IN THE MATTER OF	the Resource Management Act 1991
AND	
IN THE MATTER OF	applications by Central Plains Water Trust to: Canterbury Regional Council for resource consents to take and use water from the Waimakariri and Rakaia Rivers and for all associated consents required for the construction and operation of the Central Plains Water Enhancement Scheme Selwyn District Council for resource consents to construct and operate the Central Plains Water Enhancement Scheme
AND	
IN THE MATTER OF	a notice of requirement by Central Plains Water Limited to: Selwyn District Council for the designation of land for works associated with the construction and operation of the Central Plains Water Enhancement Scheme

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BRIEF OF EVIDENCE OF MARK CHARLES GRACE MABIN

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Qualifications and experience

1. My full name is Mark Charles Grace Mabin. I am an environmental scientist with over 25 years of experience, and am employed as a Senior Associate Environmental Scientist at the Christchurch office of URS New Zealand Limited.

2. I hold the degrees of Bachelor of Science, Master of Science and Doctor of Philosophy from the University of Canterbury. My research training concerned the environments of the Rangitata River, Ashburton River, and associated parts of the Canterbury Plains.

3. I have undertaken consulting, research, and university teaching activities in earth surface process regimes in many parts of the world. I have expertise in river processes, beach processes, lake environments and water balance studies. I have authored or co-authored research papers and reports including 15 papers in international refereed scientific publications.

4. Over the past five years I have provided assessments of effects on the environment of large-scale infrastructure projects such the Clyde Dam and Lake Dunstan, the Manapouri Hydro Scheme and the Waiau River, the Waikato River hydro schemes, the MacArthur River zinc mine in Australia, the Christchurch City Council ocean outfall, the Waimakariri District ocean outfall, and wind farm projects in Wellington and Central Otago. This work has involved writing technical report, and presenting evidence to resource consent and Environment Court hearings.

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

Scope of Evidence

6. In my evidence I will address issues related to the effects of the proposed Central Plains Water Enhancement Scheme (CPWES) on:

   - Braided river landforms and sediment transport processes in the Waimakariri River and Rakaia Rivers;

   - The water balance and lake opening regime of Lake Ellesmere.

7. In preparing this evidence I have relied on the following information:

(a) Rakaia and Waimakariri Rivers mean daily flow data for the period 1967 – 2001 that has been modelled to reflect the effects of the operation of the CPWES water takes. This has been presented in the evidence of Mr Tipler of URS New Zealand Limited.

(b) Canterbury Regional Council archive records of Rakaia River cross sections.

(c) Modelling of the Central Plains groundwater system as presented in the evidence of Mr Weir and Dr Bright of AQUALINC Research Limited.

(d) Lake Ellesmere water balance model of Mr. G. Horrell (1992)[1] that has been used to model the fluctuations of the lake level and predict the number of openings that will be required to keep the lake level within the required range.

8. In forming my opinions, I have reviewed and used information from a variety of technical reports as documented in my evidence. I have applied this understanding to my own knowledge of these environments that arises from fieldwork carried out and the training and professional experience documented above in paragraphs two to five.

9. My evidence is divided into the flowing sections.

9.1 Scheme components in the Rakaia and Waimakariri Rivers relevant to my evidence.

9.2 General comments concerning sediment transport processes in braided gravel bed rivers.

9.3 Effects of the proposed scheme on sediment issues specific to the Rakaia River.

9.4 Effects of the proposed scheme on sediment transport issues specific to the Waimakariri River.

9.5 Water balance of Lake Ellesmere and potential effect of the scheme on lake openings.

9.6 Comments on submissions.

9.7 Summary and conclusions.

SCHEME COMPONENTS IN THE RAKAIA AND WAIMAKARIRI RIVERS

10. Two intakes are proposed on the Rakaia River. The CPWES intake will be at about map reference NZMS 260 K36: 075-388, which is on the true left bank about 8.5 km downstream of the Gorge Bridge. This will take up to 20 m^3/sec of water from the river.

11. In addition, this application seeks water for the Ashburton Community Water Trust (ACWT) that is proposing the Rakaia Terrace Hydro Scheme that combined with the CPWES in a 50:50 sharing regime would take up to 40 m^3/sec of water. The ACWT intake will be at about map reference NZMS 260 K36: 050-393, on the true right bank of the river, about 6 km downstream of the Gorge Bridge. This water will be returned to the Rakaia River north of Barrhill, and so the full effect of the combined CPWES and ACWT take of 40 m^3/sec would only be felt in the 13 km of river between the CPWES intake, and the ACWT power station tailrace discharge.

12. Two CPWES intakes are proposed on the Waimakariri River. The upper intake is near Woodstock Station at about map reference NZMS 260 L35: 249-678 on the true right bank of the river about 3.5 km downstream of where it leaves its gorge to begin flowing across the plains.

13. The lower intake is just upstream of the Gorge Bridge at map reference NZMS L35: 327-760 on the true right bank of the river about 12 km downstream of the upper intake.

SEDIMENT TRANSPORT IN GRAVEL BED RIVERS

14. A natural function of rivers is to transport sediment. This can be carried as suspended load and bed load, where suspended load is the clay, silt and fine sand material that is carried along in suspension by the flow, and bed load that is sand and gravel material rolled or bounced along the river bed.

15. Suspended sediment particles are small and require only low flow velocities to keep them in motion. Bed load material is larger and requires higher velocity flows to initiate and maintain sediment transport. Therefore, when considering bed load transport, the high velocity flows that occur during flood discharges are the most important.

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[1] *Lake Ellesmere water balance model: variable analysis and evaluation* Unpublished M.Eng.Sci. Thesis in Civil Engineering, University of New South Wales, Sydney.

16. In most rivers, suspended load makes up the bulk of the sediment carried, and data presented by Hicks (1998)[2] suggests that for the Rakaia and Waimakariri Rivers the bed load to suspended load ratio is between 5 % and 15 %.

Suspended load

17. Suspended sediment is supplied from the upper catchment and results from erosion processes on slopes that strip soil and loess material which is then washed in to the main river by tributary streams (Hicks and Davies, 1997[3]). The transport of this material in the main river depends on the rate at which it is supplied, rather than the river's ability to transport it[3]. Rivers are well able to transport all the suspended sediment supplied to them.

18. These observations are important for the CPWES for the flowing reasons:

    18.1 The total amount of suspended sediment carried in the river will not change significantly as a result of the CPWES as this material is supplied upstream of the intake points; and

    18.2 The suspended sediment load will continue to be carried by the river despite the reduced discharge resulting from the CPWES water take.

19. Data on suspended sediment concentrations have been made available by Dr Hicks of NIWA (*personal communication, 20/1/06*). From these data I have derived suspended sediment rating curves that give a reasonable approximation of the relationship between suspended sediment carried and discharge in the rivers.

20. For the Rakaia River the relationship between suspended sediment and discharge takes the form:

$$Y = -2(10^{-6})x^3+0.005x^2-0.69x+16.7 \quad (R^2 = 0.94)$$

For the Waimakariri River the relationship takes the form:

$$Y = 0.09x^{1.57} \ (R^2 = 0.9)$$

Where Y = total suspended solids (TSS) in g/m^3, and x = discharge in m^3/sec.

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[2] *Sediment budgets for the Canterbury Coast – a review, with particular reference to the importance of river sediment* NIWA Client Report CHC98/2, ECan Report # U98/12, 85p.

[3] *Erosion and sedimentation in extreme events* pp115-141 *in* Mosley, P. & C.P. Pearson (eds) *Floods and droughts: the New Zealand experience* New Zealand Hydrological Society.

21. These simple relationships are not suitable for detailed analysis, but they demonstrate the rapid increase in TSS discharge with increasing flow

22. More sophisticated analyses of suspended sediment data for Canterbury Rivers have been reported by Hicks 1998)[2], and from the data in Table 1 of his report I calculate the annual suspended sediment load (measured as total suspended solids [TSS] in g/m^3) for the rivers to be:

- For the Rakaia River TSS = 6.9 x 10^6 tonnes per year, and
- For the Waimakariri River TSS = 2.2 x 10^6 tonnes per year.

23. Hicks[2] further notes that most of the suspended load is carried by larger flows. He calculates that:

- For the Rakaia River only 2.2 % of TSS load is carried by flows less than the mean flow; and
- For the Waimakariri River only 5.2 % of the TSS load is carried by flows less than the mean flow.

Thus I would expect the CPWES to have an effect on TSS load if it significantly changes the flow regime for discharges above mean flows in the Rakaia and Waimakariri Rivers.

24. Suspended sediment is an important issue for the CPWES as it would create operational difficulties if large quantities of TSS remained in the water that enters the main headrace canal. For this reason sediment settling basins and a flushing regime are included in the scheme design, as discussed in evidence by Mr Lewthwaite. I will not repeat that material here.

25. However, it is important to note that in order to operate the sediment settling basins and flushing regimes effectively, it will probably be necessary to close the intake gates during large floods in order to limit the volume of TSS that would accumulate in the basins, which in turn would increase the frequency that this material needs to be removed.

26. I estimate that when TSS concentrations exceed about 1,500 – 2,000 g/m^3 it will be prudent to close the scheme intake gates. Using the relationships shown above in paragraph 20 I calculate this would occur at flows of about 500 – 600 m^3/sec in the Waimakariri River, and 700 – 900 m^3/sec in the Rakaia River.

27. As I will discuss below, these flows represent moderate-sized floods that occur for about 4 – 6 days per year in each river. If the CPWES intake gates were closed in these flow conditions it would represent an upper flow regime limit for any potential effects of the scheme on these rivers.

28. Although suspended load is the largest component of a river's solid load, it is rarely of concern for the management of physical aspects of the river channel and floodplain. Of much more importance for these issues are river erosion and aggradation (or sediment build up), and these processes relate directly to the transport of bed load by the river.

Bed load

29. Hicks and Davies (1997)[3], and Griffiths (1979)[4] note that for the Waimakariri River, most bed load is derived from local river erosion of the channel banks and bed rather than from more distant catchment inputs as with suspended sediment.

30. There have been recent advances in understanding bed load transport in gravel bed rivers. Important concepts include:

    (a) Bed load transport is regulated by the size of material on the bed armour layer (Wilcock and Crowe[5]).

    (b) A river bed that has a coarse gravel armour layer indicates it is under-supplied with bed-load. It has sufficient flow energy to transport more bed load than is supplied from upstream (Wilcock and Crowe [3]).

    (c) Under-supplied rivers develop an equilibrium bed surface armour layer and stable bed profile that allows the river to just pass the bed load supplied to it (Wilcock and Crowe[3]). Thus, under-supplied gravel bed rivers do not necessarily degrade their beds.

    (d) When an under-supplied gravel bed river experiences a less energetic flow regime, deposition may occur, but this will result in a fining of the armour layer and a steepening of the bed profile, and these effects will allow the river to recover its sediment transporting capacity (Lisle and Smith[6]).

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[4] *Recent sedimentation history of the Waimakariri River, New Zealand* Journal of Hydrology (New Zealand) 18(1): 6 – 23.

[5] *Surface-based transport model for mixed-size sediment* Journal of Hydraulic Engineering 129(2): 120 – 128, 2003.

[6] *Dynamic transport capacity in gravel-bed river systems* pp 1-19 *in* Proceedings of International Workshop "Source-to-sink" Sedimentary Dynamics in Catchment Scale, Hokkaido University, Sapporo, Japan, 2003.

31. Bed load transport of sand and gravel will be the main focus of my assessment. However, bed load is a very difficult parameter to directly measure in any river environment, and this is especially so for wide gravel bed rivers like the Rakaia and Waimakariri. Various approaches are used including sediment traps, bed load samplers, cross section surveys, remote sensing, bed load: suspended load ratios, and empirical equations, and results can vary significantly.

32. Although this suggests there is a poor understanding of bed load sediment transport in these rivers, this is not in fact the case, particularly for the well studied Waimakariri River, and I consider that a consistent understanding is available.

POTENTIAL EFFECTS OF CPWES ON THE RAKAIA AND WAIMAKARIRI RIVERS

33. Both the Rakaia and Waimakariri Rivers are braided gravel bed rivers. Taking water from these rivers will potentially de-power them, potentially leading to several effects on the natural environment as follows:

    - Reduced sediment transport capacity potentially resulting in effects such as aggradation of the river bed, and siltation at river mouths;
    - Changes in the floodplain landform patterns of braided channels, bars and islands;
    - Reduced sediment delivery to the coast; and
    - Reduced efficiency and/or effectiveness of infrastructure (for example, irrigation intakes, flood protection works, and bridges).

    These potential effects relate directly to sediment transport issues and the physical character of the river channel and floodplain, and my assessment relates only to these issues. Matters related to river ecology, bird habitat, fish-ability, visual character and amenity values, and other issues are covered in evidence by other experts.

34. The Rakaia and Waimakariri Rivers are predominantly gravel bed rivers, so sediment transport issues are therefore related to bed load, which in turn is driven by river floods.

35. Both the Waimakariri and Rakaia Rivers are typical of many gravel bed rivers in New Zealand where the surface layer of sediment found on the bed is

generally larger gravel or cobble sized particles that form an “armour” layer over finer material directly beneath.

36. They are in this condition because the finer gravel and sand material has been transported away downstream, leaving behind the larger particles that will protect the underlying sediment from erosion until there is a flood large enough to move this surface layer.

37. Therefore, these rivers may be viewed as being effectively under-supplied with bed load, and are able to transport more bed load sediment than is supplied to them from upstream. While finer bed load (sand and small gravel particles) can be transported across the armour layer, transport of large volumes of bed load sediment can only occur when larger floods dislodge the surface armour layer of larger gravels to release the underlying layers of finer sediment.

38. The distinctive character of the Rakaia and Waimakariri Rivers arises in part from the braided river landforms of numerous channels (braids) separated by bars and islands that occur across a wide gravel fairway.

39. The organisation of these landforms changes with the passage of floods, with the larger events that cause the whole fairway to be inundated being likely to result in the most reorganisation of the fairway pattern.

40. Therefore, in respect of both sediment transport issues and floodplain landforms, I would expect the CWPES water takes to have effects if the larger flood flows are affected.

41. The question then arises, what are the significant sediment transporting and landforming flows in the river? I consider three flow levels to be important:

    41.1 The flow at which sand and fine gravel sediment begins to move across the bed surface armour layer;

    41.2 The flow at which the bed surface armour layer of larger gravel particles is moved allowing the underlying finer material to be transported; and

    41.3 The flow that covers the fairway and allows reorganisation of the channel landforms.

42. The magnitude of the sand-moving flows can be estimated from the ecological considerations. Clausen and Biggs (1997)[7] have identified through statistical analysis an ecologically significant flood flow for New Zealand rivers that is sufficiently large to disturb the riverbed ecology and prevent aquatic plant and animal communities from fully developing. This disturbance of the river bed organisms results from dislodgement by the force of the current and abrasion by sediment particles moving over the bed[8].

43. This flow has been quantified as being a flood of a magnitude three times the median flow[7] or the FRE3. I interpret the FRE3 flow to be an indicator that sediment movement of sand has started to occur over the river bed.

44. While sediment transport is likely to have started at the FRE3 flow, significant bed load transport does not occur until much higher discharges are reached[3]. This will occur when the flow is strong enough to move the armour layer of gravel and cobbles on the bed thus uncovering the finer sediment below the surface and allowing it to be transported.

45. For the Rakaia River and Waimakariri Rivers, Davies[9], Hicks and Davies[3], and Griffiths[4] have examined this issue. From this work it is apparent that the most effective bed load transporting flows occur at discharges that are 2 – 3 times greater than the FRE3 flow.

46. The sediment transport that occurs during floods will reorganise the fairway landforms of braid channels, bars and islands. The flow that covers the fairway is likely to cause the most widespread change to fairway landforms. This flow is referred to as the channel forming discharge, and in many river systems it occurs relatively frequently once every one to three years. A convenient value to use for this flow is the mean annual flood that has a return period of 1 in 2.33 years.

47. I will now apply the above understanding of sediment transport and landforming processes to the Rakaia and Waimakariri Rivers. I will address each river in turn, as although they are both large braided rivers that drain adjacent catchments in the Southern Alps, and flow across the Canterbury Plains to the coast, there are significant differences between them, as can be seen in Table 1.

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[7] *Relationships between benthic biota and hydrological indices in New Zealand streams.* Freshwater Biology 38: 327-342.

[8] Jowett, I.; P. Mosley 2004 *Analysis of instream values.* In Harding, J.; *et al* (eds) *Freshwaters of New Zealand.* New Zealand Hydrological Society and Limnological Society, Christchurch.

[9] *Modification of bed load transport capacity in braided rivers* Journal of Hydrology (New Zealand) 27(1): 69-72

48. For each river, I will briefly describe the catchment and plains setting, document the existing and future flood flow regimes, and assess the potential effects of flow regime changes on the rivers.

Table 1: Characteristics of the Waimakariri and Rakaia Rivers (Data compiled from topographic maps and Canterbury Regional Council flow records)

	Rakaia River	**Waimakariri River**
Catchment area above plains	2,625 km^2	2,182 km^2
Channel distance across plains to coast	64 km	74 km
Tributaries joining across plains	Between 0 – 9 km, four small streams join. At 11.5 km Highbank Power Station tailrace.	At 3 km Joyces Stream At 7 km Kowai River At 89.5 km Eyre River diversion At 71.5 km Kaiapoi River
Channel character	Braided gravel bed river, apart from an 8.5 km meandering-braided reach at head of plains.	Mainly a braided gravel bed river. Reach 0 – 4 km is meandering Reach 15 km is a bedrock gorge Reach 63 – 71.5 km is meandering-braided gravel bed Reach 71.5 – 74 km is straight sand bed
Channel slope	Upper 52 km: 4.2 m/km Lower 12 km: 4.9 m/km	Upper 53 km: 5.0 m/km Lower 21 km: 2.5 m/km
Flow gauging site, and catchment area monitored	At -3.5 km, Fighting Hill 2620 km^2	At 68 km, Old Highway Bridge 3120 km^2
Median flow	159 m^3/sec	96 m^3/sec
FRE3 'fresh' flow	477 m^3/sec	284 m^3/sec
Mean annual flood	1,582 m^3/sec	1,016 m^3/sec

RAKAIA RIVER

Catchment and channel characteristics

49. The Rakaia River catchment area upstream of the plains covers 2,625 km^2 and extends back into glaciated mountains along the Main Divide of the Southern Alps. It emerges from the mountains at the Gorge Bridge, and flows

in a 64 km course across the Canterbury Plains to the coast. Characteristics of the catchment and flow regime are shown in Table 1.

50. Downstream of the proposed CPWES/ACWT intakes the Rakaia River runs for 56 km to the coast in a braided gravel bed channel. There are usually two to four larger braid channels, and four to ten smaller braids. The fairway is between 1.0 and 2.1 km across, and is typically about 1.3 km wide.

51. At about 15 km from the coast, two distributary channels leave the main river and flow in courses up to 3 km northeast of the main channel. They flow around Fereday and Rakaia Islands, although the northernmost channel is only active in large floods.

52. The bed of the Rakaia River comprises gravel material all the way to the coast, and it has been calculated[2] that it transports between 80,000 and 259,000 m^3 of bed load to the coast per year.

53. The river long profile plotted from topographic maps shows it slopes uniformly at 4.2 m/km until kilometre 52. This is about 10 km downstream of the State Highway 1 Bridge, and in the region where the distributaries leave the main river. From here to the coast the bed slope steepens slightly to 4.9 m/km. This means that the slope energy gradient of the river increases downstream.

54. The Rakaia River channel across the plains is largely natural as it has no major flood protection schemes along its banks. Downstream of the State Highway 1 bridge there are a few publicly funded groynes, stopbanks, riparian tree plantings, and fairway clearing operations on both banks. Upstream of the bridge there are isolated private protection works mainly involving small banks and rock protection works. There is also a small amount of gravel extraction occurring from the river. ECan[10] (2006) documents an average extraction rate of 16,770 m^3/yr (1990-2003), which is about 5.25 % of the rate from the Waimakariri River.

55. Rakaia River bed levels have not been closely monitored, unlike the Waimakariri River. In part this reflects the fact that the Rakaia does not threaten a large city, but I also consider it relates to the fact that there are no obvious bed erosion or aggradation problems along the river. Some river cross sections were surveyed in the mid 1970s, and again in the late 1980s[11]. Six cross sections were surveyed in 1976 and 1988, and mean bed level calculations showed three slightly rose, and three slightly fell in the 12 years

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[10] *Regional gravel management report* Canterbury Regional Council Report R06/1, 132 p.

between the surveys. The overall median change was a fall of 1 cm. This may be compared to bed levels in the Waimakariri River in the same relative locations, and over the same time period that showed several 10s of cm change (see footnote 16 below). I therefore interpret this data to indicate the Rakaia River has not shown clear trends of erosion or aggradation in its bed, and this is consistent with my interpretation that the river is well able to transport all the bed load supplied to it.

Rakaia River flow regime

56. The Rakaia River braided channel and fairway system result from, and are maintained by the river flow regime. Flow is recorded at the Fighting Hill gauging station some 10 – 12 km upstream of the proposed ACWT and CPWES intakes. Only eight small streams join downstream of the gauge, thus I take this flow record to reasonably accurately represent the Rakaia River as it passes the proposed intakes.

57. Potential effects will occur downstream of the intakes but these will be different for the CPWES and ACWT takes. The CWPES take is abstractive and water is not returned to the river (apart from the minor fish by pass flow and sediment trap flushing flows). Thus potential effects may arise downstream of the intake.

58. In contrast, the ACWT take is to be used for hydro power generation purposes, and the water will subsequently be returned to the Rakaia River. Thus potential effects on the river will only arise between the points of take and discharge.

59. There are other flow gains and losses as the river crosses the plains and these may also affect the river’s ability to transport sediment.

60. Gains may arise from tributary and other inflows. As noted above a few small streams enter the river below the gauging station, but I consider these to be inconsequential additions to the flow.

61. The Highbank Power Station tailrace discharge currently enters the Rakaia River about 3 km downstream of the proposed ACWT intake. This contributes a mean flow of 12.1 m^3/sec to the Rakaia River[12], although this varies from 6.8 m^3/sec in summer to 22.5 m^3/sec in winter depending on when the Rangitata Diversion Race water is being used for irrigation purposes.

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[11] North Canterbury Catchment Board data sheets held in ECan archives. Mean bed level change s are recorded on these sheets.

62. As part of ACWT's Rakaia Terrace Hydro Scheme it is proposed to divert some the water from the Highbank Power Station Tailrace discharge into the scheme and use it for power generation purposes. The characteristics of the existing Highbank Power Station discharge would therefore change, however I will not be considering this in my assessment.

63. ACWT's Rakaia Terrace Hydro Scheme proposal will discharge a maximum of 40 m^3/sec back to the river. This discharge is the same as a maximum take of water that ACWT is applying for in the present application. The discharge will variously comprise water derived from the ACWT take, Barrhill-Chertsy Irrigation Company water take, and tailrace discharge from the Highbank Power Station. However, I do not consider the details of this sharing regime to be relevant to my assessment.

64. Flow is lost from the river through other irrigation and stockwater supply intakes and to connected groundwater takes. About half of these losses are due to the irrigation takes that affect summer flows in the river. There are currently 29 of these consented takes of surface water from the plains section of the Rakaia River on the ECan database.

65. Mr Tipler has summarised these existing water takes in his evidence noting that 34.3 m^3/sec has been allocated, although not all of these consents have yet been exercised. Taking into account the requirements of the National Water Conservation (Rakaia River) Order 1988 he identifies that in the summer irrigation season a further 35.7 m^3/sec of Rakaia River water is available for abstraction, and in winter 40 m^3/sec is available.

66. The intakes for the stockwater and irrigation abstractions are variously on the left and right banks of the Rakaia River. The ACWT intake would share the proposed Barrhill-Chertsey Irrigation Company intake about 2 km upstream of the CPWES intake across the river on the true right bank. There are six other takes on this bank, between 11.5 km and 40 km downstream of the proposed ACWT intake. On the true left bank there are 22 takes between 9 km and 46 km downstream of the proposed CPWES intake. The potential effects of the CPWES/ACWT water take on these intake structures and their efficiency of operation will be assessed below.

67. River flow is also probably lost to bed leakage. Gravel is very permeable material and in places where the water table is generally below the river bed, flow can leak from the river to recharge groundwater. This will occur where

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[12] *Rangitata Diversion Race Irrigation and Power Schemes Assessment of Environmental Effects,* December

the piezometric contours of the groundwater surface slope upwards towards the river. This occurs for much of the Rakaia River between about 8 km and 54 km downstream of the proposed CPWES/ACWT intakes. The extent of this potential bed leakage loss is not known, however, by analogy with the Waimakariri River, it could be between 5 and 20 m^3/sec.

68. The flow record from the Fighting Hill gauging station from 1st June 1967 to 31st May 2001 provided by NIWA has been used in the various analyses and modelling studies to develop the CPWES scheme, and this same record of mean daily flow has been used to characterise flow in the Rakaia River, as shown in Table 1.

69. For the period 1/6/1967 – 31/5/2001 the natural mean daily discharge was 213 m^3/sec, the median flow was 159 m^3/sec, the mean annual flood was 1582 m^3/sec, and the peak discharge was 3050 m^3/sec.

70. However, taking into account all existing consented irrigation takes, connected groundwater takes, and stockwater takes the mean flow in the Rakaia is now 191 m^3/sec, a 10 % reduction.

71. As I discussed above in paragraphs 41 – 46 the important sediment transporting and channel landforming flows are[13]:

    i) The FRE3 flow or fresh at which sand is being moved across the armour layer of gravel on the bed. For the Rakaia River this is 477 m^3/sec.

    ii) The flow that is most efficient for bed load transport, which for the Rakaia River can be calculated to be approximately 800 m^3/sec[5].

    iii) The mean annual flood flow at which the fairway is fully covered with water and braid channels, bars and islands are likely to be significantly reorganised, which for the Rakaia River I calculate to be 1,582 m^3/sec.

72. The characteristics of these flows in the present natural flow regime as recorded at Fighting Hill are as follows:

    i) Flow events equal to or greater than the FRE3 flow occur 9.9 times per year, and have an overall duration of 6.0 % of the time.

2000.

[13] Figures derived from the natural Rakaia River flow series 1967 – 2001 and assume no irrigation takes, connected groundwater takes, or stockwater takes..

ii) The flow most efficient for bed load transport will be equalled or exceeded for 1.6 % of the time, or an average of 5.9 days per year.

iii) The mean annual flood flow is equalled or exceeded 0.2 % of the time.

ASSESSMENT OF EFFECTS OF CPWES ON THE RAKAIA RIVER

73. In this section I will assess the effects of the proposed CPWES/ACWT takes on the Rakaia River. It is important to note that my assessment is based on a comparison of the natural flow regime with the flow regime that will occur after CPWES/ACWT take. In other words, it includes the effects of *all* consented takes along with the CPWES/ACWT take. It therefore over-estimates the effects of CPWES/ACWT on this environment.

74. My assessment will consider the CPWES take separately from the ACWT take. This is due to the fact the CPWES take is abstractive, while the ACWT take is a diversion, and water is therefore only temporarily removed from the river.

75. A water balance model for CPWES has been described by Mr Tipler in his evidence. From the Rakaia River section of this model I calculate that the mean daily CWPES water take will be 3.1 m^3/sec. This represents a 1.5 % reduction in the mean flow from the natural river regime. However, the cumulative effect including the other consented takes (but excluding ACWT) is an 11.7 % reduction in flow.

76. The ACWT mean take will be 7.7 m^3/sec, which is more than twice the CWPES share due to the former take also occurring during the winter. This takes into account my understanding of the ACWT proposal that includes use of winter water from the Barrhill-Chertsey Irrigation Company take that has a higher priority than the CPWES/ACWT take.

77. Taking the combined CWPE/ACWT takes, the mean annual combined take will be 10.8 m^3/sec, and including all other consented irrigation takes, connected groundwater takes and stockwater takes, the cumulative effect will be a take of 32.4 m^3/s amounting to a 15.3 % reduction in mean flow of the Rakaia River. However, on its own the CPWES/ACWT take reduces the mean flow by only 5.1 %.

78. I consider that these changes in mean flow are modest. However, it is necessary to consider in more detail the de-powering of the river that will occur in the flow bands that are most responsible for bed load sediment transport, and the reaches of the river in which this will occur. I will first consider the effects of the combined CPWES/ACWT takes, and then the CWPE take on its own.

79. The combined CWPES/ACWT take will affect the 13 km reach of the river between the intakes and the discharge point from ACWT's Rakaia Terrace Hydro Scheme tailrace. I note in passing that 3 km downstream of the CPWES/ACWT intakes the Rakaia River flow is augmented by the Highbank Power Station tailrace that discharges a mean flow of 12.1 m^3sec. This is greater than the mean CPWES/ACWT take of 10.8 m^3/sec and thus in effect the change in flow regime only occurs over a 3 km reach of the river. However, the Highbank Power Station discharge has been operating since 1945 and in terms of this application is part of the existing environment, and my assessment therefore does not take account of this flow.

80. Under the proposed combined CWPES/ACWT takes, the following changes to bed load transporting and landforming flows will occur:

   i) Flow events greater than or equal to the FRE3 flow will occur 8.0 times per year, and will last 4.4 % of the time. This is a reduction of 1.9 events/year, and overall the river will spend 1.6 % less time in this flow band.

   ii) Flows most efficient for bed load transport will be equalled or exceeded 1.4 % of the time. These would occur on average for 4.9 days per year, a reduction of 1 day per year.

   iii) The mean annual flood flow will be equalled or exceeded 0.17 % of the time. This is a 0.03 % reduction in the amount of time this flow band occurs.

81. From this it can be seen there will be a small reduction in the frequency of FRE3 flows and in their overall duration. As I discussed above in paragraphs 41 – 46 the FRE3 flows represents the discharge at which sand sediment transport has started to occur but significant gravel sediment transport does not occur until higher discharges are reached. Thus Davies (1988), and Hicks and Davies (1997) show that in the Rakaia River less than 2 % of total bed load sediment transport is expected to occur at flows less than the FRE3. In addition, the characteristics of the Rakaia River with its armour layer of gravel

on the bed indicate it is undersupplied with bed load (see paragraph 30 above). Taking these two factors together, it is my opinion that the reduced frequency of FRE3 events will have a less than minor effect on the total volume of sediment transported by the river.

82. The flows that are most efficient for transporting bed load are naturally uncommon, and will occur on average 1 day per year less often than under the natural flow regime. In my opinion this is a minor change that will be undetectable as this slight de-powering of the river should be readily accommodated in the river's ability to change its bed characteristics and recover any lost sediment transporting capacity (see paragraph 30).

83. It can be seen there will also be a slight reduction in the duration of the larger flood events with magnitudes equal to or greater than the mean annual flood. It is my opinion that the landform characteristics of braid channels, bars and islands across the Rakaia River fairway will not be affected by the CPWES and ACWT water takes.

84. As I noted above in paragraph 25 I consider it will be prudent for the CPWES/ACWT to shut its intake gates when TSS concentrations reach about 1,500 – 2,000 g/m^3. In the Rakaia River this will occur at and above the level of the most efficient bed load transporting flows (800 m^3/sec). If this were to occur there would be no effect of the scheme on these sediment transporting flows or the greater flows that affect braid channel and bar landforms across the fairway.

85. However, as I have demonstrated the potential effects at these 800 m^3/sec and greater flood flows are already less than minor, and I do not consider it necessary to recommend the scheme's intake gates to be closed at any particular discharge level. I expect this will occur for the operational reasons outlined above (paragraph 25), but the timing of this will vary depending on river conditions and other non-environmental factors.

86. This assessment applies to the Rakaia River in the 13 km reach immediately downstream of the CPWES intake. From about Barrhill downstream, such effects that do occur will be reduced by the return of water to the river by the ACWT Barrhill Power Station discharge.

87. The effects of the CWPES on the Rakaia River flow regime downstream of Barrhill will therefore relate only to the CPWES part of the combined CPWES/ACWT take (ie the 3.1 m^3/sec mean daily take required by CPWES), and this will be as follows:

i) Flow events greater than or equal to the FRE3 flow (477 m^3/sec) will occur 8.6 times per year, and will last 4.9 % of the time. This is a reduction of 1.3 events/year, and overall the river will spend 1.1 % less time in this flow band.

ii) Flows most efficient for bed load transport (800 m^3/sec) will be equalled or exceeded 1.5 % of the time. These would occur on average for 5.4 days per year, a reduction of 0.5 days per year..

iii) The mean annual flood flow (1582 m^3/sec) will be equalled or exceeded 0.19 % of the time. This represents no effective change.

88. Obviously these flow regime changes are less than those resulting from the combined CPWES/ACWT takes, and the effects will therefore also be less. Thus it is my opinion that the CPWES water take will have a less than minor effect on sediment transporting and landforming river flows downstream of Barrhill and to the coast.

89. In my opinion, the effects of the CWPES and CWPES/ACWT water takes on sediment transport and landforming processes in the Rakaia River will be less than minor. Potential adverse effects relating to sediment build-up leading to reduced effectiveness of irrigation intakes and flood protection works along the river are unlikely to occur. In addition, there will be no reduction in the volume of sediment transported to the coast and siltation of the river mouth lagoon system is unlikely to occur.

90. I also consider that this assessment is conservative as I have assessed the effects of the changed Rakaia River flow regime from its natural state to that which will pertain after all consented takes have been taken into account. The proposed CPWES/ACWT take of 10.7 m^3/sec represents only 33 % of the total of all takes. Thus CWPES/ACWT ‘share’ of the effects described above is only likely to be of this order of magnitude.

91. Summarising my assessment of the effects of CPWES and ACWT water takes on sediment transport in the Rakaia River, the passage of sediment through the river mouth, and the delivery of sediment to the coast, it is my opinion that the effects will be less than minor it is my opinion that the effects will be less than minor. I have formed this opinion on the basis that:

91.1 Changes to the Rakaia River flow regime will be minor for the discharge bands that are responsible for transporting bed load in the river;

91.2 The characteristics of the Rakaia River show it is likely to be under-supplied with gravel bed load and more than capable of transporting all the sediment supplied to it to the coast. Thus, the slight de-powering of the river resulting from the changed flow regime is unlikely to result in a reduction in the total amount of sediment transported;

91.3 Operational requirements will probably result in the scheme's intake gates being closed during moderate-sized and larger floods. In this case there will be no effect on these sediment transporting flows.

THE WAIMAKARIRI RIVER

Catchment and channel characteristics

92. The Waimakariri River catchment area upstream of the plains covers 2,128 km^2 and extends back into mountains along the Main Divide of the Southern Alps. It emerges from the mountains near Otarama and Woodstock stations, and flows in a 74 km course across the Canterbury Plains to Pegasus Bay. Characteristics of the catchment and flow regime are shown in Table 1.

93. While predominantly a braided gravel channel the river has a number of different reaches that contribute to it having a rather different character to the Rakaia River. The upper 4 km is a meandering reach, and the upper CPWES Waimakariri intake is proposed for the downstream end of this. Downstream of here the river has a wide braided channel until kilometre 15 where it meanders through a short 1 km gorge section. The lower Waimakariri intake for the CPWES is proposed for this small reach. The river continues in a braided channel for a further 48 km to about Clearwater Estate, where the braiding pattern begins to give way to a low sinuosity single thread meandering channel. At about 2.5 km from the coast the gravel bed gives way to a sand bed, and the river does not deliver any gravel bed load to the coast.

94. In the braided reaches there are usually one to two larger braid channels, and two to six smaller braids. The fairway is between 0.7 and 1.6 km across, and is typically about 1.0 km wide. At normal flow 50 – 75 % of the fairway is dry bare gravel.

95. In its natural state, the river splits into several anabranches in its lower 30 km, but extensive flood protection works beginning in the 19th Century have removed this channel pattern.

96. The river long profile plotted from topographic maps shows the upper 53 km slopes uniformly at about 5.0 m/km. However, from here to the coast the slope becomes much gentler, with an overall gradient of 2.5 m/km. This means that the slope energy gradient of the river decreases downstream, and this helps to explain why gravel does not get transported to the coast.

97. The Waimakariri River channel across the upper 40 km of the plains is largely unmodified, however, the lower 34 km has been significantly modified by major flood protection works, including stopbanks and groynes. There has also been a significant gravel extraction industry in this lower plains channel and ECan[10] documents an average extraction rate of 320,000 m^3/yr (1990-2003), which is nearly 20 times the rate from the Rakaia River.

98. Waimakariri River bed levels have been monitored numerous times since the late 1920s, and there have been a number of scientific studies that have used both this information and a number of other techniques to assess sediment transport and channel change in the lower plains parts of the river.

99. Hudson (2005)[14] presents mean bed level data derived from river cross section surveys carried out by the Canterbury Regional Council between kilometre 58 (near the SH 77 Bridge) and the coast.

100. These show that from kilometre 58 downstream to kilometre 25 the river has been degrading its bed since the 1960s. From kilometre 25 downstream to kilometre 8.75 the river changes character and the bed has been aggrading since the 1960s. From kilometre 8.75 the channel again changes character such that from here to the coast the bed has been degrading.

101. These changes reflect the interplay of natural factors in combination with management of the river through flood protection works and gravel extraction. The upper 34 kilometres are probably responding to natural forcing factors, while downstream of here flood protection works, and gravel extraction (particularly downstream of about kilometre 15) will also be influencing channel behaviour.

102. I will now describe flood flow patterns in the Waimakariri River in order to assess the potential effects of the water takes of the CPWES on sediment transport processes.

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[14] *Waimakariri River: status of gravel resources and management implications* ECan report R05/15, 22p.

Waimakariri River flow regime

103. The flow record from the Old Highway Bridge gauging station from 1st June 1967 to 31st May 2001 provided by ECan and as modified by Mr de Joux has been used in the various analyses and modelling studies to develop the CPWES scheme, and this same record of mean daily flow has been used to characterise flow in the Waimakariri River, as shown in Table 1.

104. The flow recorder is located on the Old Highway Bridge 4.5 km from the coast. It is 66 km downstream of the proposed upper intake and 55 km downstream of the proposed lower intake for the CPWES. It is the only long term flow recorder on the river, and water allocation rules for the river are referenced to data from this site.

105. The location of the flow recorder with respect to the intake sites introduces some uncertainty in interpreting the effects of flow regime on sediment transport issues. Although there are a number of tributaries joining the Waimakariri River across the plains (see Table 1), these are small and unlikely to be a significant component of the flow at the recorder. However, there are significant water losses from the river across the plains.

106. Consented irrigation, stockwater and domestic water takes now result in a potential maximum abstraction of 24 m^3/sec, although as yet ~4 m^3/sec of this has not been taken up. The flow series developed by Mr de Joux takes account of these losses.

107. In addition, there are natural losses of between 3 – 12 m^3/sec to groundwater in the lower 30 km of the river course. It is difficult to remove this effect from the long term flow record as the bed leakage cannot be directly monitored,

108. Therefore, it is likely that river flow at the proposed intake sites is up to 12^3/sec greater than that recorded at the Old Highway Bridge flow gauging site. Nonetheless, I will use the de Joux adjusted flow series in my assessment, as this will indicate the river is less able to transport sediment than it really is. Thus, my assessment will be conservative.

109. For the period 1/6/1967 – 31/5/2001 the natural mean daily discharge in the Waimakariri River was 127 m^3/sec, median flow was 95 m^3/sec, the mean annual flood was 1016 m^3/sec, and the peak discharge was 1939 m^3/sec.

110. As I discussed above in paragraphs 41 – 46, the important sediment transporting and channel landforming flows are:

i) The FRE3 flow, which for the Waimakariri River is 283.6 m^3/sec.

ii) The flow which is most efficient for bed load transport, which for the Waimakariri River I estimate to be about 550 m^3/sec.

iii) The mean annual flood flow which for the Waimakariri River I calculate to be 1,016 m^3/sec.

111. The characteristics of these flows in the present flow regime that includes all existing consented water takes are as follows:

i) Flow events equal to or greater than the FRE3 flow occur 10.9 times per year, and have an overall duration of 6.5 % of the time.

ii) The flow most efficient for bed load transport will be equalled or exceeded for 1.17 % of the time, or on average 4.3 days per year.

iii) The mean annual flood flow will be equalled or exceeded 0.17 % of the time.

These characteristics are similar to those of the Rakaia River (paragraph 72).

ASSESSMENT OF EFFECTS OF CPWES ON THE WAIMAKARIRI RIVER

112. In this section I will assess the effects of the proposed CPWES take on the Waimakariri River. My assessment will use the same principles used in my Rakaia River assessment and I will not repeat that material in detail.

113. It is also important to note that my assessment addresses the characteristics of the Waimakariri River after *all* consented takes have been taken into account. It therefore over-estimates the effects of CPWES on this environment as the CWPES take represents only 32 % of the total takes from the Waimakariri River (see paragraph 114).

114. From the water balance model for CPWES described by Mr Tipler in his evidence, I calculate that the mean daily CWPES water take from the Waimakariri River will be 7.8 m^3/sec. Taking this into account with all other consented irrigation and stockwater takes, a total 25 m^3/s would be taken from the river, amounting to a 19.6 % reduction in mean flow. On its own the CPWES take reduces the mean flow by 6.1 %.

115. While the CWPES change in mean flow is modest, it is necessary to further document the de-powering of the river that will occur in the flow bands that are most responsible for bed load sediment transport.

116. Under the proposed CWPES take, the following changes to bed load transporting and landforming flows will occur:

i) Flow events greater than or equal to the FRE3 flow will occur 9.4 times per year, and will last 5.1 % of the time. This is a reduction of 0.5 events/year, and overall the river will spend 1.3 % less time in this flow band.

ii) Flows most efficient for bed load transport will be equalled or exceeded 1.0 % of the time. This is a reduction of 0.7 days per year in the duration of this flow band.

iii) The mean annual flood flow will be equalled or exceeded 0.16 % of the time, which is no change to the duration of this flow band.

117. As I described above, the Waimakariri River has a number of different reaches, and it is therefore appropriate to assess the potential changes in sediment transport and landforming processes in each of these areas.

118. The initial effects of changes in flow regime will be felt downstream of the intakes, which are about 12 km apart in the upper plains section of the river in an unmodified gravel bed part of the river that has not showed aggradation or erosion problems requiring widespread use of flood protection measures. Therefore I interpret this part of the river between the upper and lower gorges to be broadly stable and capable in the long term of transporting the bed load supplied to it.

119. There will be a slight reduction in the frequency of FRE3 flows, and a small reduction in the overall duration of these flows. At this flow level bed load transport of sand is effectively just beginning, thus as noted above for the Rakaia River (paragraph 81) FRE3 flows are responsible for transporting only a very small proportion of the total bed load. In addition, the characteristics of the Waimakariri River bed here with its armour layer of gravel on the bed indicate it is undersupplied with bed load. In the light of these factors, iIt is my opinion that this reduced frequency and duration of FRE3 events will have a less than minor effect on the total volume of sediment transported by the river.

120. The flows that are most efficient for transporting bed load are naturally uncommon, and will occur on just 0.7 days less per year than under the present flow regime. In my opinion this level of change will be undetectable.

121. It can be seen there will be no effective change to the duration of the larger flood events with magnitudes equal to or greater than the mean annual flood. Therefore, it is my opinion that the landform characteristics of braid channels, bars and islands across the Waimakariri River fairway will not be affected by the CPWES water takes.

122. As I noted above (paragraph 25 and 84) it is likely that for operational reasons the CPWES will close its intake gates during flood flows carrying highly turbid water with TSS concentrations of 1,500 – 2,000 g/m^3. From the TSS sediment rating relationship (paragraph 20) I calculate that this will be at a discharge of 500 – 600 m^3/sec, which is approximately the flow most efficient for transporting bed load in the Waimakariri River. Thus for flows above this level there is likely to be no effect on bed load sediment transport.

123. I consider this analysis can be applied to the reaches below the lower gorge of the Waimakariri River, particularly for the gravel transport that occurs in the larger floods.

124. Downstream of its lower gorge the Waimakariri River flows in a reach that overall has been degrading its bed since about 1960 (see Hudson[13]). I interpret this to indicate the river here has been significantly under-supplied with bed load, and the particles size of the surface armour layer have not been coarse enough to limit sediment transport in small to medium sized floods. As I discussed above, the slight de-powering of the river that will result from the CPWES water take is unlikely to have a detectable effect on gravel sediment transport. However, the direction of potential change, which if it occurred would be towards promoting bed aggradation, would serve to reduce the level of bed degradation in this reach.

125. Downstream of this degrading reach, the river enters an aggrading reach from about kilometre 25 to 8.75. Given the extensive modifications to this reach by flood protection works and gravel extraction, it is likely this aggradation is not a natural behaviour.

126. In assessing the potential effect of the CPWES water take on this reach I have taken account of the fact that the overall de-powering of the river is minor, and immediately upstream if any effect does occur it will be towards reducing the bed load sediment transported downstream of kilometre 25. Thus, it is my opinion that there is unlikely to be any increase in aggradation in this reach.

127. In the lower 2.5 km of the river gravel transport ceases and the river has a sandy bed. The river is unable to transport the larger gravel-sized material, and its ability to transport sand as bed load through this reach to the coast is also probably quite low as the sand that is delivered to the coast can be accounted for as suspended sediment during Waimakariri River floods (Hicks, 1998)[2] .

128. Thus, although the CPWES scheme may de-power the Waimakariri River in the FRE3 sand-transporting flow band, this is unlikely to adversely affect the lower reaches of the river, or the mouth and Brooklands Lagoon area as there is already little bed load transport of sand in this environment.

129. In addition, this lower sand bed reach of the Waimakariri River is tidal and thus flow through the mouth occurs on the out-going tide and comprises river water augmented by a very significant volume of seawater. Thus the net effect of de-powering the river will be even less here at the mouth than was identified above for inland reaches of the river.

130. In my opinion, the effects of the CPWES on sediment transport and landforming processes in the Waimakariri River will be less than minor. Potential adverse effects on sediment build-up leading to reduced effectiveness of irrigation intakes and flood protection works along the river are unlikely to occur. Gravel sediment transport rates will not be changed and there will not be any change in the volume of material available for the gravel abstraction industry.

131. I also consider that this assessment is conservative as I have considered the effects of the changed Waimakariri River flow regime from its natural state to that after all consented takes have been taken into account. The proposed CPWES mean daily take of 7.8 m^3/sec amounts to only 31.3 % of the total of all takes. I expect the CPWES 'share' of the effects to be in this order of magnitude.

132. Summarising my assessment of the effects of the CPWES on sediment transport in the Waimakariri River, the passage of sediment through the river mouth, and the delivery of sediment to the coast, it is my opinion that the effects will be less than minor. I have formed this opinion on the basis that:

    132.1 Changes to the Waimakariri River flow regime will be minor for the discharge bands that are responsible for transporting bed load in the river;

132.2 The characteristics of the river in its upper and middle reaches indicate it is effectively undersupplied with bed load and well able to accommodate a small de-powering of sediment transporting capacity;

132.3 In its lower reaches bed load transport effectively ceases in the Waimakariri River under the present flow regime, and sediment is delivered to the coast as suspended load. The CPWES water take will not affect this situation.

132.4 Operational requirements will probably mean that the scheme's intake gates will be closed during moderate-sized and larger floods. In this case there will be no effect on these sediment transporting flows.

LAKE ELLESMERE

133. Lake Ellesmere lies at the lower margin of the Canterbury Plains and it has been extensively described by the Canterbury Regional Council Report 96(7)[15].

134. Located adjacent to the ocean, its varying levels are controlled by artificial opening to allow drainage to the sea. This limits the flooding of low lying farmland around the edges of the lake. The openings are undertaken when inflows raise the lake to trigger levels.

135. The CPWES is likely to increase inflows into the lake, and this may affect the number of openings that are required. I will assess the potential for the scheme to affect lake levels in Lake Ellesmere by analysing its water balance. I will make use of Mr Graeme Horrell's Lake Ellesmere Water Balance Model[1], which he has re-run using expected surface and groundwater inflows to Lake Ellesmere derived from AQUALINC groundwater model outputs[16].

136. The main components of the Lake Ellesmere water balance are as follows:

(a) Inputs

i. Rivers and streams. The main inflow is from the Selwyn River, but there are numerous small spring-fed streams that derive their flow from groundwater on the lower plains. In addition, there are some

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[15] Taylor, K.J.W. 1996 *The natural resources of Lake Ellesmere (Te Waihora) and its catchment.* ECan Report 96(7), 321 p.

[16] Wier, J. 2007 *preliminary CPWES Groundwater Model Report* Report to URS New Zealand by AQUALINC Research Limited, 27p. This report documents outputs from their Central Canterbury Plains Steady State Groundwater Model developed for the CPWES Scheme.

streams that drain catchments on the western side of Banks Peninsula.

ii. Groundwater inflows. Some groundwater seeps and springs contribute water directly to the base of the lake.

iii. Seawater inflows. These can be from seepage through the Kaitorete Barrier, wave wash over low parts of the barrier, and inflow through the artificial opening.

iv. Rainfall directly on the lake surface contributes to inflows.

(b) Outputs

i. Evaporation from the lake surface.

ii. Outflow through the artificial cuts to the sea made at the southwest corner of the lake.

iii. Seepage outflow to the sea through Kaitorete Spit.

137. Horrell's analysis of conditions between 1970 – 1991 produced the following estimates for the mean annual and mean monthly water balance of the lake (see Tables 1 and 2).

Table 1: Lake Ellesmere Mean Annual Water Balance (1970 – 1991)[17]

INFLOW	1970-1991	CPWES
Surface water inflow	12.27 m^3/sec	*15.84 m^3/sec*
Rainfall on lake	3.59 m^3/sec	
Groundwater inflow	0.08 m^3/sec	*0.69 m^3/sec*
Sea water at cut	2.35 m^3/sec	
Sea water seepage	1.26 m^3/sec	
OUTFLOW		
Seepage outflow	1.01 m^3/sec	
Evaporation	6.08 m^3/sec	
Outflow through cut	12.89 m^3/sec	
Lake height (m asl)	0.79 m^3/sec	
# Lake openings per year	3.36 / year	4.56 / year

138. It can be seen that surface water inflows dominate the inputs of the water balance, and peak inflows occur in late winter and spring (July to October).

The largest single contributor is the Selwyn River, which drains partly from the Canterbury foothill ranges some 60 km to the northwest, and also from lower plains springs that are less than 20 km from the lake. Other lower plains spring fed streams that make significant contributions include Hart's Creek and the LII River. Other streams drain from the western slopes of the Banks Peninsula.

Table 2: Lake Ellesmere Mean Monthly Water Balance (1970 – 1991)[14]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Surface water inflow	6.86	6.41	8.98	9.28	11.67	11.61	15.57	21.35	16.32	18.41	11.32	9.43
CPWES	*8.86*	*8.28*	*11.59*	*11.98*	*15.07*	*14.99*	*20.10*	*27.56*	*21.07*	*23.77*	*14.61*	*12.17*
Rainfall on lake	3.37	3.31	3.55	3.81	3.64	3.85	4.58	4.18	2.5	3.07	3.87	3.29
Groundwater inflow	0.01	0.02	0.06	0.08	0.11	0.12	0.12	0.12	0.11	0.09	0.07	0.06
CPWES	*0.08*	*0.17*	*0.51*	*0.68*	*0.93*	*1.02*	*1.02*	*1.02*	*0.93*	*0.76*	*0.59*	*0.51*
Sea water at cut	0.8	0.35	0.81	1.56	2.14	3.37	4.25	4.33	3.52	2.35	2.91	1.84
Sea water seepage	0.78	0.76	0.96	1.44	1.81	2.09	1.64	1.69	1.14	1.04	0.98	0.76
Seepage outflow	0.69	0.69	0.87	1.09	1.32	1.57	1.59	1.01	0.96	0.86	0.75	0.7
Evaporation	12.94	10.65	7.11	4.02	2.04	1.53	1.66	2.04	4.2	7.19	8.94	10.61
Outflow through cut	1.51	1.58	3.75	5.58	14.25	13.54	30.88	26.58	18.29	18.52	7.99	12.24
Lake height (m asl)	0.697	0.690	0.733	0.755	0.852	0.954	0.983	0.798	0.788	0.734	0.692	0.704
CWPES	*0.735*	*0.753*	*0.809*	*0.866*	*0.967*	*0.949*	*0.983*	*0.948*	*0.820*	*0.735*	*0.747*	*0.764*
Number of openings	0.05	0.03	0.12	0.15	0.23	0.44	0.63	0.54	0.41	0.32	0.22	0.20

139. The output side is dominated by flow through the artificial cut, particularly in winter and spring (July – October), but in the summer months of December to February evaporation from the surface dominates water losses.

140. Changes in the balance of inflows and outflows to the lake result in variations in lake level and consequently in the volume and area of the lake. At the mean lake level[20] of 0.79 m above sea level (asl) it covers 189 km^2, while at

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[17] Data from ECan and Crawford, S.J., G.A. Griffiths, G.A. Horrell (1996) *Surface water hydrology Chapter 7* in Taylor, K.J.W. *The Natural Resources of Lake Ellesmere (Te Waihora) and its Catchment* Report 96(7) Canterbury Regional Council pp 85-104.

the minimum level[18] of 0.195 m asl it covered 150 km^2, and at the maximum level[21] of 1.459 m asl on 31/08/04) it covered 225 km^2.

141. The lake does not have a permanent natural opening to the sea, and the level is controlled by artificially opening the lake at its southwest corner near Tuamutu when the level reaches between 1.03 and 1.15 m so that the lake area does not exceed about 210 km^2 for long periods. The managed lake levels are set by the National Water Conservation (Lake Ellesmere) Order 1990, and the openings are controlled by a number of resource consents (CRC042860 and CRC012086) and a Protocol for Opening and Closing Lake Ellesmere/Te Waihora (May 2004).

142. This lake opening management regime has been effectively in operation since about 1948, and since that time the average number of openings has been 3.33/year[19] varying between one and seven per year.

143. Taking the January 1970 – February 1991 period covered by the Lake Ellesmere Water Balance Model[1], the number of openings has been 3.34 per year, of which 44 % occur in winter and 31 % occur in spring. The Water Balance Model accurately replicating the total number of openings, although the predicted timing of some openings differed from that actually recorded.

144. The CPWES will affect the Lake Ellesmere water balance by increasing inflow to the lake, and this in turn may affect lake levels, and the number of times openings need to be established. I have estimated the changes in inflows by examining outputs of the AQUALINC groundwater model[19] that shows the expected annual average increase in baseflow for the Selwyn River and spring-fed streams that discharge into Lake Ellesmere, and the increase in groundwater discharge directly into the lake. These are the only expected changes in the water balance that will arise from the proposed CPWES. I have distributed these annual values (in Table 1) proportionally through the months as shown in Table 2.

145. The Lake Ellesmere Water Balance Model has been re-run by Mr Horrell using the above input data (*pers comm.* 9th July 2007 and 27th July 2007). The model predicted that given the other inputs to the water balance for the years 1970 to 1991, the CPWES would have increased mean lake level to 0.84 m above sea level, an increase of 0.06 m.

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[18] Digital lake level data from the Tuamutu level recorder 26/3/1994 – 10/6/2007 supplied by ECan. Older lake level data had not been digitised.

[19] Lake opening data 1901 – June 2007 compiled by Mr R. Dineen and Mr D. Aires and supplied by ECan.

146. From Table 2 it can be seen that the changed levels would be irregularly distributed through the year. The winter and spring months of June, July, and September would have little or no change in lake level (-0.005 to + 0.001 m), while autumn and late winter months of April, May and August would show the greatest increases (0.111 – 0.150 m). For the other months the increase in lake level would be 0.032 – 0.076 m.

147. Mr Horrell's model gave an output of 97 openings for the 21.25 years (1970 – 1991), and the mean annual number of openings would therefore be 4.56, and increase of 0.98 openings per year. As noted above, when the model was initially developed it did not accurately replicate the precise timing of openings, thus I consider it inappropriate to compare the exact opening times of the pre- and post-CPWES model runs. However, I would expect the extra lake opening to occur during either May or August as the increased lake levels in these months bring them to similar levels as June and July when 32 % of all openings occur (1950 – 2007)[22].

148. The increased lake level would result in an increased mean lake area. Crawford *et* al (1996)[20] show a curve of the relationship between lake level and area. From this I estimate that the mean area of Lake Ellesmere would increase under the CPWES from 191 km^2 to 194 km^2. From the 1994 – 2007 lake level data[21] and the lake level : area relationship[20], I estimate the lake area has over the last 13 years varied from about 150 km^2 to 217 km^2. The potential 2 % increase in area resulting from CPWES is minor and is well within the recent range of variability of lake area. Thus no change in lake shoreline land management practices would be required.

149. The potential CPWES increase of ~1 opening per year would have little effect on the physical environment at the Tuamutu opening site, and no mitigation measures are proposed. However, it is recommended that the cost of the extra opening be covered by the scheme and it is my understanding the applicant is proposing this course of action.

150. Potential ecological effects on the lake are described in evidence of Dr Burrell, and Dr Glova. Subject to these possible ecological constraints, the extra openings may in the future provide an opportunity to vary the opening protocols and develop different strategies for enhancing the characteristics of the lake that the Water Conservation Order (Lake Ellesmere) seeks to preserve.

COMMENTS ON MATTERS RAISED IN SUBMISSIONS

151. Submitters have raised a number of issues relevant to sediment transport processes and Lake Ellesmere. Rather than addressing each of these in turn, I have examined the submitters' database provided by ECan, and will address the matters of concern as classified therein. These cover the Waimakariri River, Rakaia River, Lake Ellesmere, lowland streams and coastal processes. I will address only those aspects relevant to the scope of my evidence.

Rakaia River

152. Submitters have raised concerns about adverse effects on the braided river character of the Rakaia River. In my evidence I have shown that it is the larger floods that are responsible for forming the pattern of braids channels and bars across the river fairway. These flood flows will not be detectably affected by the proposed CPWES/ACWT water takes, thus there will not be effects of this nature.

153. Concerns have been raised that there may be adverse effects around existing water intakes flood protection works, and other infrastructure caused by sediment build up or erosion. I have shown that sediment transport rates will not be affected by the CPWES as the water take will have only a very minor effect on the flow bands most responsible for these processes.

154. Concerns have been raised about increased flood levels. These will not occur as the scheme proposes to take water from the river, not add to the flow.

155. Concerns have been raised about gravel yield from the Rakaia River. The river is currently a very minor source of sediment for the gravel extraction industry in mid/central Canterbury. I have shown that there will be no detectable change in bed load sediment transport in the river, thus there will be no adverse effect on gravel yield.

156. Submitters have raised concerns about potential effects on the lagoon at the mouth of the Rakaia River. Potential adverse effects are not clearly identified, but from my area of expertise these could include closure of the mouth and silting up of the lagoon, and I will address these issues.

157. The Rakaia Lagoon covers about 60 ha, and is 3.7 km long and up to 0.25 km across. It can have 1 – 3 openings discharging to the ocean, and I am not aware of any reports of the river mouth ever being completely closed.

158. Kirk (1991)[20] has studied the river mouth area, and reports that flows of less than about 45 – 50 m^3/sec would be required to allow the mouth to close completely. In the 1967 – 2001 Rakaia River flow data used in this application the minimum flow never reached 50 m^3/sec, and was only below 60 m^3/sec on five days (0.04 % of the time). However, these extreme low flows in the river would not be affected by the CPWES as the minimum flow at which its take can occur is ~90 m^3/sec. Thus CPWES will result in closure of the Rakaia River mouth.

159. I have shown above that the Rakaia River flow bands that will be most affected by the CPWES take do not carry significant volumes of bed load sediment. Furthermore, there will only be a 1.5 % reduction in mean flow at the mouth (see paragraph 75). Therefore, I consider there will be no increased build up of fine material in the Rakaia Lagoon as a result of CPWES.

160. Submitters have raised concerns about sediment transport in the Rakaia River. I have demonstrated above that bed load and suspended load transport in the river is unlikely to be affected by CPWES as the flow bands responsible for transporting most of this sediment will not be significantly affected by the water takes.

Waimakariri River

161. Submitters have raised a similar range of issues with regard to the Waimakariri River. My comments above in paragraphs 152 – 155 and 160 in respect of the Rakaia River apply equally to the Waimakariri River and will not be repeated here. However, additional comments on flood protection works and mouth closure are appropriate.

162. There is an extensive system of flood protection works along the south bank of the Waimakariri River. Concerns have been raised that these may operate less effectively if either degradation or aggradation occurs in the river as a result of the CPWES. I have shown in my evidence that the flow bands that transport most bed load sediment in the Waimakariri River will not be significantly reduced by the CPWES take. Therefore I do not expect there to be any change in the patterns of aggradation and degradation along the Waimakariri River, and flood protection works will not be adversely affected.

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[20] Kirk, R. M. 1991 River-beach interaction on mixed sand and gravel coasts: a geomorphic model for water resource planning *Applied Geography* 11: 267 – 287.

163. The mouth of the Waimakariri River is rather different to the Rakaia mouth, and some further comments are therefore appropriate about the possibility of mouth closures here.

164. The mouth area of the Waimakariri River has a relatively large tidal environment covering over 250 ha, and tidal influence extends some 6 km up-river from the coast to the Old Highway Bridge and includes the Brooklands Lagoon area.

165. The mouth does not close during periods of low flow. This results from an interaction of factors including: the low wave energy environment of Pegasus Bay that means longshore drift of sand does not block the mouth; and the large volume of tidal water that passes in and out of the mouth on each tidal cycle.

166. While some reduction in river flow will occur under the CPWES, tidal flows will not be affected. From the Waimakariri River flow record and the area of the tidal compartment, I estimate that the discharge through the mouth at low flows with CPWES will not be less than about 100 m^3/sec. I consider this flow will be more than adequate to keep the mouth open.

167. In addition, the CPWES irrigation take would have ceased at 64.24 m^3/sec for most of the year and at 41 m^3/sec when filling the reservoir in winter. These flows are above the minimum flows reached by the river. Thus, as the mouth has stayed open at these previous low flows, and future extreme low flows will not be affected by the scheme, mouth closure will not occur as a result of the CPWES.

Lake Ellesmere

168. Submitters have raised concerns regarding potential effects of the CPWES on the number of lake openings and flooding around the lake margins. I have discussed lake openings above.

169. I have shown that extra inflows to the lake resulting from CPWES will be from groundwater and spring-fed streams. This increased flow will be baseflow which provides the steady background rate of inflow to the lake. Storm inflows that cause the lake to rise rapidly will not be affected. Therefore, in my opinion, the flood inundation levels around the lake margin will not be significantly affected by CPWES.

Lowland streams

170. Concerns have been raised regarding siltation in low land streams. Effects could arise from the streams being de-powered and thus depositing silt along their channel, or conversely, increased flow could result in them transporting more silt to Lake Ellesmere.

171. I have described the potential effect of CPWES on lowland steams as increasing the rate of baseflow. These low discharge flows have very slow flow velocities and thus have very low bed load sediment transporting power. Although there will be a slight increase in these flows, it is predicted to be very small, and in my opinion this will have no effect on sediment transport rates, which will continue to be dominated by natural rainfall events, which will not be affected by CPWES. I therefore consider there will be no effect either in terms of siltation adversely affecting the channels or low land streams, or enhanced delivery of silt to Lake Ellesmere.

Coastal processes

172. Coastal processes may be affected if there is reduced sediment delivery to coast. At the Waimakariri River mouth I have shown there will be no effective change in sand transport to coast and therefore there will be no change in coastal processes here.

173. At Rakaia River mouth the situation is similar, although here gravel as well as sand is being transported to the coast, and my assessment has shown there will be very little if any reduction in sediment delivery to the coast.

174. I also note that Kirk (1991)[23] undertook an analysis of the regional coastal sediment budget 5 km to the northeast and southwest of the Rakaia River mouth. He concluded (p 280):

> *There seems little prospect that water resource development on the Rakaia could contribute markedly to regional coastal erosion and/or saltwater inundation of coastal farmland through reduced beach sediment supply*.

The major water resources developments referred to in this quote related to issues traversed during the debate surrounding the National Water Conservation (Rakaia River) Order 1998. The CPWES proposal is consistent with the developments contemplated at that time.

SUMMARY

175. The natural mean flow of the Rakaia River as it flows across the Canterbury Plains is 213 m^3/sec, although due to existing consented water takes this is now reduced to 191 m^3/sec. The combined CPWES/ACWT takes will further reduce the mean flow to 180 m^3/sec, with the CPWES share of this being 3.1 m^3/sec, while the ACWT share would be 7.7 m^3/sec.

176. The natural mean flow of the Waimakariri River as it flows across the Canterbury Plains is 127 m^3/sec, although due to existing consented water takes this is now reduced to 110 m^3/sec. The CPWES take will further reduce this mean flow to 103 m^3/sec.

177. These reductions in flow may de-power the rivers and potentially cause a reduction in sediment transport, which in turn may affect other intake structures, gravel resources, braided river bed characteristics, accumulation of sediment at the river mouths, and delivery of sediment to the coast.

178. The Rakaia and Waimakariri Rivers carry substantial volumes of suspended and bed load sediment. Suspended load comprises clay, silt and fine sand, while bed load is sand, gravel and larger cobbles. Most of this material is carried by flood flows such that the bulk of suspended load is carried by flows greater than the mean flow, and the bulk of bed load material is carried by flows above three times the median flow.

179. Suspended sediment is delivered to the rivers primarily from soil erosion in the upper catchments, while bed load is largely derived from erosion of the bed and banks of the channel itself. The CPWES/ACWT takes will affect sediment transport if the de-powering of the flow regime results in a reduction in the ability of the rivers to transport suspended load, and both a reduction in the supply of bed load and the rivers' ability to transport this material.

180. The supply of suspended sediment is from the catchment upstream of the takes, thus the total volume of this material being delivered to the rivers will remain unchanged. Rivers have considerable excess capacity to transport suspended sediment, and in addition in the Waimakariri and Rakaia Rivers the main suspended sediment transporting flows above the mean flow will not be greatly affected by the proposed CPWES/ACWT takes. Therefore, I consider the proposed takes will have a less than minor effect on suspended sediment transport.

181. Both the Rakaia and Waimakariri Rivers are largely gravel bed braided rivers. Flows responsible for transporting sand and gravel bed load will be reduced from 6.0 % of the time to 4.4 % of the time in the Rakaia River, and from 6.6 % to 5.1 % of the time in the Waimakariri River. These reductions are modest. In addition, the rivers are both under-supplied with bed load and although they will be slightly de-powered, they will be able to recover their bed load transporting ability.

182. In addition, this assessment has assumed the scheme intake gates will be open during all flood conditions. This is unlikely, and it will be necessary to limit the volume of suspended sediment that enters the irrigation scheme and the intake gates will probably be closed during most moderate to large sized floods. In these conditions there will be no effects on bed load sediment transport.

183. Furthermore, this assessment assumes that the CPWES/ACWT takes will be responsible for all the reduction in flow regime in these rivers. In fact, significant volumes of water are already taken from the rivers under existing consents. The CWPES/ACWT share of the Rakaia River total water take would only be 33 %, and the CPWES share of the Waimakariri River total water takes would only be 31.3 %. Thus the effects of these takes on the sediment transporting environment of the rivers will be significantly less than I have assessed.

184. Given the above, I consider that the effects of the CPWES/ACWT water takes on sediment transporting regimes in the Rakaia and Waimakariri Rivers will be less than minor. It therefore follows that potential effects on other intake structures, gravel resources, braided river bed characteristics, accumulation of sediment at the river mouths, and delivery of sediment to the coast will also be less than minor.

185. The CPWES will result in increased groundwater flows through the central plains area. This in turn will affect the level of Lake Ellesmere due to increased discharge of baseflow in surface streams, and increased direct groundwater inflows.

186. Based on outputs of a model of the Lake Ellesmere water balance, it is expected that the mean level in the lake will rise by 0.58 m, mostly in the months of April, May and August.

187. As the level of the lake rises more marginal land is inundated, and as a result of CPWES the area of the lake would rise slightly from 191 km^2 to 194 km^2.

However, this is well within the present range of variation from 150 – 225 km^2. The level of the lake is controlled by artificial openings when it reaches between 1.03 and 1.15 m above se level.

188. As a result of the changed lake water balance due to CPWES, there will be an increase of ~1 opening per year in the number of lake openings required. It is proposed that this would be carried out at the scheme's expense. No other mitigation measures would be required.

M.C.G. Mabin
21st January 2008