Supplementary evidence of MAURICE JOHN DUNCAN.

Qualifications and experience

1. My full name is Maurice John Duncan

2. My qualifications and experience have been presented in my primary brief of evidence and have not been repeated here.

3. I have read the code of conduct for expert witnesses set out in the Environment Court practice note, and confirm that I have complied with the code in the preparation of my evidence will comply with the code in the presentation of my evidence.

Scope of evidence

4. I will provide in this section of my evidence comments about the 2D hydrodynamic modelling that many witnesses have talked about and provide results of a further application of the model that I believe is relevant to the hearing. This will include:

   - A brief description of the model and an opinion on which of the two versions of model the hearing has been told about is likely to give the most accurate information.

   - The results of using the model to investigate sediment transport on the Waimakariri River. The results add understanding to the process of sediment transport in the river and have ecological implications, such as the flows at which ecologically significant amounts of filamentous algae and benthic invertebrates are scoured from the bed.

   - I discuss the alternative take options of B Block flow sharing and delaying the B Block take until an unmodified flows of 90 and 100 m^3s^{-1} is reached,

The Waimakariri 2D hydrodynamic model.

5. The model that has been referred to by various witnesses is of a 3 km by 1 km reach at Crossbank, behind Christchurch Airport, on the Waimakariri River. The model is based on topography captured by digital photogrammetry and wet channel bathymetry in February 2000 (Hicks et al 2008). The model is described by Beffa and Connell (2001) and Connell et al. (2001).

6. I took part in the data collection for the model and input data into the modelling programme known as "Hydro2de". I ran the model and supplied depth and velocity

data output by the model to various witnesses who have presented their interpretations of that data to the Hearing.

7. “2D” means two dimensional. It means that the model computes data on depth and velocity both across the river (as in a one dimensional cross-section) and up and down the river and can be thought of as a lot of closely spaced cross-sections. The advantage of a 2D model over a 1D model is that there is no need to interpolate the data between cross-sections, and the model can take into account the effect of the varying channel shape on water depth and velocity. This is very important in a braided river.

8. “Dynamic” means that the model can handle a varying flow input and downstream conditions, e.g., floods and tides.

9. The model outputs the mean depth and mean velocity, among other parameters, of every model cell.

10. The most recent version of the Waimakariri model assumes a fixed bed, has a fixed 2 m by 2 m square grid, and uniform hydraulic roughness. This is the same model and grid size as has been used for instream habitat assessment in other studies e.g., Jowett et al. (2007) and has been referred to by witnesses to this hearing.

11. An earlier version of the model used a 2 m by 4 m rectangular grid. The smaller grid is better because it allows the model river bed to fit more closely to the digital terrain model on which it is based. Increased computer computational speed and larger memory allowed the grid size to be reduced.

Application of the model to sediment transport.

12. Earlier this year I was asked by the Canterbury Regional Council to use the model to determine the flow rate at which the portion of the river bed occupied by the median flow was sufficiently disturbed to reset the benthic invertebrate population, i.e., at what flow is the benthic invertebrate population scoured away. The full study is reported in Duncan and Bind (2008).

13. As the Central Plains Water Enhancement Scheme (CPW) is predicted to increase the “flat lining” of the hydrograph at about minimum flow of 41 m^3s^{-1} the study was extended to repeat exercise for the portion of the river bed occupied by a flow of 40 m^3s^{-1}.

14. As the size of the surface bed material is critical to the study 15 transects of 300 pebbles each (Wolman 1954) were measured. The pebbles in each transect were 0.5 m apart. The median grain size at the Crossbank site was found to be 28 mm. The result is consistent with the grain size reported by Griffiths (1979).

15. The criteria for bed movement disturbance for both surface flushing of fine sediment and for armour disturbance (deep flushing) was taken from Milhous (1998) who had a study river similar in size to the Waimakariri River.

16. The critical flow criteria for ecological resetting were taken from the literature:

    a. Filamentous algae are flushed by about twice and diatoms about five times the pre-existing flow respectively (Biggs and Close (1989), Irvine and Henriques (1984)).

    b. The maximum velocities suitable for long and short filamentous algae and for diatoms (Jowett 2003).

    c. Invertebrate resetting occurs at about three times the median flow (Sagar 1986) or when about 80% of the bed is being flushed (Jowett et al. 2008).

17. The model was run for 14 different flows between 40 m^3s^{-1} and 768 m^3s^{-1} and the degree of surface and deep flushing in the minimum and median flow beds was assessed at the thresholds detailed in paragraph 16. The degree of exceedance of threshold velocities for the three alga types detailed in paragraph 16b was also assessed.

18. Figure 1 shows the predicted relationship between flow and the percentage of the median flow bed that is disturbed sufficiently to remove fines and the armour layer. As the flow increases the percentage of median flow bed that is disturbed increases and there is no obvious inflection point. The main point to note is that there is no threshold flow at which sediment transport commences. As flow rates increase so does the amount of sediment transport.

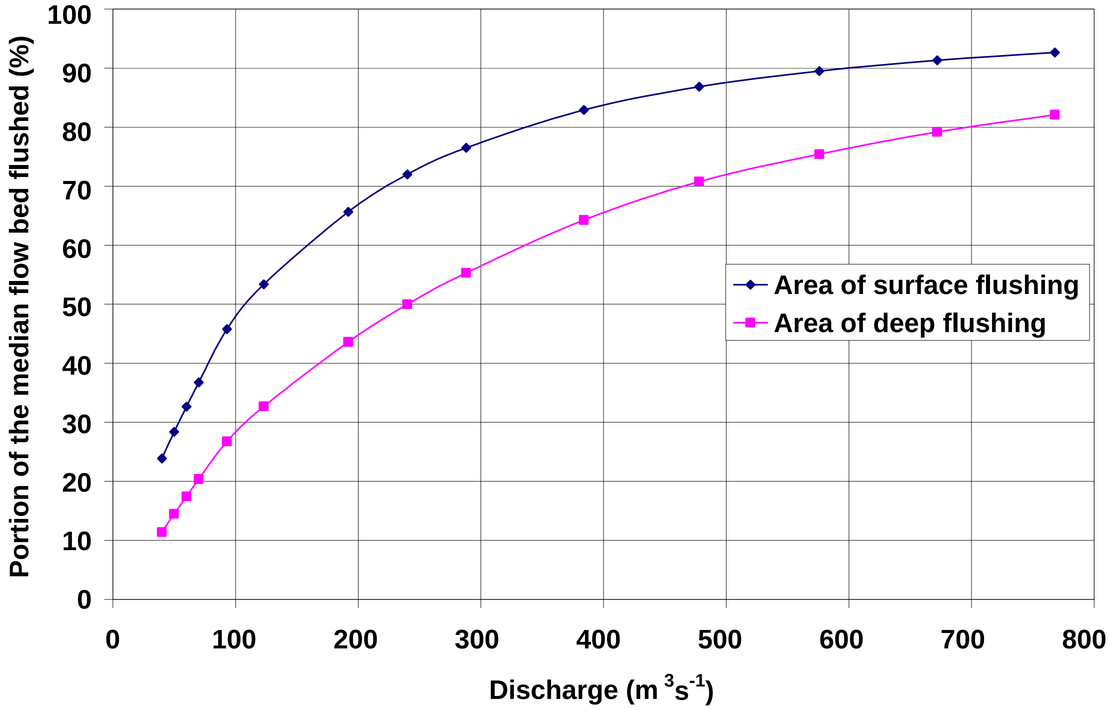

Figure 1. The proportion of median flow (96 m^{3}s^{-1}) river bed that is flushed of fine sediment (surface flushing) and the proportion of armour disturbed (deep flushing) at the Crossbank Reach of the Waimakariri River at a range of flows.

19. Figure 2 shows the area of the river bed at a flow of 93 m^{3}s^{-1} (closest model run to the unmodified median flow of 96 m^{3}s^{-1}) that is flushed of fine sediment (surface flushing) (46% of the median flow bed) and the area of armour disturbed (deep flushing) (27% of the median flow bed) in the Crossbank Reach of the Waimakariri River. There is clearly a large portion of the median flow bed that is not being flushed and it is only the deeper and faster portions of the main braids that are being flushed.

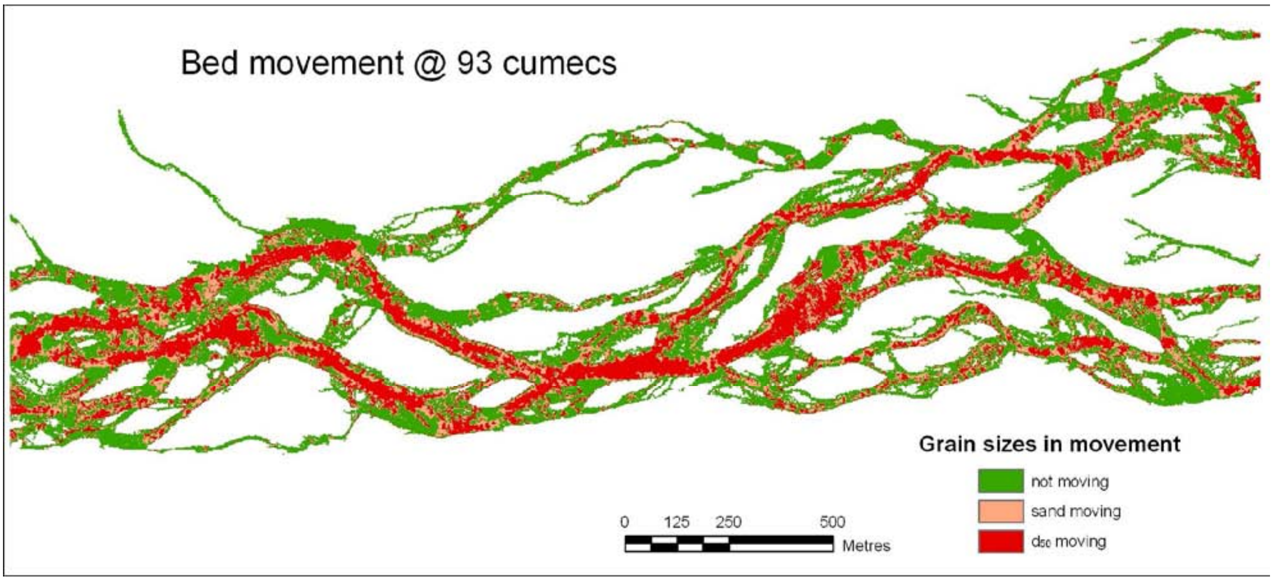

Figure 2. The location of likely surface and deep flushing (sand moving and d_{50} moving respectively) on the median flow bed when the steady flow is 93 m^3s^{-1} (approximately the unmodified median flow).

20. Figure 3 shows the degree of flushing at 288 m^3s^{-1}, i.e., at FRE3 (Clausen and Biggs 1997), the flow suggested by Sagar (1986) for invertebrate resetting. At this flow virtually all of the median flow bed major braids and many parts of the minor braids are being flushed. At a flow of 288 m^3s^{-1} 77% of the median flow bed is being surface flushed and 55% is being deep flushed. The value for surface flushing is close to the 80% suggested by Jowett et al. (2008) as the criteria for benthic invertebrate resetting.

21. The critical flow for long filamentous algae for the median flow bed is suggested by Biggs and Close (1989) to be twice the pre-existing flow or 192 m^3s^{-1}. At that flow 66% of the median flow bed is being surface flushed and 44% is being deep flushed (Figure 4). The critical flow for diatoms of 5 times the pre-existing flow is higher than that for invertebrate resetting and is clearly too high in this case.

22. Figure 5 shows the modelled relationship between flow and the percentage of the 41 m^3s^{-1} minimum flow bed that is disturbed sufficiently to remove fines and the armour layer. If the pre-existing flow is accepted as being the minimum flow of 41 m^3s^{-1} then the critical flow for long filamentous algae is 82 m^3s^{-1} (41 x 2 = 82) (see paragraph 16). At that flow 35% of the median flow bed is being surface flushed and 17% is being deep flushed (Figure 5). Most of the bed being flushed is confined to the main braids. For diatoms the critical flow would be 205 m^3s^{-1} (5 times 41 m^3s^{-1}) when 72 % and 49% of the minimum flow bed is being surface and deep flushed respectively. Using the Sagar (1986) threshold for invertebrate resetting the critical flow is 288 m^3s^{-1} when 79% of the median flow bed is being surface flushed and 58% is being deep flushed. The value for surface flushing is close to 80% suggested by Jowett et al. (2008) as being critical for benthic invertebrate resetting.

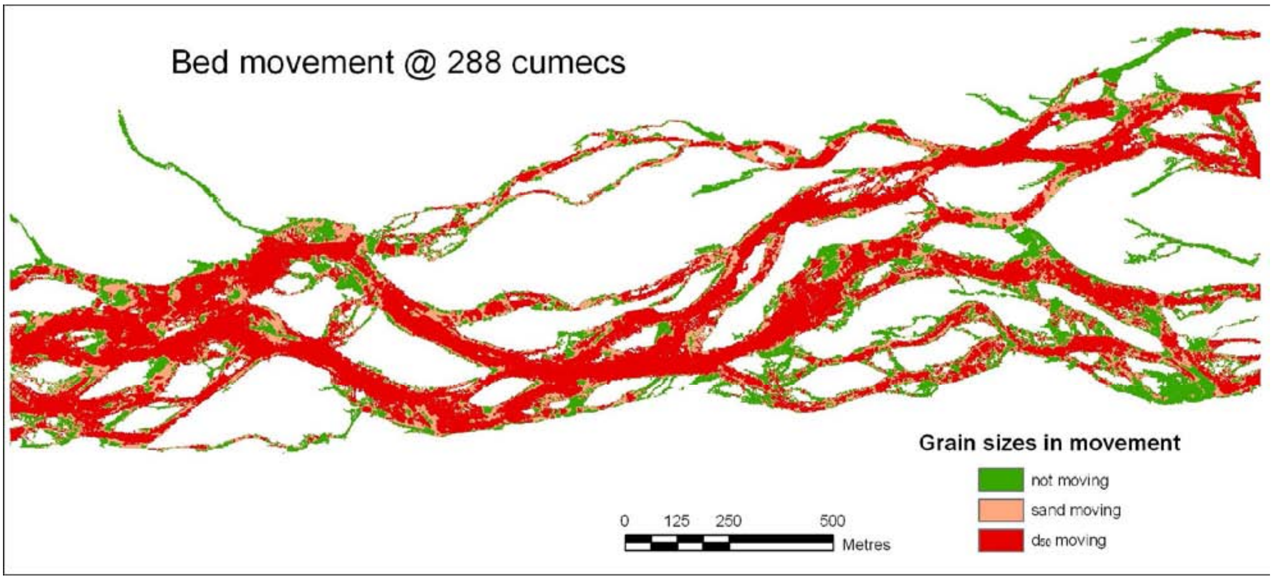

Figure 3. The location of likely surface and deep flushing (sand moving and d_{50} moving respectively) on the median flow bed when the steady flow is 288 m^3s^{-1} (3 times the unmodified median flow, i.e., at FRE3).

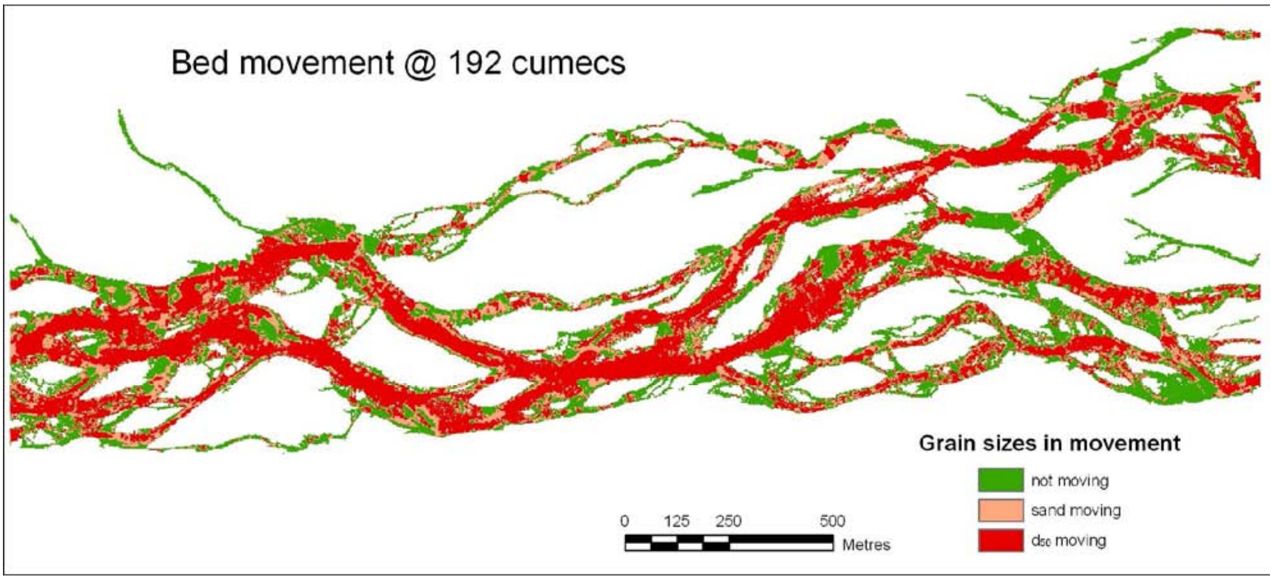

Figure 4: The location of likely surface and deep flushing (sand moving and d50 moving respectively) on the median flow bed when the steady flow is 192 m^3s^{-1}.

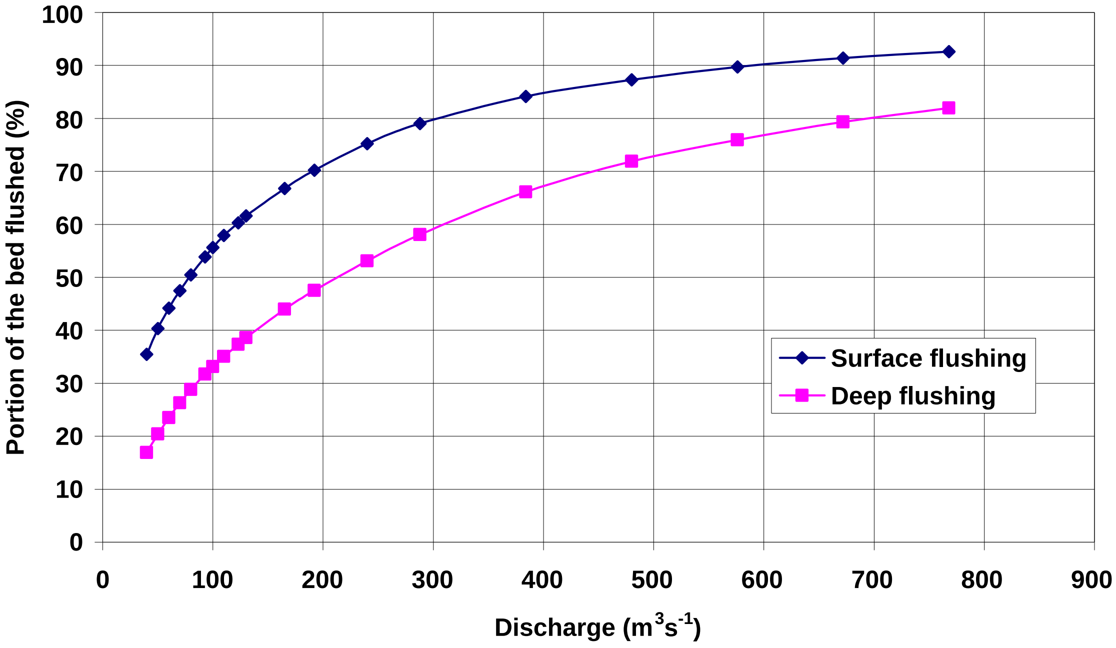

Figure 5. The proportion of the minimum flow (40 m^3s^{-1}) river bed that is flushed of fine sediment (surface flushing) and the proportion of armour disturbed (deep flushing) at Crossbank Reach of the Waimakariri River at a range of flows.

23. For determining the critical flushing flows for periphyton it may be more appropriate to use velocity criteria according the maximum velocity suitable for each periphyton type as indicated the habitat suitability curves used for the Waitaki River Project Aqua study (Jowett 2003). They are illustrated in Appendix 1.

24. Figure 6 shows the result for the minimum flow bed. The flow where only 20% of the bed has a velocity suitable for long filamentous algae is ~ 82 m^3s^{-1} and is coincidentally similar to the threshold flow predicted by (Biggs and Close (1989) and Irvine and Henriques (1984) of twice the pre-existing flow of 41 m^3s^{-1}. The flow where 20% of the minimum flow bed has a velocity suitable for short filamentous algae is 288 m^3s^{-1} that is coincidentally the flow at which almost 80% of the bed is being flushed of fine sediment. While diatoms could withstand the velocities associated with higher flows they will also be removed from ~80% of the bed by the sediment flushing at 288 m^3s^{-1}.

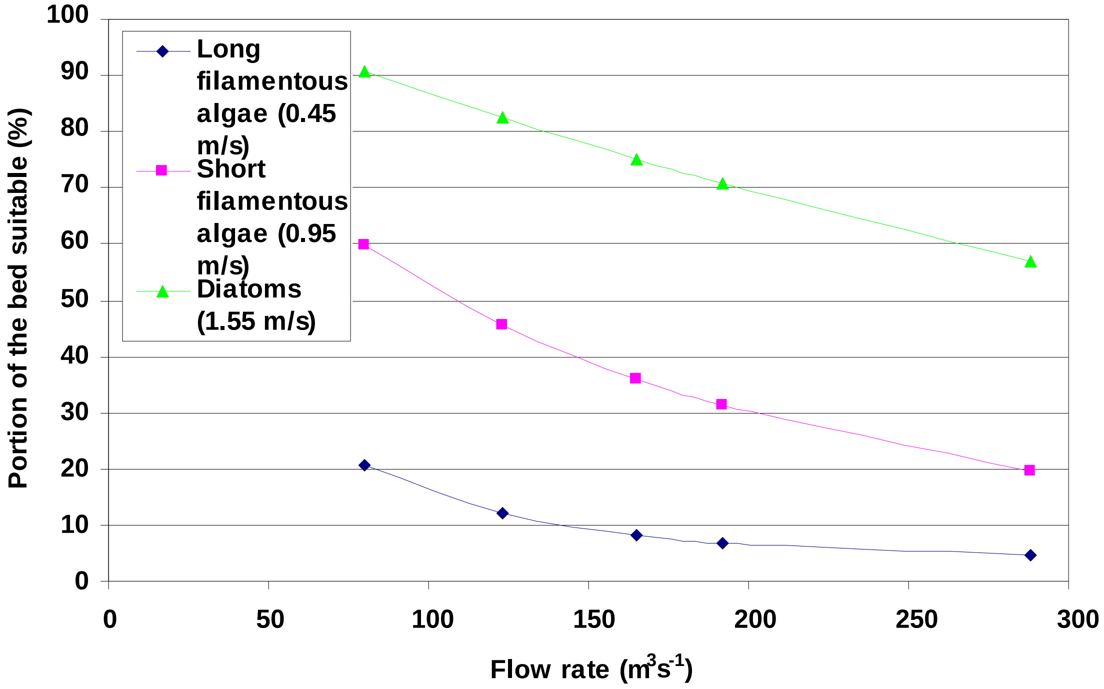

Figure 6: The proportion of the minimum flow bed where the velocity is suitable for three algae categories.

25. Figure 7 shows the result for the median flow bed. The flow where 20% of the bed has a velocity suitable for long filamentous algae is ~ 130 m^3s^{-1}. This flow is only about 1.35 times the median flow. This critical flow is much less than that indicated for long filamentous algae scour in paragraph 16 that was based on an assumption of a critical flow of twice the pre-existing flow of 96 m^3s^{-1} or 192 m^3s^{-1}. The threshold of 130 m^3s^{-1} based on velocity scour is considered to be a better indicator of flow when long filamentous algae would be scoured from the median flow bed than the one based on twice the pre-existing flow. The flow at which short filamentous algae is predicted to scoured by velocity from 80% of the median flow bed is ~300 m^3s^{-1} which is a similar flow to that that would flush fine sediment from 80% the bed. While diatoms could withstand the velocities associated with higher flows they will also be removed from ~80% of the bed by the sediment flushing at ~300 m^3s^{-1}.

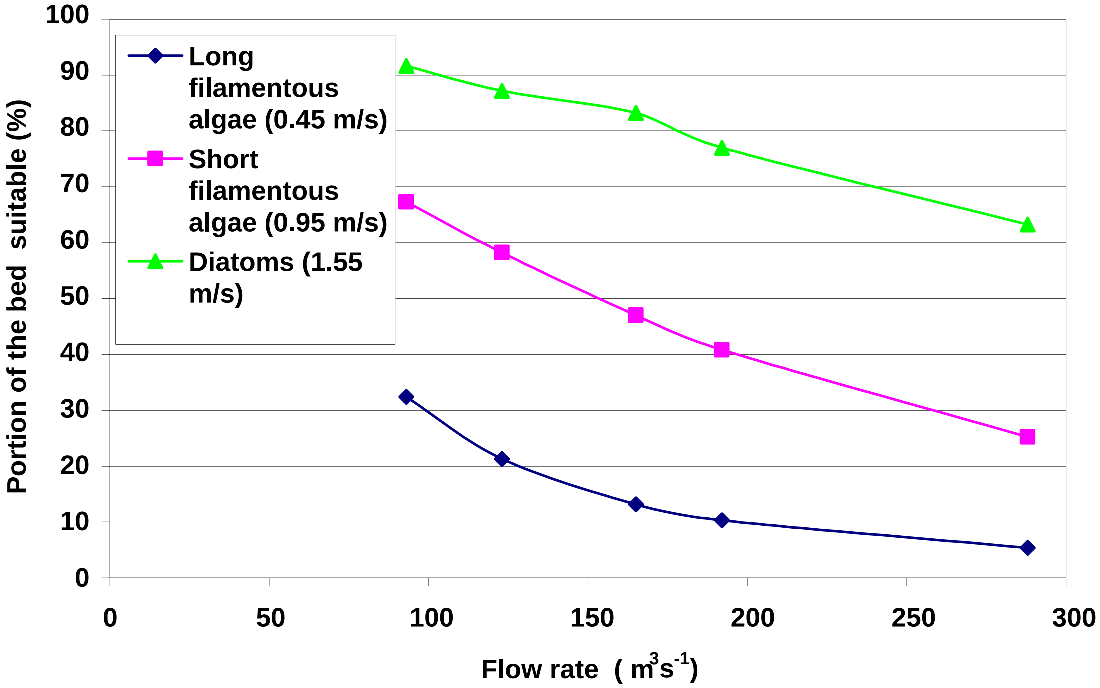

Figure 7: **The proportion of the median flow bed where the velocity is suitable for three algae categories.**

Field verification of model findings.

26. Eight days after the surface bed material survey (8 February 2008 when the flow was ~ 40 m^3s^{-1}), the river flooded to a peak value of 542 m^3s^{-1}. The flood peak was quite flat and exceeded 500 m^3s^{-1} for about 4 hours. Six days later the river was visited again when the flow was 64.5 m^3s^{-1}. Flowing channels were inspected for evidence of bed movement and presence of periphyton and invertebrates. Some areas that were dry on the first visit were flowing channels on the second visit and they too were inspected for bed movement and presence of periphyton and invertebrates.

27. There was no bed disturbance for at least 6 weeks before the first visit. This is sufficient time for a good biomass of periphyton to grow and for invertebrates to become abundant. While the braids were not specifically examined for the presence of periphyton and invertebrates during the first visit I was aware of a thick brown cover of periphyton in the smallest of the main braids where conditions were slippery underfoot.

28. During the 16 February 2008 flood most of the river bed was flooded. On the second visit on 22 February 2008 most of the flowing channels were located approximately where they had been before the flood, but the form of some channels had changed. The minor channels had parts where the bed seemed to have survived the flood intact, parts where the largest particles survived or had been turned

through 90°, and parts where the whole bed had been turned over or was covered by fresh deposits. Where the bed was still intact there were films of green algae on the lee of particles. Most green film covered particles inspected had *Deleatidium* and caddis larvae on their undersides.

29. The two major braids had been completely reworked by the flood and the particles were very clean and completely free of periphyton and invertebrates, whereas on our first visit there was a thick covering of periphyton from bank to bank on the smallest of the main braids.

30. The results from the second field visit are consistent with the results of the bed sediment transport modelling in that during flooding the bed shear stress in the main braids is more than sufficient to mobilise the bed, but in shallower areas and in minor braids there was insufficient bed shear stress to mobilise all the sediment.

Flushing flows for periphyton

31. In Mr Tipler's primary evidence paragraph 142 he offers for CPW to delay taking flow during a fresh if the flow has been at its minimum for more than 21 days until the modified flow at the Old Highway Bridge reaches 100 m^3s^{-1} or for two days which ever is the sooner. The purpose of delaying the take is to flush fine sediment and filamentous algae from the river. Mr Tipler's suggested trigger was arbitrarily chosen. The results of the work described above suggest that the flow trigger should be 130 m^3s^{-1} (see paragraph 25). This would involve a change to CRC061972, proposed condition 6 (Mr Tippler's supplementary evidence dated 4 July 2008).

Other issues

The relationship between braiding patterns and flow

32. While considering sediment transport issues I believe that there are some comments that I should make about sediment transport and river morphology that may help answer some of the questions that have been asked of various witnesses.

33. On the question of braiding pattern in relation to flow I took the modelled output from the Crossbank 2D model analysed the number of braids and their wetted width for 6 cross-sections 250 m apart in the downstream portion of the model. The reasons for taking the data from this proportion of the model will become apparent later. The results are illustrated in Figure 8 show that there are on average 7.7 braids when the flow is 40 m^3s^{-1} and they reach a maximum of 10.5 braids at a flow of 100/110 m^3s^{-1} when they decrease to 6.2-6.5 at a flows of 480-768 m^3s^{-1}. The results are consistent with the data in Dr Mabin's supplementary evidence in response to the Commissioner's minute No 4.

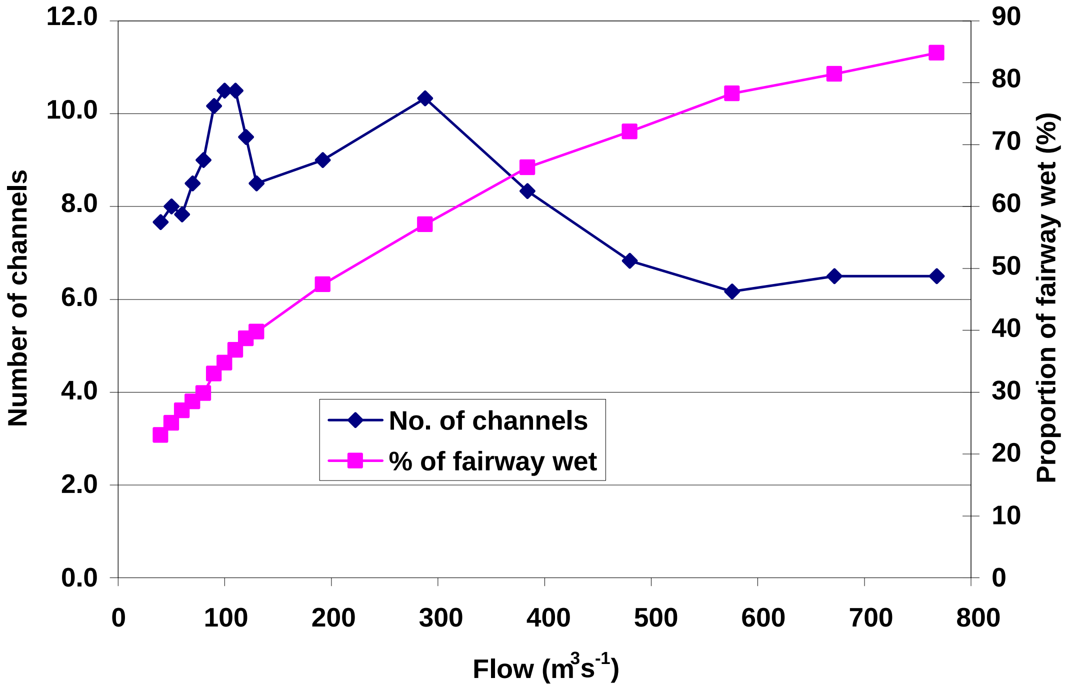

Figure 8. The relationship between flow rate and the number of channels and proportion of the bed with flow.

The relationship between flow rate and morphological change

34. From the data in the earlier section of my evidence it is clear that there is sediment movement at all flows including the mean annual low flow and it follows that the braiding pattern can change at all flows. When NIWA staff were working in the river during the summer of 2001 and when flows ranged from 30-40 m^3s^{-1} the major braid we were working on moved a whole channel width over the course of 3-4 weeks. I reported earlier in my evidence that a flood peaking at 540 m^3s^{-1} made minor changes to the morphology of both minor and major braids but did not cause large scale changes in the reach examined.

35. When the river is being flat lined at flows of ~41 m^3s^{-1} and 63 m^3s^{-1} up to 62 m^3s^{-1} are being abstracted. Without abstraction flow would be in the range 41-103 m^3s^{-1}. While there is some bed movement when flows are naturally in that range, as is shown in Figure 5, any changes in morphology would be expected to be slow and with the abstraction would be slower.

36. As the natural flow in the river increases beyond 103 m^3s^{-1} the amount of sediment transport increases and Dr Mabin has said (primary evidence paragraph 110 ii) that in the Waimakariri River a flow of 550 m^3s^{-1} the most efficient for bed load transport. He also says in Paragraph 26 that it would be prudent to close intake gates when suspended sediment concentrations were in the range of 1500-2000 gm^{-3} that he showed occurred at flows of about 500-600 m^3s^{-1} in the Waimakariri River.

It is clear from the modelling work I have presented that there is also a lot of bed load transport at flows greater than 500 m^3s^{-1}.

37. In order to minimise any aggradation caused by abstraction and to maintain the current morphology and appearance of the Waimakariri River I believe it would be prudent to introduce a condition where abstractions were prohibited when the instantaneous flow at the Otarama water level recorder indicated the flow was 500 m^3s^{-1} or more.

38. Figures 9 and 10 shows the predicted disturbance of the bed of the Crossbank Reach at flows of 480 m^3s^{-1} and 768 m^3s^{-1} that are model runs closest to the 500 m^3s^{-1} and 800 m^3s^{-1} flows commented on by Dr Mabin. It is clear from the figures that at 480 m^3s^{-1} there is a lot of bed disturbance, but the fairway is not covered bank to bank. At a flow of 768 m^3s^{-1} there is even more bed disturbance and the water is bank to bank. With this degree of disturbance it is easy to imagine that the braiding pattern would be substantially altered by floods of 768 m^3s^{-1} and greater.

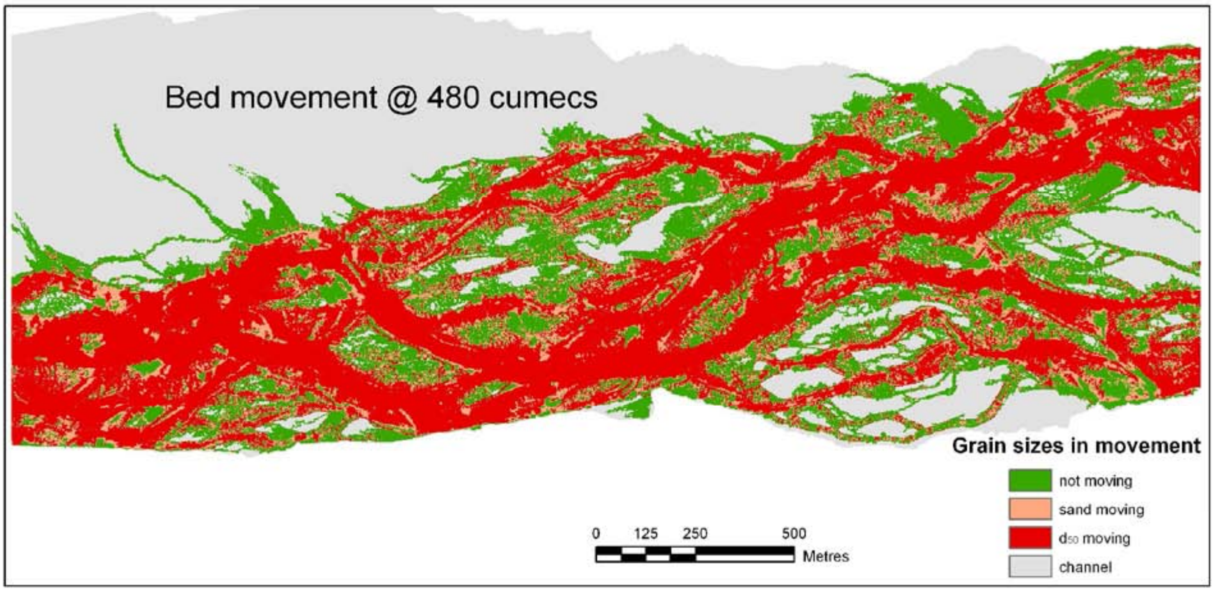

Figure 9. Output from the model of the Waimakariri Crossbank reach showing the degree of bed disturbance and fairway coverage with a flood of 480 m^3s^{-1}.

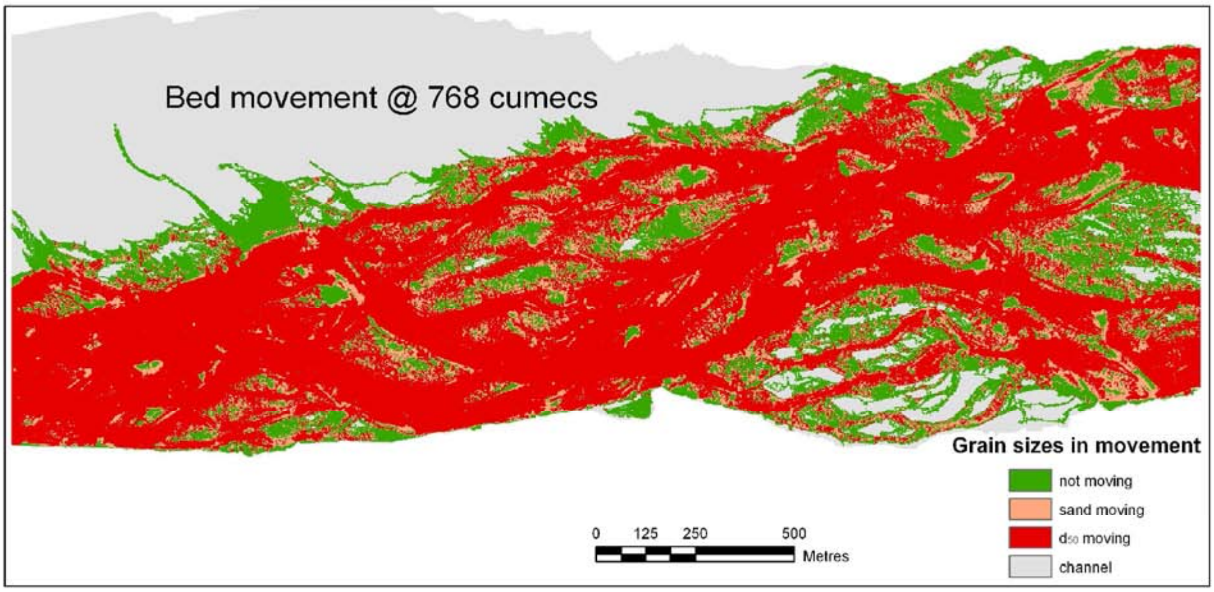

Figure 10. Output from the model of the Waimakariri Crossbank reach showing the degree of bed disturbance and fairway coverage with a flood of 768 m^3s^{-1}.

39. Both figures show an area without flooding in the top left hand side. While that area is higher than other parts of the fairway in that part of the river, floods of the size shown in Figures 9 and 10 would probably cover much of the area shown as being dry. That area of the bed was bare shingle indicating that it was disturbed from time to time. However in the model flow is introduced only to the true right of the fairway as that is where the flow was at the lower flows the model was initially designed for. As there was no measurement of the flow proportioning across the channel at flood flows it was decided to introduce the flow to the true right side at all flows rather than make an arbitrary decision where to introduce the flow.

40. In conclusion I agree with Dr Mabin's assessment that some changes in morphology can occur when flows are in excess of 500 m^3s^{-1} and large changes in morphology can be expected certainly when flood flows approach or exceed 800 m^3s^{-1}.

Effects of potential bed changes on gallery intakes.

41. I am familiar with gallery intakes of the likes of that of Grasslands and those proposed by Synlait on the Rakaia River, the more conventional intakes of the Selwyn District Council Waimakariri Gorge and Intake Road stock water intakes and the Waimakariri Irrigation Limited's Browns Rock intake.

42. I believe that as long as the galleries were some distance away (2km is suggested in Dr Davies evidence) they are unlikely to be affected by aggradation. In the event of minor aggradation (<1 m), I think the galleries would still work as the channels leading to the gallery could be lowered to cope. Minor degradation could be

overcome by moving the entrance to the channel leading to the galleries further upstream. Any aggradation process would probably be gradual and be able to be managed over time and is likely to be less of a problem than a shift of the main braids to the side of the river opposite the gallery.

43. The Grasslands gallery is about 7 km down stream of the proposed Rakaia intake and if Dr Davie's calculations are correct, and I have no reason to doubt them, then that gallery and any further down stream are unlikely to be affected.

44. The Selwyn District Council stock water intake at the Waimakariri Gorge is close to one of the proposed CPW intakes and could well be affected by aggradation if Dr Davie's calculations are correct. Aggradation could probably be accommodated by modifications to the upstream end of the tunnel. Waimakariri Irrigation Limited's Browns Rock intake is about 3.5 km downstream of the Waimakariri Gorge and is probably too far from the proposed CPW intake to be affected.

45. In Canterbury there are a number of rivers, e.g., Rangitata, Hurunui and Waiau, where substantial quantities of irrigation water have been abstracted for up to 40 years and I am aware of no long term bed elevation issues associated with those abstractions.

Ensuring that there are responses to flow increases, trigger flows and avoiding compromising the takes of other consent holders.

46. A gap between the A block and B block allocations is one way to ensure that B Block takes do not reduce the water available to current A Block consent holders.

47. There is currently a gap between the A and b Block allocations. As I understand the situation, of the 22 m^3s^{-1} A Block allocation, there is a stockwater allocation of 4.896 m^3s^{-1} leaving 17.104 m^3s^{-1} for irrigation. Irrigation water may be abstracted once the unmodified flow exceeds 41 m^3s^{-1}. When the unmodified flow reaches 58.104 m^3s^{-1} the full A Block allocation of 22 m^3s^{-1} is being abstracted and the B Block allocation cannot begin to be abstracted until the unmodified flow is more than 63 m^3s^{-1}. Thus there is a 4.896 m^3s^{-1} gap between the A and B allocation Blocks.

48. The potential for B Block takes to compromise A Block takes is most likely to occur as the flow slowly reduces during a recession. In that case it should be relatively straight forward to predict the rate of flow reduction and have CPW and others reduce their B Block take accordingly. The stage record at the Old Highway Bridge fluctuates because of the tide and thus any breach of relevant consent conditions or minimum flows can only be assessed twice daily.

49. In relation to allowing CPW to resume their take as flows increase, the Canterbury Regional Council have now established a water level recorder at Otarama which is

about 2 km or 14 km upstream of the proposed upper and lower intake locations respectively. The water-level recorder is telemetered and CPW could monitor flow increases and begin abstraction after an appropriate lag time to allow the flow increase to reach the intake. Similarly during low flows this recorder would provide a good estimate of the unmodified flow at the Old Highway Bridge if contributions from the Kowai River and losses to ground water were taken into account.

50. The Otarama water-level recorder has only been recently established and there has not yet been enough gaugings to have confidence in the stage to discharge ratings, but by the time CPW goes ahead, if their application is successful, the water-level to discharge rating and the relationship between flows at Otarama and Old Highway Bridge should be well established. This relationship should be able to be used with some confidence to ensure that flows are not drawn down to below minimum flows and that water can be abstracted from the rising limbs of hydrographs.

Flat lining flow

51. Much has been made about the increase in time caused by CPW that the hydrograph is flat lined at about the minimum flow of 41 $m^3s^{-1.}$ The Hearing Panel needs to be aware that the flat lining could occur at flows as low as 36.104 m^3s^{-1}. This is because even though, according to the Waimakariri river Regional Plan, irrigation abstractions must cease when the unmodified flow at the Waimakariri at SHB recorder reaches 41 m^3s^{-1}, up to 4.896 m^3s^{-1} of stockwater may be abstracted without restriction. Flat lining can be caused by both A and B Block allocations.

Alternative flow regimes

52. Here I intend to review the alternative abstraction scenarios for the Waimakariri River contained in Mr de Joux's evidence, Mr Tipler's primary evidence and his response contained in his supplementary evidence dated 4 July 2008 along with my analysis of the changes in the flow regime.

53. I also modelled alternative flow regimes using the following data and assumptions:

- I used Mr de Joux's unmodified flow regime.
- That CPW had priority over Ngai Tahu Properties Limited (NPT).
- That CPW could access 11.5 cumecs of A Block water during May to September.
- That 4.896 m^3s^{-1} of stock water from the A Block allocation of was taken continuously without restriction.
- That all A Block water was taken from 1 October to 31 April.

- That CPW would take 40 m^3s^{-1} when it was available, subject to the need to take it. That is what they applied for and it seems from Mr Tipler's supplementary evidence that CPW would have to take 40 m^3s^{-1} to get enough water to make the scheme viable with the mitigation measures that have been offered by CPW or suggested by submitters.

- The demand series for the 20:40:240 scenario supplied by URS.

- I checked the mean and median values of the various take scenarios I modelled with those that were in common with Mr de Joux and most of my values agreed within 1 m^3s^{-1}.

54. The point of my modelling was to provide information on the effects of the different take scenarios on matters raised by submitters. I did not model every combination of take priority and use or not of A Block winter water by CPW. Results from such a multitude of combinations can be confusing. Instead I used a single base set of conditions on which the different take scenarios were imposed. The base set was a 40 m^3s^{-1} take, CPW priority over NPT, and access by CPW to 11.5 m^3s^{-1} of A Block water in winter.

55. The different take scenarios were:

    - Flow sharing 1:1 of B Block water.
    - Taking B Block water only when the unmodified flow was >90 m^3s^{-1}.
    - Taking B Block water only when the unmodified flow was >100 m^3s^{-1}.

56. It is clear from those bodies of evidence that takes initially proposed by CPW increase the duration of the time the flow is held at or near the minimum flow and reduce the duration the flow is between 41 m^3s^{-1} and 100 m^3s^{-1} and these appear to be a matters of concern.

57. The point of the alternative abstraction scenarios appears to be to reduce the flatlining and to increase the frequency of flows in the unmodified 63 to 100 m^3s^{-1} flow range.

58. The main potential benefits are:

    - An increase in the frequency of flows at which nuisance periphyton and fine sediment may be flushed,
    - An increase in the number of islands available for river bed nesting birds (Hughey evidence),
    - An increase in the frequency of flows suitable for salmon angling,

- An increase in the wetted perimeter that would allow increased invertebrate production,

- An increase on the frequency of flows favoured by kayakers and jet boaters.

I will examine the effect of the alternative abstraction regimes on each of those potential benefits in turn:

An increase in the frequency of flows at which nuisance periphyton and fine sediment are flushed.

59. Firstly, nuisance periphyton is unlikely if freshes greater than 130 m^3s^{-1} are allowed to travel the length of the river more frequently than once every 21 days. If the trigger flow in CRC061972, proposed condition 6 was increased to 130 m^3s^{-1} then the nuisance periphyton is less likely to become an issue. Nevertheless if there will be some periphyton scour during flows in the range 41-100 m^3s^{-1} so any increase in duration of the flows in this range will have positive effect on stream health.

An increase in the number of islands available for river bed nesting birds (Hughey evidence).

60. For river bed nesting birds to thrive Dr Hughey in his evidence describes the need to retain flood size to keep the channel vegetation free, to maintain flows that maximise the number of braids and maintain flows that maximise food (benthic macro-invertebrate) production during the August to December breeding season. The latter two are influenced by the alternative flow regimes. In Dr Hughey's Figure 7 the number of braids is at a maximum between 55 m^3s^{-1} and 95 m^3s^{-1}. To determine the effect of the different take regimes on the number optimal flows for river bed nesting I counted number of days during 1 September to 31 December for 1967 to 2001 where the mean daily flow was less than 55 m^3s^{-1}, between 55 and 95 m^3s^{-1} and greater than 95 m^3s^{-1}. The results are shown in Table 1.

Table 1. The average number of days per year during September to December the mean daily flow was in various flow bands for 1967 to 2001 for various take regimes. Numbers in bold indicate the preferred flow range.

Flow band (m^3s^{-1})	Unmodified (days)	Pre-CPW (days)	Post-CPW (days)	Post-CPW 1:1 sharing (days)	Post-CPW Block take > 90 m^3s^{-1} (days)	Post-PW Block take > 100 m^3s^{-1} (days)
<55	1.6	12.2	23.9	20.4	12.2	12.1
56-94	**33.0**	**38.3**	**32.3**	**36.6**	**44.5**	**44.1**
>95	87.4	71.5	65.8	65.1	65.6	65.8

61. The first line of the table shows that any abstraction dramatically increases the number of days the flow is not optimal for river bed nesting birds, but the delaying

the B Block take until flow reaches 90 m^3s^{-1} or 100 m^3s^{-1} is the best Post-CPW extraction regime for riverbed dwelling birds.

62. The second line of the table shows that there is not a lot of difference between take regimes in the duration that flows are optimal, but the 1:1 flow sharing regime is better than the unaltered Post-CPW regime and the B Block take after 90 m^3s^{-1} or100 m^3s^{-1} is the best of the Post-CPW take regimes.

63. More analysis is possible and probably needed, e.g., on the timing of the low flows which may have a lesser effect if the were later in the breeding season and whether successive years have long periods with flows <55 m^3s^{-1} that could a cumulative effect on breeding.

64. The best B Block CPW abstraction regime for river bed nesting beds appears to be delaying the take until flows are greater than 90-100 m^3s^{-1} and the second best is the B Block 1:1 sharing regime.

An increase in the frequency of flows suitable for salmon angling.

65. According to Mr Hayes's evidence salmon anglers prefer to fish when the unmodified flows are in the range 50-80 m^3s^{-1} (his paragraph 6.37). I interpret Mr Hayes paragraph 4.22 to indicate that most salmon angling takes place between 1 December and 30 April. To determine the effect of the different take regimes on the number of days when the flow was in the preferred range for angling I counted number of days during 1 December to 30 April for 1967 to 2001 that the mean daily flow was, between 50 and 80 $m^3s^{-1}$and the number of days above and below those flows. The results are shown in Table 2.

Table 2. The number of days per year during December to April where the mean daily flow was in various flow bands for 1967 to 2001 for various take regimes. Number in bold indicate the preferred flow range.

Flow band (m^3s^{-1})	Unmodified (days)	Pre-CPW (days)	Post-CPW (days)	Post-CPW 1:1 sharing (days)	Post-CPW Block take > 90 m^3s^{-1} (days)	Post-CPW Block take > 100 m^3s^{-1} (days)
<50	21.8	62.1	97.4	75.4	62.0	62.0
50-80	**51.7**	**35.7**	**17.1**	**39.9**	**52.4**	**52.4**
>80	77.7	53.4	36.8	37.4	36.8	36.9

66. The second line in the table is of most interest. The Pre- and Post-CPW and Post-CPW 1:1 sharing regimes have a substantially decreased number of days per year with preferred fishing flows compared to the unmodified flow. However, the Post-CPW 1:1 B Block sharing has almost twice as many preferred fishing flow days as the unaltered Post-CPW take and has a similar number of preferred angling flow days to Pre-CPW take regime. From a salmon angling view point, the best Post-

CPW take regimes are the Post-CPW B Block takes when flows are >90 m^3s^{-1} or >100 m^3s^{-1} and they have three times as many days with preferred fishing flow days as the unaltered Post-CPW regime and a similar number to the unmodified flow regime.

67. In conclusion it appears that accessing the B Block allocation at flows >90 m^3s^{-1} or >100 m^3s^{-1} offers the best mitigation for preferred salmon angling flows, but the 1:1 flow sharing of the B Block allocation does offer a much increased number preferred salmon angling flows than the unaltered Post-CPW take.

An increase in the wetted perimeter that would allow increased invertebrate production

68. The assumption in Dr Olsen's evidence is that more flow equals more invertebrate production and that if a particular flow regime resulted in higher mean and median flows then there would be an increase in invertebrate production. However, if flows get too high invertebrates are flushed away, and it takes time for the invertebrates to drift to, and colonise, barren areas and for communities to build up numbers commensurate with the wetted area. Dr Burrell indicates that increased flow stability could lead to higher invertebrate numbers.

69. NIWA and Cawthron Institute staff have been working on a model that incorporates these ideas. The model is still under development. I have applied it to the December to May period as Dr Olsen's evidence (Appendixes J, K) indicates that that is when the CPW has a more than minor effect on reducing food production and *Deleatidium* weighted useable area (WUA). A typical year (1989/90) was modelled as CPW has very little impact during a dry year. The model requires:

- A flow vs WUA relationship. One was taken for the most abundant benthic macroinvertebrate, *Deleatidium,* from Dr Olsen's Figure 6. I extended this curve to 768 m^3s^{-1} using data from recent modelling runs.

- A relationship between bed disturbance and flow. A relationship for surface flushing similar to Figure 1 was used except that the percentage disturbance applied to the whole river and not just the median flow bed.

- The time between full bed disturbance and full colonisation of the bed by invertebrates. A duration of 15 days for summer colonisation was used. It was based on data from Sagar (1983) who conducted invertebrate colonisation experiments in the Rakaia River.

70. The model has these basic assumptions:
- In the absence of bed flushing *Deleatidium* WUA would be proportional to *Deleatidium* population.
- Bed flushing reduces the *Deleatidium* population.

- WUA is determined by depth and velocity alone, and is unrelated to bed flushing.
- There is a linear re-colonisation rate, with full re-colonisation occurring after a specified re-colonisation time (e.g. 15 days).

71. The model output for each flow can be summarised as summing of the daily WUA from December to May. Table 3 shows an index of the invertebrate productivity for each take regime.

Table 3. An index of *Deleatidium* productivity summed for December 1989 to March 1990 for various take regimes.

Unmodified	Pre-CPW	Post-CPW	Post-CPW 1:1 sharing	Post-CPW Block take > 100 m^3s^{-1}
16277	15969	15913	16169	16289

72. The index of productivity for the take regimes is no more than 2.5 % different from the unmodified flow regime and so the effect on *Deleatidium* productivity could be said to be less than minor. There were a number of floods during the period modelled and the flushing effect of the floods has limited the use the *Deleatidium* could make of the available physical habitat.

An increase on the frequency of flows favoured by kayakers and jet boaters.

73. Mr Tipler has suggested consent conditions that would provide some mitigation for boating interests that would probably satisfy most of the requirements for racing events, but any increase in flows in the range 63 to 100 m^3s^{-1} would probably be of benefit to be boating public. It is clear from the combined evidence of the canoeists that racing is only a small portion of their year long use of the Waimakariri River. Tony Ward Holmes summarises canoe/kayak ideal flow requirements to be 70 – 150 m^3s^{-1} with 50 m^3s^{-1} as an absolute minimum. Table 4 shows the analysis of the time when the Waimakariri River is in the flow ranges suitable and less suitable for canoes and kayaks.

Table 4. The number of days during the year where the mean daily flow was in various flow bands for 1967 to 2001 for various take regimes. Number in bold indicate the preferred flow range for canoes and kayaks.

Flow band (m^3s^{-1})	Unmodified (days)	Pre-CPW (days)	Post-CPW (days)	Post-CPW 1:1 sharing (days)	Post-CPW Block take > 90 m^3s^{-1} (days)	Post-CPW Block take > 100 m^3s^{-1} (days)
<50	32.7	81.5	140.2	106.1	89.8	89.8
50-70	65.9	66.0	43.8	75.5	87.5	62.4
70-150	**180.8**	**145.2**	**115.1**	**113.5**	**122.0**	**147.3**
>150	85.8	72.6	66.1	70.1	65.9	65.9
50-150	246.7	211.2	158.9	189.0	209.6	209.6

74. Flows are in the ideal flow range (70-150 m^3s^{-1}) for the majority of the time regardless of the flow regime, and are in an acceptable flow range (50-150 m^3s^{-1}) for many days per year. The Post-CPW regime where the B Block water is taken when the flow is >100 is the regime most like the Pre-CPW regime, with the 1:1 sharing of the B Block being only marginally better that the unaltered Post-CPW regime.

75. Ralph Adams gave evidence (paragraph 3.4) that most jet boaters prefer to flows of 50-70 m^3s^{-1} to boat in, but jet-boating was possible at flows as low as 40 m^3s^{-1} but such flows required more skill or experience and were more likely to be hazardous to others on the water because of the reduced width of navigable water. Ralph Adams comments of timing of river use were interpreted to mean that most jet boating was done during December to March. Table 5 shows the analysis on of the time when the Waimakariri River is in the flow range suitable for jet boats.

Table 5. The number of days during the year where the mean daily flow was in various flow bands for 1967 to 2001 for various take regimes. Number in bold indicate the preferred flow range for jet boats.

Flow band (m^3s^{-1})	Unmodified (days)	Pre CPW (days)	Post CPW (days)	Post CPW 1:1 sharing (days)	Post CPW Block take > 90 m^3s^{-1} (days)	Post CPW Block take > 100 m^3s^{-1} (days)
<40	7.4	33.6	73.8	37.7	35.1	35.1
40-50	8.0	14.9	4.4	22.1	13.4	13.4
50-70	**28.8**	**21.2**	**9.8**	**27.1**	**39.4**	**21.1**
>70	77.1	51.6	33.3	34.4	33.4	51.6
40-70	36.8	36.1	14.1	49.2	52.9	34.6

76. The Post-CPW B Block flows taken when the flow is >90 m^3s^{-1} appears to offer the best regime for jet boating. The Post-CPW 1:1 B Block sharing regime and the unmodified flows have a similar number preferred jet boating days. The take when flows are >100 m^3s^{-1} gives a similar number of days per year where flows are preferred for jet boating to the Pre-CPW flow regime.

77. I conclude for the alternative take regimes that the alternatives offer advantages for the activities examined and bird nesting because they increase the time the flows are in the preferred flow bands. Delaying abstraction of the B Block allocation until the unmodified flows are greater than 90 m^3s^{-1} or100 m^3s^{-1} appears to be a better alternative than 1:1 sharing of the B Block allocation.

78. There appears to be no material difference between the various flow regimes in invertebrate productivity according to the invertebrate productivity index.

Conclusions

79. The study suggests that a flow of the order of FRE3 (three times the median flow: 288 m^3s^{-1}) in the Waimakariri River is sufficient to disturb the bed to reset the benthos (both periphyton and invertebrates). At this flow the model suggests that 79% and 77% of the minimum and median flow beds respectively were surface flushed and 58% and 55% of the minimum and median flow beds were deep flushed respectively.

80. Based on modelled velocity long filamentous algae was scoured from 80% of the minimum flow bed at a flow of 82 m^3s^{-1} and from 80% of the median flow bed at a flow of 130 m^3s^{-1}. Both short filamentous algae and diatoms would be removed from the ~80 % of the minimum and median flow beds by surface and deep flushing at a flows of 290-300 m^3s^{-1} before being scoured by velocity alone.

81. It follows from this that for the suggested condition 6 for CRC061972 for the trigger flow for the recommencement of the take be amended to 130 m^3s^{-1}.

82. On the relationship between flow and braiding intensity in the Waimakariri River there are on average 7.7 braids when the flow is 40 m^3s^{-1} and they reach a maximum of 10.5 braids at a flow of 100/110 m^3s^{-1} when they decrease to 6.2-6.5 at a flows of 480-768 m^3s^{-1} at the Crossbank reach.

83. On the relationship between flow rate and morphological change in the Waimakariri River, the flat lining is unlikely to have any effect on channel morphology, because it is the flood flows that determine and change the channel morphology with the extensive changes occurring when flood peak are more than 500-800 m^3s^{-1}.

84. Most potential bed elevation changes associated with abstraction by CPW would be too far from most existing abstraction points to cause any issues. Any changes in elevation would most likely be gradual and be able to be managed. None of the existing irrigation abstraction points in Canterbury appear to have had bed elevation change issues.

85. The establishment of a telemetered water-level recorder on the Waimakariri River at Otarama upstream of the proposed abstraction points should ease abstraction management to ensure that the minimum flow is not breached, that the A Block abstractions are not compromised by B Block abstractions and enable CPW to respond to flow increases.

86. The effects of alternative abstraction regimes have been explored and delaying the B Block abstraction until the unmodified flow has reached 90 m^3s^{-1} or 100 m^3s^{-1} appears to increase the duration of desirable flows for most biota and recreational

activities. The 1:1 sharing between the river and abstraction of B Block water shows a significant but smaller advantage over the currently prescribed B Block abstraction regime.

Maurice Duncan

29-7-08

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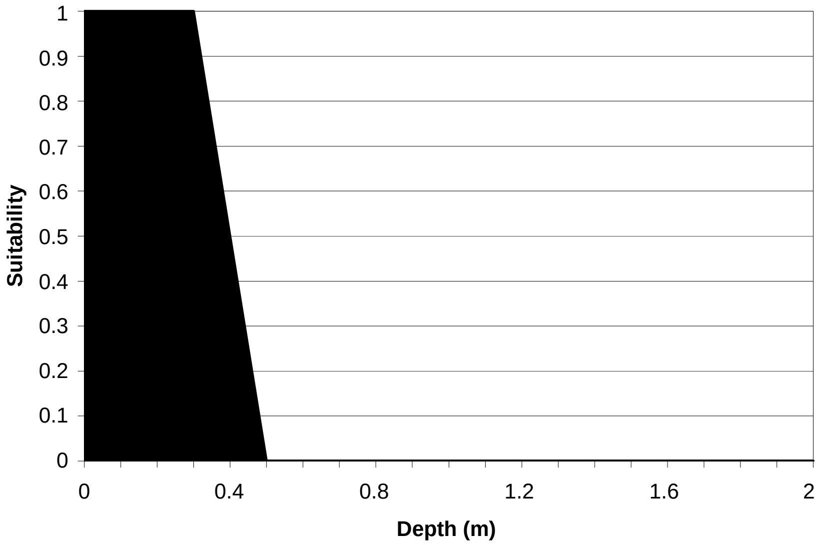
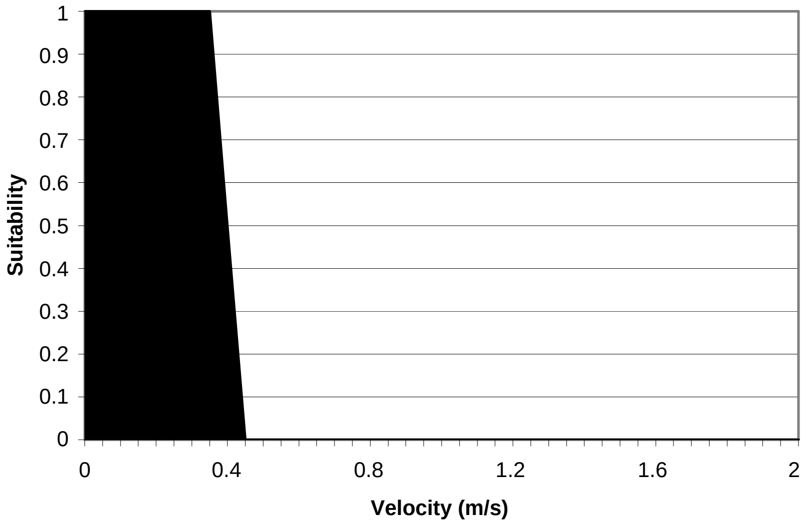
Appendix 1: Habitat suitability curves

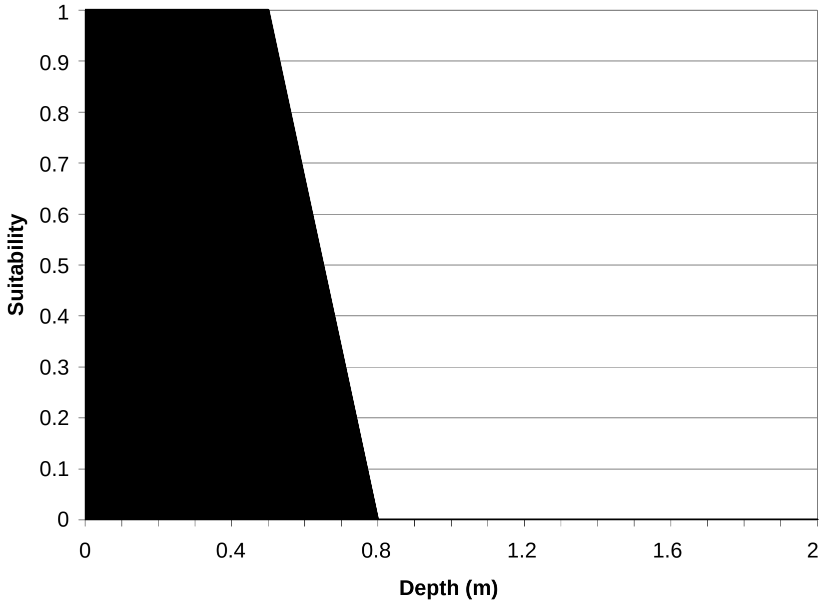
Dark areas indicate depths and velocities that are suitable for algae and white areas indicate depths and velocities that are not suitable (Jowett 2003.

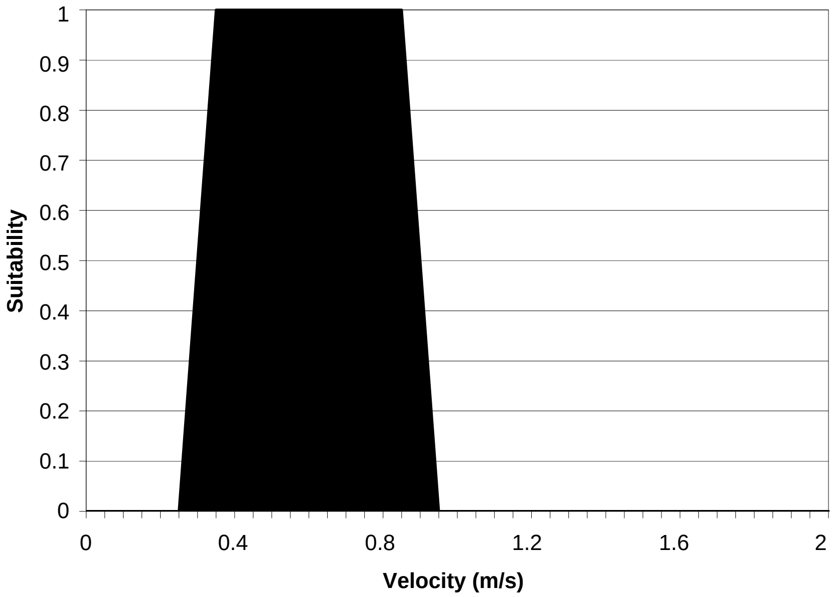
Long filamentous algae



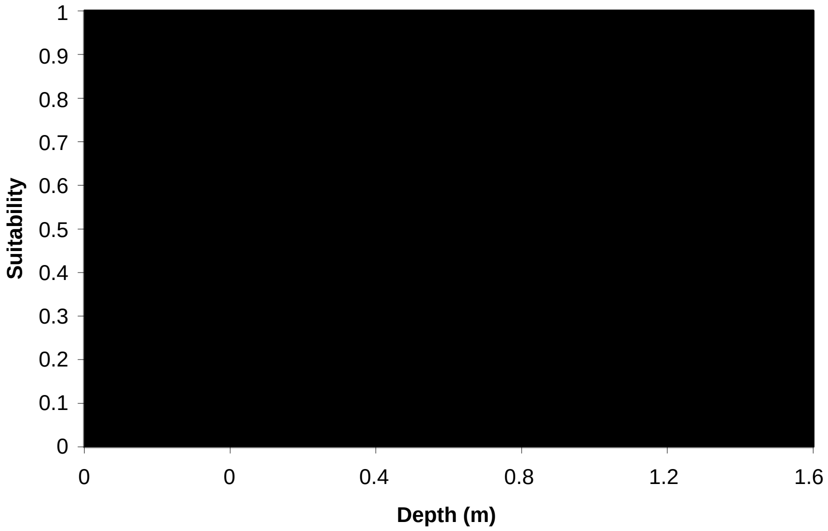


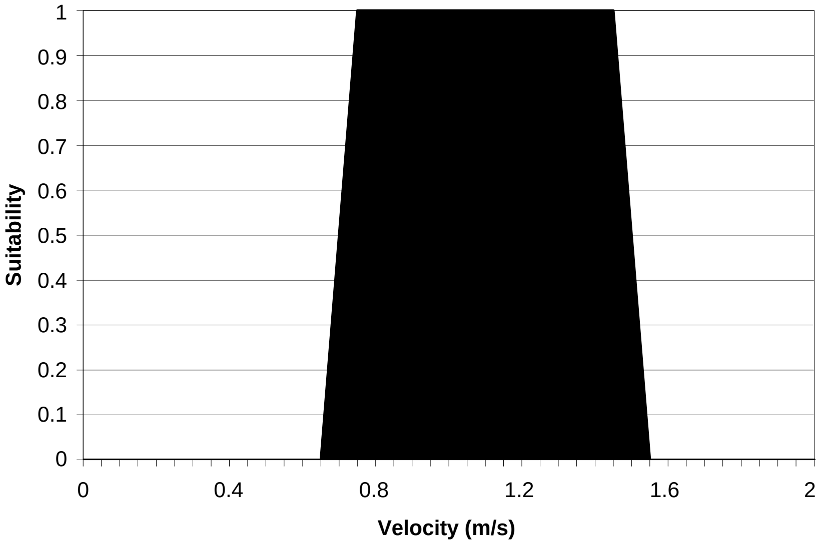
Short filamentous algae





Diatoms


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Suitability
0
0
0.4
0.8
1.2
1.6
Depth (m)


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Suitability
0
0.4
0.8
1.2
1.6
2
Velocity (m/s)