Before Environment Canterbury Regional Council

In the matter of	of the Resource Management Act 1991
And	
In the matter of	the Rangitata Diversion Race Consents

Statement of Evidence of Darryl Murray Hicks for Central South Island Fish and Game Council

11 April 2018

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Qualifications and experience

1 My name is Darryl Murray Hicks.

2 I have the following qualifications: a Bachelor of Science degree with first class honours in Geology from the University of Otago, a Bachelor of Engineering degree with first class honours in Civil Engineering from the University of Canterbury, and a Ph.D. degree in Earth Science from the University of California in which I specialised in coastal and river sediment transport. I am a member of the New Zealand Hydrological Society, the New Zealand Coastal Society, the IPENZ New Zealand Rivers Group, and the American Geophysical Union.

3 I am Principal Scientist River and Coastal Geomorphology with NIWA, based in Christchurch. In this role I undertake research and consulting projects. I specialise in the measurement of sediment loads in rivers and streams and in problems relating to sediment transport and related erosion in freshwater and coastal situations. Within this field, I have written or co-authored 81 scientific publications and over 200 consulting reports. I have more than 30 years of experience with sedimentation effects in catchments undergoing hydropower-related investigations, including the Waitaki, Clutha, Waiau (Southland), Waikato, Mohaka, Mokau, Waitaha, and Kaituna catchments. I was co-author on a recent report to Ministry for the Environment that reviewed the effects of suspended and deposited fine sediment on stream biota[1].

4 My direct experience with the Rangitata River includes measurements of the sediment-trapping efficiency of the RDR sand trap, measurements of the river's suspended load during floods at the Klondyke cableway and at Arundel Bridge, and river channel surveys and 2d numerical modelling to underpin assessment of environmental flow requirements at Arundel and at Ealing downstream from State Highway 1.

5 In preparing this evidence I have reviewed:

(a) The reports and statements of evidence of other experts giving evidence relevant to my area of expertise, including:

(i) Klondyke Storage Proposal - Hydrology Assessment (July 2016).

[1] Davies-Colley, R.M., Hicks, D.M., Hughes, A., Clapcott, J., Kelly, D., Wagenhoff, A. (2015) Fine sediment effects on freshwaters, and the relationship of environmental state to sediment load – a literature review. NIWA Client Report HAM2015-104 prepared for the Ministry for the Environment, June 2015.

(ii) Klondyke Hydrology Assessment – Further Information. Memorandum from Bas Veendrick (PDP) to Murray Hicks (NIWA), dated 22 February 2018.

(iii) Proposed Fish Screen for the RDR: Assessment on Rangitata River Water Quality and Aquatic Ecology (November 2017).

(iv) Proposed Rangitata Diversion Race fishscreen and supplementary matters (November 2017).

(v) The evidence of Alasdair John Keane prepared for this hearing.

(vi) The evidence of Gregory Ian Ryder prepared for this hearing.

(vii) The Section 42A Officer's Report prepared by Natalia Ford, Canterbury Regional Council, March 2018.

(viii) Review of Resource Consent applications to take water from, and discharge sediment to, the Rangitata River. Memorandum from Adrian Meredith to Natalia Ford, Canterbury Regional Council dated 13 April 2017 and 22 February 2018.

(ix) The Joint Witness Statement of Bas Veendrick (RDRML), Alasdair Keane (Central South Island Fish and Game), Ian McIndoe (Rangitata Water Limited), and Graeme Horrell (Canterbury Regional Council) on hydrology, dated 15 March 2018.

6 I have contributed to the Joint Witness Statement of Bas Veendrick (RDRML), Murray Hicks (Central South Island Fish and Game), and Justin Cope (Canterbury Regional Council) on Sediment Transport and Geomorphology, dated 19 March 2018.

7 I have read the Code of Conduct for Expert Witnesses in the Environment Court Practice Note. This evidence has been prepared in accordance with it and I agree to comply with it. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

Scope of evidence

8 I have been asked by Central South Island Fish and Game Council to prepare evidence in relation to Rangitata Diversion Race Consents. This includes:

(a) Comment on the LOWESS approach used in Appendix C of the Hydrology Assessment.

(b) The impact of the extra 10 m^3/s water take on silt deposition in the river downstream of the RDR intake.

(c) The minimum river flow for sand trap flushing.

(d) The optimal timing of water takes during high-flow events.

(e) Comment on the evidence of Gregory Ian Ryder.

(f) Sediment effects associated with the fish bypass.

(g) Effects of flood harvesting on bedload transport and channel morphology in the Rangitata River.

Executive summary

9 My assessment of the curve fitted to the relationship between suspended sediment concentration and water discharge by PDP leads me to the view that sediment suspended in the discharge from sand trap flushing could at times be more conspicuous in the Rangitata River than anticipated by PDP. This is because of the substantial variability in the relationship between water discharge and suspended sediment concentration in the river.

10 Fine sediment deposition from flows depleted by abstractions is a process recognised in the literature and has been acknowledged in previous water diversion schemes as an effect requiring mitigation, for example by the discharge of artificial flushing flows. The extraction of more Rangitata River flow, as with the proposed additional 10 m^3/s, at conditions when the river carries significant concentrations of fine suspended sediment is expected to result in increased rates of fine sediment settling into dead zones along the Rangitata channel between the RDR intake and the sea. The river will be particularly vulnerable to this on the recessions of high flow events. The extent of this increase from the status quo is difficult to quantify, but a way to resolve this uncertainty would be to commence a monitoring programme of river substrate fine sediment content, with the facility, if need be, to adjust the flow conditions when the 10 m^3/s could be taken.

11 Taking an extra 10 m^3/s into the RDR during or immediately after a sand-trap flushing event would increase the risk of sand deposition on the riverbed near the sediment discharge point. This risk would be mitigated by raising the minimum river flow for sand trap discharge to compensate or simply by not taking the extra 10 m^3/s on the recession of an event when the sand trap was flushed.

12 My analysis of sediment concentration and turbidity data from the Rangitata River shows that the Rangitata appears to carry more suspended sediment on

falling stages. Thus, taking and flushing during rising stages, as against during falling stages, would generally provide greater flows and more time for dispersing sediment downstream, which would reduce the likelihood of fine sediment deposition in dead zones.

13 The fish bypass and screen proposed may have the beneficial effect of reducing sand entry to the sand trap. Potential effects associated with sediment discharge to the river during construction and on flow connectivity with the river during normal operations should be able to be mitigated.

14 Existing water extractions from the Rangitata River during freshes and floods result in a significant reduction in the river's gravel transport capacity, which I expect should be resulting in a gradual reduction in the average size of the riverbed surface material and lower relative relief of channels and braids. This indeed has been observed anecdotally by river paddlers. Taking another 10 m^3/s will help drive the river along its present slow course of morphological adjustment.

LOWESS approach used in Appendix C of the hydrology assessment

Introduction

15 Fish & Game have asked me to comment on the relationship fitted by PDP (2016)[2] to data on suspended sediment concentration and water discharge at the Klondyke flow recorder site. This relationship, known as a "sediment rating curve", is important because it has been used by PDP both to estimate the mean annual withdrawal rate of suspended sediment from the Rangitata River, and thence routed through the sand trap and on into the Klondyke Storage Pond (hereafter KSP), and the suspended sediment concentration in the Rangitata River at times when the sand trap will be flushed.

16 I have extensive experience with fitting such curves to river suspended sediment data, having published scientific papers and book chapters covering the topic and having run training courses on how to fit and apply such curves for regional council staff.

Comment

17 In my Figure 1 below, I reproduce the graph of this relationship from Appendix C of Pattle Delamore partners (**PDP**) Ltd (2016). The black line shows the relationship fitted by PDP using the Locally Weighted Scatterplot Smoothing (**LOWESS**) method. I have added a red circle to show the key point

[2] Pattle Delamore Partners Ltd (2016) – Klondyke Storage Proposal – Hydrology assessment. Prepared for HOBEC on behalf of Rangitata Diversion Race Ltd, July 2016.

on this curve at a discharge of 140 m^3/s, which is the approximate current discharge threshold associated with flushing the sand trap. My double-ended arrow shows the range of data-scatter about this curve, which equates approximately to a factor of three.

18 In my view, PDP have “over-fitted” the curve to the data by using too small a “stiffness” factor, which controls the “window” of data considered in the LOWESS fitting. A larger stiffness factor would have used more data-points and so would have smoothed-out the “kinks” and represented the overall trend better. However, despite this, the concentration values extracted by PDP at 140 m^3/s (410 mg/l) appears to be reasonably close to where a smoother trend would run – so I expect insignificant impact on their derived estimates of long-term average sediment take into the RDR and the proportion diverted into the KSP.

19 What is of more importance is that use of this sediment rating curve to estimate the “background” suspended sediment concentration in the Rangitata River at any time when the sand trap is being flushed takes no account of the considerable scatter shown by the data around the curve, which is quite typical of such curves and reflects variability in the supply of water and sediment to the river upstream. For example, if flushing occurs on a flood recession at a river flow just above 140 m^3/s as measured at the Klondyke flow recorder, the background concentration in the river need not be 410 mg/l as considered by PDP but could be anywhere between about 750 and 250 mg/l. In the latter case, the flushing discharge would be conspicuously muddier than the river it was entering, although this would fade in the course of several kilometres downstream as the flush discharge mixed with the river flow.

Conclusion

20 I conclude that the sand trap flushings could at times be more conspicuous in the river than anticipated by PDP.

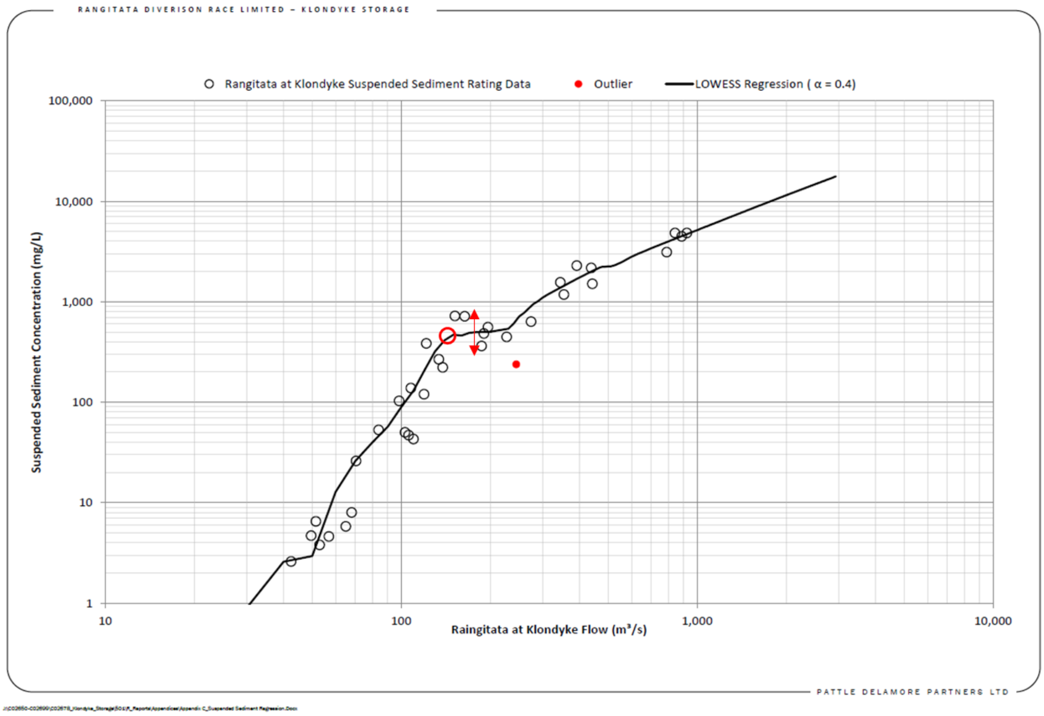

Figure 1: Suspended sediment rating curve for Rangitata River at Klondyke, developed by PDP (2016). Black line shows relationship fitted by PDP using the LOWESS method. Red circle shows key point on this curve at 140 m^3/s. Red double-ended arrow shows the range of data-scatter about this curve, equating approximately to a factor of 3. Red dot is an "outlier" data point that was not used by PDP in the curve-fitting.

Impact of additional take on silt deposition in the river downstream

Introduction

21 Fish & Game have concerns that a further 10 m^3/s water take into the RDR (potentially whenever the river flow at Klondyke exceeds 142.6 m^3/s) will lead to increased deposition of silt in the Rangitata River channel downstream of the intake point. This could arise because the same suspended sediment concentration (**SSC**) would be carried by a smaller residual flow in the river downstream of the intake, which could promote deposition. For example (using PDP's sediment rating curve, my Figure 1), if the flow at the Klondyke gauge is 142.6 m^3/s and the SSC is around 410 mg/l on average at that flow, then the existing take of 30.7 m^3/s combined with a further 10 m^3/s take would leave only 101.9 m^3/s in the river below the RDRML take but still with a SSC of 410 mg/l. Moreover, downstream of all takes from the river the same SSC would be expected at 77 m^3/s. The question is: will sediment be more likely to settle from suspension at these lower residual flows?

22 Fish & Game had similar concerns around the effects on riverbed siltation of periodically sluicing sediment from the KSP into the Rangitata River, which was in the original proposal but has since been withdrawn.

23 I explore this question using information from the Rangitata and Waitaki Rivers and reference to scientific literature. I will also comment on the view on this issue presented in the Section 42A Officer's report.

24 My experience on this issue stems from assessing the consequences of flow diversions for hydropower or irrigation on fine sediment deposition in several rivers (Waitaki, Waiau, Moawhango-Rangitikei, and Waitaha), including the needs for artificially-generated high-flows for flushing accumulated fine sediment from channels downstream of diversion points.

Literature

25 I refer first to an article written by Jowett and Milhous (2002)[3]. This noted that all natural rivers contain "dead zones" which are areas of low velocity and associated turbulence. These include pools, backwaters, areas clogged with macrophytes or algae, areas behind boulders, the interstices between cobbles, and so on. Suspended sediment diffuses into these areas, settles, and accumulates until it can be re-suspended by a subsequent high-flow event. A consequence of this settling in dead zones is that rivers carrying suspended sediment tend to get clearer downstream (unless additional sediment is added). To demonstrate this, Jowett and Milhous measured SSC along a 60-km reach of the Rangitata River. Their results (replotted here on my Figure 2) showed a trend of downstream-reducing SSC, at least until more sediment was added to the river with irrigation by-wash.

26 Jowett and Milhous concluded that if the flow in a river reduces, such as due to water withdrawal for irrigation, water velocities will be generally lower and it will take a longer time for turbid water to progress downstream, increasing the likelihood of settling in dead zones – in other words, the river bed between the intake point and the sea will be a more effective trap for fine sediment. They noted that: "*Although gravel-bed rivers have a large capacity to store sediment, gravels and other dead-zone storage could become overloaded if upstream sediment concentrations and the amount of water abstracted are high*."

[3] Jowett, Ian, Milhous, Robert (2002) Why rivers get clearer as they flow downstream. Water & atmosphere 10(1).

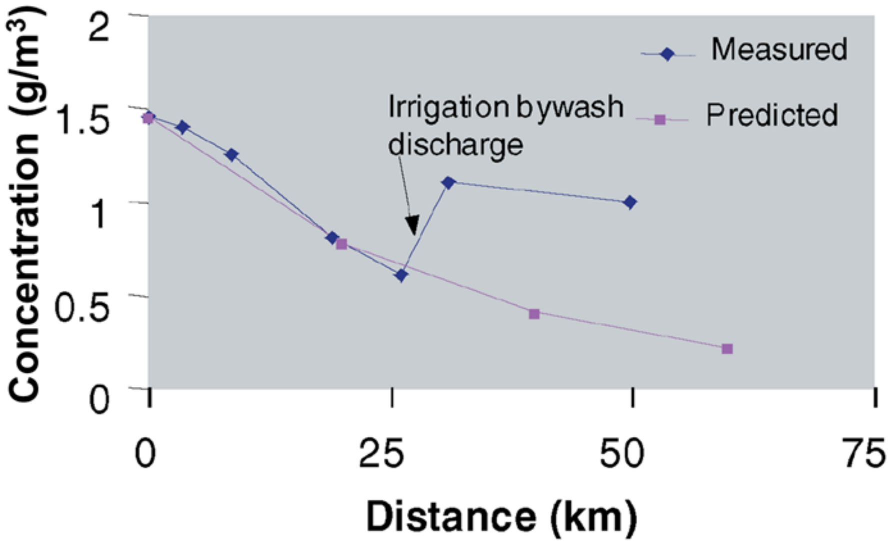

Figure 2: Plot reproduced from Jowett and Milhous (2002) showing the change in suspended sediment concentration with distance down the Rangitata River, as measured in April 2001 and as predicted by them using a theoretical model. Note the downstream decline in concentration until the addition of more turbid water from irrigation by-wash. Although not make clear by Jowett and Milhous, I infer that their zero distance corresponds to the Gorge near Klondyke.

27 Extensive observations were made of fine sediment deposition in the Lower Waitaki River bed by several investigators in the early 1980's around the effects of hydropower development. These included Jowett (1983)[4] and Graham (1985)[5]. Jowett noted that about one third of the wetted Lower Waitaki river bed was coated with silt and clay to varying degrees, focussed in low velocity areas such as pools and backwaters. Graham noted how glacial silt, which passes through both the hydro-lakes and the natural lakes in the upper Waitaki, also accumulated in the periphyton on stones in riffles. Further work in the early 2000s around the proposed Project Aqua hydropower development, which proposed to remove up to 340 m^3/s from the river so leaving residual flows in the range 100-140 m^3/s for much of the time, identified that at flows less than 300 m^3/s the Lower Waitaki River bed became a net "trapper" of fine sediment, as deposition in low-velocity zones prevailed over sediment re-entrainment from bed and bank scour, therefore the project would require regular artificial flushing

[4] Jowett, I.G. (1983) Siltation of the Lower Waitaki River bed. Unpublished report, Power Division, Ministry of Works and Development, Wellington.

[5] Graham, A. (1985) Siltation and the Lower Waitaki ecosystem. A discussion paper for the Lower Waitaki Fisheries Study Group, Fisheries Research Division, Oamaru.

flows to mitigate against fine-sediment build-up (NIWA 1983a[6], NIWA 1983b[7]). Thus, the effects of flow removal on fine sediment deposition on the Lower Waitaki River were acknowledged and planned for with Project Aqua, and indeed also in subsequent Lower Waitaki developments, including the North Bank Tunnel Concept and the Hunter Downs Irrigation Scheme.

28 An informative scientific publication is that of Baker et alia (2011)[8], who investigated the effects of variable levels of flow diversion on fine-sediment deposition, hydraulic conditions and geomorphic alteration downstream of water diversion structures in 13 streams of the Rocky Mountains in the United States. These were gravel or cobble-bed streams, and they considered fine sediment to be all grades finer than 2 mm in grain diameter. Their method included making detailed measurements of the aerial extent of fine sediment on the bed surface as well as fine sediment infilling of the cobbly substrate at paired reaches upstream and downstream of the diversion structures. They found that the reaches downstream of the diversions contained significantly more fine sediment and slow-flowing habitat as compared to the upstream control reaches.

Conclusion

29 So, from the above, the answer to my question posed in paragraph 20 is that extraction of more Rangitata River flow (such as the proposed additional 10 m^3/s) at conditions when the river carries significant concentrations of fine suspended sediment is indeed expected to result in increased rates of fine sediment settling into dead zones. The river will be particularly vulnerable to this on the recessions of high flow events, when the SSC remains elevated. I note that the Rangitata River provides reasonably frequent floods and freshes to re-mobilise deposited fine sediment, so any ecological effects from deposited sediment are liable to accrue between such events.

30 While some increase in downstream fine sediment deposition is therefore expected as a result of the 10 m^3/s water take, the extent of this increase from the status quo is difficult to quantify. One way to resolve this uncertainty would be to commence a monitoring programme that periodically measured the fine sediment content of the Rangitata River bed downstream from the intake, using

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[6] NIWA, 2003a. Project Aqua: environmental study – aquatic ecosystems: physical and chemical water quality.

[7] NIWA, 2003b. Project Aqua: Lower Waitaki River geomorphology and sediment transport.

[8] Baker, D.W., Bledsoe, B.P., Albano, C.M., Poff, N.L. (2011) Downstream effects of diversion dams on sediment and hydraulic conditions on Rocky Mountain Streams. River Research & Applications, 27: 388–401.

techniques described in Clapcott et alia (2011)[9]. Guidelines on permissible extents of fine sediment cover on cobbly substrate are also included in Clapcott et alia (2011). If significant deposition was observed, then an “adaptive management” option could be to adjust the flow conditions when the 10 m^3/s could be taken. An example would be a “flow sharing” scheme where only part of the 10 m^3/s was taken until a larger discharge threshold was exceeded. Such a scheme would be more effective at mitigating fine sediment deposition when applied on flow recessions.

Minimum flow for sand trap flushing

31 The existing consent for discharge of sediment from the sand trap requires that this occurs at a minimum flow of 140 m^3/s as measured at Klondyke. The potential physical effects of this discharge of sediment – which is largely sand grade (that is between 0.063 mm and 1 mm grain diameter) but also includes some mud grade sediment – are reduced water clarity (and more conspicuous water discolouring) and fine sediment deposition in low velocity zones downstream from the discharge point. Fish & Game has asked me to consider whether increasing the minimum flow for sand trap discharges would mitigate these potential effects.

32 Following the lines of argument that I developed in the previous section, the extent of these effects will depend on the residual river discharge below the sediment discharge point (that is, the discharge at Klondyke minus the net take into the RDR). I note that dispersion of the discharged sediment down the river will continue after the actual sand-trap flushing ceases, so it is important to consider the size of the residual river flow after its augmentation by water returned with the flushing has ceased.

33 In regard to sand deposition, the lower the residual river discharge, the more likely that measurable sand deposits will accumulate on the river bed close to the discharge point, as against the sand being dispersed over a longer length of river with a higher river discharge. I note that such deposits would be reworked and dispersed by subsequent freshes and floods, so they would be transient rather than permanent. I note also that the sand deposition effects would be concentrated within a reach no more than about ten kilometres downstream from the discharge point, so the effect of water takes further downstream, such as at Arundel, would not be significant.

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[9] Clapcott, J.E., Young, R.G., Harding, J.S., Matthaei, C.D., Quinn, J.M., Death, R.G. (2011) Sediment Assessment Methods: Protocols and guidelines for assessing the effects of deposited fine sediment on in-stream values. Nelson, New Zealand, Cawthron Institute.

34 Following the argument from my paragraph 21, taking an extra 10 m^3/s into the RDR during or immediately after a sand-trap flushing event would therefore increase the risk of sand deposition. This risk would be mitigated by raising the minimum river flow for sand trap discharge to compensate. Since Fish & Game have advised me that they consider that the 140 m^3/s limit under the status quo has not appeared to produce adverse sedimentation effects, then this state would be preserved by increasing the sand trap flushing limit to 150 m^3/s should the 10 m^3/s take be consented. An alternative mitigation would be to not take the extra 10 m^3/s on the recession of an event when the sand trap was flushed.

35 I do not envisage any significant change from the status quo in regard to effects of sand trap flushing on water clarity and discolouration. This is because (a) water clarity and colour are mainly affected by suspended mud-grade sediment rather than by sand, and (b) water takes into the RDR will not alter the mud concentration in the residual river flow at the discharge point. I do note, however, that because of the considerable natural variability of the river's suspended sediment concentration (as discussed in Paragraph 19), the visual signature of the sand trap flushing will be more conspicuous from time to time than anticipated by RDR Limited from considering the average concentration off the sediment rating curve. Increasing the minimum river flow for sand trap flushing would reduce this visual signature because the flushing would discharge into river water that carried a higher suspended mud concentration.

Optimal timing of water take and flushing during high-flow events

36 Fish & Game have asked my view of whether sediment effects relating to water takes into the RDR and flushing from the sand trap would be lessened if the extra takes and flushing activities were focussed on falling stages of high flow events. The reasoning behind this is that they expect that SSC in the Rangitata River might be generally lower at the same discharges on falling stages compared to rising stages – which, in my experience, is a common trait of many rivers but certainly not all rivers.

37 I have explored whether SSC is lower on Rangitata River recessions from two lines of evidence: the dataset of measured SSCs shown in Figure 1, and records of turbidity from the Rangitata River. I have analysed such datasets from several hundred New Zealand rivers.

38 With regard to the data shown in Figure 1, I have identified whether the measurements were made on rising or falling stages. These are identified on Figure 3. This shows that while most of the measurements were made during falling stages, the few rising-stage data points plot in the same "space" as the falling stage points. So, there is no evidence in these data of any significant and

systematic difference between rising- and falling-stage concentrations in the Rangitata River.

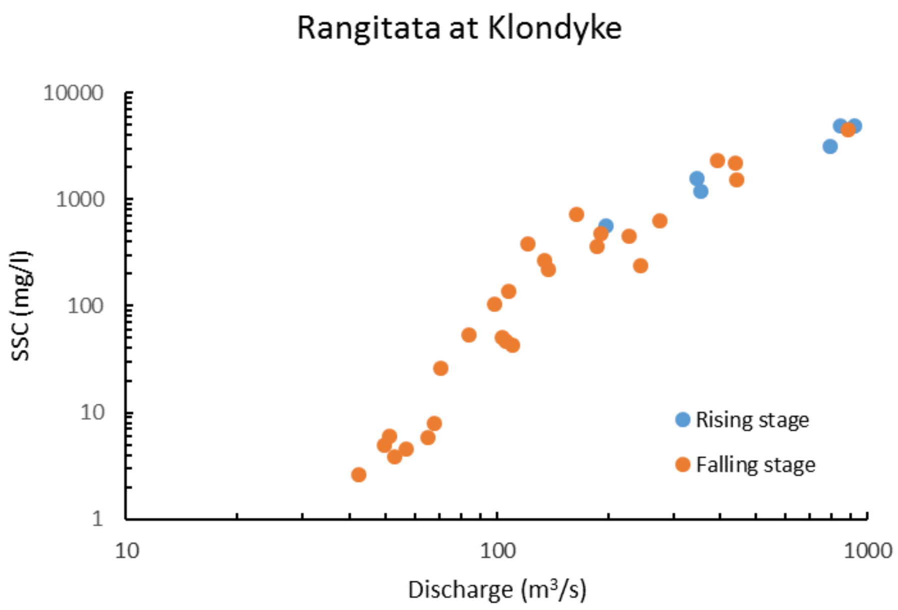

Figure 3: Relationship between suspended sediment concentration (**SSC**) and water discharge for Rangitata River at Klondyke, with rising-stage and falling-stage data distinguished.

39 The second line of evidence stems from a record of turbidity collected from the Rangitata River near the RDR over the period 16 October 1998 through 30 April 1999. Although provided to me by Fish & Game, my understanding is that this record was collected by the RDR Management Ltd. From my experience deploying turbidity sensors on many rivers, it is reasonable to assume an approximately linear relationship between turbidity and SSC, thus turbidity may be treated as a proxy for SSC.

40 I have examined the phasing of turbidity and water discharge over high flow events captured by this turbidity dataset. I show in Figure 4 three freshes over the period 22 March to 14 April 1999 for which the data appear reliable. The top plot shows the “hydrographs” for discharge and turbidity. The lower plot traces the relationship between turbidity and discharge through each event. The dashed arrowed curves show the direction of time progression through each event. In all three events the trace follows an anti-clockwise “loop”, showing that turbidity values were lower on rising stages compared to falling stages.

41 Thus, I see no evidence that the Rangitata tends to carry less suspended sediment on falling stages – indeed, if anything it carries more. On that basis, I conclude that restricting water takes and sand trap flushes to falling stages would not mitigate the risk of fine sediment deposition in dead zones downstream. In contrast, flushing and taking water only during rising stages would mitigate this risk by providing more competent flows and more time for dispersing the flushed sediment and residual river sediment downstream during recessions.

42 I note that this conclusion around optimal phasing of water takes and flushes relates only to the risk of downstream fine sediment deposition and does not consider other effects.

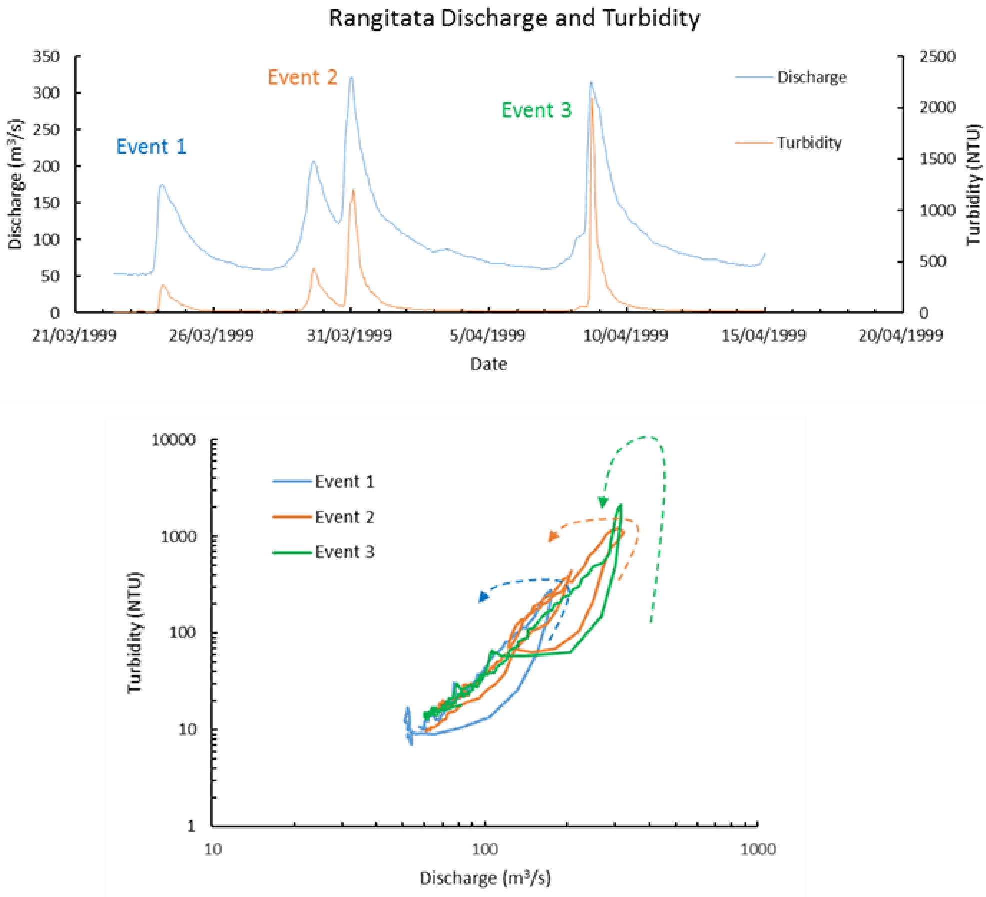

Figure 4: Discharge and turbidity in Rangitata River at Klondyke during three freshes in March-April 1999. Lower plot traces the relationship between turbidity and discharge through each event. Dashed arrowed curves show the direction of time progression.

Comment on evidence of Gregory Ian Ryder

43 Fish & Game have asked that I comment on the evidence of Dr Gregory Ian Ryder in his paragraphs 135 to 136 where he responds to issues raised in submissions around the effects of the extra 10 m^3/s take on fisheries and other ecosystem components. He concludes that this will have no effect because, since the 10 m^3/s will be taken when the river flow is high, it won't influence river processes that influence river ecosystems. In his response he cites braid-formation, scour, and sediment transport as example processes, but does not mention fine sediment deposition, which is a key process at issue. I note he does consider fine sediment deposition in his paragraph 39, where he considers, based on his opinion, that it would not be a significant consequence, particularly for benthic invertebrates.

44 In his paragraph 136, Ryder concludes that the RDR water takes are "*highly unlikely to alter the downstream water clarity based on existing monitoring data and the likely relationship between flow and clarity*". This conclusion is based firstly off his Figure 7, which shows downstream variations in water clarity measured near-concurrently by ECan at three Rangitata River sites (Arundel, SH1 bridge, and the river mouth) in relation to the discharge recorded at Klondyke. He notes "*flows around 140 m^3/s (at Klondyke) or higher do not result in significant changes in downstream river clarity, and there is no indication of a reduction in clarity with distance downstream despite abstraction occurring at least via the RDR intake*". I have several comments regarding this:

(a) Actually, what is of greater interest is whether water clarity shows a trend to <u>increase</u> downstream, associated with a trend for reducing suspended sediment concentration (**SSC**), since this is what is anticipated to occur due to progressive downstream settling of sediment from the suspended load in low velocity dead zones.

(b) On Ryder's Figure 7, there are only two sets of measurements when the discharge exceeded 140 m^3/s: on 4/11/2014 at a discharge of approximately 145 m^3/s, no consistent downstream trend was indicated; however, on 6/5/2015 at a discharge of 220 m^3/s, there was a consistent trend for increasing clarity downstream. It should be appreciated that clarity is inversely related to SSC, so on 6/5/2015 the approximately 20% increase in clarity between Arundel and the river mouth (that is from 0.8 m to 1.0 m) equates to a 20% reduction in SSC – which suggests that about 20% of the suspended sediment load was deposited onto the channel bed along the intervening reach.

(c) At discharges less than 140 m^3/s, Ryder's Figure 7 shows that four out of eight sets of measurements show a trend for increasing clarity downstream (3/5/2016, 7/4/2014, 13/11/2013, and 1/8/2013).

(d) The Arundel site is around 25 km downstream from the RDR, so I would expect to see the greater signature of effects of the RDR in this intervening reach, less so between Arundel and the coast. In other words, the ECan dataset shown in not ideal for assessing RDR effects because it lacks any measurement between the RDR intake and Arundel.

(e) Caution should be assigned to the data on Ryder's Figure 7 because it is not clear what sequence the "concurrent" measurements were made – for example, if the measurements were made going upstream from the mouth on a recession when the SSC was declining with time (and clarity was increasing), then the temporal trend could confuse the apparent spatial one.

(f) A further caution is that water clarity is influenced mainly by the finest grades of sediment in suspension (in the fine silt and clay grades, finer than 8 microns), which are the grades least likely to settle from suspension in dead zones. Thus, examination of water clarity downstream trends for evidence of suspended sediment deposition is likely to mute the true sediment deposition signal.

45 Based on the above points, I disagree with Ryder's conclusions drawn from his Figure 7. If anything, this figure contains evidence that RDR water takes may well be having a significant impact on spatial water clarity trends downstream and the underpinning deposition of fine sediment from the river's suspended load. However, I caution that the dataset behind Ryder's Figure 7 is not ideal for this purpose, particularly because of the lack of data near the RDR intake. Collecting such data there in association with a regular water quality monitoring network containing multiple stations downstream (such as ECan's) would be an informative consent condition.

46 The second part of Ryder's conclusion in his paragraph 136 (that is "*and the likely relationship between flow and clarity*") is based off his Figure 8 which shows modelled flows and water clarity in the river downstream of the RDR intake during example average, wet, and dry years for the cases of the existing take and with the proposed additional 10 m^3/s take. Ryder concludes that the water takes "*are highly unlikely to alter the downstream water clarity*". I have no issues with his modelled flows but I have several comments regarding the modelled water clarity:

(a) Water clarity appears to have been "modelled" off a power-law regression fit to ECan's water clarity measurements at Arundel and time-matched flows at Klondyke. I note that this regression model is shown in the lower plot in Figure 3 of his evidence, not in his Figures 4 and 5 as referenced in the captions to his Figures 8 a, b, and c.

(b) With an exponent of -2.818, this regression relation shows a high-sensitivity of water clarity to discharge. For example, reducing the water discharge by a factor of 0.71 from 140 m^3/s to 100 m^3/s results in water clarity increasing from 0.14 m to 0.35 m. While these water clarity numbers may be small in an absolute sense, they show water clarity increasing by a factor of 2.58, and, by inference, SSC reducing by around a factor of 2.58. Even reducing the water discharge from 140 m^3/s to 130 m^3/s would increase the water clarity by a factor of 1.23 (that is, by 23%) and so would reduce the SSC by 23%. Thus, if the regression model is to be applied and interpreted in the way it has been by Ryder, then significant fine sediment deposition should be anticipated downstream of the RDR intake to accommodate the increased clarity, even for a take of 10 m^3/s from a river discharge of 140 m^3/s.

(c) However, I note some cautions. Firstly, despite the apparently good visual fit of the trendline to the data on the lower plot of Ryder's Figure 3, there is considerable data scatter. For example, at a discharge of 70 m^3/s where the predicted clarity is about 1 m, the clarity data scatter ranges between 0.2 m and 3.9 m, indicating a factorial range of almost 20. At higher discharges, the relative scatter is less apparent simply because the clarity values are all small. This substantial uncertainty in predicted water clarity is not captured in the plots in Ryder's Figure 8.

(d) Secondly, in my view, it is not appropriate to use this empirical relation to predict water clarity in the river after reducing the discharge due to a water take. Doing so presumes that the water discharge reduction must reduce the capacity of the residual discharge to maintain a suspension – but the scatter of the data (which shows a very wide variation in clarity at a given discharge) indicates otherwise.

47 I conclude that the data shown in Ryder's Figure 8, when audited back to the regression model used to predict water clarity off discharge, technically do not support Ryder's conclusion that the water takes "*are highly unlikely to alter the downstream water clarity*". Indeed, the data suggest the opposite, implying the likelihood of fine sediment deposition even with an additional take of only 10 m^3/s. However, I don't read much into this because of the underlying uncertainty in the clarity discharge relationship and its questionable application in this instance.

Sediment effects associated with the fish bypass

48 Fish & Game have asked my view on any sediment issues relating to the fish screen. I have no experience with the performance of fish screens in sediment-carrying channels, so I can only offer the following general comments:

(a) The 2 mm mesh size of the screens and the geometry of their deployment indicates that they will not be totally efficient at passing sand, thus I would expect sand to settle at the toe of the screens and be flushed back to the river with the fish. This should lessen the amount of sand continuing into the sand trap and thus the amount of sand needing to be periodically flushed out of the sand trap. It is my view that continual return of sand to the river in this fashion at the fish screen is preferable to it being returned to the river in periodic large lumps from the sand trap. Thus, the fish screen may provide the additional service of being a partial sand screen. I note that Dr Adrian Meredith shares this view in his contribution to the Section 42A Officer's Report.

(b) It is possible that sand and fine gravel discharged directly to the river at the fish screen may form a transient fan-delta at the discharge-point – which could hinder fish connection with the main river channel. Such local deposits would likely be removed by floods and freshes. However, another effect of a flood may be to shift the main river flow away from the discharge point and deposit a gravel bar at the discharge point, which again could hinder connectivity for fish. Both of these situations could be mitigated by regular inspection of the discharge point, with machinery used to improve connectivity with the river flow as need be.

(c) The return to the river of a portion of its suspended load (with 3-5 m^3/s) will induce only a very small change in the suspended load and its concentration in the river downstream of the return point. Basically, what will happen is that 5 m^3/s of muddy water will bypass the river for 1.5 km then return to it.

(d) The 3-5 m^3/s diversion for the fish bypassing will have a small additional effect on the bedload transport capacity of the bypassed 1.5 km of Rangitata River channel (that is, additional to the effect of the permanent 40.7 m^3/s diversion down the RDR). As I discuss below, this may contribute to some fine gravel deposition in the bypassed reach of river. The incremental effect would be small, but it would add to the cumulative effect of all abstractions. There would be no effect downstream from the fish screen discharge point.

(e) It would appear that the discharge of sediment to the river during fish-screen construction should be largely mitigated by building the new screening device in the dry in a new elbow of the RDR. The commissioning of this will generate some sediment, but the impact of that should be minimised by commissioning it during a high river flow event.

49 My conclusion is that the fish screen proposed may have the beneficial effect of reducing sand entry to the sand trap, while potential effects associated sediment discharge to the river during construction and operation are able to be mitigated.

Effects on bedload transport and channel morphology in the Rangitata River

Introduction

50 The "flood harvesting" (that is, the diversion of river flow during high-flow events) being proposed will have consequences for the Rangitata River channel downstream of the RDR intake.

51 PDP (2018)[10] have calculated that the gravelly bedload transport capacity of the river in the Arundel area under the natural flow regime and after water extraction, and I accept that their calculations have been undertaken with an adequate approach. Their results show that under the natural river flow regime the bedload transport capacity would average about 109,700 tonnes per year. After allowing for all existing consented extractions, this bedload transport capacity would reduce by 14.1% to 94,200 tonnes per year, while the additional proposed RDR take of 10 m^3/s would reduce this another 2.3% to 91,700 tonnes per year – a cumulative reduction in transport capacity from the natural regime of 16.4%. While the effect of the extra 10 m^3/s take might be viewed as having little significance because of the marginal change from the status quo, Fish & Game have asked whether this effect should be viewed in the context of cumulative effects of all takes, particularly if the extra 10 m^3/s may push the river over some morphological threshold – in other words, could it be the proverbial "straw that breaks the camel's back"?

52 I have assessed this question based on my understanding of how gravel-bed rivers respond to reductions in their bedload transport capacity as informed by the scientific literature, computer modelling, and data from other rivers similar to the Rangitata. This is well within my field of expertise: I have considerable experience on this topic, having been involved with scientific publications and numerical modelling of gravel-bed and braided rivers and having undertaken technical investigations and provided expert evidence around the effects of flow

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[10] Memorandum of 20/2/2018 from Bas Veendrick, PDP, to Murray Hicks, NIWA, re Klondyke Hydrology assessment – Further Information.

diversions associate with hydro-power schemes (notably the Waiau River in Southland and the Lower Waitaki River).

Theoretical expectations

53 From a theoretical perspective, important concepts are those of bedload supply and transport capacity. In river systems like the Rangitata, most of the bedload moved is in the gravel grades (finer than 64 mm grain diameter), even where the channel bed surface may be dominated by boulders that rarely if ever move. Thus, it is the supply of the gravel phase from upstream versus the capacity of the river flow to move it through any particular reach that is of primary concern.

54 River reaches that are “supply limited” have (by virtue of their flow, gradient, and channel shape) more than enough capacity to transport the gravel supplied from upstream. They are typically gorges or semi-confined, single-channel or semi-braided reaches, with channels of relatively high local relief, and with bed surfaces comprising a mixture of rarely mobilised bouldery bed material and patches of the mobile gravel phase which is moved typically under “partial transport” conditions – that is, conditions when the flow is competent to entrain only the finer fractions available on the bed surface. Example reaches are the Rangitata Gorge and the semi-braided reach from there downstream past the RDR intake to around the location of the proposed KSP.

55 In contrast, “capacity limited” reaches are those that have no surplus gravel bedload transport capacity, and these typically show a bed surface dominated by the finer, mobile gravel phase, are wider and braided with channels of low relative relief, and they may possibly be aggrading (that is, their bed level is rising over time because of gravel deposition). An example reach is the braided reach upstream of the Rangitata Gorge.

56 In a supply limited reach, an imposed reduction in bedload transport capacity (for example due to flood harvesting) results in an adjustment involving greater accumulation of the mobile gravel phase on the bed, and associated changes in channel morphology. The adjustment ceases when the increased availability of gravel on the bed surface compensates for the reduced transport capacity. If the reduction in transport capacity is great enough, the reach may become a capacity limited reach wherein no further textural adjustment is possible. In that case, further flow-induced reductions in transport capacity will lead to ongoing gravel deposition - until the gradient of the aggraded reach is adequate to recover a balance between gravel supply and transport capacity.

57 I note that such changes as described above may require decades to develop, since the rate of adjustment is controlled by the supply rate of gravel and the occurrence of high-flow events to move it.

58 A common misconception is that reductions in the bedload transport capacity of a supply-limited reach will have no morphological effect. As explained above, this is not the case. The misconception is a legacy of the time when the only conceived morphological adjustment was a change in channel gradient promoted by deposition when the bedload supply exceeded the transport capacity. This misconception underpins the argument promoted by Pattle Delamore Partners Ltd (2018), based on the thesis of Healey (1997)[11], that the existing and proposed RDR abstraction should have no geomorphic effects downstream of the intake.

59 It is my view that the Rangitata River channel downstream from the RDR intake, at least as far downstream as the wider, full-braided section starts around Peel Forest, is a supply-limited reach that should be experiencing the type of adjustment described above due to irrigation water withdrawal during high flow events.

Supporting evidence

60 An important scientific study indicating the impacts of flood harvesting on river morphology was published by Parker et alia in 2003[12]. They used a laboratory flume experiment scaled to represent natural gravel-bed rivers. The flume was supplied with a mixture of sediment sizes (with sand representing mobile river gravel and pea-sized gravel representing cobbles), and a flood hydrograph was continuously cycled until an equilibrium channel morphology evolved. The hydrograph was then progressively depleted to simulate increasing amounts of water extraction, and the new equilibrium channel morphologies and bed-surface grainsizes were measured. Parker et alia wrote that *"The experiments indicated an increase in sand content on the bed surface and a decrease in the standard deviation of fluctuations in bed elevation with increasing severity of floodwater extraction."* Scaled back up to the prototype rivers, these results predicted that increasing flood harvesting should increase the proportion of the riverbed surface composed of the mobile gravel phase and should reduce the size of local elevation differences between bar tops and channel beds.

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[11] Healey, M.O. (1997) Investigation of flood risk and erosion mitigation on the Rangitata River. A dissertation submitted in partial fulfilment of the requirements for the degree of Master of Engineering (Natural Resources) at Lincoln University.

[12] Parker, G., Toro-Escobar, C.M., Beck, S. (2003) Effect of floodwater extraction on mountain stream morphology. Journal of Hydraulic Engineering 129: 885-895.

61 While I have no river survey data on-hand from the Rangitata River, data collected from the Waimakariri River where it crosses the Canterbury Plains supports this style of response to changes in gravel transport capacity. On Figure 4, the blue line shows the cross-section surveyed by Environment Canterbury at Halkett, 32.18 km upstream from the coast. The Halkett reach of the Waimakariri is known from previous surveys to be degrading – that is, cutting down because it has greater gravel transport capacity than is being supplied from upstream - hence it is a supply limited reach. The orange line is a cross-section surveyed at Crossbank, 15.6 km downstream from Halkett and 16.6 km from the coast. At Crossbank, the Waimakariri River's gradient and so also its transport capacity are less than at Halkett, and gravel is depositing (and being removed by gravel extractors) – hence it is a capacity limited reach. Notice that the local relief of the braided channel topography at Crossbank, as indexed by its standard deviation (equal to 0.46 m), is less than half that at Halkett (standard deviation equals 1.08 m). This supports my theoretical discussion given above.

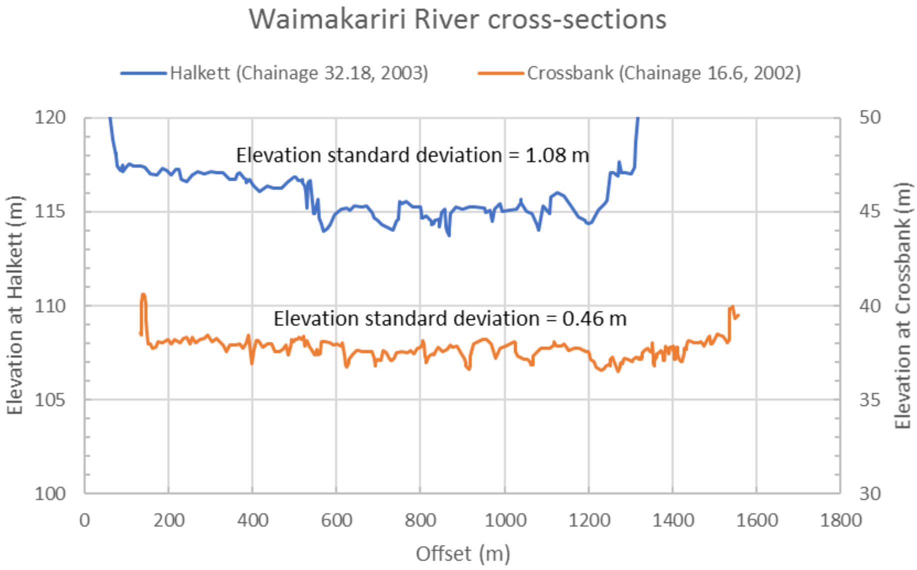

Figure 4: Cross-sections of the Waimakariri River bed surveyed at Halkett (32.18 km upstream from the coast) in 2003 and at Crossbank (16.6 km upstream from the coast) by Environment Canterbury. The Halkett section is degrading, while the Crossbank section is aggrading and has a lower standard deviation of its riverbed elevation.

62 Lastly, I note a conversation I had on 20 February 2018 with Dr Doug Rankin, a long-time recreational paddler of the Rangitata River and member of Whitewater NZ. He noted that he and other paddlers have observed a gradual change in the morphological character of the Rangitata channel in the reach

downstream from Klondyke over recent decades. The changes include the riverbed now being: wider, more even in its topography, more gravelly and less armoured, with fewer narrow deep braids, and with pools becoming shallower and tending to be more infilled with gravel. Unfortunately, Dr Rankin had no "hard" evidence such as repeat surveys or photographs to underpin these observations, but they are exactly the changes that I would expect to observe in a reach adjusting to a reduced bedload transport capacity.

Conclusion

63 I conclude that the existing floodwater extraction from the Rangitata River results in a significant reduction in the river's gravel transport capacity, and I expect that this should be resulting in a gradual reduction in the average size of the riverbed surface material and lower relative relief of channels and braids – indeed, as observed by Dr Rankin and his paddling colleagues. While I do not expect that the relatively small additional reduction in transport capacity associated with the 10 m^3/s take will be enough to result in some morphological threshold being exceeded - in the sense of a change in morphological type - it will, nonetheless, help drive the river along its present slow course of morphological adjustment involving a reduction in the average size of gravel on the river bed surface and lower relative relief of channels and braids. Moreover, this morphological adjustment may lead to some "tipping point" in its value to river users such as paddlers.

Monitoring recommendations

64 I recommend that this morphological effect be recognised and monitored by adding a consent condition that requires periodic (I suggest five-yearly) surveying of river channel cross-sections, a riverbed long-profile, and surface bed-material grading – at least as far downstream as Arundel. This information would inform on future consenting and particularly any future Regional Plan change that seeks to manage the cumulative effects on river morphology of multiple small water harvesting operations.

65 Should the monitoring confirm a river morphological response (and it would likely require several repeat surveys over one to two decades to confirm a trend), then the extent to which the changes are considered adverse and requiring mitigation will depend on criteria established by affected parties. For example, river paddlers or jet-boaters may define limits to average water depth over riffles at a given discharge, or fishers could provide limits on the extent of pool-infilling by gravel.

66 Should monitoring show such limits being exceeded, then reversing the trend would require a reduction in water take from floods and freshes, and even then, the morphological recovery would lag in time. I note that a "flow sharing" system

would be unlikely to increase the bedload capacity unless it also involved a reduction in total water take during floods and freshes.

Conclusions

67 My main conclusions are:

(a) Sediment suspended in the discharge from sand trap flushings could at times be more conspicuous in the Rangitata River than anticipated by PDP. This is because of the substantial variability in the relationship between water discharge and suspended sediment concentration in the river.

(b) Extraction of more Rangitata River flow, as with the proposed additional 10 m^3/s, at conditions when the river carries significant concentrations of fine suspended sediment is expected to result in increased rates of fine sediment settling into dead zones along the Rangitata channel between the RDR intake and the sea. The river will be particularly vulnerable to this on the recessions of high flow events. The extent of this increase from the status quo is difficult to quantify. A way to resolve this uncertainty would be to commence a monitoring programme of river substrate fine sediment content, with the facility, if need be, to adjust the flow conditions when the 10 m^3/s could be taken.

(c) Taking an extra 10 m^3/s into the RDR during or immediately after a sand-trap flushing event would increase the risk of sand deposition on the riverbed near the sand discharge point. This risk would be mitigated by raising the minimum river flow for sand trap discharge to compensate or simply by not taking the extra 10 m^3/s on the recession of an event when the sand trap was flushed. I do not envisage any significant change from the status quo in regard to effects of sand trap flushing on river water clarity and discolouration.

(d) The fish screen proposed may have the beneficial effect of reducing sand entry to the sand trap, while potential effects associated sediment discharge to the river during construction and operation of the fish screen should be able to be mitigated.

(e) If anything, the Rangitata appears to carry more suspended sediment on falling stages, thus restricting water takes and flushes to falling stages would be unlikely to reduce any effects on fine sediment deposition in dead zones downstream. Conversely, taking and flushing during rising stages would provide greater flows and more time for dispersing sediment downstream, which would reduce the likelihood of fine sediment deposition in dead zones.

(f) Existing water abstractions from the Rangitata River during freshes and floods result in a significant reduction in the river's gravel transport capacity, which I expect should be resulting in a gradual reduction in the average size of the riverbed surface material and lower relative relief of channels and braids, as has been observed anecdotally by river paddlers. Taking another 10 m^3/s would add to the cumulative effect of these existing takes.

68 My recommendations for monitoring, should the consents be approved, are:

(a) Periodic surveys of channel morphology and bed-material size-grading downstream of the RDR intake to record the morphological change anticipated with flood harvesting.

(b) Monitoring fine sediment deposition in low energy environments downstream of the RDR intake.

(c) The connectivity of the proposed fish bypass channel with the Rangitata main channel at the discharge point.

69 Should the above monitoring show changes that have significant adverse consequences for the river environment or river users, then an adaptive management response would be required. For example, for (a), (b), and (c) above respectively: reducing the frequency of flood-harvesting, altering the timing of sand trap flushing, and use of earth-moving machinery to improve fish bypass connection with the main channel.

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11 April 2018

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