Assessment of Environmental Effects: Hydrology and Irrigation Demand for the Hurunui Water Project

Prepared for:
Hurunui Water Project

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Limitations:

This report has been prepared on the basis of information on potential future land use assumed by the Hurunui Water Project Ltd and environmental conditions determined by other parties.

The report describes a numerical modelling simulation of a natural hydrological regime. Due to the variability of natural processes, the modelling output cannot be guaranteed.

The report has been prepared for Hurunui Water Project, according to their instructions, for the particular objectives described in the report. The information contained in the report should not be used by anyone else or for any other purposes.

Executive Summary

This report considers the effects of operating a large scale storage scheme on the upper reaches of the Hurunui River to meet irrigation demand for a 42,000 hectare area in the lower Hurunui catchment.

Two storage sites considered in this AEE are Lake Sumner on the North Branch of the Hurunui River and a reservoir on the South Branch located approximately 3 km upstream of the confluence between the Hurunui River South Branch and the North Esk River. Active storage in Lake Sumner uses its natural historical operating range of approximately 3 meters. A two meter control gate defines the region of active storage, approximately 27 million m^3, the upper one meter is used to buffer peak inflows into the lake. Flood flows into Lake Sumner are controlled by releasing water in advance and/or lowering the control gates. Active storage in the South Branch Reservoir is based on an operating range between 605 and 630 m RL giving an active storage capacity of 111 million m^3.

The effects of the scheme were simulated over a 36 year period (1972-2007) using a computer model which estimated irrigation demand, computed run-of-river water availability subject to the proposed Hurunui River River flow regime Variation 8, and water availability within the two storage reservoirs. Lake Sumner was assumed to be the primary storage with the South Branch reservoir providing supplementary water. Water is harvested into storage subject to maintaining environmental flows on Lake Sumner and the South Branch Reservoir outlets.

The model is driven by a combination of historical and synthetic inputs, primarily inflows into the storage sites and evapotranspiration and rainfall data. Modified flows and reservoir levels were compared with estimated or historical natural flows/levels to assess the effects of the scheme.

Upstream of the Hurunui at Mandamus recorder the scheme creates a redistribution of the natural flows, the general effect being an increase in the magnitude of lower flows due to daily irrigation releases of up to 31.5 m^3/s, and periods of stable flow when water is being harvested into storage.

The need to make controlled releases to manage flood inflows to Lake Sumner may result in an increase in frequency of outflows in the 100 m^3/s range, although this is somewhat dependent on the time of year. The magnitude of stable low flows is in general no lower than the estimated natural low flows.

The effects are more pronounced at the South Branch Reservoir outlet due principally to the lower inflows into the reservoir and the much larger storage volume that may need to be replenished. Periods of stable flow may exist for up to 8 months in years after the reservoir has been significantly drawn down. However, flow variability downstream of the confluence with the North Esk River is maintained due to the contribution of flow from this river. Furthermore, except in the most extreme years, the scheme has the ability to

make environmental flushing flows including periods when flows are naturally low for sustained periods.

In terms of reliability the scheme described in this report may be described as extremely reliable. Supply meets demand in the majority of years and when this does not occur, the periods of no supply coincide with the latter months of the irrigation season. The scheme could be described as unreliable only two years in the 36 year simulation period, viz. 1972 and 2007, when the soil moisture balance is less than 50% for sustained periods leading to shorter irrigation periods for these two seasons.

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Appendices:

1.0 Introduction

Pattle Delamore Partners Ltd (PDP) has been engaged by the Hurunui Water Project (HWP) to assess the hydrological effects from the development of an irrigation scheme in the Hurunui and Upper Waipara catchment.

The irrigable area of the Hurunui Water Project is located in the Amuri Basin, Omihi and Scargill Valley and includes the existing Balmoral Irrigation Scheme. It has been determined through scoping and feasibility studies that the project will involve the taking of water from the Hurunui River and will deliver water through a system of water races. With adequate storage in place the system will be able to irrigate an area of 42,180 ha, with a high level of reliability.

The key elements of the project as shown in Figures A1 and A2 include:

- An intake on the Hurunui River downstream of the confluence with the Mandamus River.
- A control gate structure at the outlet of Lake Sumner which will control the lake level in order to provide storage for irrigation.
- A dam and consequent reservoir in the Hurunui River South Branch to provide storage for irrigation.
- A distribution network of water races across the plains providing water to all shareholder properties in the scheme.

The operation will involve delivering water to the supply area from run-of–river water via a race system when water is available in the rivers with the shortfall in demand being made up with water from storage. During periods when the water supply exceeds the demand water will be harvested into the storage reservoirs to replenish water levels if required.

This assessment of Environmental Effects report deals with hydrology and irrigation demand and has been produced to technically support the HWP resource consent application. The activities to which this report relates are:

- The storage of up to up to 27 million m^3 water in Lake Sumner and up to 111 million m^3 of water in the South Branch reservoir
- Use of water to irrigate 42,180 hectares within a command area of 54,344 hectares.

This report assesses effects of the proposed activities and explains what changes may arise in the natural hydrology of the upper reaches of the Hurunui River as a result of these activities. The scale and significance of these effects are reflected in the level of detail provided within each section of the report. Measures to avoid, remedy or mitigate any potentially adverse effects of the project operation are also indicated along with alternatives being considered during the different stages of the project.

2.0 Background

In 2002 the Hurunui Community Water Development Project working group was formed with representation from Enterprise North Canterbury, the Hurunui Irrigation and Power Trust (HIPT), Ngai Tahu, Mainpower and the owner of Eskhead Station. The HIPT represents the interests of more than 200 Hurunui farmers who formed a trust in 2002.

Its purpose is to improve the prosperity of the project area through a water management project that enhances agricultural diversity while maintaining the ecological and recreational values of the area.

3.0 Description of the Irrigation Scheme

3.1 Physical Description

The scheme area is defined as the area that will be serviced by water from the irrigation supply network. The total area covered is approximately 54,340 ha as shown in Appendix A, Figure 1. The northern boundary is marked by the Pahau River and the southern boundary by the southern margin of the Amuri Basin and the Waipara River in the Omihi Valley. The western boundary will run along the margin of the Amuri basin and the eastern boundary will follow the margins of Omihi and Scargill Valley.

Some of the farmland in this area will not be irrigated as the gross irrigable area will be larger than the net irrigable area.

Table 1 provides a summary of the irrigable areas as identified by the Project team. The gross and net irrigable areas reported in Table 1 are based on the District Scoping Report (Tonkin & Taylor, June 2004). In this report it was assumed that 20% of the gross area would not be irrigated to account for hardstand areas, shelter belts and other non-irrigable areas. For the existing Balmoral Scheme the numbers reported by Amuri Irrigation were used. Taking these considerations into account the net irrigable area will be 42,180 ha.

Table 1: Gross and Net Irrigable Areas

Irrigation Area	Gross Irrigable Area (ha)	Net Irrigable Area (ha)
Existing Balmoral Scheme	5,500	5,240
Balmoral forest & adjacent area	9,150	7,320
Peaks	6,288	5,030
Hawarden south of Waitohi	11,200	8,960
Upper Waipara/Mason’s Flat	6,888	5,510
Scargill Valley	5,880	4,700
Omihi	6,780	5,420
Total	**51,686**	**42,180**

Irrigation will be primarily spray irrigation with a small proportion (approximately 1,955 ha) of the existing Balmoral Scheme being Borderdyke irrigation.

For this project it has been assumed that the area will be used for dairy. This assumption is conservative and maintains the capacity to irrigate almost any other crop in the future.

3.2 Storage Reservoirs

As explained above storage for irrigation will be provided by managed lake levels in Lake Sumner and a reservoir in the Hurunui River South Branch.

For Lake Sumner the HWP is proposing to manage the lake within the 3 meters of the historical operating range. The first two meters is to be used for live storage amounting to 27 million m^3, while the upper meter is to be used to buffer flood inflows.

For the South Branch reservoir the HWP are proposing to construct a dam with an operating range of 605-630 m above mean sea level, and a live storage of 111 million m^3. The lowest water levels in the reservoir will be from January to May which is typically a period of low river flows combined with high irrigation demand.

3.3 Water Take of Proposed Scheme

The water requirements for on farm use is based on a peak daily water application rate of 0.578 L/s/ha. An allowance has been made in this assessment for 20% loss of flow from the races meaning that a total of 0.69 L/s/ha is required from the river. For 40,280 hectares of spray irrigation the total maximum abstraction from the river is 27,793 L/s (27.7 m^3/s). When adding another 1900 ha for borderdyke irrigation from the Amuri Scheme the total maximum abstraction will be 31.5 m^3/s.

The actual requirements for irrigation will depend upon the environmental conditions prevalent at the time and will vary between nothing and the maximum value above. A more detailed description of the expected irrigation water demand is provided in section 6

3.4 Availability of Water

The rate at which run of river water can be abstracted is subject to the Hurunui River flow regime. Currently there are three flow regimes operative for the Hurunui River, the 1980 Plan Water Allocation regime (current regime), the Balmoral Irrigation Scheme regime and the modified Mosley Regime (Familton, July 2007). It is recognised by ECan that having three different flow regimes is not desirable and recently a new Hurunui River Flow Regime has been notified by ECan (Variation 8) which is currently going through a submission process. Table 2 shows the minimum flows for each of the flow regimes (A-block).

Table 2: Minimum Flow for the Current, Balmoral Irrigation Scheme, Modified Mosley and Variation 8 flow regimes

Flow Regime	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	10	10	10	10	10	10	10	11	13	17	16	11.5
Balmoral Irrigation Scheme	12	12	12	12	12	12	12	13	15	19	18	13.5
Modified Mosley	15	12	15	15	15	15	15	15	20	20	20	20
Variation 8	15	12	12	15	12	12	12	13	15	15	15	15

In addition to these minimum flows the current flow regime has a 1:1 flow sharing provision which limits the proportion of the available flow that can be abstracted at flows above the minimum flow. All other flow regimes presented in table 2 do not have a sharing regime above the minimum flow.

This AEE focuses on Variation 8 since the proposed scheme will need to comply with this regime.

Variation 8 proposes new minimum flows and allocation blocks for different reaches of the Hurunui mainstem and for its tributaries. This proposed flow regime sets monthly variable A-block and B-block allocation limits for the Amuri Reach of the Hurunui River. Table 3 shows the proposed flow regime based on Variation 8 that we have assumed to be the correct version for the Amuri Reach. In the notification of Variation 8 there is an overlap between A and B blocks between May and September which is unlikely to go ahead. Where this overlap occurs a separation of 5 cumecs has been made between A and B blocks. Thus the allocation and minimum flow conditions for the A block remain as for Variation 8, while the allocation limits for the B block remain as for Variation 8, although the minimum flow condition may be greater. The following table summarises our interpretation of the proposed flow regime:

Table 3: Proposed Flow Regime (Based on Variation 8) for Hurunui River (Amuri Reach)

Month	Minimum Flow (A Permits)	Allocation Limit (A Permit)	Flow at Mandamus to allow 100% use of A Permits	Minimum Flow for B Permits	Gap	Allocation Limit (B-permit)	Gap	Minimum Flow (B-Permit) Extension	Allocation (B Permit) Extension	Total Allocation
January	15	6.7	21.7	26.7	5.0	10.0	3.3	40.0	5.0	21.7
February	12	6.7	18.7	23.7	5.0	7.5	8.8	40.0	7.5	21.7
March	12	6.7	18.7	23.7	5.0	7.5	8.8	40.0	7.5	21.7
April	15	6.7	21.7	26.7	5.0	10.0	3.3	40.0	5.0	21.7
May	12	15.0	27.0	32.0	5.0	10.0				25.0
June	12	15.0	27.0	32.0	5.0	10.0				25.0
July	12	15.0	27.0	32.0	5.0	10.0				25.0
August	13	15.0	28.0	33.0	5.0	10.0				25.0
September	15	15.0	30.0	35.0	5.0	10.0				25.0
October	15	6.7	21.7	26.7	5.0	15.0				21.7
November	15	6.7	21.7	26.7	5.0	15.0				21.7
December	15	6.7	21.7	26.7	5.0	15.0				21.7

3.5 Existing Water Takes

Currently the natural hydrology of the Hurunui River has only been modified by abstractions of water below the Mandamus River. Based on resource consent data supplied by Environment Canterbury (October 2008) and Familton (July 2007) the current abstractions in the Hurunui catchment can be summarised as follows:

- There are currently 113 water permits that authorise the abstraction of surface water and hydraulically connected groundwater from the Hurunui River and its tributaries. An additional 7 applications for water permits are in process as at October 2008. A list with all water abstractions is included in Appendix C.
- The maximum total surface water allocation for all surface water bodies in the Hurunui Catchment is 11.461 cumecs.
- Apart from a small amount of domestic and stock water use, the demand for water is to provide an irrigation water supply.
- Current mainstem allocation totals 8.209 cumecs with the Amuri Irrigation Company Ltd taking 5.0 cumecs and other irrigators taking 3.209 cumecs. A total of 6.7 cumecs is taken above the Pahau confluence and 1.5 cumecs downstream in the Domett Plains reach.

- The largest take is by the Amuri Irrigation Company Ltd which takes 5 cumecs from the Hurunui River just below the Mandamus River confluence.

Currently all irrigators rely on run-of-river water supply which does not have a high reliability of supply and therefore irrigators are interested in joining the scheme. This AEE assumes that that the Amuri Irrigation Company Ltd will become part of the scheme. It is further expected that other consent holders in the area will buy into the scheme as well since the project will provide a high degree of reliability of supply to irrigators.

4.0 Description of the Environment

4.1 Location

The irrigable area to which this application relates is approximately 54,340 ha as shown in Appendix A, Figure 1. The northern boundary is marked by the Pahau River and the southern boundary by the Waipara River. The western boundary will run along the margin of the Amuri Basin and the eastern boundary will follow the margin of Omihi and Scargill Valley.

4.2 Climate

The climate in this area is similar to the Canterbury plains with a fairly consistent rainfall from month to month and a seasonal variation in temperature and evapotranspiration. Table 4 shows the mean monthly rainfall, evapotranspiration and temperature for the command area.

Table 4: Monthly Rainfall and Evapotranspiration Data for the Command Area

Month	Rainfall[1] (mm)	Evapotranspiration[1] (mm)	Temperature[2] (°C)
January	47	133	17.25
February	49	105	16.89
March	58	83	14.66
April	51	48	11.68
May	50	29	8.36
June	57	20	5.75
July	66	20	5.27
August	65	32	6.80
September	57	56	9.32
October	60	88	11.34
November	53	108	13.05
December	55	127	15.86
Average	668	848	11.35

(1) Based on synthetic daily rainfall and PET data from 1972 to 2008 produced by NIWA on a 5km x 5km grid.

(2) Based on data from Culverden climate station from 1983-2009 (NIWA agent number 4527)

There is some variation in the rainfall and evapotranspiration data between the Omihi/Scargill area and the Amuri Basin as a result of the influences of the mountains and the sea. This is further detailed in section 6.2.

4.3 Climate Change

As recognised in the report *'Climate Change Effects and impacts Assessments, A Guidance Manual for Local Government in New Zealand 2nd Edition' (Ministry for the Environment, 2008)* there is a lot of uncertainty associated with developing projections of future climate changes. However an indication of what is likely to happen in New Zealand and on a more regional scale has been described in the report mentioned above. A summary of this report with relevant information for the Hurunui Catchment has been given by Gareth Renowden in his evidence for the Hurunui Water Conservation Order (March 2008). In addition McKercher and Henderson (2003) have researched shifts in flood and low flow regimes in New Zealand rivers associated with the shift in phase of the Interdecadal Pacific Oscillation (IPO). This section provides a summary of the available information on climate change relevant to the Hurunui Water Project and is primarily drawn from the three sources mentioned above.

Global warming and the climate change it brings are caused by the build-up of greenhouse gases in Earth's atmosphere. NIWA have recently modelled the expected temperature increase for New Zealand based on global climate models (GCMs). The projections for Canterbury are for an increase in average temperature of 0.9 ^{O}C by the 2040's and 2.0 ^{0}C by the 2090's. Rainfall is projected to decline only slightly at Christchurch and Hanmer, but increase by up to 8% at Tekapo. This reflects the trend towards increasing rainfall on the West Coast and at the Main Divide as a consequence of increasing westerly winds. The expectation is that flows in Canterbury rivers that have their catchments up, at, or near the Main Divide will increase, at the same as the incidence of drought increases nearer to the coast. This would be in effect an intensification of the frequently observed pattern of northwester conditions in Canterbury: plenty of water in the rivers while surrounding farmland is dry.

Climate change associated with the Interdecadal Pacific Oscillation (IPO) however indicates a different trend. McKercher and Henderson (2003) have researched shifts in flood and low flow regimes in New Zealand rivers associated with the shift in phase of the IPO that occurred in 1977/1978. They found that flood and low flow regimes for many rivers were different in the periods 1947-1977, and 1978-1999, and that since 1999 there may have been a shift back to the 1947-1977 pattern.

The results of this study showed that there was no significant change in flood flows for the Hurunui River between the 1947- 1977 period and the 1978 – 1999 period. More importantly however the low flows in the Hurunui River were significantly higher over the 1978-1999 period (Increase in the order of 10 – 15 % in the medians of the low flow). At the time of writing this study however it is not clear whether the IPO moved to a state similar to that which prevailed for 1947-1977. If the IPO does move back to this state then low flows in the Hurunui River may be more of a constraint on water supply in the coming decades.

In summary there are two processes which potentially affect future climate change in the project area. Climate change associated with global warming predicts a different effect on Hurunui River flows than climate change associated with the Interdecadal Pacific Oscillation. It is therefore hard to predict the effect of climate change on flow in the Hurunui River and the availability of run-of river water. However research does indicate that temperatures are expected to rise in the coming decades and that the incidence of draughts in the lower Hurunui catchment is likely to be increasing. This may warrant a conservative approach on required storage volumes.

4.4 Soils

Figure A3 shows a map with the soils in the command area. The majority of the soils in the Amuri Basin are identified as Balmoral, Glasnevin and Culverden silt and sandy loams some of them stony (Sheet 6, Soil map of the South Island, DSIR, 1968). The soils bordering the Pahau River consist of Templeton and Eyre-Paparua silt and sandy loams and the soils bordering the Hurunui and Waitohi River are Waimakariri and Waimakariri shallow sandy to silt loams. A small proportion of the area in the Amuri Basin consists of other soils (see Figure A3 and Table 5.). Soils in the Scargill and Omihi Valley mainly consist of Glenmark silt loams to sandy loams and Waipara silt loams.

Table 5 identifies the soils in the command area and their estimated water holding capacities (WHC) has been taken from the district scoping report (Tonkin and Taylor 2004).

Table 5: Soils Characteristics of the HWP Command Area

Id	Soil Name	Soil Description	Estimated WHC (mm)
13a	Glasnevin	Stony sandy loams, silt loams and shallow silt loam	90
13b	Balmoral	Mostly stony silt loams, some sandy loams	90
14b	Culverden	Mostly silt loams, stony silt loams	90
96a	Templeton	Silt loams, sandy loams, some stony loams	120
96c	Eyre-Paparua	Mainly shallow silt loams, some sandy loams, often stony	120
95	Waimakariri	Sandy loams to silt loams	60
95a	Waimakariri Shallow	Sandy loams to silt loams; shallow and stony loams	60
95d	Willowbridge	Silt loams to sandy loams	90
22hH	Makerikeri Hill Soils	Mostly stony silt loams	60
28a	Okuku	Mostly silt loam	90
18d	Domett	Mainly silt loams	120
15e	Waipara	Mainly silt loams, some shallow silt loams	90
16H	Amberley Hill Soils	Fine sandy loams, stony loams, silt loams	120
89	Temuka	Silt loams to clay loams, some peaty loam topsoils	150
72	Omihi	Mostly clay loams	90
16fH	Tipapa Hill Soils	Mostly silt loams	120
16b	Glenmark	Silt loams to sandy loam	120

4.5 Hurunui Catchment

4.5.1 General

Several reports describe the hydrology of the Hurunui catchment in detail. The most notable reports include Mosley (January 2002), Facer (2003), Bowden (1977) and Morland (1994). This description of the Hurunui catchment draws on information from these reports and available flow data from several sites in the Hurunui catchment provided by ECan.

The total Hurunui Catchment area is approximately 2671 km^2 and is bounded by the Waiau catchment to the north and the Waimakariri, Ashley and Waipara catchments to the south.

The river has two main branches upstream of the Hurunui/Mandamus confluence, these being the North Branch including Lake Sumner and the Hurunui South Branch. Lake Sumner influences the magnitude and duration of flood waves moving down the North Branch. The peak of a flood is lowered as water passes into storage and the rate of recession decreases as water is released from storage after the peak has passed. Both branches have their headwaters in the Southern Alps but the North Branch has a significantly greater portion of its area in the Alps. There are numerous alpine, foothills and lowland tributaries. Both branches flow through dry, extensively grazed grass and shrublands before forming a single channel as far as the Amuri plains. There the river becomes braided, and with the exception of a gorge through the Lowry Peaks Range, remains so to the sea.

Important tributaries are the Waitohi and Waikari rivers; some of the water balance in the Culverden area has been modified by the irrigation scheme. Some formerly dry streams now carry water. The river enters the Pacific Ocean approximately 11 km south of Cheviot and the river mouth is narrow, having no delta or mudflats.

Elevations in the Hurunui catchment range from 0m at the River mouth to 1980m at its headwaters. The catchment has one extensive flat area, the Amuri Plains, formed by broad coalescing glacial outwash fans. The plains lie between the Main Divide and the coastal hills and vary in elevation from 150-275m. 44 5 %of the catchment is at an elevation less than 400 metres and 8% of its headwater at elevations in excess of 1500 m.

4.5.2 Hydrological Regions and Rainfall

Hydrologically the catchment contains three regions:

- The Eastern Alps region covers the upper reaches of the catchment, characterised by prevailing winds from the west and highest rainfall.
- The Canterbury Plains hydrological region covers the area of the Amuri plains. This is the area of lowest rainfall and small surface runoff especially in the summer months.
- The Hurunui hydrological region, which comprises the rolling hill country and includes some of the ranges just east of the main divide. Average annual precipitation is in the order of 800 - 2,000 mm.

Figure A5 is a isohyetal map which shows average annual rainfall totals within the Hurunui catchment sourced from NIWA. Rainfall ranges from around 6000 mm/year in the Southern Alps to around 700 mm in the Amuri Basin. Most of the rain in the catchment occurs with northwesterly rains resulting in heavy falls over and just east of the Divide. The isohyetal map indicates a rapid decrease in rainfall totals with distance further east of the divide.

4.5.3 Sub-Catchments and Flow Characteristics

There are a number of river flow recorder sites in the Hurunui catchment. The sub-catchments with recorder sites relevant to this application are included in Table 6 together with their catchment areas, specific discharge and key flow statistics. The sub-catchment areas are shown in Appendix B, Figure B1. Comments on the record period and accuracy of the data for the relevant recorder sites are included in Appendix D. The statistics provided in Table 6 provide an indication of the differences in flow characteristics between the sub-catchments of the Hurunui River. It should be noted that the significantly differing record lengths for these sites means that comparisons are simply for indicative purposes.

Table 6: Recorder Sites, Catchment Area, Specific Discharge and Flow Statistics for Several Sub-Catchments of the Hurunui River

Recorder Site	**Catchment Area (km^2)**	**Specific Discharge (l/s/Km^2)**	**Flow (m^3/s)**					
			Mean Flow	**Median Flow**	**7-Day MALF**	**Lower Quartile**	**Upper Quartile**	**Mean Annual Flood**
No.2 Hut	182	97	17.6	11.3	4.7	7.6	18.0	331
Lake Sumner outlet	317	80	25.5	19.5	8.3	13.8	30.7	135
South Branch at Gorge	148	54	8.0	5.6	2.7	4.1	8.3	205
South Branch at Esk Head	305	47	14.2	10.1	5.0	7.4	15.2	201
Hurunui at Mandamus	1070	49	52.4	39.0	17.2	27.4	60.7	526
State Highway 1	2518	29	71.7	55.6	19.9	37.6	82.74	755

The specific discharge from the No.2 Hut and Lake Sumner sub-catchments is relatively high compared to the other sites reflecting the high runoff from the heavy rainfall close to the divide. The South Branch at Esk Head for example has a larger catchment than No.2 Hut but its mean flow is less, due to the lower rainfall totals this catchment receives. These differences in specific discharge are also reflected in the proportion of flow each of the tributaries provide to the Hurunui at Mandamus flow recorder. While both the Lake Sumner outlet and the South Branch catchment areas are each about 30% of that at the

Mandamus site the relative contribution of flow to this site is substantially different. Lake Sumner contributes about 49% to the mean flow at the Mandamus site whereas the South Branch only contributes about 27%. The remaining 42% of the catchment area, which consists of the area downstream of Lake Sumner not including the South Branch, contributes in the order of 24% to the flow at the Mandamus recorder.

With rainfall totals rapidly decreasing in the catchment area downstream of the Hurunui/Mandamus confluence the specific discharge decreases as well. State Highway 1 has a specific discharge of 29 l/s/km^2 substantially lower than the other sites.

When reviewing the mean annual flood for the flow records the significant reduction in the value upstream (No.2 Hut) and downstream of Lake Sumner Outlet is most notable. This shows the attenuation effects of Lake Sumner on flood flows. Appendix B, Figure B2 illustrates the influence of Lake Sumner on storm hydrographs. The peak discharge of 450 m^3/s at No.2 Hut is reduced to 237 m^3/s downstream of Lake Sumner at the Hurunui confluence with Jollie Brook. The peak discharge at Lake Sumner outlet will be lower and the rising and falling limb of the hydrograph will not be as steep. Note that there are tributaries below the Lake Sumner outlet and the gauging site at Jollie Brook which would tend to increase the flood peak. It is therefore likely that the flood peak at the Lake Outlet would have been lower than 237 m^3/s for the example given in Figure B2.

In Table 6 it can also be seen that the annual flood at the South Branch at the Gorge is higher than the South Branch at Esk Head. This is probably due to the short record length of the Gorge site which only has recorded flows from 2005-2008. This period experienced a few large flood flows which cause the mean annual flood at the Gorge to be higher than the mean annual flood at Esk Head which is taken over a longer record period. In reality peak flood flows are (as expected) lower at the Gorge than at Esk Head.

4.5.4 Seasonal Flow Variability

As mentioned before most of the flow of the Hurunui River as it enters the scheme area is derived from precipitation in the upper catchment. In winter, much of this falls as snow, and this is not released to the river until spring. Therefore there is a strong seasonal pattern to the typical pattern of river flow, with higher flows from September to December. The summer and autumn months of February to April have the lowest flows. Table 7 summarises the mean monthly flows for the Hurunui at Mandamus recorder site.

Table 7 : Mean Monthly Flow for the Hurunui at Mandamus Recorder Site (1956-2008)

Month	Mean monthly flow (m^3/s)
January	47
February	34
March	34
April	40
May	49
June	52
July	50
August	54
September	63
October	79
November	72
December	56
Yearly average	52

Flood flows can occur at any time of the year in response to heavy rainfall in the catchment but typically the months with the largest floods are August – December. February and March are least influenced by floods.

4.5.5 Lake Sumner Historical Lake Levels

Table 8 lists the mean monthly levels (1957-1972 and 1986-1992) of Lake Sumner. The lake levels in this table are relative to the recorder datum (an assumed level was adopted when the water level recorder was installed).

Table 8: Mean, Minimum and Maximum Monthly Levels of Lake Sumner (relative to recorder datum of RL 540.882 m)

Month	Mean Monthly Level (m)	Minimum Mean Monthly Level (m)	Maximum Mean Monthly Level (m)
January	1.490	1.028	2.170
February	1.399	1.006	1.882
March	1.387	0.968	1.768
April	1.448	0.954	1.742
May	1.560	1.156	2.170
June	1.501	1.223	1.805
July	1.423	1.183	1.950
August	1.515	1.259	2.000
September	1.631	1.237	2.591
October	1732	1312	2506
November	1747	1341	2347
December	1616	1176	2825

The lowest (instantaneous) recorded level of Lake Sumner was 0.896m on 10 April 1971 and the highest 4.108m on 14 September 1988 (range of 3.2 m). The lake level is normally at its maximum in September, October, November and December with November recording the highest mean monthly level. The level drops to a minimum during February, March and April with the lowest mean monthly level occurring in March. The annual fluctuation of lake level varied over the period of record from 1.076m (1966) to 3.011m (1988) with a mean of 1.863m.

Figure B2 shows a typical inflow/outflow hydrograph for Lake Sumner. This plot shows the natural attenuating effect that Lake Sumner has on inflows. Figure B3 shows the historical lake levels (above mean sea level). The histogram in Figure B4 lumps together all the historical data, and indicates a natural maximum variability of around 3.1 meters, and a ‘normal’ operating range of around 2 meters. The flow duration curve in Figure B5 gives an alternative view of the historical operating range of Lake Sumner. The top plot in Figure B6 shows historical stage/discharge data for Lake Sumner together with the quadratic fit which has been assumed in the modelling. The bottom plot shows the same data with respect to mean sea level.

5.0 Model Methodology

5.1 Modelling Approach—General Overview

The water balance/irrigation demand model was coded in Matlab, an advanced computational language used in scientific and engineering research and design. The model integrates hydrological routing and water balance with irrigation demand and is driven by hydrological input data and irrigation demand.

The immediate benefit of this integrated approach is that interaction between the hydrological and irrigation components occurs within model simulations avoiding the need for information transfer between different programmes, which is both computationally inefficient and limits output.

Figure A2 shows the proposed scheme area with the proposed storage sites, Lake Sumner and the South Branch reservoir. The principal hydrological input data are the inflows into the reservoirs. Using the Hurunui at Mandamus flow record, and available flow records in the Hurunui catchment, these inflows have been constructed using a combination of statistical and hydrological techniques.

To model irrigation demand it was assumed that the scheme area may be divided into 4 soil types with different water holding capacities. Representative evapotranspiration and rainfall data sets have been used to update daily soil moisture content.

All irrigation areas are assumed to be spray irrigated. The following irrigation rule has been assumed for areas which are spray irrigated: a sub-area has an irrigation demand when the soil moisture balance for that area falls below 55% of the PAW (profile available water), and the daily irrigation demand continues until the PAW is reached. For the 1,955 hectares of border dyke irrigation, a 14 day rotation period has been assumed, and that a sub-area is irrigated if the PAW falls below 75% of the average PAW for that area.

The way the hydrological routing has been coded is as follows: for a given reservoir and period when water is harvested for storage, it has been assumed that all inflow into the storage is harvested subject to maintaining an environmental flow condition at the outlet of the reservoir. If the natural flow is less than the environmental flow on that tributary a release is made to meet the environmental flow condition. This modified flow is reflected at Hurunui at Mandamus.

If there is an irrigation demand, water is first abstracted from the modified run of river flow. If there is a deficit, water is released from the storage dam(s) into the river to allow the irrigation demand to be abstracted.

5.2 Simulation Period

Based on the availability of flow and environmental data the simulation period was chosen to be 1972-2008. This was the longest period for which the flow record at the Hurunui at Mandamus flow recorder overlaps the environmental data (evapotranspiration and rainfall). The flow data includes extremely dry years (eg 1972, 2008), ‘average’ and ‘wet’ years, and therefore simulates the effects of the scheme over a range of extreme and average conditions.

As noted above, except for the Hurunui at Mandamus flow record, the input flows are synthetic. The available historical flow records for the inflows into the models have been extended to the simulation period 1972-2008. The Hut No 2 data which generates the inflow into Lake Sumner is relatively complete, and has been used to generate a natural inflow and outflow series for Lake Sumner. The South Branch at Gorge data covers June 2005 onwards, and has been extended using data from South Branch at Esk Head and Hurunui at Mandamus to generate a natural inflow series for the South Branch reservoir. Further details are given below on how the hydrological inputs were synthesised.

6.0 Input data

6.1 Introduction

This section provides a more detailed description of the required inputs for the demand and supply model. Some of this information given below will overlap with the information provided in section 4.0 (Description of the Environment).

6.2 Climate

Limited Potential Evapotranspiration (PET) data exists from a climate station in Culverden and a more extensive series is available at Hanmer, 30 km outside the catchment (Site G22581 and G22582). Due to the distance from the project area and its geographical orientation the data from this site is considered unsuitable to represent potential evapotranspiration (PET) for the potentially irrigable area. The PET data at the Culverden climate station (Site H22783) is too short to be of any practical use.

Two rainfall sites with long term daily rainfall records are available close to the project area. These sites are Riverside (H22781), located close to Rotherham and Waipara, Wattle Grove (H32072) located in Waipara Township. Both records, however, have significant gaps in the data (several months) and are therefore considered unusable as a continuous input series for our model.

Synthetic daily rainfall and PET data is available from 1972 to date produced by NIWA on a 5km x 5km grid. This data has been produced by spline interpolation using all short and long term climate data available in the area and also takes into account other factors such as topography. These daily time series are considered the best available continuous long term dataset in the project area. Since the dataset from NIWA provides daily time series on a 5km x 5km grid, analysis on local variations in rainfall and evapotranspiration have been carried out within the command area. Table 9 provides a summary of the PET and rainfall variability within the different subareas of the command area. Between brackets representative average rainfall totals are shown for the areas which have relevant long term rainfall data available between 1972 and 2008.

Table 9: Average Yearly Rainfall and Potential Evapotranspiration for the Different Irrigation Areas (1972-2008)

Irrigation Area	**Average Yearly Rainfall (mm)**	**Average Yearly Potential Evapotranspiration (mm)**
Existing Balmoral Scheme	720 (703[1])	837
Balmoral forest & adjacent area	655	847
Peaks	723	826
Hawarden south of Waitohi	652	823
Upper Waipara/Mason's Flat	677	814
Scargill Valley	673	878
Omihi	649 (633[2])	903

(1) Riverside (H22781), (2) Waipara, Wattle Grove (H32072)

The data indicates that the PET and rainfall variability within the project area is relatively small when comparing average yearly totals. Although the variability for average yearly totals is relatively small, the data does indicate that local rainfall and ET variability on a daily basis can vary significantly. Consequently three different sets of data were used to represent different areas within the project area. For this study one PET and rainfall series was used to represent the existing Balmoral Scheme, one PET and rainfall series for the Balmoral Forest & adjacent area, Peaks, Hawarden south of Waitohi and Upper Waipara/Masons Flats area and another PET and rainfall series to represent Omihi and Scargill Valley. All six data-series consist of the average daily rainfall or PET from the NIWA 5km x 5km grid data located within one of the three identified areas mentioned above.

6.3 Soils and Water Holding Capacities

The soils identified in Table 5 (section 4.4) have been classed into four different categories based on their estimated Soil Water Holding Capacities for the purpose of modelling irrigation water demand, namely 60, 90, 120 and 150 mm. The spatial distribution and net areas for each irrigation area are shown in Figure A4 and Table 10.

Table 10: Net Area in Each Soil Water Holding Capacity Category

Irrigation Area	**Net Area in Each Soil WHC Category (ha)**				
	60 mm	**90 mm**	**120 mm**	**150 mm**	**Total**
Existing Balmoral Scheme	400	3340	1500	0	5240
Balmoral forest & adjacent area	1210	6110	0	0	7320
Peaks	500	3620	850	60	5030
Hawarden south of Waitohi	2040	4380	1860	680	8960
Upper Waipara/Mason's Flat	2890	1960	480	180	5510
Scargill Valley	1450	1570	1680	0	4700
Omihi	840	3560	1020	0	5420
Total	**9330**	**24540**	**7390**	**920**	**42180**

6.4 Hydrological Inputs

The hydrological inputs are synthetic hydrographs for three tributaries of the Hurunui River (Lake Sumner inflow, South Branch at gorge and Mandamus River), together with two miscellaneous flow series to account for the cumulative flows of the minor tributaries of the Hurunui North Branch and South Branch River. This section provides a description of the methodology for constructing the synthesized hydrographs. A description of the flow recorder sites is included in Appendix D and the regressions, associated statistics and overlay plots are provided in Appendix E.

6.4.1 Lake Sumner Inflow

Measured flows for the Hurunui North Branch are available approximately 4 km upstream of Lake Sumner at ECan recorder site No.2 Hut (site number 65108). About 14 years of flow data is recorded for this site and in order to construct a continuous (synthesised) inflow hydrograph for Lake Sumner for the complete 36 year modelling period the No.2 Hut data has been extended using linear regression with a recorder sites in the Hope catchment (site 64608 Hope at Glen Wye). Apart from a good statistical correlation between flows at the Hope at Glen Wye recorder site and Hut no.2 both catchments also share similar environmental conditions (i.e. Alpine catchments, geographical orientation etc.) and therefore can be expected to show similar runoff characteristics.

Minor gaps in the Hope at Glen Wye data were filled using linear regression with ECan flow recorder site Waiau at Marble Point(site 64602). To improve the regressions a lag time was added to the flow data by comparing the peaks of the flood flows.

Once a continuous record was created for No 2 Hut a scaling factor was determined to account for the additional catchment area flowing into Lake Sumner. The scaling factor was estimated by routing inflows into Lake Sumner and using the natural stage discharge relationship on Lake Sumner (Figure B6) to predict historical outflows from Lake Sumner. Figure F1 shows an overlay plot of historical and simulated outflows from Lake Sumner over the calibration period, and Figure F2 shows a comparative flow duration curves for the historical and simulated data. It is important to note that the inflow series is itself synthetic data and the calibration period is quite short. Despite this the predicted pattern of flows is in good agreement with the historical flows at the Joliebrook recorder, Figure F3, approximately 10 km downstream.

The scaling factor may also be compared with the ratio of catchment sizes of 1.858:1 of (area of inflow catchment to area of Hut No 2 catchment). However, higher elevation parts of the catchment are contributing a higher proportion of inflow since they receive higher rainfall. This is also supported by the NIWA isohyetal data mentioned before which shows higher total yearly rainfall in the higher elevation parts of the Hurunui North Branch catchment area.

6.4.2 South Branch at Gorge: Inflow at Proposed Dam Site

Measured flows for the Hurunui South Branch are available at the proposed dam site (EQS site 165116, South Branch at Gorge) from 18/6/2005 onwards and at ECan recorder site 65109 (South Branch at Esk Head) which is approximately 8 km downstream of the potential dam site. In constructing a continuous (synthesised) inflow hydrograph at the proposed South Branch Dam for the 36 year modelling period we used linear regression with the ‘South Branch at Esk Head’ flow recorder sites. Gaps in the flow record of ‘South Branch at Esk Head’ were filled using linear regression with ‘Hurunui at Mandamus’ (NIWA site 65104). To improve the regressions a lag time was added to the flows by comparing the peaks of the flood flows.

6.4.3 Mandamus River

Environment Canterbury installed a flow recorder on the Mandamus River in November 2005 and flows have been recorded since 16/11/2005. This flow recorder (Site 65102, Mandamus at Tekoa Road Bridge) is located just upstream of the confluence with the Hurunui River. Since there are no long-term flow records available which can provide a satisfactory regression a rainfall-runoff model was used to construct a flow series using HEC-HMS (Hydrologic Engineering Center – Hydrologic Modelling System, US Army Corps of Engineers). This software package is designed to simulate the precipitation-runoff processes of watershed systems and is applicable in a wide range of geographic areas.

HEC-HMS uses a separate model to represent each component of the runoff process. For this study a loss model was used to compute runoff volumes and consequently a direct runoff model to simulate overland flow and generate hydrographs.

The deficit and constant-rate loss model computes runoff volumes for a catchment. The deficit model calculates a Soil Moisture Balance based on monthly evaporation data and previous wetting conditions (i.e. rainfall) and the constant rate is the infiltration capacity of the soil.

The Clark unit hydrograph method was used for developing hydrographs for the Mandamus catchment. This model derives a watershed Unit Hydrograph (UH) by representing the following processes:

- Translation of the excess precipitation from its origin throughout the drainage to the watershed outlet.
- Attenuation or reduction of the magnitude of the discharge as the excess is stored throughout the watershed.

This model uses synthetic rainfall series provided by NIWA which are representative for the catchment. Different parameters (i.e. time of concentration, infiltration rate and storage ratio) in the model have been calibrated to provide a good match with the measured flow data at the Mandamus recorder site. In order to obtain a flow record for the full 36 year period the calibrated model was run with the continuous rainfall series for the catchment. After calibration the model accurately predicts the measured flow data at the Mandamus flow recorder. An overlay plot of the measured and modelled flow hydrograph is shown in Appendix D.

6.4.4 Miscellaneous Flow Series

The first miscellaneous flow series represents the flow generated from the catchment area between the ‘South Branch at the Gorge’ and the ‘South Branch at Esk Head’ flow recorder. It represents a catchment area of 157km^2 (see also Figure A5) and the main tributary is the North Esk River which confluences with the Hurunui South Branch approximately 1.5 kilometres downstream of the proposed dam site. This flow series was constructed by subtracting the flow data for the ‘South Branch at Gorge’ from the flow data for the ‘South Branch at Esk Head’ for the 36 years modelling period.

The second miscellaneous flow series represents the catchment area (448 km^2) downstream of Lake Sumner up to the Hurunui at Mandamus flow recorder not including the South Branch. The main tributaries are Jollie Brook and Sisters stream. This flow series was constructed by subtracting the flow data for ’Lake Sumner Outlet’ and ‘South Branch at Esk Head‘ from ‘Hurunui at Mandamus’.

6.5 Natural Flow Characteristics

Figures F4-F5 shows measured flows at Hurunui at Mandamus, Lake Sumner synthesised inflows/outflows and South Branch reservoir natural inflows/outflows. The histograms of the historical/synthesised flows in Figure F6 clearly demonstrate the relative variability and contribution of flows. The same information is summarised as flow durations curves in Figure F7. The large scale plot for Lake Sumner inflows/outflows is in Figure F8 gives a further demonstration of the natural attenuating effect of Lake Sumner on inflows.

Summary flow statistics are shown in Table 11. Note that these flow statistics are slightly different than the statistics provided in Table 6 since they are based on the modelling period of 36 years and not on the (often much shorter) record period from the recorder sites in the catchment.

Table 11: Recorder Sites, Catchment Area, Specific Discharge and Flow Statistics for Several Sub-Catchments Of The Hurunui River Between 1972-2008

Recorder Site	**Catchment Area (km^2)**	**Specific Discharge (l/s/km^2)**	**Flow (m^3/s)**				
			Mean Flow	**Median Flow**	**7-day MALF**	**Lower Quartile**	**Upper Quartile**
No.2 Hut	182		17.6	11.3	4.7	7.6	18.0
Lake Sumner outlet	317		28.6	22.7	8.6	15.4	34.8
South Branch at Gorge	148		8.7	6.5	3.5	4.9	9.6
South Branch at Esk Head	305		14.7	10.5	5.0	7.5	16.4
Hurunui at Mandamus	1070		54.4	40.5	17.0	28.1	63.4
State Highway 1*	2518	29	71.7	55.6	19.9	37.6	82.74

*Flow statistics for State Highway 1 are based on actual record period since this data has not been synthesized for the 36 year modelling period.

6.6 Hurunui Flow Regimes and Minimum Flow Conditions

It has been assumed that the minimum environmental and flow allocations are given by the interpretation of Variation 8 summarised in Table 3.

In order to maintain minimum flow conditions on both the North and South Branch tributaries and at the Hurunui at Mandamus flow recorder site minimum flow releases have been set at the outlet of Lake Sumner and the South Branch Dam. These minimum flows are based on the MALF's of Lake Sumner outlet and the Gorge given in Table 11, and are assumed to be 9 m^3/s and 4.5 m^3/s respectively. These flows were recommended by Boffa Miskell are based on an assessment of ecological values.

7.0 Modelling Assumptions

It is important to recognise that the current model works on a daily time scale—all inputs are given as daily totals/averages. As a consequence it is not possible to accurately simulate effects that occur on a much finer time scale, e.g. continuous time flow variability and attenuation effects of Lake Sumner.

The biggest challenge for the model is to demonstrate that Lake Sumner can both fulfil its natural role as an attenuator of inflows so that modified outflows follow the natural pattern of lake outflows as much as possible, and be used for storage. Unless inflows/outflows are properly managed there is a potential for lake levels to be substantially higher than the historical upper ranges and/or for outflows to be substantially greater. In the model this is simulated by making early flow releases a day ahead and using the natural stage discharge relationship and the buffer zone to attenuate the inflows. It is recognised that these assumptions do not fully describe the likely operation of the control gates, i.e. the model does not accurately replicate the continuous operation of the control gates. This has the tendency to over predict the frequency and magnitude of peak outflows from Lake Sumner. However, this is a limitation of using a model driven by daily inputs. In practice, the management of peak outflows will be controlled by making early flow releases a few hours or a day before a large flood flow is expected depending on rainfall and flow predictions/measurements in the upper catchment.

To induce some flow variability in the lower range of outflows from Lake Sumner the minimum environmental flow release of 9 m^3/s was assumed to depend on the inflow. Specifically, for inflows of less than 9 m^3/s an environmental flow release of 9 m^3/s was set and for inflows of 50 m^3/s or greater an environmental flow release of 13.5 m^3/s was set. For inflows between 9 and 50 m^3/s the environmental flow release depends linearly on the inflow.

8.0 Reliability of Supply

In estimating the reliability of the proposed irrigation scheme and the corresponding storage volumes it is necessary to consider the physical reality. Flows are subject to considerable variability which results in considerable variability in the availability of run of water for irrigation. Very dry years like 1972 are rare and occur approximately 10% of the time over 1972-2008. During these years there can be significant water deficit and large storage requirements to meet demand. Any reasonable measure of reliability will identify these extreme events.

In a broad sense there are two kinds of storage: short term storage designed to meet demand in 'average' years and bulk storage to meet demand during extreme events. The proposed scheme is a bulk storage scheme designed to meet the majority of extreme hydrological conditions.

No bench mark measure of reliability has been used to infer required storage volume. Instead, the effects of a proposed scheme are analysed in terms of effects on flows and the environment, supply and demand reliability, and effects on soil moisture content and irrigation season duration.

8.1 Supply and Demand Reliability

The traditional approach to reliability is based on considering supply and demand: a day is counted as unreliable if there is an irrigation deficit on that day, i.e. supply does not meet demand, all other days are counted as reliable. Different measures of reliability are obtained by using different statistical summaries, some of which are given below:

Average Reliability: This is based on the proportion of days over each irrigation year when supply meets demand; average reliability is then defined to be the average over all the irrigation years. The drawback of this commonly used measure is that over a long simulation period, a few 'bad' years when there have been significant numbers of days when there is an irrigation deficit are averaged over.

Full Reliability considers that an irrigation year is reliable if supply meets demand on all days during the irrigation season. Typically the scheme is said to be fully reliable if 9 out of 10 irrigation years are reliable.

Consecutive Reliability is based on counting the number of consecutive days in each irrigation season when supply is less than demand. Under the *'10 consecutive day rule'* a scheme is said to be reliable if each irrigation year has no more than 10 consecutive days when supply is less than demand.

Average reliability corresponds to short term storage described in the previous section while full and consecutive reliability captures the effects of extreme years. While these measures can be helpful in summarising the effects of the scheme they are non-robust and highly sensitive to the disparity between the occurrence of extreme years and average years. In addition, it is important to recognise that bulk storage schemes are fundamentally different to run-of-river schemes: for the former storage tends to run out towards the end of the irrigation season, while for the latter water deficits may be intermittent throughout the irrigation season, and provided the duration of restricted and/or no water supply is not too long it may be possible for pasture to grow throughout an irrigation season. Therefore ‘run-of-river’ measures of reliability, while they give indicative information about an irrigation scheme, are not really very useful in measuring the real benefits of a bulk storage scheme. For a bulk storage scheme a prolonged period of water deficit towards the end of the irrigation season will tend to result in a shortening of the irrigation season by a few months.

8.2 Soil Moisture

Soil moisture reliability considers the effects of the scheme on soil moisture content, and hence measures the real benefits of the scheme. Growth conditions are optimised when the soil moisture content is greater than 50 % of the PAW. The daily soil moisture index for a given soil type is the ratio of the moisture content to the PAW. This is averaged over the soil types to give a daily soil moisture index (SMB index) for the scheme. A day is counted as reliable provided the SMB index is greater than 50 %. In a good irrigation year the SM index is always greater than 50 %. In extreme years the SMB index tends to drop off in the last 2 or 3 months of the irrigation season. It is therefore interesting to consider the duration for each irrigation season that the SMB index is greater than 50 %.

9.0 Scheme Description and Operating Rules

In the proposed scheme it is intended to use both Lake Sumner and the South Branch reservoir as storage. Lake Sumner is used as primary storage with the South Branch as back up.

9.1 Irrigation Season

The irrigation season is taken to be 1 September through 31 May.

9.2 Lake Sumner

For Lake Sumner it is intended to operate the Lake within the historical operating range of approximately 3 meters. The first 2 meters is assumed to be active storage while the upper 1 meter is to be used to buffer flood inflows. It is intended to open the control gates at the end of the irrigation season (1 June) and close the gates 1 August, I month before the start of the irrigation season. Inflows are harvested subject to maintaining an environmental outflow of 9 m^3/s. In theory it would be possible to close the gate later and manage since flows are high from august through to December. However closing the gate in September or October and consequently harvesting flood flows in these months would be less favourable from an ecological point of view.

9.3 South Branch Reservoir

For the South Branch reservoir it is intended to have a maximum reservoir level of 630 m above mean sea level with an operating range of 25 meters. This corresponds to a live storage of 111 million m^3 of water. Water is harvested into storage whenever the inflow is greater than the environmental flows of 4.5 m^3/s.

9.4 Operational Rules

The scheme is operating subject to the following rules:

- On days when there is an irrigation demand water is first abstracted from run of river water subject to the minimum flow and allocation conditions of Variation 8,
- When there is a deficit in run of river supply, water is then abstracted from Lake Sumner.
- Any remaining deficit is abstracted from the South Branch reservoir

10.0 Assessment of Environmental Effects

10.1 Introduction

This section contains an assessment of the environmental effects of operating the proposed scheme described in the previous sections over the 36 year simulation period. Assuming 20% losses the peak irrigation demand for the 42,000 ha scheme is 31.5 m^3/s.

10.2 General Description of Effects

Figure G1 shows estimated available storage in Lake Sumner and South Branch reservoir during the simulation period. The peaks in the Lake Sumner plot correspond to peak flood inflows which are stored in the 1 meter buffer zone of the Lake. In practice there is less storage available in Lake Sumner than the 27 million m^3 of active storage since the natural stage discharge relationship in Figure B6 limits the volume of water that can actually be delivered. The full live storage of 111 million m^3 in the South Branch is used 5 years in 36 years, and more than half the storage is used 11 years in 36 years.

Figures G2 and G3 translate the storage volumes in Lake Sumner and the South Branch reservoir into lake/reservoir levels. It will be noted that Lake Sumner operates within its natural range. Figures G4-G7 show histograms and level duration curves for the two storage sites. The level duration curves in Figures G5 and G6 show, in particular, the proportion of time the levels are kept at their maximum storage capacity.

Figure G8 shows an overlay plot of simulated and historical lake levels over the period where lake level data is available. During the irrigation season when the storage is full the lake level is approximately 1.9 meters above the minimum over this period. Peak inflows are attenuated by temporarily raising the lake levels to a maximum of 545.2 m RL. Levels are lowered following irrigation demand and follow the natural pattern when the control gates are open between June and July.

10.3 Effects on Flow in the Hurunui River

10.3.1 Lake Sumner Outlet

The overlay plot of modified and natural outflows from Lake Sumner in Figure H1 gives an overall indication that while the modified outflows can be greater than the natural outflows they follow a similar pattern to the natural outflows.

The error bar plots in Figure H2 give an indication of the relative variability of the average mean daily flow by month. The greatest effect on the outflows is observed in August when the control gates are closed and the majority of the active storage is harvested. In general the storage is full by the end of August. There is a potential for the mean daily flow to increase between October through January due to the release of water for irrigation and/or controlled release of flood inflows. The majority of irrigation demand occurs in February through April; this corresponds to the period when inflows tend to be smallest. In June it is assumed that the control gates are opened which leads to the substantially greater mean flow observed in this month if Lake Sumner contains significant quantities of water. In practise this water is likely to be released progressively.

The error bars in Figure H3 show the average, average minimum and maximum flows by month. The increase in average maximum flow is largely a result of the model's inability to simulate continuous time attenuation of an incoming flood wave. In practise this is likely to be managed by making flow releases depending on the measured flow at No 2 Hut and/or weather forecasts resulting in outflows that match more closely in magnitude and frequency the pattern of natural outflows from Lake Sumner.

Figures H4-H5 show comparative flow duration curves by month for the natural and modified outflows from Lake Sumner. Appendix H also contains flow duration tables. In general there is a greater frequency of modified flows between 50 and 130 m^3/s. As discussed in section 7 this is largely due to a modelling assumption that the control gates are fully opened allowing higher flow releases than may happen in practise. August shows significant flat-lining corresponding to the period when the majority of water is harvested. In the months which are most affected by the scheme, namely December through April the modified scheme shows a greater frequency of outflows around 30-40 m^3/s when irrigation releases are made.

With regard to flat-lining Figure H6 shows comparative bar plots of the number of days each month by year that the mean daily flow is smaller than 9 m^3/s. Figure H7 shows the same plots for January through March. Overall the low flows in the river are no less frequent under the scheme than under the natural estimated historical regime.

Figure H8 shows the largest number of consecutive days that the mean outflow from Lake Sumner is no greater than 9 m^3s. Broadly speaking, the periods of low flow for the modified scheme correlate with the periods of low flow for the natural regime. The following table shows the start dates of low flow for the modified and natural flows together with the duration of the low flow periods. The data for 1998 is likely to be an anomaly since both the Hut No 2 and South Branch at Esk Head historical data record extremely low flows during this period while the Hurunui at Mandamus recorder records flow in excess of 100 m^3/s.

Table 12: Periods of Low Flow (≤9m³/s) – Lake Sumner Outlet

	Modified		Normal	
Irrigation year	**Start Date**	**Duration (days)**	**Start Date**	**Duration (days)**
1972	31-Jan-1973	75	1-Jan-1973	75
1973	26-Mar-1974	9	31-Mar-1974	4
1974	03-Jan-1975	18	03-Jan-1975	18
1975	25-Apr-1976	3		
1976				
1977	09-Feb-1978	44	08-Feb-1978	45
1978	11-Feb-1979	4	10-Feb-1979	5
1979	12-May-1980	3		
1980	06-May-1981	7	11-May-1981	2
1981	20-Apr-1982	19	18-Mar-1982	22
1982				
1983	04-Apr-1984	2		
1984	20-Mar-1985	31	19-Mar-1985	32
1985	26-Mar-1986	3		
1986				
1987	07-May-1988	3	02-May-1988	8
1988	10-Feb-1989	2		
1989	02-Sep-1989	41	03-Sep-1989	40
1990	15-May-1991	2	19-Mar-1991	10
1991	02-May-1992	13	03-May-1992	12
1992	07-May-1993	5	04-May-1993	8
1993	28-Mar-1994	10	02-Apr-1994	13
1994				
1995	18-Feb-1996	2	10-Mar-1996	6
1996				
1997				
1998	07-Feb-1999	21	07-Feb-1999	21
1999	05-Mar-2000	9	28-Feb-2000	15
2000	21-Feb-2001	36	21-Feb-2001	36
2001				

Table 12: Periods of Low Flow (≤9m^3/s) – Lake Sumner Outlet

	Modified		Normal	
Irrigation year	**Start Date**	**Duration (days)**	**Start Date**	**Duration (days)**
2002			27-Mar-2003	3
2003	01-May-2004	3	01-May-2004	3
2004	26-Apr-2005	5	28-Apr-2005	3
2005	26-Mar-2006	9	28-Mar-2006	8
2006	23-Feb-2007	19	22-Feb-2007	20
2007	16-Mar-2008	46	16-Mar-2008	46

10.3.2 South Branch at Gorge (South Branch Reservoir Outlet)

The overlay plot of modified and natural flows in Figure I1 give an overall impression of the effects of harvesting water into the South Branch reservoir: while there are significant periods when the modified flows follow the pattern of natural flows there are equally significant periods when the outflow from the South Branch reservoir is held at a steady flow equal to the environmental flow release for the South Branch outlet of 4.5 m^3/s.

The error bars in Figure I2 give an indication of the relative variability of the average mean daily flows by month. The greatest effect tends to be during the late irrigation season when there is irrigation demand which requires the release of water from the South Branch reservoir. Figure I3 shows that average minimum flows are comparable and between February and May slightly greater than the natural regime. However, between April and August average maximum flows may be much greater for the modified flows due to irrigation release.

Figures I5-I6 show comparative flow duration curves by month for the modified outflows from the South Branch reservoir. January through March outflows tend to be greater due to irrigation demand. Between July and November there are significant periods when the outflow is flat-lined due water harvesting. This is further demonstrated by the plots in Figures I6 and I7 which show comparative bar charts for the number of days each month by year for which the mean daily flow is less than or equal to 4.5 m^3/s.

Figure I8 shows the longest number of consecutive days for which the mean daily outflow from the South Branch reservoir is no greater than 4.5 m^3/s; these correspond to continuous periods when water is being harvesting. Since water harvesting can take place across irrigation seasons flat-lining (and hence reservoir replenishment) may take of the order of 8 months. The following table shows the start date and durations of periods of low flow for the modified and natural flows.

Table 13: Periods of Low Flow (≤4.5 m^3/s) – South Branch Gorge (South Branch Reservoir Outlet)

	Modified		Normal	
Irrigation year	**Start Date**	**Duration (days)**	**Start Date**	**Duration (days)**
1972	06-Mar-1973	41	13-Jan-1973	93
1973	15-Feb-1974	106	23-Jan-1974	12
1974	26-Feb-1975	95	10-Jan-1975	10
1975	09-Apr-1976	40	14-Mar-1976	26
1976	24-Apr-1977	38	13-Mar-1977	48
1977	29-Mar-1978	64	28-Jan-1978	58
1978	18-Feb-1979	103	02-Mar-1979	14
1979	01-Sep-1979	13	12-May-1980	7
1980	30-Mar-1981	63	06-Jan-1981	42
1981	07-Apr-1982	55	14-Mar-1982	60
1982	25-Mar-1983	22	17-Feb-1983	22
1983	28-Feb-1984	11	22-Apr-1984	6
1984	21-Apr-1985	41	21-Feb-1985	59
1985	01-Sep-1985	118	05-Feb-1986	9
1986			12-Jan-1987	3
1987	04-Feb-1988	105	17-Apr-1988	22
1988	13-Mar-1989	80	05-May-1989	19
1989	01-Sep-1989	74	15-Sep-1989	23
1990	29-Mar-1991	64	06-Mar-1991	28
1991	17-Mar-1992	34	13-Apr-1992	31
1992	01-Apr-1993	61	05-Mar-1993	26
1993	23-Apr-1994	39	28-Mar-1994	24
1994	24-Feb-1995	38	09-Feb-1995	14
1995	18-Mar-1996	29	25-Jan-1996	10
1996	06-Feb-1997	27	27-Jan-1997	8
1997	30-Mar-1998	63	27-May-1998	5
1998	28-Feb-1999	93	02-Feb-1999	25
1999	01-Sep-1999	112	18-Feb-2000	24
2000	03-May-2001	18	10-Feb-2001	47
2001	10-Oct-2001	123	07-Feb-2002	24

Table 13: Periods of Low Flow (≤4.5 m^3/s) – South Branch Gorge (South Branch Reservoir Outlet)

	Modified		Normal	
Irrigation year	**Start Date**	**Duration (days)**	**Start Date**	**Duration (days)**
2002	30-Mar-2003	59	14-Apr-2003	18
2003	10-Jan-2004	42	19-Apr-2004	16
2004	07-Mar-2005	86	24-Jan-2005	24
2005	08-Sep-2005	62	27-Oct-2005	25
2006	01-May-2007	31	15-Feb-2007	56
2007	11-Mar-2008	50	11-Mar-2008	50

10.3.3 South Branch at Esk Head

The overlay plot of modified and natural flows Figure J1 gives an overall indication that while modified flows from South Branch at Gorge can have significant periods flows are flat-lined, there is significant flow variability due to the contribution of flow from the North Esk River.

The error bars in Figure J2 give an indication of the relative variability of the average mean daily flow by month and the error bars in Figure J3 show the average, average minimum, and average maximum flows by month. Comparing with Figures I2 and I3 for the South Branch at Gorge shows the mollifying effect of the North Esk on higher flows.

Figures J4-J5 show comparative flow duration curves for month for modified and natural flows for the South Branch at Esk Head. Appendix J also contains flow duration tables. The greatest effects on flows are seen January through March corresponding to irrigation demand. The frequency of higher flows is noticeably lowered from April through August corresponding to harvesting on the South Branch reservoir.

Figure J6-J7 show the comparative bar charts of the number of days each month that the mean flow is smaller than 5 m^3/s. Overall the low flows in this stretch of the river are less under the scheme than under the estimated natural historical regime.

Figure J8 shows the largest number of consecutive days that the mean flow at Esk Head is no greater than 5 m^3/s. In general lows flows are greater for the modified scheme. The following table shows the start date and durations of low flow for the modified and natural flows.

Table 14: Periods of Low Flow (≤5 m³/s) – South Branch Esk Head

	Modified		Normal	
Irrigation year	**Start Date**	**Duration (days)**	**Start Date**	**Duration (days)**
1972	06-Mar-1973	41	30-Jan-1973	76
1973				
1974				
1975				
1976			07-Apr-1977	2
1977	15-Mar-1978	9	25-Feb-1978	27
1978				
1979				
1980				
1981			20-Mar-1982	18
1982			06-Mar-1983	4
1983				
1984			19-Mar-1985	32
1985				
1986				
1987			27-Apr-1988	7
1988			04-Mar-1989	8
1989			09-Mar-1990	8
1990				
1991			04-May-1992	5
1992			04-May-1993	8
1993			05-Apr-1994	10
1994				
1995				
1996				
1997				
1998	24-Feb-1999	3	06-Feb-1999	21
1999			29-Feb-2000	13
2000	03-May-2001	8	20-Feb-2001	36

Table 14: Periods of Low Flow (≤5 m^3/s) – South Branch Esk Head

	Modified		**Normal**	
Irrigation year	**Start Date**	**Duration (days)**	**Start Date**	**Duration (days)**
2001				
2002			22-Mar-2003	7
2003				
2004			25-Apr-2005	5
2005	09-Jan-2006	3	15-Mar-2006	20
2006			20-Mar-2007	23
2007	17-Mar-2008	44	17-Mar-2008	44

10.3.4 Hurunui at Mandamus

The overlay plot of modified and natural flows past the Hurunui at Mandamus recorder in Figure K1 gives an overall impression of the results of redistributing the natural flows through Lake Sumner and the South Branch reservoir; low flows in the modified scheme are in general no worse than in the natural scheme, and here it should be noted that the Hurunui at Mandamus data is historical and not synthesised.

The error bars in Figure K2 give an indication of the relative variability of the average mean daily flows by month. Flows tend to be greater January through March corresponding to irrigation demand. Predicted flows are greater in June due to the control gates in Lake Sumner being opened, and as noted in section 10.3.1 this is likely to be managed more progressively than was coded into the model. Flows are lower in August when the control gates are closed on Lake Sumner. The error bars in Figure K3 show that the extreme ends of flows are largely comparable to the natural state.

Figures K4 and K5 show comparative flow duration curves for the natural and modified flows past Hurunui at Mandamus recorder. Modified flows are increased with greater frequency in January through March corresponding to irrigation demand. April and May correspond to periods when Lake Sumner may be refilled resulting in the modified flow duration curve dipping below the natural flow duration curve. As noted above the control gates for Lake Sumner are open at the beginning of June and closed at the start of August resulting in the greater frequency of reduced flows in August.

Figures K6-K7 shows the total number of days the mean daily flow is smaller than 17 m^3/s. Overall low flows in the river are no less frequent under the scheme than under the historical regime. Between January and March low flows are in fact less frequent under the irrigation scheme.

Figure K8 shows the largest number of consecutive days that the mean daily flow past the Hurunui at Mandamus recorder is no greater than 17 m^3/s. The following table shows the start dates and durations for the modified and natural flows. For the majority of years the duration of periods of low flow is somewhat less than under the modified scheme.

Table 14: Periods of Low Flow (≤17 m³/s) – Hurunui at Mandamus

	Modified		**Normal**	
Irrigation year	**Start Date**	**Duration (days)**	**Start Date**	**Duration (days)**
1972	06-Mar-1973	41	01-Feb-1973	74
1973				
1974			14-Jan-1975	2
1975	14-Apr-1976	16	20-Apr-1976	9
1976				
1977	14-Mar-1978	11	14-Feb-1978	39
1978				
1979				
1980			25-Jan-1981	5
1981	19-Apr-1982	19	19-Apr-1982	19
1982			07-Mar-1983	3
1983				
1984	26-May-1985	4	19-Mar-1985	32
1985	04-Feb-1986	2		
1986				
1987	05-Feb-1988	5	29-Apr-1988	10
1988			08-Mar-1989	4
1989				
1990			19-Mar-1991	10
1991				
1992	07-May-1993	5	05-May-1993	7
1993	01-May-1994	2	06-Apr-1994	9
1994	26-Feb-1995	13		
1995				
1996				
1997				
1998	24-Feb-1999	3	07-Feb-1999	20

Table 14: Periods of Low Flow (≤17 m^3/s) – Hurunui at Mandamus

	Modified		**Normal**	
Irrigation year	**Start Date**	**Duration (days)**	**Start Date**	**Duration (days)**
1999	16-Mar-2000	5	01-Mar-2000	12
2000	03-May-2001	8	21-Feb-2001	35
2001	26-May-2002	6		
2002	28-Apr-2003	4	23-Mar-2003	6
2003				
2004			04-Feb-2005	8
2005	17-Feb-2006	2	26-Mar-2006	9
2006	13-May-2007	5	20-Feb-2007	23
2007	20-Mar-2008	42	20-Mar-2008	41

10.3.5 Hurunui River Downstream of Take Point

The overlay plot of modified and natural flows downstream of the take point in Figure L1 gives an overall indication of the effects of abstracting water to meet irrigation demand.

The error bars in Figures L2 and L3 show the broad-scale effects of abstracting water under Variation 8 using Lake Sumner and South Branch reservoir. Higher flows in June are a result of opening the control gates in Lake Sumner.

Figures L4 and L5 show comparative flow duration curves by month for the natural and modified flows past the take point. Appendix L also contains flow duration tables. The greater frequency of lower flows January through April corresponds to irrigation demand and/or replenishment of Lake Sumner or the South Branch reservoir. The reduced flows in August correspond to water harvesting in Lake Sumner, while reduced flows between September and December may be due either to irrigation demand or reservoir replenishment.

Figures L6-L7 shows comparative bar plots of the number of days each month by year that the mean daily flow is less than 18.1 m^3/s. Overall the duration of periods of flat-lining are somewhat greater than for the natural regime. However this is due to the minimum flow limits set by Variation 8.

Table 14: Periods of Low Flow (≤18.1 m³/s) – Downstream of Take Point

	Modified		Normal	
Irrigation year	**Start Date**	**Duration (days)**	**Start Date**	**Duration (days)**
1972	15-Jan-1973	91	02-Feb-1973	73
1973	20-Jan-1974	16		
1974	20-Dec-1974	27	12-Jan-1975	4
1975	29-Feb-1976	39	21-Apr-1976	8
1976	10-Mar-1977	35		
1977	27-Jan-1978	56	12-Feb-1978	40
1978	30-Nov-1978	15		
1979				
1980	01-Jan-1981	47	25-Jan-1981	5
1981	19-Mar-1982	20	20-Apr-1982	18
1982	16-Feb-1983	29	06-Mar-1983	4
1983	14-Apr-1984	14		
1984	15-Mar-1985	37	21-Mar-1985	30
1985	28-Jan-1986	19		
1986	02-Jan-1987	13		
1987	20-Jan-1988	25	27-Apr-1988	12
1988	14-Feb-1989	29	08-Mar-1989	4
1989	22-Feb-1990	19		
1990	04-Mar-1991	30	19-Mar-1991	11
1991	10-Apr-1992	31		
1992	28-Feb-1993	31	07-May-1993	5
1993	25-Apr-1994	17	06-Apr-1994	9
1994	29-Jan-1995	24		
1995	19-Jan-1996	16		
1996	22-Jan-1997	14		
1997	21-Oct-1997	18		
1998	17-Jan-1999	40	07-Feb-1999	19
1999	25-Feb-2000	16	03-Mar-2000	9
2000	10-Feb-2001	47	21-Feb-2001	35

Table 14: Periods of Low Flow (≤18.1 m^3/s) – Downstream of Take Point

	Modified		Normal	
Irrigation year	**Start Date**	**Duration (days)**	**Start Date**	**Duration (days)**
2001	01-Feb-2002	45		
2002	09-Mar-2003	20	23-Mar-2003	6
2003	17-Dec-2003	13		
2004	19-Jan-2005	29	04-Feb-2005	8
2005	15-Feb-2006	38	28-Feb-2006	7
2006	11-Feb-2007	60	21-Feb-2007	22
2007	19-Apr-2008	43	20-Mar-2008	41

10.4 Detailed Comparisons

While the previous sections discuss the effects of the scheme over the whole 36 year simulation period it is helpful consider a shorter period to demonstrate the operation of the scheme. Figures M1-M5 show overlay plots of modified and natural flows, and Lake Sumner and South Branch Reservoir levels between September 1984 and August 1986. This includes a period in 1985 when the South Branch is drawn down almost a half.

The overlay plot of modified and natural outflows from Lake Sumner in Figure M1correlates clearly with Lake Sumner levels. For example, the peak outflow during late November 2004 corresponds to a sharp increase in the level in Lake Sumner, when a proportion of the peak inflow is held in storage so that the modified flood outflow is comparable to the natural outflow. During February 1985 the lake is drawn down corresponding to irrigation demand resulting in a period of increased outflow. Late April 1985 the natural outflow is reduced when water is harvested for storage. In June and July the natural outflows are similar to the modified outflows when the control gates are opened. This pattern continues throughout the simulation period.

Figure M2 shows the effects of drawing down the South Branch Reservoir; this corresponds to irrigation demand in February, March and April 1985. In late April water is harvested for an 8 month period resulting in a substantial period of flat-lining of outflows from the reservoir. Figure M3 shows the effect at Esk Head; flows from the North Esk River contribute flow variability to the South Branch, despite outflows from the reservoir maintaining a significant period of stable low flow.

Figure M4 shows the effects at Hurunui at Mandamus. Increases in low flows can be seen in February to April 1985 corresponding to irrigation demand, and reductions in flow can be seen corresponding to water harvesting. Figure M5 shows the effects of the scheme downstream of the take point.

10.5 Summary

The following table shows summary statistics for natural and modified flows:

Table 15: Summary Flow Statistics for Natural and Modified Flows (Period 1972-2008)

	Mean	Median	MALF	Upper Quartile	Lower Quartile
Lake Sumner Outlet natural flows	28.6	22.7	8.6	34.8	15.4
Lake Sumner Outlet modified flows	29.1	22.2	8.4	34.9	13.3
South Branch Gorge natural flows	8.7	6.5	3.5	9.6	4.9
South Branch Gorge modified flows	8.8	5.4	4.3	9.7	4.5
Esk Head natural flows	14.7	10.5	5.0	16.4	7.5
Esk Head modified flows	14.8	10.5	4.9	17.2	7.3
Hurunui at Mandamus natural flows	54.4	40.5	17.0	63.4	28.1
Hurunui at Mandamus modified flows	55.1	42.7	18.4	59.7	29.6
Hurunui downstream of take point natural flows	57.2	42.8	18.1	66.6	30.1
Hurunui downstream of take point modified flows	48.8	32.4	15.0	57.4	19.6

The summary statistics in Table 15 indicates that upstream of the Hurunui at Mandamus flow recorder that the overall distribution of modified flows is a relatively small shift of the distribution of estimated (except in the Hurunui at Mandamus case which is historical) natural flows. In general very lows flows (less than the MALF) particularly at South Branch Gorge are stabilised. As discussed in the previous sections flow patterns will differ by month depending on irrigation demand or harvesting of water.

In general the effect of the scheme on the frequency of flood flows propagating through the upper stretches of the Hurunui River is quite small. The FRE3 statistic is a measure of the frequency that floods occur on an annual basis. Specifically, the FRE3 statistic is the mean annual frequency that the daily flow exceeds 3 times the median flow. Normally the FRE3 statistic is calculated on the peak daily flow. The following table summarises the FRE3 statistic for natural and modified flows calculated on mean daily flows:

Table 16: FRE3 Statistic for Natural and Modified Flows (Period 1972-2008)

	Median Natural Flow	**FRE3**	
		Natural Flow	**Modified Flow**
Lake Sumner Outlet	22.8	18.3	18.3
South Branch Gorge	6.5	21.8	33
Esk Head	10.5	27.3	28.3
Hurunui at Mandamus	40.5	23.9	24.7
Hurunui downstream of take point	42.8	26.3	20.7

The statistics indicate that the modified stretches of the Hurunui River, namely Lake Sumner outlet and South Branch Gorge will be no worse off on average in terms of the frequency of flood flows. The frequency of flood flows on South Branch Gorge is somewhat greater under the modified scheme due to irrigation releases of the order of 30 m^3/s. Downstream of the take point the frequency of flood flows is slightly reduced.

11.0 Reliability of Supply for the Scheme

The upper plot in Figure N1 shows the total number of days that supply does not meet demand, and the lower plot shows the longest number of consecutive days that supply is less than demand. While there are 5 years in which supply does not meet demand throughout the irrigation season (*full reliability* of 86 % in the sense defined in section 8) there are only two irrigation years, namely 1972 and 2007 where the deficit may be regarded as significant, and corresponds to the storage available in both Lake Sumner and the South Branch reservoir being empty.

As noted in section 8.2 the *soil moisture index (SMI)* for a given soil is defined to be soil moisture balance divided by the PAW class. The SMI for the scheme is the average SMI over the soil types. Figures N2-N4 show the SMI by irrigation year. In all years except 1972, 1997 and 2007 the SMI is greater than 50 % throughout the irrigation season. During the irrigation 1997 there was no actual water deficit, ET levels were uncommonly high in January through March 1998, frequently greater than the irrigation application rate. Due to uncommonly low flows during the Summer of 1971/72 the storage in Lake Sumner and the South Branch reservoir are emptied resulting in an SMI less than 50 % from mid March onwards. 2007 is more extreme and shows two periods when the SMI is less than 50%: end of January to mid February and mid March onwards. Therefore in these years the irrigation year is shortened by up to 4 months.

The simulation suggests that for the vast majority of years the scheme has enough water for a complete irrigation season and is therefore highly reliable. For extreme years like 1972 and 2007 the irrigation season will be shortened.

Uncertainty rests with the frequency of hydrological conditions which lead to extreme years of the type discussed. Climate change and the Interdecadal Pacific Oscillation have been discussed in broad terms in section 4.3, and while it is not possible to quantify the level of uncertainty, it is prudent to assume that the incident of droughts in the lower Hurunui Catchment may increase and therefore years like 1972 and 2007 may increase in frequency.

12.0 Consideration of Alternatives

12.1 Introduction

The following section provides summary information on other options available to the scheme.

12.2 No Further Irrigation

The Hurunui region is a water short area and the absence of irrigation developments limits the area with regard to land use. Several Hurunui farmers provided evidence at the Hurunui River Water Conservation Order hearings supporting the need to develop bulk storage options.

12.3 Irrigation Without Storage

While under Variation 8 it is possible to irrigate without storage, as noted in the Section 3 the A-block is already fully allocated leaving only the B-block for allocation. This does not provide a reliable source of water. In addition even if the existing users become part of the scheme, the peak irrigation demand of 31.5 m^3/s is not met by the A and B blocks.

12.4 Multiple Small Schemes

While on-farm storage has been considered as an option it is not a financially viable option for storage. Most properties do not have the topography that is conducive to suitable sized storage reservoirs. Referring to section 8 on reliability of supply, on-farm storage is designed to cope with ‘short-term’ storage. Bulk storage of the kind considered here is the only viable option to meet most hydrological conditions that have existed in the area except years like 1972 or 2007 where the irrigation season will be shortened.

12.5 Alternative Water Sources and Storages

In the Stage 1 District Scoping Report for the Hurunui Community Water Development Project, Tonkin and Taylor (2004) carried out an assessment of storage options. 62,000 hectares was initially considered for irrigation development and thirty seven storage sites were initially identified to meet irrigation demand. This preliminary list was reduced on the basis of risk and engineering factors, as well as the statutory framework and environmental factors to 5 short listed sites summarised in the following table:

Table 17: Storage Options Identified in District Scoping Study

	Indicative Maximum Reliable Capacity ($x10^6$ m^3)	**Basis for Capacity**
Lake Sumner	20	Environmentally driven to mitigate adverse effect by managing the existing operating range and neglecting storage from a lake raising
Hurunui River South Branch	90-175	Capacity influenced by flow regimes and inflow availability
Waitohi	130	Likely practical maximum recognising pumping requirements
Pahau	20	Suits north side of Hurunui requirements
Mandamus	120	Predominantly topographically constrained but also dependent on flow regime and possible Hurunui River transfer—potentially constrained by active faulting

Although the Waitohi storage option has a potentially large capacity, with an estimated mean flows of 2m^3/s it has a relatively small water supply and would require substantial transfer from the Hurunui River to be effective. The resulting supply volume is estimated to be only 25 to 40 million m^3. The 98 m height of the dam, together with the need for several kilometres of pumped piping both for supply and demand, makes this option several times more expensive than the others.

The Pahau is a credible option for the north side of the river, to supplement existing consents for farmers in the Amuri scheme or adjacent. Again, it is a low flow river in comparison, and has a limited size.

The Mandamus was not favoured for various reasons, not least the active faulting and the diversity of ownership in the valleys, some of whom are known to have an adverse view of the project. The mean flow is much lower than the Hurunui at 3.2m^3/s and the storage site would undoubtedly require supplementing from the Hurunui River.

The HWP therefore identified Lake Sumner and the South Branch reservoir as the most viable options, Lake Sumner on account of its capacity to meet short-term irrigation demand and its ability to refill quickly and the South Branch reservoir on account of its potential capacity.

12.6 Just South Branch Storage

While the South Branch reservoir would be a stand-alone option the storage capacity is limited by engineering design to be around 111 million m^3 and would give a substantially reduced level of reliability. The full-reliability, for example, would be reduced to around 68 %.

12.7 Just Lake Sumner Storage

As discussed above Lake Sumner provides short term storage. The theoretical live storage of Lake Sumner, 27 million m^3, amounts to 9.9 days of peak irrigation demand at 31.5 m^3/s. Lake Sumner is more efficient in terms of replenishment and supply than the South Branch reservoir because it fills much more quickly than the South Branch reservoir. To achieve the same level of reliability the irrigable area would need to be reduced to around 15,000 hectares.

12.8 Summary

The Lake Sumner and South Branch storage options are the results of a distillation of storage options considered in previous studies. They provide the best opportunity for land development within the command area.

13.0 Mitigation Measures and Monitoring

13.1 Mitigating Adverse Effects on the Environment

A large component of mitigation has already been built into the scheme operation so that the modified regime does not stray significantly from the natural situation, and can comply with the allocation rules defined in Variation 8.

This section summarises further mitigation measures that have been proposed by the HWP, based on environmental requirements determined by Boffa Miskell. These can be achieved in most years due to the surplus water that is held in storage as shown in Figure G1..

13.1.1 Minimum Environmental Flows

Minimum environmental flows of 9 m^3/s and 4.5 m^3/s on the Lake Sumner outlet and the South Branch Reservoir Outlet respectively have been set in consultation with Boffa Miskell.

13.1.2 Environmental Flow Releases

The frequency and occurrence of flat-lining has been discussed in section 10. For Lake Sumner it was noted that long periods of flat-lining for the modified scheme tended to correlate strongly with the periods under the natural system being largely dependent on the prevailing hydrological conditions, and it would appear based on the synthetic outflow data for Lake Sumner that there is an existing state of stable low flows in some years from the outlet of Lake Sumner particularly during January through March. Periphyton levels are typically above nuisance levels during these months (V. Keesing, Boffa Miskell).

The existence of a control structure at Lake Sumner provides an opportunity to release a fresh which under natural circumstances could not occur. To mitigate the effects of flat lining it is proposed to make flushing flows during the irrigation season when this is possible.

For the South Branch reservoir there is an increased probability of substantially higher flows in the South Branch due to irrigation demand. This mitigates the lower less variable flows resulting from harvesting into storage. Should periphyton issues arise in the lower South Branch, which currently do not exist, (V. Keesing, Boffa Miskell) there is, in general, the opportunity to make an effective flushing flow.

13.1.3 Managing Lake Sumner Reservoir Levels

Lake Sumner levels should be managed within the natural historical operating range of 3.2 meters. During the period when Lake Sumner is being used for storage should the level of Lake Sumner exceed 545 m RL, the control gates shall be opened until the lake level has been lowered to 543.75 m RL.

13.2 Management and Operational Plans

Plans will be prepared for the management of the scheme and operation of the control gates. A draft of these plans shall be submitted 6 months prior to the operation of the scheme.

Apart from maintaining environmental flow requirements the actual operation of the scheme can only be confirmed with experience, therefore this plan will need to be reviewed annually.

13.3 Proposed Monitoring

13.3.1 Water Takes

The rate of water abstracted from the intakes shall be monitored on a continuous basis.

13.3.2 Reservoir Levels

It is proposed that water levels in Lake Sumner and the South Branch reservoir be monitored on a continuous basis.

13.3.3 Environmental Monitoring

As noted in section 6 there is an absence of reliable rainfall and evapotranspiration data. Consequently the HWP is proposing to install a number of weather stations to provide reliable rainfall, evapotranspiration and soil moisture data. This will provide information to shareholders so they can plan their irrigation and make the most efficient use of water.

With regard to flow monitoring it is proposed to monitor the flows at the following points:

- Hut No 2,
- Lake Sumner outlet,
- South Branch inlet,
- South Branch reservoir outlet (Gorge),
- South Branch Esk Head,
- Hurunui at Mandamus,
- Hurunui downstream of take point,

It is recommended that a three yearly report be prepared on the modified hydrology of the Hurunui River system. This shall include analysis of the flows at the points listed above and levels in Lake Sumner and South Branch reservoirs.

14.0 Conclusions

Using historical and synthesised hydrological and environmental data to drive a computer model of irrigation demand, water availability, and 27 million m^3 of water storage in Lake Sumner and 111 million m^3 in a proposed South Branch Reservoir this report describes the potential effects of irrigating a 42,000 hectare area in the lower Hurunui catchment. Irrigation water is first abstracted from the Hurunui River subject to minimum flow and allocation constraints set out by a proposed flow regime on the Hurunui River, Variation 8.

Lake Sumner is used as a primary storage site, with the South Branch providing supplementary water. Water is harvested in Lake Sumner and the South Branch reservoir subject to maintaining minimum flows of 9 m^3/s and 4.5 m^3/s the respective outlets.

The general effect on both Lake Sumner and the South Branch reservoir outlets is to change the overall pattern of flows. In particular there is an increase in the frequency of higher flows during the irrigation season (principally January through March) due to irrigation releases of up to 31.5 m^3/s and a tendency to induce periods of stable flows when water is being harvested into storage.

While there are plainly significant changes to the flows on a monthly or daily basis, the summary statistics given in Tables 16 and 17 indicate that in the case of Lake Sumner outlet, the changes in flow are quite small in an average sense. Furthermore, periods of sustained low flow (no greater than the minimum environmental release of 9 m^3/s) for the modified scheme are broadly comparable to the (estimated) natural flows.

Flood inflows into Lake Sumner are controlled by a combination of using a buffer zone (the upper meter of the 3.2 meter historical range of lake levels) and making early releases a day ahead. This gives the potential to increase the frequency of higher flows in the 50-130 m^3/s range as is seen in Figures H4 and H5. This is partly due to the modelling assumption that the control gate will be fully opened when there is a flood inflow. In practise this is likely to be managed by partially opening the control gates depending on the magnitude of the inflows reducing the frequency of flows in this flow range.

Due principally to the lower inflows into the South Branch Reservoir and the much larger storage volume that may need to be replenished, the effects on the South Branch reservoir outlet are somewhat more pronounced. Periods of stable outflow may exist for up to 8 months in years when the reservoir is significantly drawn down. However, flow variability downstream of the confluence with the North Esk River 3 km downstream of the South Branch Reservoir outlet is maintained due to the contribution of flow from this river.

Except in most extreme hydrological years the scheme has the potential to make environmental flushing flows. Sustained irrigation demand will tend to increase the magnitude of flows by up 31.5 m^3/s upstream of the take point even in extremely dry years, which may be beneficial when flows might otherwise have been very low.

In terms of reliability the scheme described in this report may be described as extremely reliable. Supply meets demand in the majority of years and when this does not occur, the periods of no supply coincide with the latter months of the irrigation season. The scheme would be described as unreliable in only two years in the 36 year simulation period, viz. 1972 and 2007. In these years the average soil moisture balance is less than 50% for sustained periods leading to shorter irrigation seasons for these two years.

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