Waimakariri River: B/C Block allocation review

Environment Canterbury
Your regional council

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Prepared for Environment Canterbury by
NIWA
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August 2008

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NIWA Client Report: CHC2008-107
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Executive Summary

Environment Canterbury wish to assess for the Waimakariri River the environmental effects of different sizes of B/C allocation blocks and appropriate flow regime requirements to minimise these effects.

Planning for the Waimakariri River Regional Plan (WRRP) did not envisage a large uptake of the B Block allocation because of the unreliability of run-of-river water and so the B Block allocation was not capped. Off-stream storage can use unreliable water and so there is now a need to review the B Block allocation to consider what the limits should be on allocation, and what flow regime requirements might be needed to minimise the effects on instream values of different allocation scenarios.

This report reviews community concerns on environmental effects of B/C Block abstractions and determines that the critical issue is the need to have flows in the range 55-96 m^3s^{-1} during September to December for riverbed nesting bird breeding and to have flow in the range 60-100 m^3s^{-1} during December to April for salmon angling. If flows were sufficient for these activities then there would be sufficient flow for salmon passage, kayaks and jet boats. Other issues, such as flow regimes to flush periphyton and fine sediment and to preserve bedload transport and channel forming capacity, are discussed.

The effects of allocation mechanisms such as abstraction limits, flow sharing and gaps between allocation blocks on the critical values are discussed with flow limits and gaps between allocation blocks appearing to be the most useful in preserving environmental values.

Simulations of the different allocation mechanisms were carried out on a naturalised record to quantify their effects on the critical flows resulting in a gap between the A and B Block of 27 m^3s^{-1} showing marked advantages over having smaller gaps (including no gap) or 1:1 sharing.

An allocation regime is recommended that allows certain freshes and large floods to pass without take, a maximum 40 m^3s^{-1} B Block allocation with a 27 to 37 m^3s^{-1} gap between the A and B Blocks from September to April and a 5-10 m^3s^{-1} C Block allocation without a gap between B and C Blocks. Allowance could be made for flow manipulation by abstractors to bring flows closer to preferred flows for kayak and jet boat races, fishing contests etc on the river for a limited number of occasions.

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1. Introduction

1.1. Background

Environment Canterbury wish to assess for the Waimakariri River the environmental effects of different sizes of B/C allocation blocks and appropriate flow regime requirements to minimise these effects.

The hydrological investigations and plan development work that was done for the Waimakariri River Regional Plan (WRRP) identified it as a relatively unreliable source of water for major run of river irrigation schemes, especially if dairying was a significant land use. This is because the river commonly has low flows during the February – March period and often is unable to meet the full demand of the A block provided for in the plan. With this background, the plan provided for a B block but did not place an upper limit on its size. This was because the B block was so unreliable that a further run of river large irrigation scheme would not be economic. A large irrigation scheme founded on takes into storage at higher flows, such as the Central Plains Water Enhancement Scheme (CPW), was not contemplated during plan preparation. With CPW, and potentially other requests to take water, it is timely to consider what the limits should be on allocation, and what flow regime requirements might be needed to minimise the effects on instream values of different B/C Block allocation scenarios.

While this report is primarily about B and C flow allocation blocks, some information is provided about the A Block so the reader can distinguish between the effects of A block abstraction and combined A and B/C Block allocations.

1.2. Key environmental values to conserve

Before deciding on an allocation framework the community needs to indicate the instream and out of stream values that are important. It has become apparent from the CPW hearings that there are a number of key values that are of concern:

- The need to maintain flows in a range suitable for providing the maximum number of islands suitable for the breeding of riverbed nesting birds during the breeding season,

- The need to provide flow regimes that are not detrimental to invertebrate life suitable as food for native fish, salmonids and river birds,

- The need to retain freshes capable of flushing undesirable periphyton growths that can smother the gravel any time of year when flows are stable, so maintaining the rivers suitability as habitat for aquatic insects that are prey for birds and fish,

- The need for a flow regime that retains the channel forming flows that are responsible for the morphology of, appearance of, and sediment transport in, the river. Such flows need to be capable of removing, and preventing encroachment of, exotic vegetation into the riverbed. Maintaining a bare gravel river bed is essential to providing habitat for riverbed nesting birds,

- The need to maintain flows in a range suitable for salmon angling during the key angling months,

- The need to maintain flows most favoured by jet boaters during the summer,

- The need to maintain flows suitable for kayaking.

1.3. Tasks

- Analyse different sizes of B Block and their effect on:

  (a) flushing flows that remove periphyton and fine sediment;

  (b) floods that maintain sediment transport, riverbed appearance and remove exotic vegetation from the fairway,

  (b) the availability of flows within the desired flow range for salmon fishing;

  (c) the frequency and duration of "flatlining" and whether this creates any specific issues, e.g., promoting periphyton growth, impacts if any on salmon/boat passage, encroachment of exotic vegetation;

- Determine whether there should be a gap between the A and B Block, and/or flow sharing within the B Block, along with a robust justification.

- Determine whether a C Block should be provided that may be useful for storage abstractions and which does not have significant environmental impacts. Matters that probably need to be considered include: where would it best be located in the hydrograph having regard to recommendations for the B Block; what size might it be; what would the reliability be; what additional flow management provisions (gap, sharing etc) would need to be considered; what impacts might there be on flows that reset the bed and maintain braiding variability; and impacts on the same matters raised for the B Block.

2. Approach

2.1. Alternative approaches

There are a number of approaches to conserving the values outlined in Section 1.2. By using the word “conserving” I wish to indicate not a preservation of the current flow regime, but a regime that would allow most of the values to be retained at a level acceptable to most of the community.

The alternative approaches to defining a B Block allocation could include combinations of:

- Limiting the size of the B/C Blocks
- Providing a flow gap between the allocation blocks.
- Implementing a flow sharing regime whereby for each increment of flow abstracted an increment is left in the river.
- Having a minimum flow for the abstraction block that varies with time.
- Having rules to preserve particular aspects of the flow regime such as small freshes to flush periphyton or large floods to maintain channel forming flows, sediment transport and a vegetation-free open gravel riverbed.
- Having a set number of specified days where recreational interests could request that consents not be exercised if that would result in flows being within a desirable flow range.

3. Preferred flow ranges

The information that follows has been obtained primarily from evidence presented at the CPW consent hearings. Some of the evidence has not appeared in peer reviewed literature, and there were variances of opinion between witnesses. Thus some of the flow requirements may be less precise than presented here. Precise numbers were used in the report to enable simulations of different take regimes to be carried out.

Under the WRRP abstraction from the B Block will cause flatlining at 41 m^3s^{-1} in summer (assuming all the A Block is being abstracted) and at ~63 m^3s^{-1} in winter depending on the degree to which the A Block is being abstracted. The flatlining at those flows is of little value to river users. One of the approaches detailed here is the use of 1:1 flow sharing or flow gaps between the A and B Blocks to manipulate the residual flows to bring them into the desired flow range for longer.

Jowett et al (2008) show in a habitat assessment based on velocities and depths from 2D modelling at Crossbank that all species examined benefitted from increased physical habitat with increased flow in the range 20-120 m^3s^{-1} but habitat quality may reduce as flows get larger, especially for native fish.

3.1. Periphyton and fine sediment flushing

Duncan and Bind (2008) suggest that long filamentous algae would be flushed from the minimum flow (41 m^3s^{-1}) channel at a flow of 82 m^3s^{-1} and from the median flow channel when the flow is 130 m^3s^{-1}. NIWA’s national water quality monitoring data base indicates that at the Gorge and the State Highway One Bridge, where the river is single thread, that blue/green mat-forming cyanobacteria predominate and filamentous algae are only a minor component. Flows capable of flushing long filamentous algae are capable of flushing thick blue/green cyanobacteria mats, but thin films may be more resistant.

Abstractions are likely to reduce the magnitude and frequency of small freshes capable of flushing sediment and periphyton. In order to mitigate this effect, consent conditions are required that maintain the frequency of flows >80 m^3s^{-1} and preferably >130 m^3s^{-1} after a period of low flow of sufficient duration to potentially allow the growth of periphyton to nuisance levels.

In a poorly armoured river like the Waimakariri the turbulent water in the steep rising limb of the hydrograph is likely to entrain fine sediment capable of abrading periphyton, and provide sufficient shear stress to flush periphyton, so a prolonged period at 130 m^3s^{-1} is probably not required. For flushes <130 m^3s^{-1} a longer duration (say 2 days) is required to provides the abrasion and stressing because there will be less sand in suspension than for larger freshes.

Duncan and Bind (2008) and discuss whether the Crossbank reach is representative. Duncan and Bind (2008) conclude that as the grain size, bed slope and braiding intensity are more or less in equilibrium throughout the river it is likely that the results of the model also apply elsewhere on the river. Jowett et al (2008) conclude that the 2D hydraulic modelling produced results that are consistent with hydraulic relationships measured in the Waitaki River which is also a large braided river. Any differences in hydraulic parameters between the Waimakariri and Waitaki Rivers were consistent with the lower gradient of the Waimakariri River.

3.2. River bed nesting birds

River bed nesting birds require predator free and weed-free islands to breed on and a large wetted area to maximise invertebrate feeding opportunities. Recent research (Boffa Miskell and Urtica Consulting 2007) has shown that the presence of water has a deterrent effect on potential mammalian predators regardless of their swimming ability. Thus river bed nesting bird breeding success could be enhanced by encouraging flows that maximise the number of islands large enough to provide nesting sites. Hughey (2008) has shown that the number of islands in the Crossbank Reach of the Waimakariri River (~12 km upstream of the State Highway One Bridge) is maximised at flows of 60-90 m^3s^{-1}. The river bed bird breeding season is from September to December.

3.3. Salmon angling

Most salmon anglers prefer to fish the Waimakariri River when the measured flows are in the range 50-80 m^3s^{-1} (Hayes 2008) and most salmon angling takes place between 1 December and 30 April (Hayes 2008), although expert anglers may fish in flows up to 100 m^3s^{-1} because the relationship between turbidity and flow shows wide scatter (Hayes 2008b). Salmon angling is most successful when the turbidity is the clarity range of 0.4 to 1.0 m. As this level of turbidity is caused by very fine particles abstractions are unlikely to alter turbidity levels in the river. Allowing for abstraction of about 20 m^3s^{-1} these measured flows are equivalent to naturalised flows of 70-100 m^3s^{-1}. The most frequently fished flows go as low as naturalised 60 m^3s^{-1} but this lower figure was not used in the analysis later in the report.

3.4. Salmon passage and migration

Instream habitat modelling at Crossbank indicates that 41 m^3s^{-1} will provide continuous fish passage depths greater than 0.3 m and this exceeds the 0.25 m minimum depth requirements for salmon passage (Hayes 2008). Nevertheless radio tagging has indicated salmon more slowly migrating up river at low flows than during freshes (Glova and Docherty 1986). Long periods of low flows delay upstream migration, cause extra abrasion of their bodies and ultimately affect reproductive success (Hayes 2008). A gap between A and B Block allocations would reduce the period of flatlining at or about 41 m^3s^{-1}.

Any B Block allocation would reduce recession flows and potentially impact on upstream migration (Hayes 2008).

3.5. Invertebrate production

Maintaining production of particular invertebrates is a key to providing food for birds and fish. Those particular invertebrates are sensitive to excessive nuisance periphyton growth and deposition of fine sediment. Thus there is a need for regular flushing of the bed to remove the nuisance periphyton and fine sediment with the risk that the preferred invertebrates will be flushed as well although most preferred invertebrates are expected to be affected less by flushing than less desirable species that are often associated with periphyton proliferations.

Modelling work (Jowett et al 2008) has shown that as the flow in the Waimakariri River increases so does the suitable habitat characterised as Weighted Useable Area (WUA) for the food producing invertebrates that can utilise that habitat given that the flow remains stable for a sufficient time (15 days (Sagar 1987)). This appears to indicate that any reduction in flow would reduce WUA and invertebrate production. However, if the flow reduction also led to more flow stability the invertebrate population may have a greater opportunity to exploit the available physical habitat. The other factor that needs to be taken into account is that all freshes and floods are likely to reduce invertebrate populations with floods greater than about 300 m^3s^{-1} likely to substantially reduce (reset) invertebrate populations (Duncan and Bind 2008). Duncan and Bind (2008) also showed that even in large (~800 m^3s^{-1}) floods there are significant areas with suitable depths and velocities to act as refugia for invertebrates that can then repopulate channels as flow recedes.

Research and preliminary modelling initiated by Cawthron Institute staff and carried out by NIWA staff takes into account the flow vs WUA relationship, the effects of high flows on invertebrate populations and the time to repopulate after a flushing event to provide a time series of an index of invertebrate production. The time series can be totalled, or averaged, for a variety of abstraction scenarios. Preliminary results indicate that the abstraction regime has little effect on the index of invertebrate production. The modelled time period had several high flow events that would have meant that habitat (as measured by WUA in the model) is not likely to be limiting. Details of the assumptions for and results of, this work can be found in Appendix 2. This work is in its early stages and has not been verified by field observations; nevertheless it indicates that the presence of extra physical habitat as a result of flow regime manipulation may not result in extra invertebrate production.

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

Ideal flows for kayakers are 70 – 150 m^3s^{-1} with 50 m^3s^{-1} as an absolute minimum and the river is used all year. Because of its proximity to Christchurch the river is popular for kayaking (Ward-Holmes 2008).

Most jet boaters prefer flows of 50-70 m^3s^{-1}. Jet-boating is possible at flows as low as 40 m^3s^{-1} but such flows require more skill or experience and are more likely to be hazardous to others on the water because of the reduced width of navigable water (Adams 2008). Most jet boating is done during December to March (Adams 2008).

3.7. Summary

Figure 1 shows the preferred flow ranges for each of the key values of concern and the time when they are required. It is clear that kayaks can use a large range of flows and that any flows that are targeted for other values will be suitable for kayaks. The preferred range of flows for jet boats (if we exclude the 40-50 m^3s^{-1} marginal boating range) is below range for salmon angling. Thus the target flows for any new allocation regime should be 55-95 m^3s^{-1} from September to December and 50 or 70 to 100 m^3s^{-1} for January to April. For May to August it may be possible to apply fewer restrictions on takes because they would not impinge on the key values of community concern.

4. Likely effects of alternative approaches

During the CPW hearing many flow duration curves were presented that illustrated the effects discussed in this section. Section 6 has flow duration curves that illustrate the effects on flows of the alternative approaches.

4.1. Limiting the size of the B Block

There should be some limit on the amount of water in the B (or C) Block allocation. If the B Block was large (>40 m^3s^{-1}) the river would be flat lined (unless there was flow sharing) for a long period of time at flows much less than required to meet the requirements for the key environmental values and would only meet the required values for short periods of time.

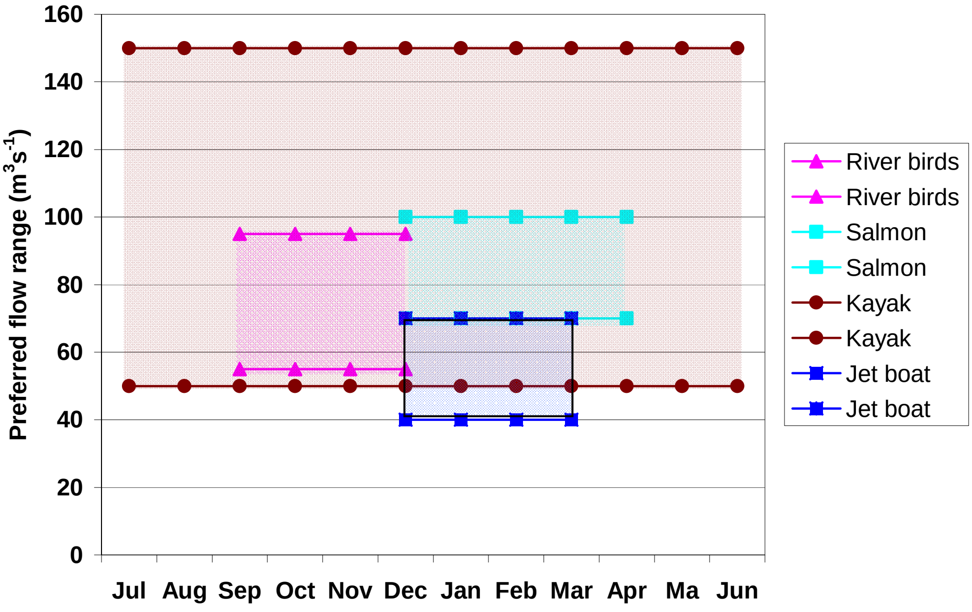

Figure 1: The preferred flow ranges for key values of community concern and the times when they are required.

If the B Block allocation was <40 m^3s^{-1} there could still be long periods of flatlining as flows are in the range just above the A Block allocation for a lot of the time, but the time flows are in a useful range for key environmental values would be longer than for large B/C Blocks.

Accordingly, on its own limiting the size of the B Block may not be particularly useful as water will be taken when flows would otherwise be in a useful range for key environmental values.

4.2. Providing a flow gap between the A and B Block allocations.

Currently B Block allocations would cause flatlining at flows of little value to river users and reduce the time flows are in a useful range. Providing a flow gap between the A and B Block has potential to mitigate this issue.

Providing a gap between A and B Blocks is a very useful tool for reducing the ecological effects of water abstraction. It allows the flow to remain in the range most useful to the key environmental values for the longest time, albeit detrimentally affecting the reliability of the abstraction. B Block water is less reliable than A Block water and storage is probably needed to obtain a reliable water supply from B Block water. Reducing the reliability of abstraction would require an increase in the storage capacity to retain the same water supply reliability. One effect of allowing a gap between the A and B Blocks is to create a flat line hydrograph at the level of the minimum flow for the B Block. Thus if the gap between the A and B Block was varied with season the flow at which the flat line occurred would maximise the flow in the preferred range for the season.

4.3. Implementing a sharing regime whereby for each increment of flow abstracted an increment is left in the river

Instream values may be protected in a number of ways. One way is to have a relatively low minimum flow where instream values are probably compromised, but reduce the probability of flows getting that low by having, say, a 1:1 sharing ratio, e.g., the Rangitata flow regime. An alternative is to have a higher minimum flow that adequately protects instream values and no flow sharing, e.g., the WRRP. While the two approaches are not mutually exclusive usually one or other approach is used. It is clear from the arguments being presented to the CPW hearing that most instream values are protected by the Waimakariri minimum flow and the discussion appears focussed on recreational issues that require higher flows.

One of the arguments for flow sharing is that it moves someway to preserving the natural flow regime. In my view there is nothing particularly useful about this concept. In fact the natural Waimakariri flow regime is responsible for severely limiting the productivity of the river and some flow stability might enhance its productivity. However, there are aspects of the Waimakariri River flow regime that are characteristic and need to be retained. Flow sharing is probably not the best way to ensure that these characteristics are retained. Rather there should be particular rules and consent conditions that ensure that these characteristics are retained (see Section 4.5).

Flow sharing is a fairly blunt tool for getting particular flows to enhance or increase the time the river spends in particular preferred flow ranges, but is more likely to keep the river within the preferred range of flows than allocation without flow sharing.

One piece of the flow regime that is required are flows that will flush periphyton. Duncan and Bind (2008) show that flows between 80 m^3s^{-1} and 130 m^3s^{-1} are required in the Waimakariri River to flush periphyton and fine sediment to keep the river healthy. If the B Block minimum flow is 63 m^3s^{-1}, the B Block take is 40 m^3s^{-1} and there is 1:1 sharing, when the naturalised flow is 143 m^3s^{-1} the residual flow in the river is 80 m^3s^{-1} (assuming an A Block allocation of 23 m^3s^{-1} without flow sharing). That is just on the threshold for periphyton flushing if the pre-existing flow was at the minimum flow of 41 m^3s^{-1}. In that case 1:1 sharing does not cause the flow to cross the threshold for periphyton flushing, but flows approaching 80 m^3s^{-1} would have some periphyton flushing effect.

4.4. Having a minimum flow for the abstraction B Block that varies with time

As is shown in Section 3 the preferred flow ranges vary with time so by varying the gap between the A and B Blocks the flat lining caused by the B Block allocation could be varied to maximise the time the flow was the either at the optimum for the activity (e.g. bird breeding or salmon angling) or possibly at the lower end of the preferred range to enhance the reliability of any abstraction.

4.5. Having rules to preserve particular aspects of the flow regime such as small freshes to flush periphyton or large floods to maintain channel forming flows and sediment transport

Regardless of the main B Block allocation rules (flow sharing, gaps between allocation blocks or allocation limits) there need to be specific rules to promote periphyton and fine sediment flushing and to maintain channel forming flows.

Duncan and Bind (2008) show that long filamentous algae are flushed from the minimum flow channel at a flow of 82 m^3s^{-1} and from the median flow channel when the flow is 130 m^3s^{-1}. Similar flows should flush the blue/green cyanobacteria mats that predominate in the Waimakariri River. Thus during periods of low, stable flows when periphyton grows to nuisance levels after about 21 days (Biggs 2000) freshes occurring after 21 days of minimum or low flow should be allowed to flow untapped until the flow has exceeded 130 m^3s^{-1} or after two days which ever is the sooner.

Duncan and Bind (2008) also show that much of the river bed is being deep flushed at flows > 500 m^3s^{-1} and it can be inferred at such floods channels are being formed, and sediment transport is occurring at significant rates. In theory (Davies 1988) any reduction in flow will result in aggradation of the bed in the long term (many decades). In the short term, pulses of more or less sediment will probably mask any long term aggradation. Significant aggradation has not been apparent at any of Canterbury’s larger irrigation take locations. The largest of these has been in place for ~60 years and others for several decades. To limit sediment ponds, prudent irrigation company managers may voluntarily shut intakes when flows and sediment concentrations are high. Thus requiring irrigation companies to cease abstractions when natural flows are >500 m^3s^{-1} is unlikely to impose any burden and may not be required. If water was abstracted via infiltration galleries some restrictions may be necessary. An alternative approach would be to require consent holders of large takes to monitor bed levels in the vicinity of intakes and to review consent conditions if aggradation became apparent.

4.6. Having a set number of days where recreational interests could request that consents not be exercised to keep flows within a desirable flow range

The Waimakariri River is a nationally important recreational river and hosts a number of formalised recreational events. It is probably reasonable to manage takes for a limited number of days per year, e.g., 6, to ensure the success of such events. Any rules could be structured to limit or prohibit abstractions so as to maintain flows within the preferred flow range during the event. Such events are normally held in the summer and autumn when flows are naturally low and when B Block takes would probably be limited so imposing restrictions on takes is unlikely to place a significant burden on B Block abstractors.

4.7. Summary

It appears from the discussion above that the ideal B Block allocation regime would have the following characteristics:

- A limit on the total maximum allocation,

- Provide a gap between A and B Block allocations to better target the preferred flow regime. This would be achieved by having a minimum flow within the target band so the flatlining caused by the allocation would keep the flow in that band for longer. In the winter months (May to August) between the salmon angling season and the start of the riverbed nesting bird breeding a gap would not serve any useful purpose and would not be necessary. Not having a gap would assist in improving reliability for storage takes.

- Have rules to promote surface flushing of fines and nuisance periphyton after a specific duration of low flows when natural flow increases occur.

- Have monitoring measure the effects of takes at high flows that are necessary to preserve the transport capacity of the river at channel forming flows: to preserve the bare, vegetation-free, braided character of the river and to reduce the possibility of aggradation at major abstraction sites.

- Have rules that restrict takes if necessary on a restricted number of days per year to increase the possibility of having flows in a preferred flow range when the river is wanted for formalised recreational activities.

5. Should there be a C allocation Block?

To a certain extent the need for a C Block really depends on the size of the B Block. Blocks have normally been used to retain priority for those first in time for consent allocations and the purpose of a C Block would be to give access to water to consent holders who are still to apply for consents and give the B Block consent holders some certainty about access to their allocation.

A C Block could be used to further enhance the possibility of keeping flows within the preferred flow range. It could be contiguous with the B Block or there could be a gap and still keep the flow in the preferred range if the B Block was aimed at keeping flows at the lower end of the preferred range.

Any C allocation Block should be subject to the same rules as indicated in Section 4.7.

A C Block would provide the opportunity for small users to gain access to some water should the B Block allocation be allocated to single entity. However it would be quite unreliable: if there was a 40 m^3s^{-1} B Block take and no sharing or gap, ,water could start to be taken ~36 % of the time and the full take of 10 m^3s^{-1} could be taken only~20% of the time.

6. Simulations

The effects of alternative B Block allocations were modelled using the following data and assumptions:

- Mr de Joux’s naturalised Waimakariri at Old Highway Bridge (site number 66401) flow as used by all parties in the CPW hearings.

- That the A Block allocation is 22 m^3s^{-1} and of that 4.896 m^3s^{-1} is stock water that can be taken continuously without restriction. It is acknowledged that the

A Block allocation is now ~23 m^3s^{-1} and any planning will have to take that into account.

- That all A Block water was taken from 1 October to 31 April when flows allowed it and the 4.896 m^3s^{-1} of stock water was taken all year. This assumption reflects the status quo, but some existing consents allow winter abstraction and some consent holders are exploring storage options that will use winter water to fill them.

- That B Block allocations would be taken all year flows permitting.

- B Block allocations of 20, 40, and, 60 m^3s^{-1} were simulated.

- One group of simulations would be for 1:1 flow sharing from a minimum naturalised flow of 63 m^3s^{-1}.

- Other group of simulations would have gaps between the A Block and B Block of 7, 17, 27, 37 and 47 m^3s^{-1}, i.e., abstractions beginning at naturalised flows of 70, 80, 90, and 100 m^3s^{-1}.

The 2D modelling at Crossbank was not used in these simulations, but the criteria used in this section for the optimum flows for riverbed nesting birds and the criteria for periphyton flushing was based on that modelling.

6.1. The effect of different size B Block allocations

The predominant effect of different B Block allocations is to increase the duration that flow is flat lined at 41 m^3s^{-1} and 58 m^3s^{-1}. Flow duration curves of B Block takes of 20, 40 and 60 m^3s^{-1} are shown in Figure 2. The takes cause flatlining at 41 m^3s^{-1} for 9%, 17% and 23 % of the time respectively (Table 1) and at 58 m^3s^{-1} for 9%, 15% and 19% of the time respectively (Table 1). With reference to Figure 1, flatlining the flow at 58 m^3s^{-1} puts the flow in the suitable range for all activities except salmon angling. Table 1 shows the percent of the year when the naturalised flow is in the preferred range for salmon angling (70-100 m^3s^{-1}) and for riverbed nesting birds (55-95 m^3s^{-1}). It is clear that the larger the take the longer the time that the flow is flat-lined at 58 m^3s^{-1} and the longer the time the flow is in the preferred flow ranges. Salmon anglers may argue that as well as the flow, freshes and turbidity also affect angling success. If the flow is suitable for riverbed nesting birds then it is also suitable for kayaks and jet boats. In Table 1 the median flow for both the 40 m^3s^{-1} and 60 m^3s^{-1} take is 58 m^3s^{-1} because the median lies in the area of flatlining for both sizes of take.

Table 1: The effect of different sized B Block allocations on flow statistics (1967-2007).

	Naturalised	**A Block Summer**	**A Block Summer + 20 m^3s^{-1} B Block**	**A Block Summer + 40 m^3s^{-1} B Block**	**A Block Summer + 60 m^3s^{-1} B Block**
Mean flow	125	112	97.7	87.6	80.2
Median flow	95	81	62	58	58
% time at 41 m^3s^{-1}	0	0	9	17	23
% time at 58 m^3s^{-1}	0	0	9	15	19
% time at 70-100 m^3s^{-1}	27.0	21.6	14.9	10.5	7.5
% time at 55-95 m^3s^{-1}	38	33.5	34.5	34.3	34.7

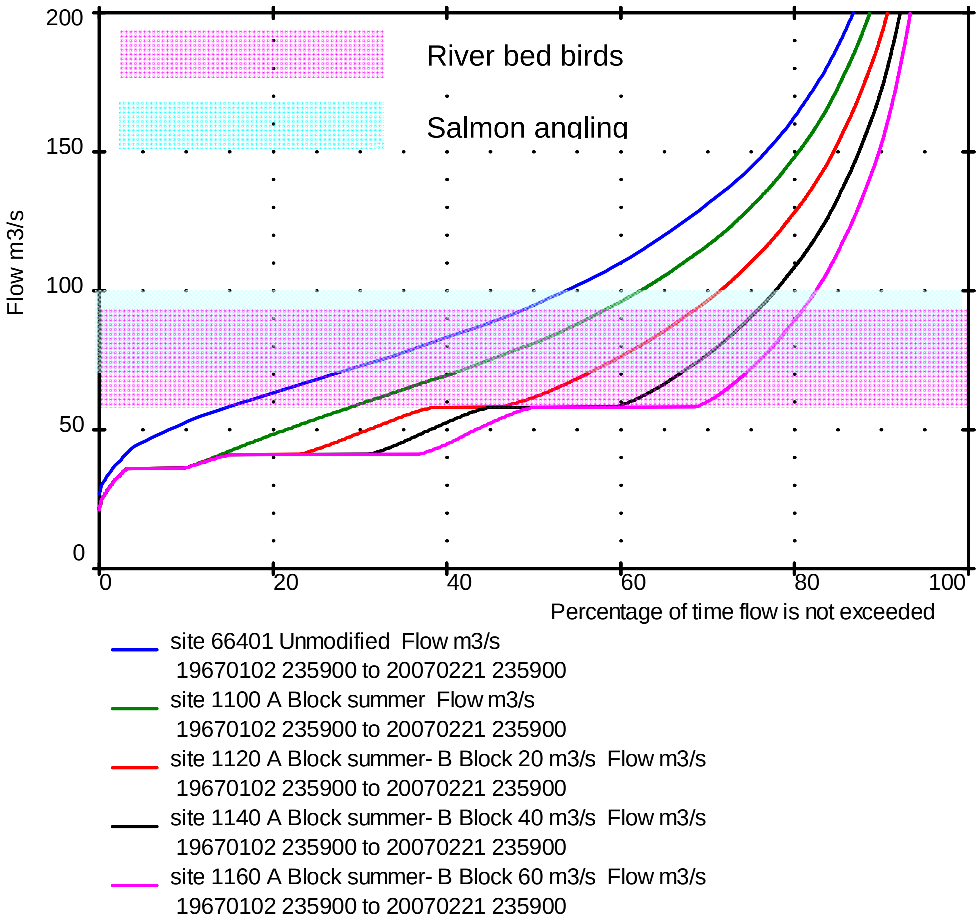

Figure 2: Flow duration curves for the naturalised flow, the A Block and A Block abstracted in summer plus B Block takes of 20, 40 and 60 m^3s^{-1} abstracted all year for 1967-2007.

Please note that tables 1 to 6 and 9 contain rows that indicate the period of time that flows are in particular ranges.

Figure 2 shows flow duration curves for the naturalised flow, the A Block abstracted in summer and A Block abstracted in summer plus B Block takes of 20, 40 and 60 m^3s^{-1} abstracted all year for 1967-2007. The curves show flat lining at 41.0 and 58.104 m^3s^{-1}. The larger the take the longer the period of flatlining at both flow rates. The area between the B Block line and the A Block summer flow line indicates the volume of the B Block take.

Table 2 shows similar data to Table 1 but for the critical period and flows for riverbed nesting birds (55-95 m^3s^{-1}, September to December) and for salmon angling (70-100 m^3s^{-1}, December to April). Table 2 also shows that a take of 40 m^3s^{-1} would lead to the flow being in the preferred flow range for 9.5% more time than for the naturalised flow. The other abstraction rates shown result in similar durations within the preferred flow range to that for the naturalised flow. Takes during the salmon angling season substantially reduce the duration of the preferred flow range with greater reductions for higher takes.

Table 2: The effect of different sized B Block allocations on flow statistics (1967-2007) for critical periods for river dwelling birds and salmon angling.

	Naturalised	**A Block Summer**	**A Block Summer + 20 m^3s^{-1} B Block**	**A Block Summer + 40 m^3s^{-1} B Block**	**A Block Summer + 60 m^3s^{-1} B Block**
September - December					
Mean flow	162	145	128	112	101
Median flow	127	109	89	69	58
% time at 55-95 m^3s^{-1}	26.5	31	24	36	29.3
December - April					
Mean flow	109	89.7	77.9	69	63.9
Median flow	83	61	43	41	41
% time at 70-100 m^3s^{-1}	25.9	15.7	30	19	13

6.2. The effect of different size B Block allocations and 1:1 sharing of the B Block

Table 3 shows the effect of 1:1 sharing of the B Block allocation for three B Block sizes for the whole year. There is flatlining at 36.104 m^3s^{-1}, which is common to all abstraction scenarios, but no flatlining at 41 or 63 m^3s^{-1} (Figure 3). As more water is taken the residual mean and median flows reduce, but the duration within the critical flow zones increases. In comparison with no flow sharing the time within the critical flow zones is increased by about one third and is generally greater than for the naturalised flow or for the residual flow when the A Block is taken in summer for riverbed nesting birds, but not for salmon angling.

Table 3: The effect of different sized B Block allocations and 1:1 flow sharing on flow statistics (1967-2007).

	Naturalised	**A Block summer**	**A Block summer 20 m^3s^{-1} B Block**	**A Block summer 40 m^3s^{-1} B Block**	**A Block summer + 60 m^3s^{-1} B Block**
Mean flow	125	112	99.8	93.1	86.4
Median flow	95	81	60	66	63
% time at 70-100 m^3s^{-1}	27	21.6	17.7	21.5	24.3
% time at 55-95 m^3s^{-1}	38	33.5	37	43.5	45.5

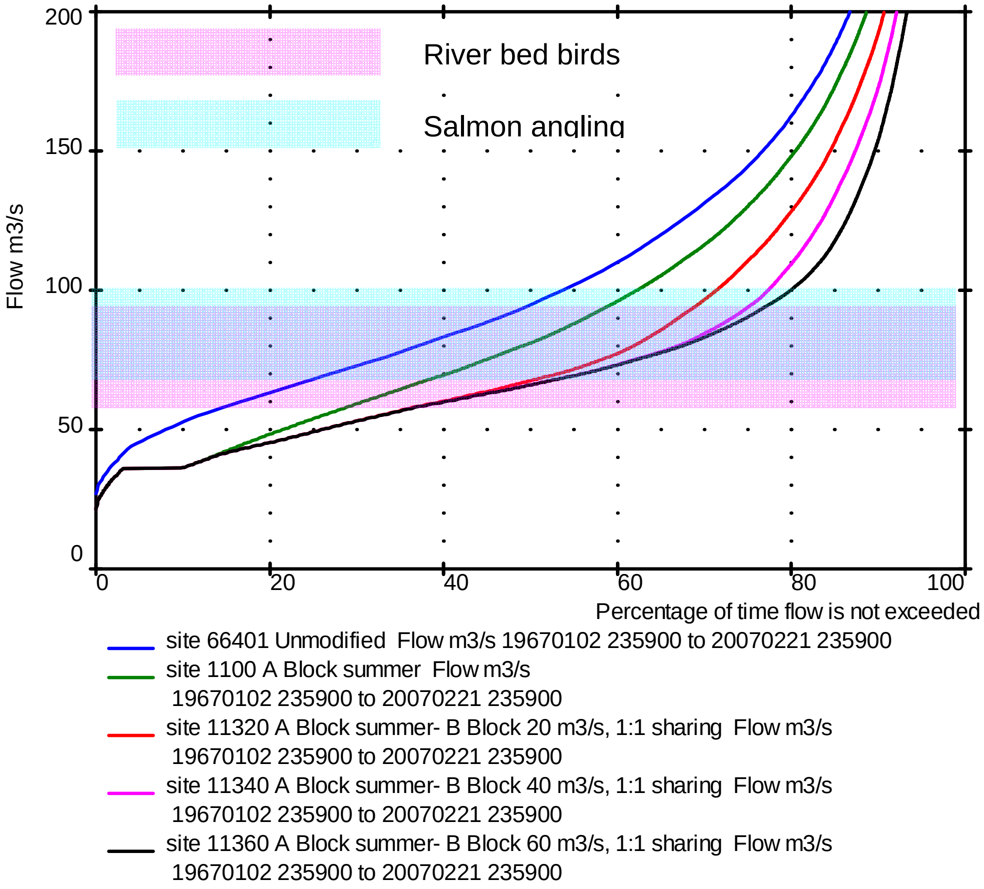

Figure 3: Flow duration curves for the naturalised flow, the A Block abstracted in summer and A Block plus 1:1 flow sharing of B Block takes of 20, 40 and 60 m^3s^{-1} for (1967-2007).

Figure 3 shows flow duration curves for the naturalised flow, the A Block abstracted in summer and A Block plus 1:1 flow sharing of B Block takes of 20, 40 and 60 m^3s^{-1} for (1967-2007). In contrast to Figure 2 there is no flatlining associated with the B Block takes. The B Block curves are closer to the A Block summer take curve indicating that the 1:1 sharing reduces the take compared to no sharing for the same maximum take rate.

Table 4 shows similar data but for the critical time riverbed nesting birds (September to December) and for salmon angling (December to April). Table 4 also shows that flow sharing increases the time in the preferred flow zone over the naturalised and A Block summer take for the river dwelling birds, but decreases the time in relation to the naturalised regime for the salmon angling. In comparison with no flow sharing (Table 2), flow sharing provides more time in the preferred flow zones for riverbed nesting birds and less for salmon angling.

Table 4: The effect of different sized B Block allocations on flow statistics (1967-2007) for critical periods for river dwelling birds and salmon angling where there is 1:1 flow sharing.

	Unmodified	A Block summer	A Block summer + 20 m^3s^{-1} B Block	A Block summer + 40 m^3s^{-1} B Block	A Block summer + 60 m^3s^{-1} B Block
September – December					
Mean flow	162	145	129	118	112
Median flow	127	109	89	77	77
% time at 55-95 m^3s^{-1}	26.5	31	36	45	48
December - April					
Mean flow	109	89.7	79.7	74.7	71.7
Median flow	83	61	51	51	51
% time at 70-100 m^3s^{-1}	25.9	15.7	10.1	10.2	13.2

6.3. The effect of different sized gaps between the A and B Block allocations.

The effect of different sized gaps between the A Block and B Block allocations is illustrated by discussion of different gap sizes with a single B Block size of 40 m^3s^{-1}. The Waimakariri River Regional Plan says the minimum flow for the B Block is 63

m^3s^{-1}. The gaps discussed are 7, 17, 27 and 37 m^3s^{-1} to give minimum flows for the B Block at 70, 80, 90 and 100 m^3s^{-1}.

Table 5 shows the effects of gaps on annual flow statistics. There is flatlining, but it occurs at different flows for different sized gaps and is different in the summer and the winter with the summer flatlining occurring at the lower flow (Figure 4). The durations and flow rates for flatlining are shown in the table. For the 40 m^3s^{-1} take, as the gap size increases so does the mean and median flow of the residual river indicating that the volume able to be taken reduces with increasing gap size. The time in the preferred flow ranges varies irregularly with gap size and preferred flow range but is greater than for the naturalised flows and A Block summer take except for the zero gap option for riverbed nesting birds, but is only better for the larger gaps for salmon angling.

Table 5: The effect of different sized gaps between A and B Block allocations for a 40 m^3s^{-1} B Block Allocation.

	Naturalised	**A Block Summer**	**A Sumer+ 40 m^3s^{-1} B 0 gap**	**A Sumer+ 40 m^3s^{-1} B 7 m^3s^{-1} gap**	**A Sumer+ 40 m^3s^{-1} B 17 m^3s^{-1} gap**	**A Sumer+ 40 m^3s^{-1} B 27 m^3s^{-1} gap**	**A Sumer+ 40 m^3s^{-1} B 37 m^3s^{-1} gap**
Mean flow	125	112	87.6	90.2	93.2	95.8	97.9
Median flow	95	81	58	65	66	68	78
Flat-line time (percent of time at flow rate)	0	8% @ 36 m^3s^{-1}	14% @ 41 m^3s^{-1}	15% @ 48 m^3s^{-1}	13% @ 58 m^3s^{-1}	11% @ 68 m^3s^{-1}	9% @ 78 m^3s^{-1}
Flat-line time (percent of time at flow rate)	0	0	0	14% @ 65 m^3s^{-1}	10% @ 75 m^3s^{-1}	6% @ 85 m^3s^{-1}	5% @ 95 m^3s^{-1}
% time at 70-100 m^3s^{-1}	27	21.6	10.5	10.5	24.5	24.5	37.3
% time at 55-95 m^3s^{-1}	38	33.5	53	35.3	49.3	50	48

Table 6 shows the effect on flow statistics (1967-2007) for critical periods for river dwelling birds and salmon angling for a 40 m^3s^{-1} B Block allocation where there are different sized gaps between the A and B Blocks. As the gap increases so do the mean and median flows indicating lower potential takes. All gaps illustrated larger than 7 m^3s^{-1} give substantially more time in preferred flow ranges than smaller gaps and lower or no takes for river bed nesting birds. Only when the gap is 37 m^3s^{-1} is there more time in zone for salmon angling. Gaps of 17-37 m^3s^{-1} gives marginally more time in zone than other gap sizes for riverbed nesting birds, but only a gap of 37 m^3s^{-1} gives a similar time on zone as the naturalized flow.

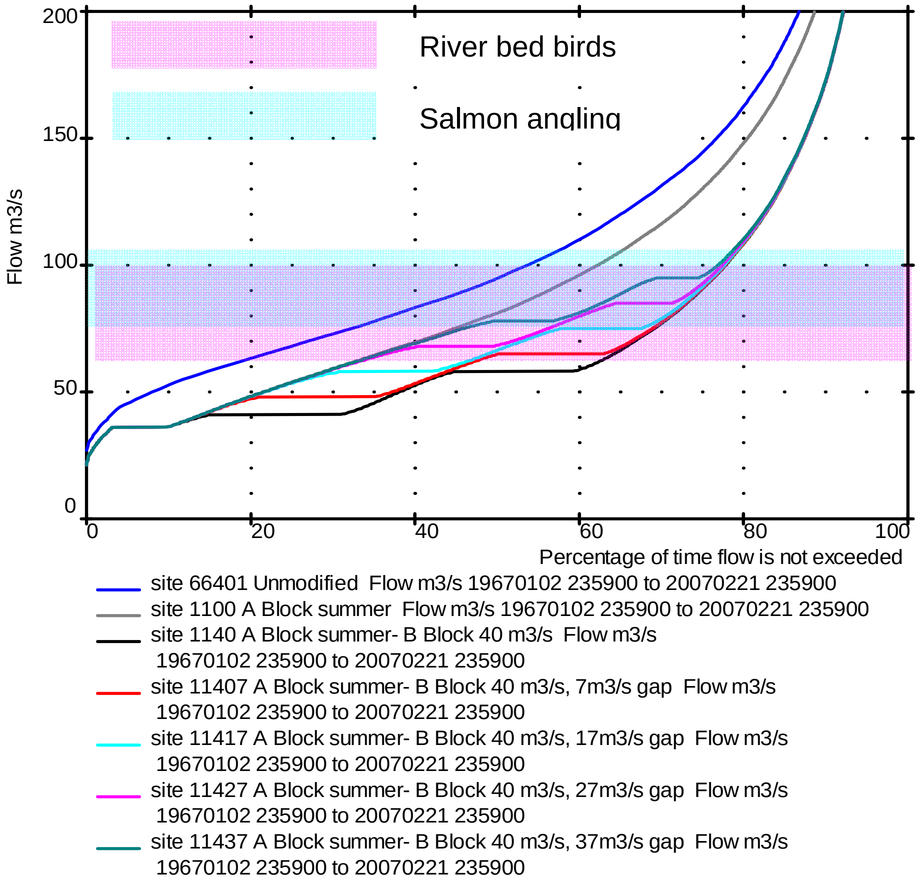

Figure 4: Flow duration curves for the naturalised flow, the A Block abstracted in summer and A Block plus B Block takes of 40 m^3s^{-1} with gaps of 0, 7, 17, 27 and 37 m^3s^{-1} between the A and B Blocks (1967-2007).

Table 6: The effect of different sized gaps between the A and B Blocks for a B Block allocation of 40 m^3s^{-1} on flow statistics (1967-2007) for critical periods for river dwelling birds and salmon angling.

	Naturalised	**A Block summer**	**A summer 40 m^3s^{-1} B 0 gap**	**A summer 40 m^3s^{-1} B 7 m^3s^{-1} gap**	**A summer 40 m^3s^{-1} B 17 m^3s^{-1} gap**	**A summer 40 m^3s^{-1} B 27 m^3s^{-1} gap**	**A summer 40 m^3s^{-1} B 37 m^3s^{-1} gap**
September - December							
Mean flow	162	145	112	115	118	121	124
Median flow	127	109	69	70	75	81	83
% time at 55-95 m^3s^{-1}	26.5	31	36	32	54	53	52
December - April							
Mean flow	109	89.7	69	72.1	75	77.3	79.1
Median flow	83	61	41	48	57	60	61
% time at 70-100 m^3s^{-1}	25.9	15.7	6.5	6.5	6.5	6.5	25.9

The gap sizes that will maximise duration of flows within the preferred flow range (55 to 80 m^3s^{-1}) range from 14 to 22 m^3s^{-1} because they cause flatlining within the preferred range. Those gaps are equivalent to a minimum flow for the B Block between 77 and 85 m^3s^{-1}. The lower the minimum flow the higher the reliability of the abstraction and the larger the potential take volume.

6.4. Potential abstraction volumes for the B Block scenarios

Table 7 shows the maximum take volumes for selected B Block take scenarios. The larger the rate of take the larger the volume able to be taken. Sharing 1:1 reduces the volume that can be taken and difference between not sharing and sharing increases with the nominated take. Increasing the gap between allocation the A and B Blocks reduces the volume of take. For example a 40 m^3s^{-1} take with 1:1 sharing or a 17 m^3s^{-1} gap would result in ~22% less water able to be taken than having no sharing or no gap.

Table 7: Maximum take volumes for selected B Block take scenarios.

Take scenario	Take rate m^3s^{-1} (m^3s^{-1})	Potential take (m^3 x 10^6)
No gap	20	451
No gap	40	769
No gap	60	1003
1:1 sharing	20	385
1:1 sharing	40	596
1:1 sharing	60	719
7 m^3s^{-1} gap	20	401
17 m^3s^{-1} gap	20	347
27 m^3s^{-1} gap	20	315
37 m^3s^{-1} gap	20	252
7 m^3s^{-1} gap	40	687
17 m^3s^{-1} gap	40	593
27 m^3s^{-1} gap	40	511
37 m^3s^{-1} gap	40	445
7 m^3s^{-1} gap	60	905
17 m^3s^{-1} gap	60	779
27 m^3s^{-1} gap	60	675
37 m^3s^{-1} gap	60	577

6.5. Reliability of supply

Table 8 shows the reliability of supply of selected take scenarios. Column three lists the percentage of time that the take can start to be taken and column four the percentage of time that the full take can occur. Where there is no gap between the A and B allocation Blocks or 1:1 sharing, water starts to become available for 85% of the time. Having gaps reduces the reliability of supply and as the size of the gap increases the reliability of supply of the initialisation of water supply decreases. Sharing at a ratio of 1:1 and introducing gaps, approximately halves the reliability of supply of a full take compared to no sharing.

Table 8: The reliability of supply of selected take scenarios. Column three lists the percentage of time that the take can start to be taken and column 4 the percentage of time that the full take can occur.

Take scenario	Take rate ($m^3s^{-1)}$)	Start take % time take available	Full take % time take available
No gap	20	85	54
No gap	40	85	41
No gap	60	85	32
1:1 sharing	20	85	30
1:1 sharing	40	85	18
1:1 sharing	60	85	12
7 m^3s^{-1} gap	20	79	33
17 m^3s^{-1} gap	20	70	30
27 m^3s^{-1} gap	20	60	25
37 m^3s^{-1} gap	20	43	22
7 m^3s^{-1} gap	40	79	20
17 m^3s^{-1} gap	40	70	18
27 m^3s^{-1} gap	40	60	16
37 m^3s^{-1} gap	40	43	14
7 m^3s^{-1} gap	60	79	13.5
17 m^3s^{-1} gap	60	70	11.5
27 m^3s^{-1} gap	60	60	10.2
37 m^3s^{-1} gap	60	43	9.3

6.6. Conclusions from the simulations

Table 9 shows the duration in preferred flow ranges at preferred times and annual take volumes for a maximum take rate of 40 m^3s^{-1} for different take scenarios. The gap scenario is near optimum (for riverbed nesting birds and salmon angling) at a gap size of 37 m^3s^{-1}. It is quite clear that the 37 m^3s^{-1} gap option substantially increases the time in zone for both riverbed nesting birds and salmon angling over other take options.

From an abstracter's view point both 1:1 sharing and leaving a gap reduce the potential take to about the same volume. Both no gap and 1:1 sharing can start to take for more of the time than when there is a gap. The full allocation can be taken for 1:1 sharing for only half the time of the no gap option and the gap option is intermediate between the two.

Table 9: Duration in preferred flow ranges at preferred times and annual take volumes for a maximum take rate of 40 m^3s^{-1} for different take scenarios. (nr = not relevant).

	Naturalised	A Block summer	A summer+ 40 m^3s^{-1} B 0 gap	A summer+ 40 m^3s^{-1} B 1:1 sharing	A summer+ 40 m^3s^{-1} B 37 m^3s^{-1} gap
September - December					
Mean flow	162	145	112	118	124
Median flow	127	109	69	77	83
% time at 55-95 m^3s^{-1}	26.5	31	36	45	52
December - April					
Mean flow	109	89.7	69	74.7	79.1
Median flow	83	61	41	51	61
% time at 70-100 m^3s^{-1}	25.94	15.7	19	21.5	25.9
All year					
Potential take volume	nr	nr	769	596	445
Start take (% time)	nr	nr	85	85	43
Full take (% time)	nr	nr	41	18	14

It can be concluded that a gap between the A and B Blocks of 14-22 m^3s^{-1} substantially increases the time in the preferred flow ranges for riverbed nesting birds, while allowing a good volume of abstraction and reasonable security of supply. The gap of 14-22 m^3s^{-1} would provide these advantages regardless of take size. Larger gaps would be required to optimise the flows for salmon angling. If the preferred angling flow range of 70-100 m^3s^{-1} is used then the gap needs to be 37 m^3s^{-1} from the angling point of view. If the most fished range of flows of 60-100 m^3s^{-1} is used then the gap could be reduced to 27 m^3s^{-1}.

Figure 5 shows the flow duration curves for the take scenarios in Table 9 along with the preferred flow ranges for riverbed nesting birds and salmon angling and it can be seen that the flatlining associated with the 27 m^3s^{-1} gap option prolongs the time within the preferred zones compared to the other options.

7. Recommended B and C Block flow regimes

- After more than 21 days of flatlining at any flow, there should be no B or C Block takes during freshes or floods until the measured flow has exceeded 130 m^3s^{-1} **or** has persisted for 2 days if the peak flow rate does not reach 130 m^3s^{-1}.

- Riverbed levels should be monitored in the vicinity of large takes and if aggradation occurs consent conditions should be revised so that when the naturalised flow is more than 500 m^3s^{-1}, B and C Block abstractions should cease until the flow has reduced to less than 500 m^3s^{-1}.

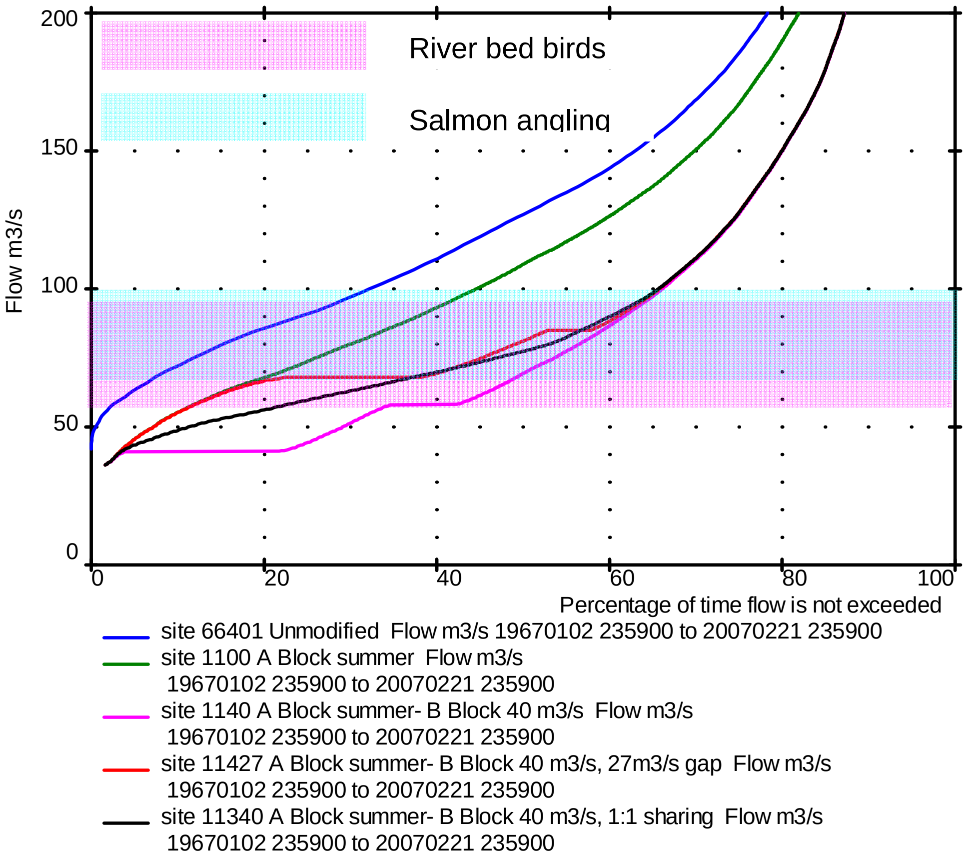

Figure 5: Flow duration curves for the take scenarios in Table 9 along with the preferred flow ranges for riverbed nesting birds (pink shading) and salmon angling (blue shading).

- On up to 6 occasions per year at the request of recreational organisations B and C Block abstractions should cease if by doing so it would bring the flow within, or closer to, the preferred flow range for the activity.

- The maximum B Block allocation should be 40 m^3s^{-1} with a 27 m^3s^{-1} gap between the B Block and A Block allocations.

- A maximum C Block allocation of 5-10 m^3s^{-1} with no gap between B and C Blocks.

- The gap between A and B Blocks could be removed from May to August as there is no need to prolong flows in the 50-95 m^3s^{-1} range as this time is outside of the riverbed bird breeding and salmon angling seasons. The purpose of the gap removal would be to increase the reliability of supply of abstractions. Winter kayaking may be disadvantaged by gap removal during this period.

8. Summary

The values associated with instream uses and community concerns about abstraction from the Waimakariri River were reviewed. From this information the critical flows and their timing were assessed.

The effects on instream values of alternative approaches to setting a flow regime were discussed.

Simulations were made of the alternative take regimes and assessed against the critical flows.

The preferred flow regime allowed for:

- Periphyton and fine sediment flushing,

- Preservation of channel forming and bedload transporting flows,

- Special flows for formal recreational activities on the river,

- A maximum B Block allocation of 40 m^3s^{-1} with a 27 m^3s^{-1} gap between the A and B allocation blocks,

- A maximum C Block allocation of 10 m^3s^{-1} with no gap between the B and C allocation blocks,

- Suspension of the gap requirement between A and B Blocks from May to August.

9. Acknowledgements

The constructive comments of Environment Canterbury staff and Dr Dean Olsen of the Cawthron Institute are gratefully acknowledged.

10. References

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Appendix 1: Project brief

Environment Canterbury Project Brief for the Waimakariri River to assess the environmental effects of different sizes of B/C allocation blocks and appropriate flow regime requirements to minimise these effects

1. Background

The hydrological investigations and plan development work that was done for the Waimakariri River Regional Plan identified it as a relatively unreliable source of water for major run of river irrigation schemes, especially if dairying was a significant land use. This is because the river commonly has low flows during the February – March period and often is unable to meet the full demand of the A block provided for in the plan. With this background, the plan provided for a B block but did not place an upper limit on its size. This was because the B block was so unreliable that a further run of river large irrigation scheme would not be economic. A large irrigation scheme founded on takes into storage at higher flows, such as CPW, was not contemplated during plan preparation. With CPW, and potentially other requests to take water, it is timely to consider what the limits should be on allocation, and what flow regime requirements might be needed to minimise the effects on instream values of different allocation block scenarios.

Small freshes are important for the river's ecological health because they flush off undesirable slimy periphyton growths that can smother the gravel during mid-late summer when flows are lower and the water warmer. Freshes also help to flush fine sediment that settles between the gravel, maintaining its suitability as habitat for aquatic insect larvae that birds and fish feed on.

Large takes

Whatever sized B block (and possible C block) is put into the Waimakariri Regional Plan, it is important that it does not reduce the frequency, duration and magnitude of these freshes to such an extent that the aquatic ecosystem and other instream values are adversely affected.

2. Tasks

- Analyse different sizes of B block and their effect on: (a) flushing flows that remove periphyton and fine sediment; (b) the availability of flows within the desired flow range for salmon fishing; (c) the frequency and duration of "flatlining" and whether this creates any specific issues eg promoting periphyton growth, impacts if any on salmon /boat passage;

- Determine whether there should be a gap between the A and B block, and/or flow sharing within the B block, along with a robust justification.

- Can a C block be provided that may be useful for storage abstractions and which does not have significant environmental impacts? Matters that probably need to be considered include: where would it best be located in the hydrograph having regard to recommendations for the B block; what size might it be; what would the reliability be; what additional flow management provisions (gap, sharing etc) would need to be considered; what impacts might there be on flows that reset the bed and maintain braiding variability; and impacts on the same matters raised for the B block.

- Prepare a report that addresses the above points

3. Outputs

The consultant is to provide the following:

- A draft report three weeks ahead of the completion date
- A copy of the final report as a bound copy; an unbound copy; and an electronic copy

4. Timetable for outputs

- draft report is to be received by ECan three weeks ahead of the final report completion date. ECan staff will provide comments within 5 working days of receiving the draft. A meeting may be needed during this period to discuss any issues

- the date for receiving the final report is 11 July 2008.

5. Contract management

The contract will be managed by John Glennie for ECan.

Appendix 2: Invertebrate time series modelling.

Invertebrate time series modelling is likely to be especially relevant in braided rivers. such as the Waimakariri River. where there is a monotonic increase in WUA with flow over the relevant flow range and where hydrological disturbance is likely to be an important factor influencing invertebrate population dynamics.

Flow vs invertebrate WUA curves for the Waimakariri River (Jowett et al 2008) show that more flow implies more potential invertebrate habitat (which is expected to lead to a corresponding increase in invertebrate production). This implies that some flow regimes (such as those with flow sharing or gaps between allocation blocks) would result in higher mean and median flows and increased invertebrate production, than no flow sharing or no gap regimes. 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. Increased flow stability as a result of abstractions could lead to higher invertebrate numbers provided the period of stability was long enough. In normal or above normal flow years there are probably sufficient floods to limit invertebrate productivity.

NIWA and Cawthron Institute staff are developing a model that incorporates these ideas. NIWA staff have applied it to the December to May period when the abstractions have a more than minor effect on reducing food production and *Deleatidium* weighted useable area (WUA) (Olsen 2008 (Appendixes J, K)). A typical year (1989/90) was modelled because during a dry year there may be insufficient water for B Block consents to be exercised sufficiently to substantially effect residual flows.

The model requires:

A flow vs WUA relationship. One was taken for the most abundant benthic macroinvertebrate, *Deleatidium,* from Olsen (2008, Figure 6). That relationship was extended to 768 m^3s^{-1} using data from recent 2D modelling runs (Duncan and Bind 2008).

A relationship between bed disturbance and flow. A relationship for surface flushing similar to those in Duncan and Bind (2008) was used except that the percentage disturbance applied to the whole river and not just the minimum or median flow beds.

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.

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). (Duncan and Bind (2008) show that after even large floods there are sufficient invertebrate refugia to adequately supply any disturbed bed with invertebrate colonists, but recolonization is more likely to be exponential than linear).

1. The model output for each flow can be summarised as summing of the daily WUA from December to May. Table A1 shows an index of the invertebrate productivity for a variety of take regimes.

Table A1: An index of *Deleatidium* productivity summed for December 1989 to March 1990 for various take regimes.

Naturalised	A Block take 22 m^3s^{-1}	A+B Block take 62 m^3s^{-1}	A Block + 1:1 sharing of B Block 62 m^3s^{-1}	A Block +B Block minimum flow of 100 m^3s^{-1} 62 m^3s^{-1}
16277	15969	15913	16169	16289

2. The index of productivity for any of the take regimes is no more than 2.5 % different from the naturalised 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.

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