should automatically be subject to elevated scrutiny.

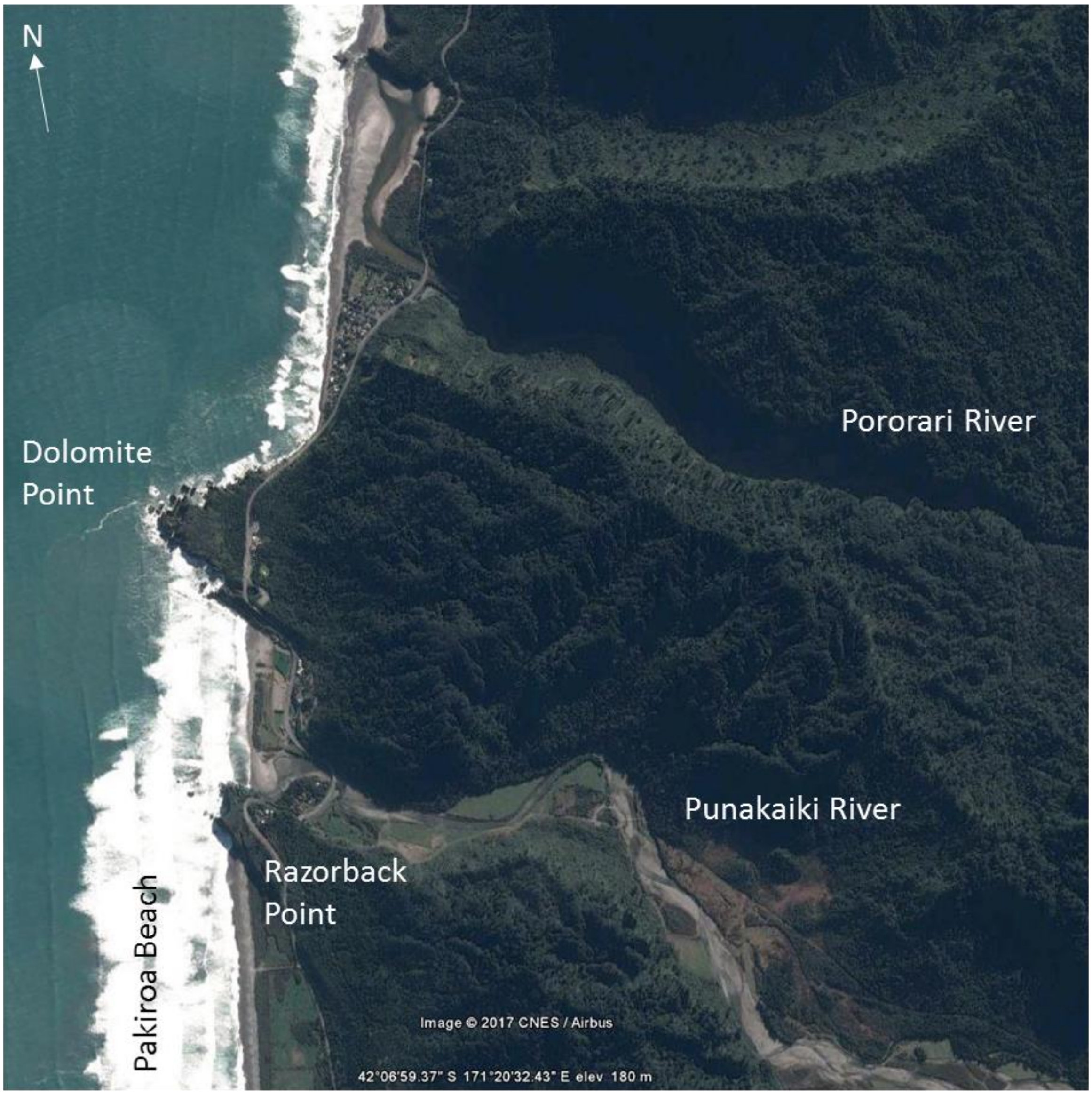

Figure 3-1: Punakaiki and Pororari River mouths at Punakaiki. The Punakaiki River has semi-braided gravel channel connecting to the coast, but its beach is separated from Pakiroa Beach by only a short headland (Razorback Point) and there is a spit across the river mouth, suggesting it is dominantly stocked by littoral drift from the south. Nonetheless, the shore fronting Punakaiki Village north from Dolomite Point is retreating, hence significant extraction from the Punakaiki River would not help this situation. The Pororari River appears to carry relatively little gravel load and its mouth is spanned by a spit built from the south, indicating the main beach sediment source is littoral drift passing Dolomite Point.

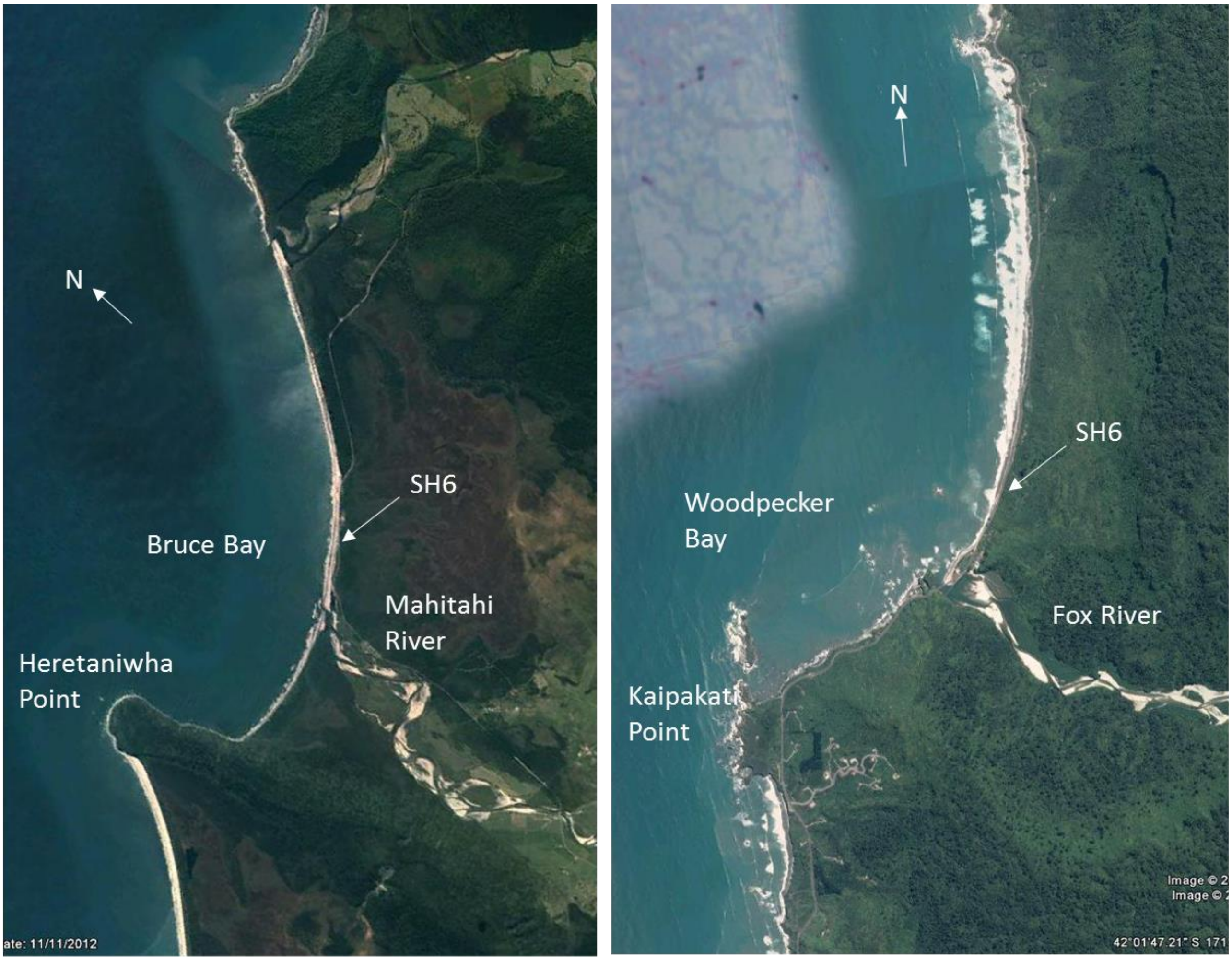

Figure 3-2: Mahitahi River and Fox River mouths. Both rivers have semi-braided channels connecting their gravel loads to the coast and their mouths are located close downdrift (north) of a large headland (that likely diverts littoral drift offshore from the river mouth), thus they likely are dominant sediment sources for the beaches to their north. Also, SH6 runs along the low backshore of both so is vulnerable to any erosion. Thus extracting significant proportions of their gravel loads should be avoided, particularly at Fox River where the only access is close to the mouth.

Table 3-1: Coastal Hazard Areas on the West Coast, identifying those potentially vulnerable to reduced river gravel exports. From NIWA (2012).

Coastal hazard area	Location	Potentially impacted by river gravel supply?
CHA 1	Karamea	✓
CHA 2	Mokihinui	✓
CHA 3	Hector, Ngakawau and Granity	✓
CHA 4	Orowaiti Lagoon	
CHA 5	Carters Beach	
CHA 6	Omau	
CHA 7	Tauranga Bay	
CHA 8	Nine Mile Beach	
CHA 9	Little Beach	✓
CHA 10	Woodpecker Bay	✓
CHA 11	Maungahura Point to Meybille Bay	
CHA 12	Punakaiki Village (Pororari Beach)	✓
CHA 13	Punakaiki River Beach	✓
CHA 14	Pakiroa (Barrytown) Beach	
CHA 15	17 Mile Bluff to 10 Mile Creek	
CHA 16	Rapahoe	
CHA 17	Cobden	✓
CHA 18	Blaketown to Karoro	✓
CHA 19	South Beach to Camerons	✓
CHA 20	Taramakau to Arahura	✓
CHA 21	Hokitika	✓
CHA 22	Ōkārito	
CHA 23	Hunts Beach	✓
CHA 24	Bruce Bay	✓
CHA 25	Okuru to Waiatoto	✓
CHA 26	Neils Beach	✓

4 Guidance for assessing effects of extraction on coastal erosion

The questions posed in Sections 3.1 and 3.2 have been collated into a decision-tree for assessing effects of extraction on coastal erosion (Figure 4-1).

A worked example is provided here for the lower Mokihinui River (Figure 2-1). The consented gravel extraction totals 15,000 m^3/yr from four sites over the next 5 years. Based on my previous work for the Mokihinui HEP investigations using a bedload formula with channel hydraulic and substrate size data, I estimated that the Lower Mokihinui's bedload is approximately 20,000 m^3/yr. The consented extraction amounts to 37.5% of this if the 5 years of extraction are averaged over 10 years, thus the extraction amounts to a substantial portion of the bedload. Moreover, the gravel load connects to the coast (there are no aggrading reaches in between), and the coast is known to be eroding on both sides of the river mouth and is a Coastal Hazard Area. Thus, this extraction ticks all the "yesses" on Figure 4-1, leading to the conclusion that significant coastal effects are likely to result from this extraction.

We are not aware of any other New Zealand guidance specific to river gravel extraction that includes coastal effects. While river gravel extraction is covered in the River Managers Guide e-book (NIWA 2010), the page on coastal effects in that document is empty.

This lack of national guidance likely reflects a general difficulty in unequivocally linking coastal erosion to specific causes such as reduced river gravel supply. However, there are a few New Zealand cases where river gravel extraction (or at least reduced gravel load) has been considered a contributing factor to coastal erosion. These include the:

- Tukituki River and Haumoana coastline in Southern Hawkes Bay. This situation is currently under active investigation and management, but the current situation is that extraction has ceased from the lower reaches of the Tukituki River (R Measures, NIWA, pers. comm.).
- Waipara and Kowai Rivers and Amberley Beach, Pegasus Bay in North Canterbury. Excessive gravel extraction in the Kowai and Waipara Rivers has been linked to erosion of Amberley Beach at the north end of Pegasus Bay in Canterbury. This beach changed from a trend of historical accretion to erosion coincident with the extraction and required artificial beach nourishment (Geotech Consulting 2000, Environment Canterbury 2012).
- Waitaki River and coast, South Canterbury. Dams and HEP-related damping of the natural flood regime have reduced the delivery of gravel from the Lower Waitaki River to its mouth, and this is acknowledged to have contributed to increased erosion of the South Canterbury coast (Hicks 2011). While unrelated to gravel extraction, this nonetheless provides an example of the effects of reduced coastal gravel delivery.
- Motueka River and Tasman Bay. There has been concern that gravel extraction in the Motueka River has contributed to erosion of the Tasman Bay coast, and it has certainly contributed to lowered river bed levels (Fuller et al. 2014).

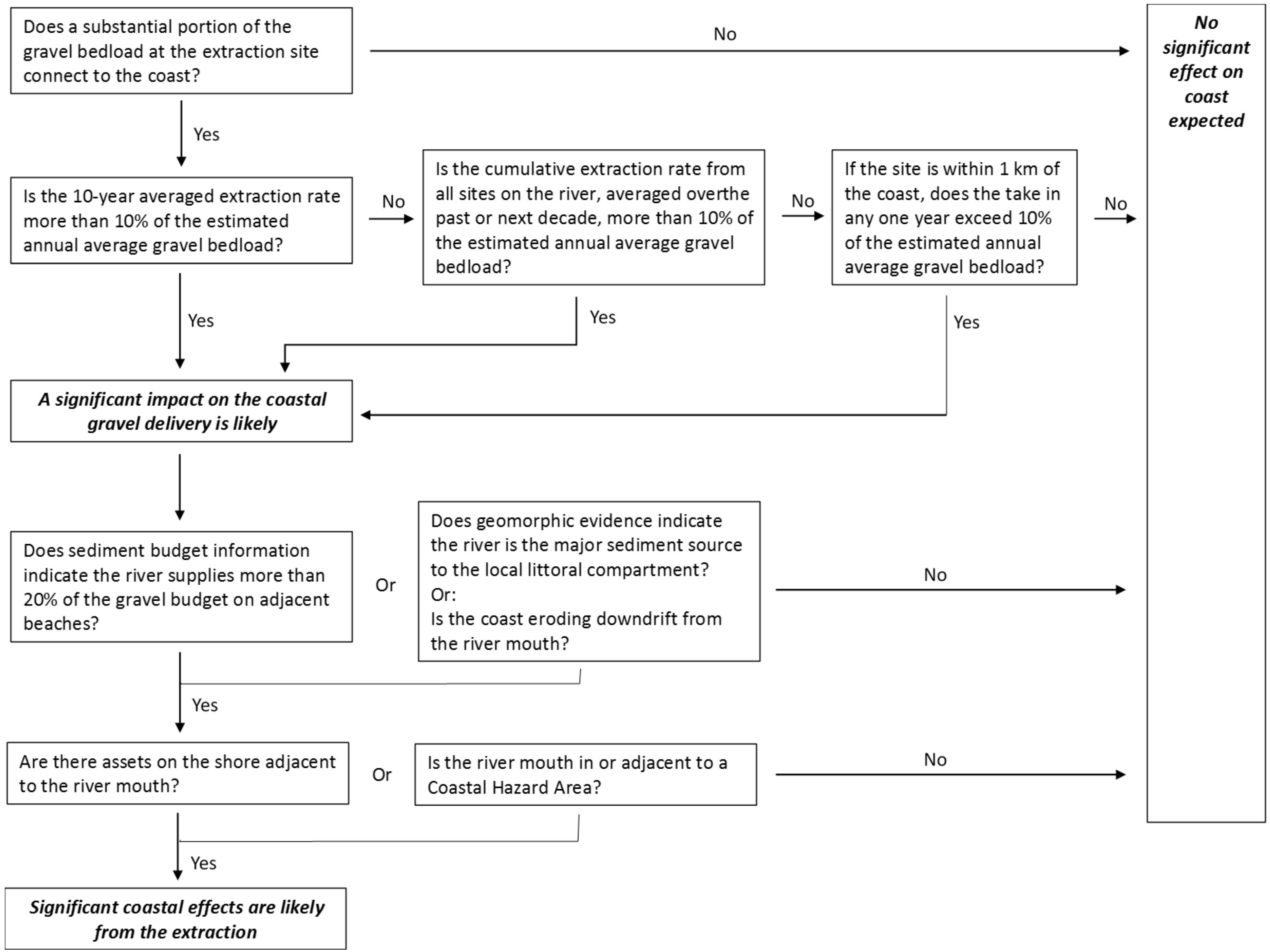

Figure 4-1: Decision-tree for assessing if river gravel extraction could have significant effects on coast.

5 Conclusions

The main conclusions from this investigation are as follows:

- West Coast beaches are typically formed of sand and gravel which is sourced at least in part from rivers. While the gravel may only form part of a beach, it is usually concentrated on the upper foreshore where it protects the shore against storm waves. Depleting a beach gravel stock is a recipe for shore retreat and backshore flooding. Another good reason for preserving beach sediment stocks (and their sources) is to mitigate the effects of rising sea level, which is expected to accelerate in the coming decades and most shores are expected to erode as a consequence.

- The extent and timing of the effect of a river gravel extraction operation on gravel delivery to the coast depends on the extent that the extraction site is ‘connected’ to the coast and how far upstream it is. Only connected gravel pathways will induce coastal effects, and these effects will be more delayed and diffused over time the further upstream the extraction site is. If the site is close to the coast, even a short phase of extraction may cause a substantial albeit temporary reduction in the gravel delivery to an adjacent beach, increasing the risk that the beach backshore may experience erosion and/or flooding.

- When assessing the potential effects of any particular river gravel extraction proposal on coastal stability, two key considerations are: (i) the impact on the load delivered to the mouth; and (ii) the river load contribution to the beach sediment budget. Assessing the impact on the gravel load delivered to the river mouth should consider: the delivery of the load from the extraction site to the river mouth; the proportion of the load passing the extraction site that is intercepted by the extraction; the term of the extraction; the distance from the coast; and the cumulative effects of multiple extractions on the same river, whether current or past. Assessing if the river gravel load makes a significant contribution to the beach sediment budget is straight-forward where information on the coastal gravel budget exists, however, this is rarely the case and so geomorphic evidence is required. The last step is assessing the coastal hazard associated with any increased risk of coastal erosion due to the river gravel extraction, and extra scrutiny should automatically be given to cases where rivers discharge gravel to existing Coastal Hazard Areas.

- Beyond the guidance provided in this report, there does not appear to be any national scale guidance directed at assessing coastal effects of river gravel extraction. However, there are several case examples where river gravel extraction (or at least reduced gravel load) has been considered a contributing factor to coastal erosion.

6 References

Allis, M. (2016) Managing and adapting to coastal erosion at Granity, Ngakawau and Hector. *NIWA Client Report* HAM2016-009 prepared for West Coast Regional Council, January 2016.

DoC (2016) Department of Conservation submissions on Proposed Coastal Plan and on Proposed Regional Policy Statement Chapter 11 Natural hazards. Document supplied by West Coast Regional Council, 4 January 2017.

Fuller, I., Basher, L., Hicks, D.M. (2014) Towards understanding sediment dynamics as a basis for improving river management in the Motueka catchment, Nelson, New Zealand. *International Journal of River Basin Management*. DOI: 10.1080/15715214.2014.885437.

Environment Canterbury (2012) Canterbury Regional Gravel Management Strategy. Environment Canterbury, Christchurch.

Geotech Consulting (2000) Hurunui District Engineering Lifelines Project: Natural Hazards Assessment, Christchurch.

Gibb, J.G. (1987) A coastal hazard management plan for Hokitika. *Water & Soil Technical Publication* No. 29, Ministry of Works and Development, Wellington.

Hicks, D.M. (2003) Impacts of stone harvesting from the Houhou-Kaihinu foreshore. *NIWA Client Report* CHC2003-090 prepared for Stoneweavers Ltd, Hokitika.

Hicks, M., Dickson, M., Gorman, R. (2007) Mokihinui River Proposed Hydropower Scheme: Shoreline change around the Mokihinui River mouth, *NIWA Client Report* CHC2007-136.

Hicks, D.M., Shankar, U., McKerchar, A.I., Basher, L., Lynn, I., Page, M., Jessen, M. (2011) Suspended sediment yields from New Zealand Rivers. *Journal of Hydrology (New Zealand)* 50: 81-142.

Hicks, D.M. (2011) *Downstream effects of a large hydro-power scheme on a gravel-bed braided river and alluvial-fan coast*: Waitaki River, New Zealand. Published in Proceedings of RCEM2011: River, Coastal and Estuarine Morphodynamics, Beijing, China, September 2011.

Hicks, D.M. (2014) Stability of seawall at Punakaiki. Letter-report provided by NIWA to Michael Meehan, West Coast Regional Council, 8 September 2014.

Hicks, D.M. (2016) Rivermouth-related shore erosion at Hokitika and Neils Beach, Westland. *NIWA Client Report* CHC2016-002 prepared for West Coast Regional Council, February 2016.

NIWA (2010) River managers guide v.11.2010. An e-book compilation of river management advice, practices and examples contributed by New Zealand river managers. Available on request from NIWA, Christchurch.

NIWA (2012) Review of West Coast Region Coastal Hazard Areas. *NIWA Client Report* CHC2012-081, prepared for the West Coast Regional Council: 65 pp. Revised December 2015.

WCRC (2015) Proposed West Coast Regional Policy Statement. The West Coast Regional Council, March 2015.

WCRC (2016) Proposed West Coast Regional Plan. The West Coast Regional Council, January 2016.