IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of applications for resource consent by the Central Plains Water Trust and a notice of requirement for the designation of land by Central Plains Water Limited associated with the construction and operation of the Central Plains Water Scheme

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STATEMENT OF EVIDENCE OF TIMOTHY REGINALD HOWARD DAVIES ON BEHALF OF THE NORTH CANTERBURY FISH AND GAME COUNCIL AND THE DIRECTOR GENERAL OF CONSERVATION

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1. INTRODUCTION

Qualifications and Experience

1.1 My full name is Timothy Reginald Howard Davies. I am presently employed as an Associate Professor in Engineering Geology at the University of Canterbury. I hold the degrees of Bachelor of Science with Honours (Civil Engineering), Master of Science (Irrigation and Land Drainage) and PhD (Civil Engineering), all from Southampton University, UK.

1.2 I was, for 20 years prior to 2003, an Associate Member of the Institution of Professional Engineers (New Zealand), and have since 1975 been a member of the New Zealand Hydrological Society.

1.3 I have held academic positions in Civil Engineering (UK, 5 years), Natural Resources Engineering (Lincoln University, 28 years) and since 2003 in Geological Sciences (University of Canterbury). From 1999 to 2003 I held a Personal Chair in Natural Resources Engineering at Lincoln University.

1.4 I have been actively engaged in teaching, research and postgraduate supervision in the field of braided gravel-bed rivers for the last 32 years. On this topic I have published 27 research papers in refereed international journals; written 11 book chapters; and completed 28 consultancies, both within New Zealand and overseas.

1.5 I confirm that I have read and agree to comply with the Code of Conduct for Expert Witnesses (Environment Court Consolidated Practice Note 2006). This evidence is within my area of expertise, except where I state that I am relying on facts or information provided by another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

2. SCOPE OF EVIDENCE

2.1 My evidence first addresses the written evidence of Mr Mark Mabin, related to the effects on the Waimakariri and Rakaia Rivers of proposed abstractions for the Central Plains Water (CPW) Scheme.

2.2 I then present the results of an analysis I have undertaken to quantify these effects for one proposed abstraction regime (CPW 20-40-220) and one intake site (Upper Waimakariri) on the Waimakariri River. This is based on the methodology I developed for the same purpose at the Rakaia River Water Conservation Order Hearing in the 1980s. It is referred to in the AEE (URS, 2005), but it appears that the analysis has not been carried out by the Applicant in relation to proposed abstractions.

2.3 Finally I describe the likely long-term effects of this particular water abstraction on the Waimakariri River.

2.4 The intent of my evidence is to demonstrate that techniques are available to quantify the effects of water abstraction on the morphology of the Waimakariri and Rakaia Rivers, and that the likely effects are such as to require further analysis. As stated above, due to time and resource constraints, and in the absence of any assessment of these effects by the Applicant, I have only one abstraction regime for one intake site. I consider that analysis of the effects I consider should have been provided by the Applicant.

3. SUMMARY OF FINDINGS

3.1 I do not agree with the evidence of Mr Mark Mabin, that the presence of a coarse surface armour layer indicates that a gravel-bed river is undersupplied with bedload sediment. Having regard to the flow behaviour of the Waimakariri and Rakaia Rivers, under low-flow conditions all gravel-bed rivers, including those that are in the process of active aggradation, show such an armour layer. This is caused by declining flow during the recession limb of a flood. An armoured bed is an indication of undersupply only when it is present on the bed surface during active bedload transport. The bed surface in Waimakariri and Rakaia Rivers is unable to be seen under these conditions because it hidden by some depth of sediment-laden water.

3.2 The proposed CPW water abstraction regime investigated here (CPW 20-40-220) will reduce the bedload transport capacity of the Waimakariri River by about 10 - 20%, depending on the flow rate at which bedload is assumed to start moving. This is equivalent to about 20 000 – 40 000 m^3 per year based on the URS (2005) estimates of total annual bedload transport. This quantity of sediment will accumulate in the vicinity of the offtake every year, causing the bed level there to increase with time.

3.3 This will cause both an upstream backwater effect, raising the level of the bed upstream, and downstream progradation of the aggradation, increasing river slope and raising bed levels downstream. The character of the river (notably its braiding pattern) will alter accordingly in the affected reaches. Accurate quantification of the bed level increases will require sophisticated numerical modelling, but over a decade-to-century timespan my analysis suggests that it can be expected to be of the order of metres or more, and may therefore be significant in terms of increased flood risk and bank erosion.

3.4 The nature of the alteration to behaviour of the river is difficult to predict accurately; however it is known that increase of bedload concentration is associated with reduction of flow depth and increased intensity of braiding (average number of channels at a cross-section), and that increase of slope resulting from aggradation results in reduction of channel sinuosity (wiggliness).

3.5 Effects of CPW abstraction under different abstraction regimes, and at other intake sites will be of the same character. The analyses need to be repeated for these situations to quantify the effects.

4. BEDLOAD SUPPLY

4.1 The evidence of Mr Mabin states that the presence on the bed of the Waimakariri River of a coarse armour layer is evidence that the river is under-supplied with bedload sediment. If this were true then all gravel-bed rivers would be undersupplied with bedload sediment, because they all display such an armour layer at low flow – including the Waiho River in Westland which has aggraded more than 10 metres in the last 50 years. It may be the case that the continued presence of an armour layer *during active bedload transport* indicates undersupply; but the beds of the

Waimakariri and Rakaia rivers are not visible during active bedload transport, being covered by water containing high concentrations of suspended load, hence it cannot easily be ascertained whether or not this is the case.

4.2 The armoured bed commonly seen in gravel-bed rivers is a result of the reduction in flow rate as a flood declines. The larger grains deposit on the bed and are unable to be moved by the reducing flow velocity, but smaller grains can still be carried away; since there is little sediment carried on the falling limb of a flood, these are not replaced and the result is a layer of larger grains. This has nothing to do with long-term undersupply of bed load – it is simply the result of conditions during reducing flow after the peak of a flood.

4.3 Figure. 1 (attached in the Appendix) illustrates a section through the bed of a gravel-bed river (Waiho River, Westland) which has undergone recent aggradation of some metres; the depth of sediment in the view is about one metre. This bed has an armour layer at its surface, caused by the process outlined in the preceding paragraph.

4.4 Thus it does not follow that abstracting water from the Rakaia and Waimakariri Rivers will have a reduced effect on bedload deposition; this might be true if there was evidence that they are normally undersupplied with bedload, but that is not the case.

4.5 The further evidence of Mr Mabin discusses the effect of water abstraction from the rivers in general terms. There is no attempt to quantify this effect.

4.6 In view of the above matters I do not agree with Mr Mabin's conclusion at paragraph 181 of his evidence that: "… the rivers are both under-supplied with bed load and although they will be slightly de-powered, they will be able to recover their bed load transporting ability".

5. BEDLOAD TRANSPORT CAPACITY

5.1 I have carried out an analysis of the way in which bedload transport in the Waimakariri River will be affected by reductions in flow rate due to a proposed CPW abstraction regime over the whole range of flows of the river. The method used is that outlined in Davies (1988), which was used for a corresponding analysis of the

Rakaia River at that time. This methodology was peer-reviewed prior to publication in *Journal of Hydrology (New Zealand)*.

5.2 Briefly, the proportion of the total river flow that takes place at each flow rate Q is calculated from flow records, giving what is called a "flow duration curve" (FDC). A FDC for the flow as modified by the particular abstraction regime I have analysed (CPW 20-40-220) is provided in the evidence of Mr Duncan, and I used this in preparing my evidence.

5.3 I obtained the FDC for the unmodified river flow from NIWA. For each flow rate, the rate at which bedload transport occurs is calculated with a commonly-used formula that assumes that the total bedload transport rate Q_b depends on the excess flow rate $(Q – Q_c)$ and river slope S as follows:

$$Q_b = k (QS – Q_cS)^{1.5} \qquad \text{Eq. 1}$$

where Q_c is the flow rate at which bedload first starts to be transported, and k is a constant for a given reach of a given river (Bagnold, 1977). In the unmodified river, S is also a constant at all but long time-scales. Thus one can calculate (in arbitrary units, because k is unknown although constant as noted) the proportion of the long-term bedload transport volume that takes place at each flow rate, and by summing these one obtains the total long-term bedload volume able to be transported by the river.

5.4 Carrying out this calculation for both unmodified and modified FDCs, the percentage reduction of total long-term bedload transport due to abstraction can be calculated; in this process the unknowns due to k cancel out.

5.5 The value of Q_c for the Waimakariri River is poorly known and is presently under investigation by NIWA for Ecan. It appears that the onset of bedload motion with increasing flow is not well-defined, meaning that some bedload may be transported in deeper and steeper parts of the river at quite low flows (M.J. Duncan, NIWA Christchurch, personal communication 12 March 2008). For this reason I repeated the above calculation at 10 m^3s^{-1} intervals from zero to 100 m^3s^{-1}. A well-defined relationship resulted:

$$R = 21.014 - 0.0577Q_c \qquad \text{Eq. 2}$$

where R is the percentage reduction in bedload transport rate. For this relationship the value of r^2, which indicates how well the equation represents the data, is 0.9994 – an exceptionally good result, which means it can be extrapolated reliably to higher values of Q_c.

If $Q_c = 0$, $R = 21.0\%$; if $Q_c = 100$, $R = 15.3\%$; and if $Q_c = 150$, $R = 12.7\%$. Hence I conclude that the proposed CPW abstraction will reduce the long-term average bedload transport ability of the Waimakariri River by about 10 – 20%, depending on the flow rate at the onset of bedload motion.

5.6 The AEE for the Waimakariri River Take near the Kowai River Confluence (URS, 2005) quotes values for the annual bedload transport rate of the Waimakariri of 233,000, 209,000 and 246,000 m^3. Using 200,000 m^3 as a conservative figure, a 10 – 20% reduction means 20,000 – 40,000 m^3 per year of bedload sediment would not be able to be transported past an offtake section. This sediment would accumulate at the offtake, raising the bed level. The effect of the bed level rise is to increase the river's slope downstream of the offtake, so that the reduced flow rate of water available can transport the full sediment load in the steeper reach (Figure 2 in the Appendix). As bed level rises at the offtake the water surface slope upstream decreases, forming a backwater curve; the consequently reduced sediment transport rate here causes sediment to accumulate, the accumulation extending upstream with time.

5.7 The rate of bed level rise depends on the length of river over which the deposition is distributed; this will clearly increase as the bed level at the offtake rises. To increase the sediment transport capacity by, say, 15% to restore it to its original value, Eq. 1 shows that the slope S must increase by 10% downstream of the offtake, an increase of 0.0005 m per metre of river length (the river bed slope under normal conditions is 0.005). If we assume that sediment accumulation upstream of the offtake has a horizontal surface, then if 40,000 m^3 of sediment accumulate in one year this will build up to a maximum depth of 0.16 m at the offtake, with the tail of the deposit extending 200 m downstream. The upstream accumulation would extend 35 m from the offtake. After 10 years, under these assumptions, the increase in bed level would be 0.48 m, and after 100 years, 1.6 m, with the downstream effects at that time extending 2 km and the upstream effects 0.35 km.

5.8 These figures are based on simplified river geometry (constant width of 1000 m, linear longitudinal profiles) and are therefore obviously approximate, but in my opinion they represent the likely order of magnitude of the effects. At the Upper Waimakariri intake the effects will be complicated by the narrow river width at the intake site and the widening downstream (URS, 2005, Fig.3); the above aggradation estimates refer to the wide section, and will probably be greater in the narrower abstraction reach because the same volume of sediment accumulating in a narrower river will accumulate to greater height.

5.9 In practical terms, the impacts will be increased flooding of river banks in the aggrading reaches both upstream and downstream of the intake, with increased bank erosion in the downstream reach. These effects will be cumulative, building up gradually but steadily and becoming apparent after some years to a decade. They will continue for as long as the abstraction regime is maintained.

5.10 The aggradation and steepening of the river bed downstream of the intake will have consequential effects on the form of the river (Davies and McSaveney, 2006) in that reach. These effects are qualitatively predictable using the river response equations of Schumm (1977); their quantification would require sophisticated numerical modelling. The increase in bedload sediment concentration will cause the river to become more intensely braided, that is, there will be more, and narrower, channels in a given river cross-section; and the increase in gradient will reduce the sinuosity or “wiggliness” of the channels. It also generally causes a reduction in flow depth while channels are forming, so at low flows the depths of water in the channels may reduce.

5.11 Farther downstream, beyond the aggradation reach, the river gradient will be steady at its pre-abstraction value; it will have the reduced water flow rate remaining after abstraction, and the sediment transport rate that it can carry with the reduced flow. The width and depth of flow channels throughout this reach are likely to reduce (Schumm, 1977).

5.12 Upstream of the intake, in the reach in which reduced slope causes aggradation, the braiding intensity is likely to increase.

5.13 I have not carried out the corresponding analyses for other abstraction regimes and sites on the Waimakariri, or for the Rakaia River. However I would expect the results to be similar in character; water abstraction will cause long-term cumulative aggradation at the intake, with increased river water levels extending both upstream and downstream. The magnitude of the effects I have predicted on the Waimakariri (at the intake and with the abstraction regime I have considered), however, suggests that the appropriate calculations for the other situations need to be carried out.

6. CONCLUSION

6.1 There is no evidence that the Rakaia and Waimakariri Rivers are undersupplied with bedload sediment; hence any reduction in flow due to water abstraction could in principle cause a reduction in bedload transport capacity, leading to a cumulative long-term aggradation at the offtake, extending upstream and downstream with time. If the aggradation is sufficient it will lead to noticeably increased flooding and bank erosion upstream and downstream of the offtake, and alterations in the river channel pattern.

6.2 The proposed CPW 20-40-220 water abstraction regime from the Waimakariri will cause a reduction in bedload transport capacity of the order of 10%-20%, depending on the flow at which bedload sediment first starts to move (this latter value is poorly known at present).

6.3 A 15% reduction in bedload transport capacity at the Upper Waimakariri offtake site will cause a sediment deposit to develop, increasing in height to at least 1 m after about 30 years and 2 m after about 100 years; at the latter time it would affect flow conditions over at least 2 km downstream and 350 m upstream of the offtake. This gradual alteration will probably be noticeable after a decade or so.

6.4 The aggradation and steepening of the riverbed will have consequential effects on the form of the river . There will be an increased number of channels, and these will be narrower and straighter, with reduced flow depths.

6.5 Further downstream, beyond the aggradation reach, reduced flow is likely to result in a reduction in the width and depth of flow channels.

6.6 The corresponding analyses need to be carried out for the various CPW abstraction scenarios and offtake sites, and for the Rakaia River, in order to assess the impacts of the CPW scheme on river behaviour.

T Davies
May 2008

References

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Schumm, S.A. (1977). *The Fluvial System*. Wiley, New York.

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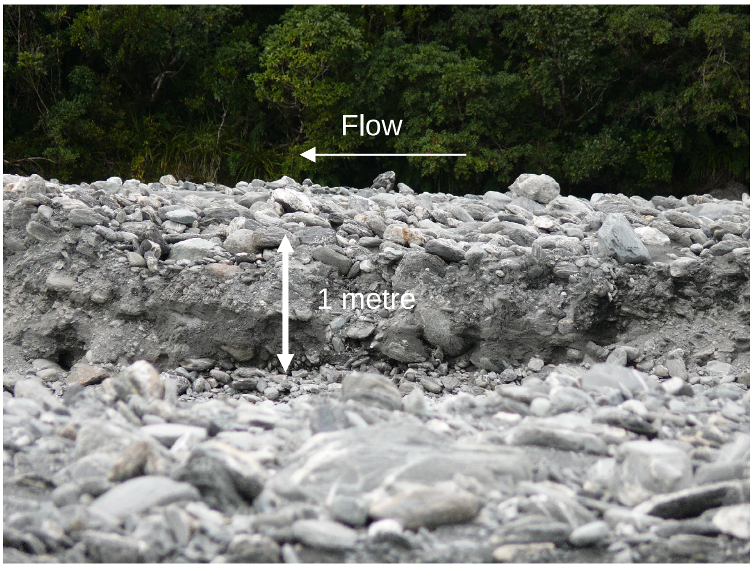
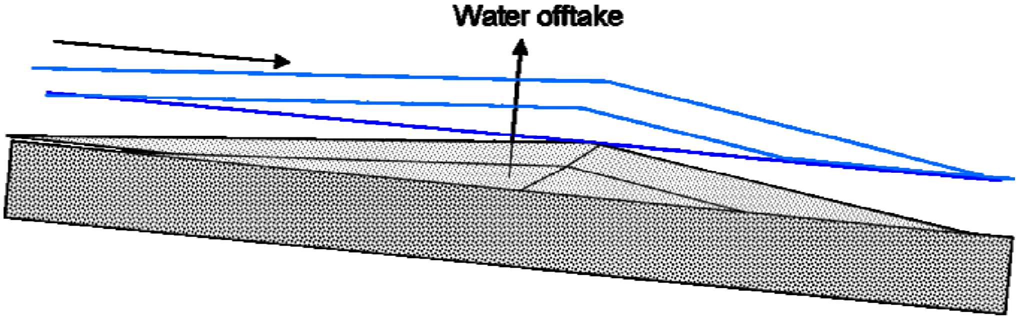
APPENDIX

Figure 1



Aggraded river bed – the Waiho River, Westland. Note the coarse imbricated surface (“armour”) layer. Flow was from right to left.

Figure 2



Progress of aggradation deposit at a water offtake