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Supplementary Material

Assumptions, probability distributions and CPT values for Hurunui BBN Model

This document is the record of the evidence and assumptions used to develop the Bayesian Belief Network for the Culverden Basin/Hurunui system.

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A. Water source options

The total current water abstraction allocation from the Hurunui River is 6.2 $m^3 s^{-1}$, with 5 $m^3 s^{-1}$ of this for the existing Balmoral Irrigation Scheme just downstream of site CH1 (pers. comm. Jeff Smith, Environment Canterbury). Most abstraction consents (permits) have a summer low flow (below which abstraction is halted) of 10 $m^3 s^{-1}$ at site CH1 and have progressively greater restrictions as flows decline below 25 $m^3 s^{-1}$.

Irrigation water provision options from the Canterbury Water Strategy report (Morgan et al., 2010) are summarised in Table A1.

Table A1: Supply options, storage and peak flow demand at 5 mm/day (from Morgan et al. 2010)

Supply	Potential net irrigable area (ha)	Peak water demand at 5 mm/day ($m^3 s^{-1}$)	Estimated storage requirement (Mm^3)
South Branch high dam	27750	160	111
Lake Sumner storage normal range	6750	4	27
Mandamus (catchment supply)	12500	7.	50
Mandamus with Hurunui flow storage	35000	20	140
Waitohi (catchment supply)	5000	3	20
Waitohi with Hurunui flow storage	32500	19	130
Pahau	5000	3	20

The data in Table A1 were used to calculate the peak irrigation demand that could be supplied and therefore areas that could be irrigated for different options (Table A2). A new maximum abstraction take was set at 15 $m^3 s^{-1}$, equivalent to the flow required to irrigate 25,200 ha (with a total of 42000 ha at the full irrigation level) at 5 mm/day. Some of the combinations in Table A2 are not plausible because upstream dams would have already taken water before reaching downstream dams, and model users need to be alert to this when developing scenarios.

Table A2: Predicted effects of water source options on peak abstracted flow and probability distributions for the node 'Huru Abstraction' (derived from information in Table A1)

Parent node states					Peak abstracted flow ($m^3 s^{-1}$)	State probabilities	
South Branch	**Lake sumner storage**	**Mandamus**	**Waitohi**	**Pahau**		**No change**	**Up 15 $m^3 s^{-1}$ or more**
Dam	False	None	None	NoDam	16	0	100
Dam	False	None	None	Dam	19	0	100
Dam	False	None	DamNoHuruQ	NoDam	19	0	100
Dam	False	None	DamNoHuruQ	Dam	22	0	100
Dam	False	None	DamPlusHuruQ	NoDam	35	0	100
Dam	False	None	DamPlusHuruQ	Dam	38	0	100
Dam	False	DamNoHuruQ	None	NoDam	23	0	100
Dam	False	DamNoHuruQ	None	Dam	26	0	100
Dam	False	DamNoHuruQ	DamNoHuruQ	NoDam	26	0	100
Dam	False	DamNoHuruQ	DamNoHuruQ	Dam	29	0	100
Dam	False	DamNoHuruQ	DamPlusHuruQ	NoDam	42	0	100
Dam	False	DamNoHuruQ	DamPlusHuruQ	Dam	45	0	100
Dam	False	DamPlusHuruQ	None	NoDam	36	0	100

Dam	False	DamPlusHuruQ	None	Dam	39	0	100
Dam	False	DamPlusHuruQ	DamNoHuruQ	NoDam	55	0	100
Dam	False	DamPlusHuruQ	DamNoHuruQ	Dam	42	0	100
Dam	False	DamPlusHuruQ	DamPlusHuruQ	NoDam	55	0	100
Dam	False	DamPlusHuruQ	DamPlusHuruQ	Dam	58	0	100
Dam	True	None	None	NoDam	20	0	100
Dam	True	None	None	Dam	23	0	100
Dam	True	None	DamNoHuruQ	NoDam	23	0	100
Dam	True	None	DamNoHuruQ	Dam	26	0	100
Dam	True	None	DamPlusHuruQ	NoDam	39	0	100
Dam	True	None	DamPlusHuruQ	Dam	42	0	100
Dam	True	DamNoHuruQ	None	NoDam	27	0	100
Dam	True	DamNoHuruQ	None	Dam	30	0	100
Dam	True	DamNoHuruQ	DamNoHuruQ	NoDam	30	0	100
Dam	True	DamNoHuruQ	DamNoHuruQ	Dam	33	0	100
Dam	True	DamNoHuruQ	DamPlusHuruQ	NoDam	46	0	100
Dam	True	DamNoHuruQ	DamPlusHuruQ	Dam	49	0	100
Dam	True	DamPlusHuruQ	None	NoDam	40	0	100
Dam	True	DamPlusHuruQ	None	Dam	43	0	100
Dam	True	DamPlusHuruQ	DamNoHuruQ	NoDam	43	0	100
Dam	True	DamPlusHuruQ	DamNoHuruQ	Dam	46	0	100
Dam	True	DamPlusHuruQ	DamPlusHuruQ	NoDam	59	0	100
Dam	True	DamPlusHuruQ	DamPlusHuruQ	Dam	62	0	100
No Dam	False	None	None	NoDam	0	100	0
No Dam	False	None	None	Dam	3	81	19
No Dam	False	None	DamNoHuruQ	NoDam	3	81	19
No Dam	False	None	DamNoHuruQ	Dam	6	61	39
No Dam	False	None	DamPlusHuruQ	NoDam	19	0	100
No Dam	False	None	DamPlusHuruQ	Dam	22	0	100
No Dam	False	DamNoHuruQ	None	NoDam	7	52	48
No Dam	False	DamNoHuruQ	None	Dam	10	32	68
No Dam	False	DamNoHuruQ	DamNoHuruQ	NoDam	10	32	68
No Dam	False	DamNoHuruQ	DamNoHuruQ	Dam	13	13	87
No Dam	False	DamNoHuruQ	DamPlusHuruQ	NoDam	26	0	100
No Dam	False	DamNoHuruQ	DamPlusHuruQ	Dam	29	0	100
No Dam	False	DamPlusHuruQ	None	NoDam	20	0	100
No Dam	False	DamPlusHuruQ	None	Dam	23	0	100
No Dam	False	DamPlusHuruQ	DamNoHuruQ	NoDam	23	0	100
No Dam	False	DamPlusHuruQ	DamNoHuruQ	Dam	26	0	100
No Dam	False	DamPlusHuruQ	DamPlusHuruQ	NoDam	39	0	100
No Dam	False	DamPlusHuruQ	DamPlusHuruQ	Dam	42	0	100
No Dam	True	None	None	NoDam	4	74	26
No Dam	True	None	None	Dam	7	55	45
No Dam	True	None	DamNoHuruQ	NoDam	7	55	45
No Dam	True	None	DamNoHuruQ	Dam	10	35	65
No Dam	True	None	DamPlusHuruQ	NoDam	23	0	100
No Dam	True	None	DamPlusHuruQ	Dam	26	0	100
No Dam	True	DamNoHuruQ	None	NoDam	11	26	74
No Dam	True	DamNoHuruQ	None	Dam	14	6	94
No Dam	True	DamNoHuruQ	DamNoHuruQ	NoDam	14	6	94
No Dam	True	DamNoHuruQ	DamNoHuruQ	Dam	17	0	100
No Dam	True	DamNoHuruQ	DamPlusHuruQ	NoDam	30	0	100
No Dam	True	DamNoHuruQ	DamPlusHuruQ	Dam	33	0	100
No Dam	True	DamPlusHuruQ	None	NoDam	24	0	100
No Dam	True	DamPlusHuruQ	None	Dam	27	0	100
No Dam	True	DamPlusHuruQ	DamNoHuruQ	NoDam	27	0	100

No Dam	True	DamPlusHuruQ	DamNoHuruQ	Dam	30	0	100
No Dam	True	DamPlusHuruQ	DamPlusHuruQ	NoDam	43	0	100
No Dam	True	DamPlusHuruQ	DamPlusHuruQ	Dam	46	0	100

<u>Irrigation water from efficiency gains through border-dyke to spray irrigation conversions and Increased Waiau water input</u>: The Canterbury Water Management Strategy (CWMS, Morgan et al. 2010) states that changing the current border dyke areas to spray in the Balmoral scheme (36% of area) and Waiau Plains scheme (41%) could increase the area irrigated by 34%. However, we (Harris data present to Catchment 2010 Workshop 3) predict that under BAU scenario conversion of existing border dyke to spray would increase the irrigated area by only 13% (2260 ha to 19,094 ha) leaving 25% of the irrigated areas by border dyke. The CWMS indicates that increased abstraction from the Waiau River could supply a peak demand of 7.685 m^3 s^{-1}irrigating 13,250 ha. This information on additional irrigation water sources informed the development of the ‘Irrigable Area’ node (Table A3).

Table A3: Predicted effects of the peak abstraction from the Hurunui and the Waiau and border to spray water efficiencies on the total irrigable area and conditional probabilities of the BBN Node ‘Irrigable Area’ calculated by linear interpolation between current and maximum area suitable for irrigation

Parent node states			Total calculated irrigable area (ha)	State % probabilities	
Huru Abstraction	**Border to spray**	**Waiau**		**Current 16800 ha**	**42000 ha**
no change	TRUE	TRUE	32344	38	62
no change	TRUE	FALSE	19094	91	9
no change	FALSE	TRUE	30084	47	53
no change	FALSE	FALSE	16834	100	0
up15cumec or more	TRUE	TRUE	58198	0	100
up15cumec or more	TRUE	FALSE	44948	0	100
up15cumec or more	FALSE	TRUE	55938	0	100
up15cumec or more	FALSE	FALSE	42688	0	100

B. Channel form and flow variability

The South Branch is the major tributary providing bedload supply from the Southern Alps to the lower Hurunui River because, unlike the North Branch, it lacks lakes on its mainstem. The river channel is highly braided in the plains sections across the Culverden Basin and downstream of site CH2 to the coast (Fig. 1 in main paper). Braided channels are rare internationally and Canterbury provides 60% of this habitat type in New Zealand. They are maintained by high sediment bedload and flooding that controls vegetation encroachment (Mosley, 2004). Dams typically eliminate downstream transport of upper catchment suspended sediment and bedload and reduce the frequency flushing flows and flood flow magnitude (Young 2004). This is expected to result in reduced channel migration (Shields et al., 2000), with consequently reduced braiding and channel narrowing, although changes may decades to centuries (Petts, 1984). A dam on the South Branch, that is the source of most of the lower river bedload (ca. 50%) and flow variability (i.e. the South Branch), is expected to have a strong influence on downstream channel form (Hicks, 2010). Hicks (2010) rates the Mandamus as a minor sediment bedload, whereas the Pahau is rated a very minor source and Waitohi is rated as minimal. The Mandamus River drains a lower rainfall area than the South Branch, so has less influence on flushing frequency than the South Branch (Duncan 2010). The CPT of influences of dam options on the frequency of flushing flows in the Hurunui mainstem (Table B1) on bedload in the mainstem (Table B2), and on vegetation encroachment onto mainstem gravel bars

(Table B3), are based on our analysis of this information. Also based on this analysis, the BBN assumes (Table B4) that a dam on the South Branch would reduce the probability of the channel form in unconstrained reaches being highly braided from 100% to 43% through its effects of reduced flushing flows (by about 45%) and reduced bedload (by 40%). Increased storage at Lake Sumner is assumed to have no effect on bedload (Hicks 2010) and a minor influence on flushing flow frequency (5% reduction). Other water source options are assumed to have more minor influences on flooding and bedload and are not included as influences on these variables in the BBN.

Table B1: Conditional probability table for the BBN Node 'Huru Flush Freq'

Parent node states			State % probabilities	
Lake Sumner Storage	**S Branch Dam**	**Mandamus Dam**	**No change**	**red50%**
FALSE	Dam	none	10	90
FALSE	Dam	DamNoHuruQ	5	95
FALSE	Dam	DamPlusHuruQ	5	95
FALSE	None	none	100	0
FALSE	None	DamNoHuruQ	80	20
FALSE	None	DamPlusHuruQ	80	20
TRUE	Dam	none	5	95
TRUE	Dam	DamNoHuruQ	0	100
TRUE	Dam	DamPlusHuruQ	0	100
TRUE	None	none	90	10
TRUE	None	DamNoHuruQ	80	20
TRUE	None	DamPlusHuruQ	80	20

Table B2: Conditional probability table for the BBN node 'Huru Bedload'

Parent node states		State % probabilities	
S Branch Dam	**MandamusDam**	**current**	**red 50%**
Dam	none	20	80
Dam	DamNoHuruQ	0	100
Dam	DamPlusHuruQ	0	100
None	none	100	0
None	DamNoHuruQ	80	20
None	DamPlusHuruQ	80	20

Table B3: Conditional probability table for the BBN node 'Veg Encroachment'

Parent node states	State % probabilities
Huru Flush Freq	**Veg encroachment'**
No Change	No change
Reduced 50%	Abundant

Table B4: Conditional probability table for the BBN Node 'Huru Channel Form'

Parent node states		State % probabilities	
Bedload	**Huru Flush Freq**	**High Braiding**	**Low Braiding**
Current	Current	100	0
Current	Reduced 50%	80	20
Low	Current	60	40
Low	Reduced 50%	30	70

C. Salmon

Salmon (Chinook, *Oncorhynchus tshawytscha*) are a key value for the Hurunui River that could be impacted by the irrigation water supply infrastructure associated with increased irrigation in the Culverden Basin, through flow/channel form effects on upstream passage of returning spawners (Duncan 2010) and dams preventing access to spawning sites (Unwin, 2006; Unwin, 2008). Estimates of the annual run of spawning salmon range from 65 to 786 fish between 2001-2009 (Fish and Game NZ data reported in Keesing (2011)).

Salmon have greater depth requirements for upstream passage as adults journey from the sea to the headwater to spawn than for any other species in the river (Davis, 1980; Duncan, 2010). The critical reach for salmon passage is the reach between the State Highway 7 Bridge and the Pahau River confluence, because the greatest abstraction occurs upstream of this reach and this reach is more braided than further upstream and so likely to be shallower (Duncan, 2010).

C1 Salmon Spawning: The BBN assumes salmon spawning is affected by access to key spawning areas (assuming South Branch is a key spawning area but some spawning also occurs in North Branch and the mainstem, based on Unwin's (2008) evidence to National Conservation Order Hearings) (Table C1). Unwin (2006) reviewed an earlier inventory of salmonid spawning sites in the Canterbury Region, and re-evaluated all sites with respect to their importance for Chinook salmon. This review identified three Hurunui Catchment sites of regional importance (Landslip Stream, Homestead Stream (South Branch Tributary), and the South Branch above the North Esk confluence), and one of local importance (the main stem of the Hurunui North Branch above Lake Sumner. The lower rating for the Hurunui North Branch reflected the relative usage of the two main branches by spawning fish, with the South Branch generally accounting for a higher and more consistent proportion of the total than the North Branch. Surveys of adult spawners by Fish and Game NZ from 2001-2010 indicate a 60:40 split of spawning salmon between the South and North branches of the Hurunui (Keesing, 2011). Based on this evidence, the model assumes that a dam on the South Branch would reduce the salmon spawning are by 60%, but other storage options would have minimal effect (Table C1).

Table C1: Conditional probability table for the BBN Node "Salmon Spawning OK"

Parent node states	State % probabilities	
South Branch Dam	**True**	**False**
Dam	40	60
None	100	0

C2 Salmon Passage: We assumed that the current resource consent conditions for the Balmoral Scheme allow upstream migrations of spawners in autumn (pers. comm. Ian Jowett, Fisheries Consultant) but reductions in baseflow would cause increasing constraint (Davis, 1980; Duncan, 2010). Duncan (2010) reported on hydraulic modelling that indicates there is sufficient water depth (0.25 m) for adult salmon to traverse the critical Amuri reach (between SH 70 and the Pahau, at a Hurunui flow (at Mandamus) of 10 m^3s^{-1}. Duncan (2010) also concluded that salmon could probably traverse the reach when the flow was 5 m^3s^{-1}, but water depths in some riffles would be less than ideal, and that the when flow was 13.5 m^3s^{-1} all the riffles surveyed over a 17 km long reach were at least 0.25 m deep. Salmon spawning migrations are often initiated by spates/flood flows (Banks, 1969; Bunn and Arthington, 2002; Jensen et al., 1986). Spates during the autumn season provide turbidity cover and depth that facilitate salmon migration. Hence reduction in the frequency of spates during this period due to water harvesting, could plausibly reduce success of upstream spawner migrations. A change in channel form from highly braided to low braiding is assumed to result in deeper main channel for a given flow.

The above information was used to develop the conditional probabilities for parent node influences on the child nodes ‘Salmon Passage OK’ (Table C2), and the ‘Salmon OK’ (Table C3).

Table C2: Conditional probability table for the BBN Node ‘Salmon Passage OK’

Parent node states			State % probabilities	
Lowflow Limit	**Huru Flush Freq**	**Plains Channel Form**	**True**	**False**
Red 23%	Current	High Braiding	90	10
Red 23%	Current	Low Braiding	95	5
Red 23%	Red 50%	High Braiding	60	40
Red 23%	Red 50%	Low Braiding	80	20
Current	Current	High Braiding	97	3
Current	Current	Low Braiding	100	0
Current	Red 50%	High Braiding	70	30
Current	Red 50%	Low Braiding	85	15

Table C3: Conditional probability table for the BBN Node ‘Salmon OK’

Parent node states		State % probabilities	
Salmon upstream passage OK	**Salmon spawning OK**	**True**	**False**
True	True	100	0
True	False	40	60
False	True	20	80
False	False	5	95

D. Wading birds:

Braided river habitats are a key habitat for many bird species, providing much wider variety of micro-habitats than single thread channels (O'Donnell, 2004). Islands within the braided section of the river provide important refuges from predators for breeding populations of river birds in the Hurunui, and hydraulic modelling of the braided reach downstream of SH 70 indicates that the number of islands and their area decrease as flow decreases from 50 to 10 $m^3\ s^{-1}$ (Duncan 2010). Based on this information, the CPT for ‘Wading Birds OK’ assumes that a change from a highly braided to a less braided channel would have a major impact of the Hurunui's populations of wading birds because this would reduce island refuges from predators and allow vegetation to consolidate on banks and bars – reducing habitat for waders such as black-fronted terns and dotterels (O'Donnell 2004, pers. comm. Paul Sagar, NIWA) (Table D1). Such impacts have been reported anecdotally below the Opuha Dam in South Canterbury.

Table D1: Conditional probability table for the BBN Node 'Wading Birds OK'

Parent node states		State % probabilities	
Veg Encroachment	**Plains Channel Form**	**True**	**False**
No change	High Braiding	100	0
No change	Low Braiding	40	60
Abundant	High Braiding	60	40
Abundant	Low Braiding	20	80

E. Natural Character

The natural character of the Hurunui River is influenced strongly by the presence of braided channel sections and the natural flow regime. Canterbury Rivers that drain the Southern Alps are renowned internationally for their braided sections (Collier and McColl 1992). Our assumption in the BBN is that natural character would be degraded by a change in channel form from high to low braiding in currently braided, unconstrained, sections and by vegetation encroachment and reduced baseflows (Table E1).

Table E1: Conditional probability table for the BBN Node 'Natural Character OK'

Parent node states			State % probabilities	
Plains Channel Form	**Veg encroachment**	**Low Flow Limit**	**True**	**False**
High Braiding	Current	Reduced 23%	85	15
High Braiding	Current	Current	100	0
High Braiding	Abundant	Reduced 23%	50	50
High Braiding	Abundant	Current	60	40
Low Braiding	Current	Reduced 23%	20	80
Low Braiding	Current	Current	25	75
Low Braiding	Abundant	Reduced 23%	5	95
Low Braiding	Abundant	Current	10	90

F. Nutrient Losses

The changes in areas of irrigated and total land use in the Culverden Basin assumed for each Land Scenario are shown in Table F1.

Table F1: Irrigated and total areas by land use type in the Culverden Basin assumed for each Land Scenario in modelling of nutrient losses

Land use	Current	Target 1990 WQ	Business as usual	New Water
Irrigated area (ha) by scenarios				
Sheep and Beef	4114	4114	2704	11173
Dairy	11727	16004	15371	25505
Arable	425	1287	425	4595
Horticulture, viticulture	71	71	98	195
Other	497	0	497	497
Forestry	0	0	0	0
Total	16834	21476	19094	41965
Total area (ha) by scenarios				
Sheep and Beef	80,583	69,550	77,911	74,263
Dairy	15,250	18,363	17,896	27,510
Arable	1,287	1,287	1,287	4,595
Horticulture, viticulture	71	71	98	195
Other	103,439	103,437	103,439	103,439
Forestry	9,476	17,397	9,476	105

Annual nutrient (N and P) losses (Table F2) for the four develop land scenarios of “Target 1990 Water Quality”, Current”, “Business as Usual” (BAU: intensification by conversion of border to spray irrigation) and “New Water” were calculated using the land areas for different land use types as irrigated and non-irrigated areas and N and P losses, with and without full mitigations applied, in a spreadsheet model derived largely from application of the OVERSEER® Nutrient Budget Model (Wheeler et al., 2006). Arable land losses were derived from (Zemansky et al., 2006) as 14 and 21 kgN/ha/y for non-irrigated and irrigated land and 0.1 kg P/ha/y for both land types (ECan lookup Table reported in Fig A2.1 in Campbell et al. 2011 (AgResearch Benchmarking appendix)). N and P from Forestry were from CLUES prediction for Balmoral forest area (Lilburne et al., 2011).

The predicted reductions in N and P losses shown in Table F2 assume that a suite of measures would be required on farms and that these measures would vary from farm to farm according to soil type and other landscape features. The mitigation modelling was divided into 3 steps. The first involved modifying the Farmax (Bryant et al., 2010; White et al., 2010) model setups to ensure that all farm management responses required for implementation of each mitigation option were captured and their effects on stocking rate etc were identified. The OVERSEER® model was then re-run to capture these and other assumed management changes and provide estimates of N and P loss risk for each mitigation option. The cost-effectiveness of each mitigation measure was then calculated to identify where the largest reductions in N or P loss could be achieved at least cost. For some mitigations it was necessary to deduct additional costs that were not captured in the Farmax modelling. These included the cost of dicyandiamide (DCD, anitrification inhibitor) application ($140/ha/yr), annualised pivot irrigation costs ($507/ha/yr in total) and an annualised cost of $599/ha/yr for utilising a Herd Shelter (Herd Home® assumed) that considered the cost of capital (8%), emptying bunkers, depreciation, and additional labour costs. A weighted N loss estimate was calculated for the model dairy + support unit scenarios to account for the different areas of dairy land under each soil type x irrigation (spray or border dyke) combination. Values for this weighted calculation were derived from GIS data-layers for the Hurunui Basin.

For dairy farms, the mitigation measures evaluated included upgrading farm dairy effluent systems, off-paddock wintering (particularly for farms on shallow soil types), the use of nitrification inhibitors, conversion from border dyke to spray irrigation and installing wetlands where landscape features allow. Additional measures such as duration-controlled pasture grazing during autumn or reductions in fertiliser N inputs would also help to achieve the sizeable reductions assumed in Table F3, although at greater cost per unit of N conserved. For dry stock farms, some of the more cost-effective measures considered include converting border dyke systems to spray irrigation, livestock exclusion from riparian areas, erosion control and installing wetlands where landscape features allow.

Table F2: Summary of nutrient losses assumed in relation to land use

Land use	N kg/ha/y	P kg/ha/y
Border dyke Dairy	50	0.57
Spray Dairy	38	0.44
Dairy support dryland	38	0.44
Arable Irrigated	21	0.50
Arable Dry	14	0.50
Forestry	3	0.25

Combining these yields with land areas under different uses, irrigation regimes (Table F3) gave the annual losses by significant production land use (horticulture and “other” omitted) in Table F4.

Table F3: Predicted overall effectiveness of a suite of mitigations applied to land management types in the Hurunui Basin

Land use	% N reduction with maximum feasible mitigation	% P reduction with maximum feasible mitigation
Arable	30	10
Dairy Milking platform	50	20
Dairy milking plus support	50	20
Dairy support dryland	25	20
Intensive irrigated Sheep and beef	20	20
Intensive dryland sheep and beef	10	20
Hill country Sheep and beef	0	20
Other productive	10	20

Table F4: Predicted total annual N and P losses (kg) from production land in the Hurunui catchment for 4 scenarios with and without mitigations

Nutrient	Scenario	Sheep & Beef	Dairy	Arable	Forestry	Total	Total as %current
N Loss kg/y	Target 1990 WQ	611088	609169	27023	69590	1316870	102
N Loss kg/y	Target 1990 WQ +mitigation	549979	304585	18916	69590	943070	73
N Loss kg/y	Current	611088	635468	20988	28428	1295972	100
N loss kg/y	Current + mitigation	577414	317734	14691	28428	938267	72
N Loss kg/y	BAU	590822	681206	20988	28428	1321444	102
N Loss kg/y	BAU + mitigation	561281	340603	14691	28428	945003	73

N Loss kg/y	New Water	563158	1047165	96486	314	1707122	132
N Loss kg/y	New Water +mitigation	506842	523583	67540	314	1098278	85
P Loss kg/y	Target 1990 WQ	39486	7065	643	4349	51543	104
P Loss kg/y	Target 1990 WQ +mitigation	31589	5652	579	4349	42169	85
P Loss kg/y	Current	39486	7294	643	2369	49792	100
P loss kg/y	Current + mitigation	31589	5835	579	2369	40372	81
P Loss kg/y	BAU	38176	7900	643	2369	49089	99
P Loss kg/y	BAU + mitigation	30541	6320	579	2369	39809	80
P Loss kg/y	New Water	36389	12144	2297	26	50856	102
P Loss kg/y	New Water +mitigation	29111	9715	2068	26	40920	82

These predictions were checked against calculated loads of DIN and DRP at sites CH1 (Hurunui below Mandamus confluence above the Culverden Basin) and CH2 (downstream of the Culverden Basin) (Norton and Kelly, 2010) using the median ratios of TN/DIN and TP/DRP to convert their load estimates to TN and TP loads (Table F5).

Table F5: Calculated Dissolved N and P loads converted to total loads

Hurunui N load (kg/y) estimates at CH2 (Norton & Kelly 2010) 2004-2009					
min DIN	MaxDIN	Est TN Min	Est Max TN	Ratio Mean TN/NO_3-N since 2005	Ratio Median TP/DRP since 2005
454000	1381000	564621	1717493	1.3	1.2

Hurunui P load (kg/y) estimates at CH2 (Norton & Kelly 2010) 2004-2009					
min DRP	Max DRP	Est min TP	Est Max TP	Ratio Mean TP/DRP since 2005	Ratio Median TP/DRP since 2005
7380	12600	34241	58461	20	4.6

The predicted TN load from the production land area under current conditions (1,295,972 kg/y) is within the range (564,621-1,717,493) of the estimated TN load at CH2 (Tables F4 and F5), indicating the predictions are plausible and that most of the TN load comes from the production area (TN load at CH1 is <10% of that at CH2). The TP load at CH2 calculated from Norton and Kelly (2010) was 69-93% of our modelled load for the production area of the catchment, which again is plausible. This suggests that our spreadsheet model predictions can be used to estimate effects of land use changes and mitigations on loads of total N and P and dissolved inorganic N and P (using the instream ratios of TN/DIN and TP/DRP) at CH2 and to scale effects on dissolved nutrient concentrations.

The information in Table F4 was used to calculate conditional probabilities for the effects of land use scenarios and mitigations on annual TN and TP losses from the production land in the catchment as percentages of the current loads (Tables F6 and F7). The minor increase in TP load with the ‘New Water’ scenario is at first surprising, but reflects the complete change from border to spray irrigation that eliminates irrigation runoff which is a major source of P loss. This is supported by the trend of reducing DRP (by 35%) at CH2 between 2000 and 2010 (see below), following introduction of bunding at the downstream end of irrigation field to reduce irrigation water runoff.

Table F6: Farms submodel predictions of land use scenario and mitigation effects on annual total nitrogen (TN) losses as percentages of the current loads and conditional probabilities of the state of the BBN node ‘N Leaching’ calculated by linear interpolation between maximum and minimum submodel values

Parent nodes and states		Predicted TN load (% of Current)	State % probabilities	
Land Scenario	**Mitigation**		**72% current TN**	**132% current TN**
Target 1990 WQ	Full	73	99	1
Target 1990 WQ	Nil	102	51	49
Current	Full	72	99	1
Current	Nil	100	53	47
BAU	Full	73	98	2
BAU	Nil	102	50	50
NewWater	Full	85	79	21
NewWater	Nil	132	0	100

Table F7: Farms submodel predictions of land use scenario and mitigation effects on annual total phosphorus (TP) losses as percentages of the current loads and conditional probabilities of the state of the BBN node ‘P Loss’ calculated by linear interpolation between maximum and minimum submodel values

Parent nodes and states		Predicted P load % Current	State % probabilities	
Land Scenario	**Mitigation**		**80% current TP**	**104% current TP**
Target 1990 WQ	Full	85	80	20
Target 1990 WQ	Nil	104	0	100
Current	Full	81	95	5
Current	Nil	100	17	83
BAU	Full	80	100	0
BAU	Nil	99	23	77
NewWater	Full	80	91	9
NewWater	Nil	99	8	92

G. Tributary Dissolved Inorganic Nitrogen (DIN) and Dissolve reactive Phosphorus (DRP) concentrations and Nitrate Toxicity:

The influence of land use scenarios and mitigations on the weighted average DIN and DRP concentration was calculated as follows.

(1) A weighted mean concentration for all the main tributaries draining the part of the catchment with intensive production land uses (Waitohi, Pahau, Dry Stream, St Leonards Drain) was calculated using average concentrations of these tributaries at the most downstream point sampled over 2005-2008 (Ausseil, 2010), weighted by their relative loads (calculated using the averaging method for 2005-2010) in Tables 5a and 5b of Norton and Kelly (2010). This produced an average DIN for the current conditions of 1820 mg $m^{-3}$and an average DRP of 13.4 mg m^{-3}. Our groundwater spreadsheet model predicted a load weighted average DIN of 2040 mg m^{-3}, close to the weighted average from monitoring, and was used as the “Current” value in calculations of effects of

the tributaries on downstream water quality at CH2. The CPTs for average tributary DIN and DRP are shown in Tables G1 and G2 below.

(2) St Leonards Drain had the highest average DIN of 3.0 g/m^3 during 2004-2008 (Ausseil 2010) and this was also used as the current level for this stream to evaluate the worst case nitrate-N levels in tributary streams in relation to the 1.7 g/m^3 guideline for 95% protection of aquatic life from toxicity effects of nitrate (Hickey and Martin, 2009). The DIN was assumed to be NO_3-N for these calculations because NH_4-N contribution to DIN is very minor. None of the scenario/mitigation combinations were predicted to reduce NO_3-N in St Leonards Drain below the 1.7 g/m^3 guideline.

(3) The influence of land use and mitigation scenarios on these average current DIN and DRP concentrations were calculated assuming they would change in proportion to the changes in TN and TP loads in Tables F4 and F5 above.

Table G1: Conditional probabilities for the BBN node 'Trib Av DIN' in relation to the state of 'N Leaching'

Parent node (N Leaching) states	**'Trib Av DIN' states**
72% current	1400 ppb
132% current	2700 ppb

Table G2: Conditional probabilities for 'Trib Av DRP' in relation to the state of 'P Loss

Parent node (P Loss) states	**'Trib Av DRP' states**
80% current	10.7 ppb
104% current	13.9 ppb

Average groundwater nitrate concentrations: Average groundwater nitrate concentrations were calculated by combining the farm systems nitrogen leaching model for each combination of the land scenarios and mitigation with the groundwater model (Lilburne et al., 2011) (Table G3).

Table G3: Conditional probabilities for the BBN node 'GW av NO3-N' in relation to the state of 'N leaching'

Parent node (N Leaching) states	**'GW av NO3-N' states**
72% current	2000 ppb
132% current	5300 ppb

Nitrate toxicity in tributaries: Compliance with the nitrate toxicity guidelines in the four main tributaries was determined by taking the ECan current average values for each of the four main Culverden Basin tributaries, applying % change in 'N Leaching' from current (Table F4) and comparing the predicted result with the 1.7 g/m^3 guideline for 95% protection of aquatic life and the results were used to formulate the CPT (Table G4).

Table G4: Conditional probability table for land use scenario and mitigation effects on the child node ‘Trib NO_3-N Tox OK’

Parent node state		State % probabilities	
Land Scenario	**Mitigation**	**TRUE**	**FALSE**
Target 1990 WQ	Full	75	25
Target 1990 WQ	Nil	50	50
Current	Full	75	25
Current	Nil	50	50
BAU	Full	75	25
BAU	Nil	50	50
New Water	Full	75	25
New Water	Nil	25	75

H. Economic indicators

The effects of the 4 land scenarios and application of the suite of mitigations on economic indicators (Table H1) were derived from our economic sub-model that made predictions made for three key indicators: (1) Farm Jobs, (2) Farm Cash Surplus allowing annualised transition costs (sourced from the Canterbury Water Management Strategy as supplied by Stuart Ford) (Table H2), and (3) Regional Gross Domestic Product (GDP) associated with farming activity (from a regional input-output model (Butcher, 2010)). The annualised transition costs (calculated under a standard assumption that the cost of capital is 8% per annum) are generalised per hectare irrigated (Table H2), rather than specific to particular water supply options that vary in their costs (Morgan et al 2010). Note that there is no scenario involving ‘Target 1990-95 water quality’ without mitigation because full mitigation was required to achieve the target, so that the economic indicators were set as the same as for the mitigated option in the BN. Estimates of the Current and BAU scenarios with full mitigation were obtained by multiplying the ‘No mitigation’ scenario data for each by the ratio of full/no mitigation for the New Water scenario.

These conditional probabilities between the parent variables (scenario and mitigation option) and the economic indicators were developed in the BBN using the predictions in Table H1 by linear interpolation between minimum and maximum values and results are shown in Tables H3, H4 and H5.

Table H1: Predicted economic indicator responses to four land development scenarios in the Hurunui/Culverden Basin

Land Scenario	Mitigation	Cash Farm Surplus after capital costs of transition	Contribution to Regional GDP (including flow on)	On farm employment (job numbers)
Target 1990 WQ	Full	$24,029,063	$134,803,164	397
Current	Full	$25,327,061	$107,400,127	372
Current	None	$30,547,339	$103,149,538	355
BAU	Full	$40,340,140	$155,822,564	545
BAU	None	$48,654,833	$149,655,553	519
New Water	Full	$37,412,064	$231,841,290	700
New Water	None	$45,123,238	$222,665,676	667

Table H2: Capital costs per hectare of transition for irrigation development

Capital costs irrigation transition/ha	On farm system change capital costs	On farm surface water irrigation development costs	On farm groundwater irrigation development costs	Off farm infra-structure	Total
Sheep and Beef	$2,200	$2,800	$2,300	$5,457	$12,757
Dairy	$8,610	$4,200	$3,700	$5,457	$21,967
Arable	$300	$5,000	$4,500	$5,457	$15,257
Horticulture, viticulture	$32,500	$2,300	$2,800	$5,457	$43,057
Lifestyle/Grapes/horticulture	$2,200	$2,800	$2,300	$5,457	$12,757

Table H3: Economic submodel predictions of influences of land scenario and mitigation on contribution to regional gross domestic product ('Regional GDP') and conditional probabilities calculated by linear interpolation between maximum and minimum values

Parent node state		Submodel predictions	State % probabilities	
Mitigation	**Land Scenario**		**$103,000,000**	**$232,000,000**
Full	Target 1990 WQ	$134,803,164	75.3	24.7
Full	Current	$107,400,127	96.6	3.4
Full	BAU	$155,822,564	59.1	40.9
Full	New Water	$231,841,290	0.1	99.9
None	Target 1990 WQ	$134,803,164#	75.3#	24.7#
None	Current	$103,149,538	99.9	0.1
None	BAU	$149,655,553	63.8	36.2
None	New Water	$222,665,676	7.2	92.8

= dummy values inserted because this scenario is not a real possibility

Table H4: Economic submodel's predicted influences of land scenario and mitigation on farm cash surplus allowing for transition costs ('Farm Cash-Costs') and conditional probabilities calculated by linear interpolation between maximum and minimum values.

Parent node states		Submodel predictions	State % probabilities	
Land Scenario	**Mitigation**		**$24,000,000**	**$49,000,000**
Target 1990 WQ	Full	$24,029,063	99.9	0.1
Target 1990 WQ	None	$24,029,063#	99.9#	0.1#
Current	Full	$25,327,061	94.7	5.3
Current	None	$30,547,339	73.8	26.2
BAU	Full	$40,340,140	34.6	65.4
BAU	None	$48,654,833	1.4	98.6

New Water	Full	$37,412,064	46.3	53.7
New Water	None	$45,123,238	15.5	84.5

[#] = dummy values inserted because this scenario is not a real possibility

Table H5: Economic submodel's predictions of influences of land scenario and mitigation on 'Farm Jobs' and conditional probabilities calculated by linear interpolation between maximum and minimum values

Parent node states		Submodel predictions	State % probabilities	
Land Scenario	**Mitigation**		**350 Jobs**	**700 Jobs**
Target 1990 WQ	Full	397	86.5	13.5
Target 1990 WQ	None	397[#]	86.5[#]	13.5[#]
Current	Full	372	93.7	6.3
Current	None	355	98.7	1.3
BAU	Full	545	44.4	55.6
BAU	None	519	51.7	48.3
New Water	Full	700	0.0	100.0
New Water	None	667	9.3	90.7

[#] = dummy values inserted because this scenario is not a real possibility

I. Hurunui River nutrients and algae:

I1 Monitoring summary: The National Water Quality Monitoring Network (NRWQN) results at CH2 show that dissolved reactive phosphorus (DRP) increased from 1989-2000 and then declined 35% between 2000 and 2010 (Fig. 1). Algal (filamentous + mats) cover was substantially higher downstream of the inflows from the Culverden Basin, at CH2, than upstream, at CH1, in summers of 2001, 2003 and 2005 but has been low since 2006.

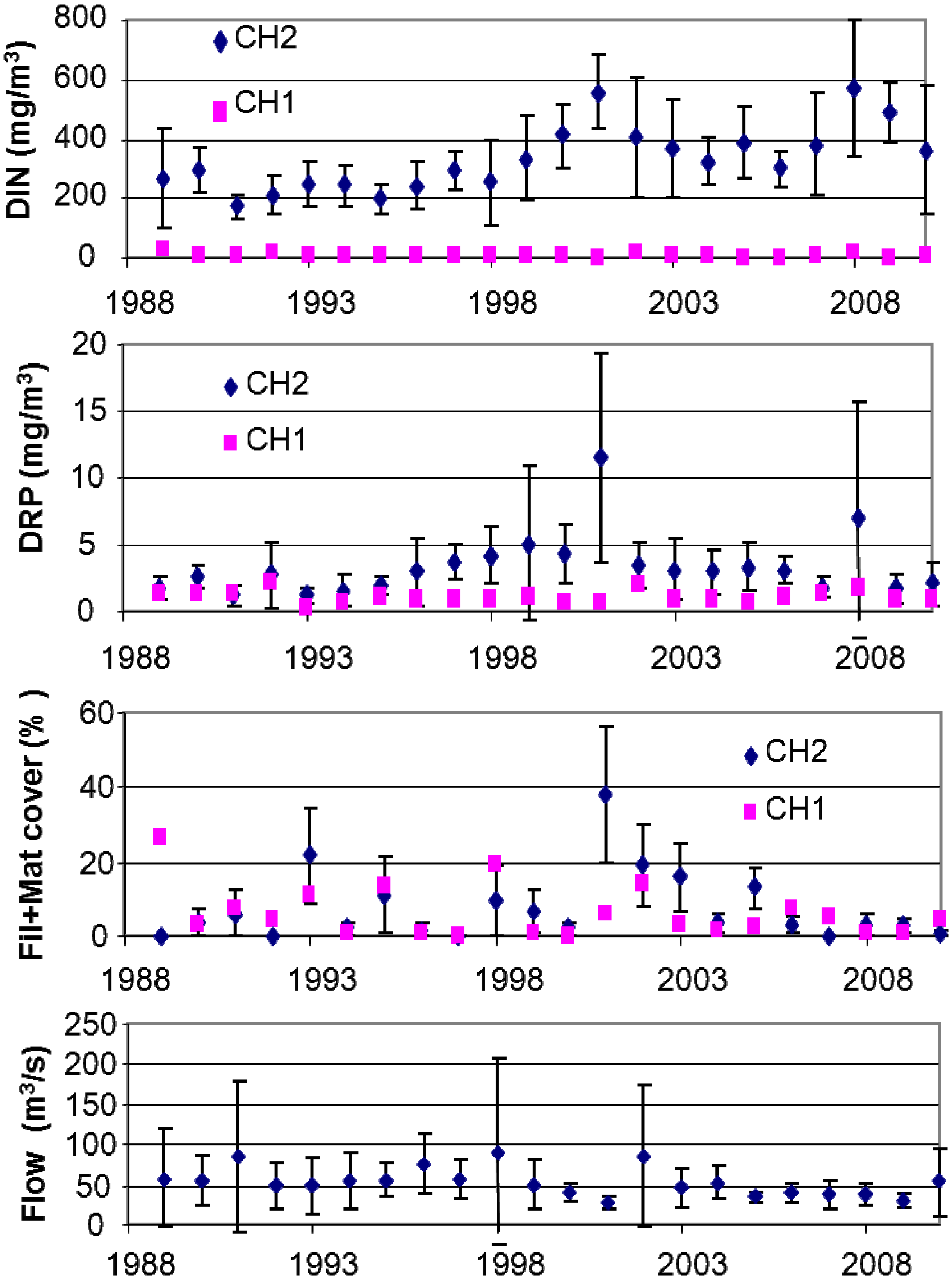

Figure 1: Summary of NRWQN monthly monitoring of dissolved inorganic nitrogen (DIN), dissolved reactive phosphorus (DRP), algal periphyton cover (filamentous growths + thick mats) and flows (means and standard deviations as whiskers) upstream (CH1) and downstream (CH2) of Culverden Basin inflows to the Hurunui River during summer (December-March) 1989-2010.

I2 Nutrients: Nutrient DIN/DRP ratios (>50 Wt:Wt) at CH2 indicate strong P limitation (Fig. 1), such that reduction of DIN would need to be very substantial to control periphyton, whereas periphyton cover appears to have responded to the decline in DRP from a summer average of 6.8 mg m^{-3} in the early 2000-2003 to 3.6 mg m^{-3} in 2007-2010 when no blooms occurred (see Fig. 1). The average DRP in summer (December to April inclusive) at CH1 in 2007-2010 was 1.2 g/m^3. A simple mass conservation calculation based on the DRP concentration and flows at Mandamus (above the Culverden basin) and the basin tributaries (using the flow weighted average DRP for the tributaries of 13.4 mg m^{-3}) predicted DRP concentrations at CH2 of 4.5 and 3.5 mg m^{-3}, at the 10%ile and 50%ile river flows at CH1 (12.2 and 28.3 m^3s^{-1}., respectively). The median flow on monthly monitoring days in summer 2005-2010 was close to the 50%ile at 25.9 m^3s^{-1}. The DRP calculated at the 50%ile flow is close to the current (2007-2010) measured summer DRP concentration at CH2, justifying the use of this approach to calculate the response of DRP at CH2 to land use scenarios and mitigations. Varying the tributary weighted mean DRP concentration over the predicted range for the combinations of scenarios and mitigations (10.7-13.9 mg m^{-3}) resulted in predictions of downstream DRP at CH2 of 2.95 to 3.54, i.e., similar to or less than the current level (Fig. 1). Mean summer DRP levels in this range were associated with mean total algal cover above 20% in 5 of 16 years (30%) since 1989.

If abstraction reduces the upstream flow of low DRP water whilst maintaining the tributary flows (which could increase with greater irrigation) this reduces the dilution available in the river, thus increasing the nutrient concentrations at CH2. An arbitrarily adopted maximum reduction of flow at CH1 of 23% allowed in the model is predicted to result in an increase in DRP at the median (50%ile) flow from current 3.5 to 4.0 mg m^{-3} under reduced flows. Natural reductions in flow also increase calculated DRP. For example, when the flow at CH1 was at the 10%ile level, the calculated DRP at CH2 was 4.8 mg m^{-3} and if this flow was reduced 23% calculated DRP increased to 5.1 mg m^{-3}.

The conditional probability table for effects of flow reduction and tributary average DRP during summer is shown in Table I1.

Table I1: Conditional probabilities for effects of ‘Low Flow Limit’ and summer average Culverden Basin tributary DRP on Hurunui River summer average DRP downstream at CH2

Parent node states		State % probabilities	
Trib Av DRP (ppb)	**Low Flow Limit**	**3 ppb**	**4 ppb**
10.7	current	100	0
10.7	down23%	65	35
13.9	current	46	54
13.9	down23%	0	100

The same approach as outlined above was taken for calculating the influence of river baseflow and scenarios/mitigations on Hurunui DIN. The prediction for the DIN at CH2 under current conditions is 383 mg/m^3, which is close to the measured summer average in Figure 1 above. At the median Hurunui flow, the range of tributary DIN values (1400-2700 mg/m^3) due to different scenarios/mitigations result in predicted DIN concentrations at CH2 from 265 to 505 mg/m^3. Reducing the baseflow by 23% would increase the upper prediction to 895 mg/m^3. The conditional probabilities describing these combined effects are shown in Table I2.

Table I2: Conditional probabilities for effects of low flow rule and average summer Culverden Basin tributary DIN (‘Av Trib DIN’) on Hurunui River DIN downstream (‘CH2 DIN’)

Parent node states		State % probabilities	
Trib Av DIN	**Low Flow Limit**	**250ppb**	**900ppb**
1400ppb	Reduced 23%	88	12
1400ppb	Current	98	2
2050ppb	Reduced 23%	66	34
2050ppb	Current	79	21
2700ppb	Reduced 23%	1	99
2700ppb	Current	61	39

I3 Influences on potential nuisance (filamentous and mat) algae cover in the Hurunui at CH2.

The influences on periphyton cover are complex. Analysis of monthly observations at CH2 during the summer period data (December – April) indicates a negative relationship between % algal cover and flow at the time of observation and positive correlations with clarity, DIN, accrual period, temperature and DRP when data were lagged by 1 month (i.e., DRP for the previous month correlated with algal cover observations) (Table I3, Figs 2 & 3). This lagged relationship between DRP and periphyton cover was expected because periphyton accrual removes nutrients (particularly the limiting nutrient) from the water column.

The density of invertebrate grazers (measured once/year during summer/autumn) is also expected to influence periphyton cover (Welch et al., 1992), but monthly invertebrate data are not available.

The NRWQN data indicate that at least 33 days of accrual (flow < 3x median) is required at CH2 to get filamentous cover >15% (= half MFE aesthetic nuisance guideline, (Biggs, 2000) and > 21 accrual days to get >30% mat cover (= half MFE aesthetic nuisance guideline, Biggs 2000).

Table I3: Spearman and Pearson correlations between average algal cover of the bed as filamentous, mat and total (Filamentous + Mat) at monthly observations during summer (December – April) between1989 and 2010. N = 82. -1M = DIN or DRP the month before algal cover observations. Italicised values are statistically significant at P < 0.05

	Spearman Rank Correlations			Pearson Correlations		
Variable	Filamentous	Mats	Total	Filamentous	Mats	Total
Mat	*0.40*			*0.26*		
Total	*0.78*	*0.81*		*0.57*	*0.94*	
Accrual days	*0.23*	0.21	*0.28*	0.09	0.08	0.10
Temp	*0.24*	0.16	0.20	0.07	0.14	0.15
Flow	*-0.49*	-0.39	*-0.56*	-0.20	-0.18	-0.22
Clarity	*0.45*	0.40	*0.49*	0.17	*0.23*	*0.25*
NO3-N	*0.34*	0.14	*0.32*	*0.35*	0.08	0.19
DIN	*0.34*	0.14	*0.32*	*0.35*	0.08	0.19
DIN-1M	0.18	0.17	*0.22*	0.12	*0.24*	*0.25*
TN	*0.37*	0.13	*0.32*	*0.38*	0.07	0.19
DRP	-0.09	-0.18	-0.17	0.07	0.00	0.03
DRP-1M	0.12	0.08	0.13	*0.24*	*0.35*	*0.38*
TP	*-0.28*	*-0.27*	*-0.34*	-0.11	-0.13	-0.15

Irrigation-driven land development is likely to influence flow (due to abstraction), accrual period (due to water storage changing flushing flow frequency), and inputs of DIN and DRP. Clarity is influenced mainly by rain events in the foothills and Southern Alps, although dams that trap sediment would also likely increase the downstream clarity. Temperature could be influenced marginally by riparian shading of the tributary streams. However this is likely to be a minor effect, given the width of the main sources of flow (making a high level of riparian shading difficult to achieve), and has not been included as an influence on algal cover.

Anecdotal evidence from a trout fishing guide in personal discussions at Hurunui Catchment workshop #5 and observations of Young (2009) and Duncan (2010) indicate that the recent invader algae *Didymosphenia geminata* is more prevalent upstream than downstream of the South Branch confluence due to greater flow stability and lower bedload upstream of the confluence. The frequency of flows > 3x median (FRE3) is 11.9 in the South Branch at Esk Head compared with 2.9 at Lake Sumner outlet and 5.6 at Mandamus (Duncan, 2010).

Examination of these data and our judgement were used to derive the conditional probabilities for influences on periphyton cover shown in Table I4.

Table I4: Conditional probabilities describing influences on ‘CH2 Algae OK’ (i.e., summer average cross-section periphyton cover <20%)

Parent node states				State % probabilities	
Huru Flush Freq	**CH2 DRP(ppb)**	**CH2 DIN (ppb)**	**Low Flow Limit**	**TRUE**	**FALSE**
no change	3	250	down23%	85	15
no change	3	250	Current	90	10
no change	3	900	down23%	80	20
no change	3	900	Current	85	15
no change	4	250	down23%	75	25
no change	4	250	Current	80	20
no change	4	900	down23%	65	35
no change	4	900	Current	70	30
50% redn	3	250	down23%	70	30
50% redn	3	250	Current	75	25
50% redn	3	900	down23%	65	35
50% redn	3	900	Current	70	30
50% redn	4	250	down23%	65	35
50% redn	4	250	Current	70	30
50% redn	4	900	down23%	50	50
50% redn	4	900	Current	55	45

J. Periphyton cover effects on invertebrate metrics

Invertebrates interact with periphyton in complex ways. Periphyton is a key food resource for invertebrates, so invertebrates both benefit from, and may control, periphyton growth. However, when periphyton forms blooms it can degrade the river water quality (altering pH, DO) and bed habitat in ways that may not favour sensitive invertebrates and the large behavioural “drifting” invertebrates, (such as mayflies) that are important food resources for drift feeding fish, like salmonids (Hayes et al., 2007). ECan uses the Quantitative Macroinvertebrate Community Index (QMCI) as a target to monitor the health of the river invertebrate communities and has a target of 5 for the Hurunui at CH2 in the Natural Resources Regional Plan (NRRP).

The average summer periphyton cover and invertebrate data collected in late summer at CH2 as part of the NRWQN were analysed to investigate relationships between these variables. The invertebrate metric generally had weak negative correlations with total summer periphyton cover (Table J1). These weak relationships probably reflect the generally low average periphyton cover at CH2 (Fig. 1).

Table J1: Spearman rank correlations at CH2 between invertebrate metrics from annual collections and summer maximum and summer average periphyton accrual period and cover from 1990-2010. None of the correlations are statistically significant at P < 0.05)

Spearman Rank Correlation	**QMCI**
Mean algal accrual period	-0.30
Maximum algal accrual period	-0.30
Average filamentous cover	-0.40
Maximum filamentous cover	-0.39
Average mat cover	-0.08
Average filamentous +mat cover	-0.15
Maximum mat cover	-0.08
Maximum filamentous +mat cover	-0.11

The variations in QMCI at CH1 and CH2 since 1989 are shown in Figure 2. QMCI was similar at both sites on most years (14/21) but was lower at CH2 during 1998-2005. In 2010 both sites had low QMCI due to an unusual abundance of a chironomid species at both sites – indicating the low QMCI results were due to natural faunal variability. EPT abundance is generally similar or higher at CH2 than Mandamus, indicating that the fish food production is not markedly impaired at CH2.

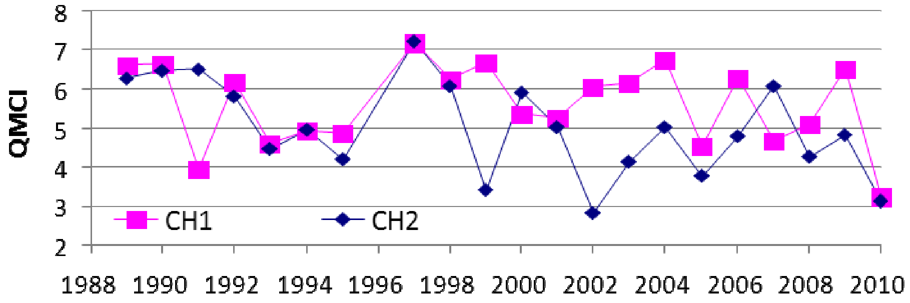

Figure 2: NRWQN invertebrate Quantitative Macroinvertebrate Community Index (QMCI) results at Hurunui River sites above (CH1) and below (CH2) the area of intensive agricultural development in the Culverden Basin, 1989-2010.

These data were used to inform the conditional probability table for periphyton cover effects on QMCI (as ECan's key indicator; Table J2).

Table J2: Conditional probabilities for effects Algal cover on whether the Quantitative Macroinvertebrate Community Index (QMCI) meets the ECan target of >5

Parent node states	State % probabilities	
CH2 Algae OK	**CH2 QMCI>5**	
	TRUE	FALSE
TRUE	70	30
FALSE	30	70

K. Water clarity

The median black disc horizontal sighting distance (Davies-Colley, 1988) over 2005-2010 from NRWQN monitoring at CH1 was 2.2 m and 1.5 m at CH2 (corresponding median turbidities are 1.4 and 2 NTU), and black disc met the recreational water quality guideline of >1.6 m (MFE, 1994) at CH2 48% of the time. Attenuation balance calculations (after converting black disc to the beam attenuation coefficient *c*, and inherent optical property of water that is rigorously additive (Davies-Colley 1988)), indicate the median black disc of the tributary inputs was 0.6 m (corresponding to a turbidity of 4.4 NTU) over this period. Ausseil (2010) reports median turbidities for the 4 Culverden Basin tributaries ranging from 0.6 NTU in Waitohi to 4.4 NTU in St Leonards Drain.

Clarity upstream of the Culverden Basin (e.g., at CH1) could be altered by any impoundments developed to store water for irrigation trapping sediment during floods (Young et al., 2004) thus increasing downstream water clarity. A dam on the South Branch of the Hurunui, that has headwaters in the Southern Alps, would have the greater influence on this than storage on the North Branch at Lake Sumner that already acts as a natural impoundment. The growth of phytoplankton within reservoirs may counteract the effect of sediment trapping on river water clarity, but this is likely to be minor in the low nutrient waters headwaters (Pridmore and McBride, 1984). The conditional probabilities assigned to define the effects on upstream water clarity (at CH1) of storages dams are our judgements based on this information (Table K1).

Table K1: Conditional probabilities describing effects of water storage options on BBN node 'CH1 clarity'

Parent node states		State % probabilities	
S Branch dam	**L Sumner storage**	**No change**	**30% increase**
Dam	True	0	100
Dam	False	10	90
No dam	True	80	20
No dam	False	100	0

Land use change scenarios and mitigations have the potential to influence the tributary clarity and hence the clarity at CH2 below the area of intensive production agriculture. The current median tributary clarity is estimated at 0.6 m. Mitigation measures that reduce livestock access to riparian areas and waterways and control irrigation runoff and general surface runoff are capable of increasing water clarity in tributaries by reducing fine sediment input. Experience elsewhere and the predicted reductions in P loss through land use change and mitigations (Table F3, that is related in part to reduced sediment particle losses) suggest tributary clarity could increase by about 50%.

This information was used to inform the CPT for factors influencing the average water clarity of the Culverden Basin tributaries ('Trib Clarity') in Table K2 and the flow on effects on clarity in the Hurunui downstream of these inputs ('CH2 Clarity OK') in Table K3.

Table K2: Conditional probabilities describing effects of land scenarios and mitigation on the node 'Trib Clarity'

Parent node states		State % probabilities	
Mitigation	**Land scenario**	**No change**	**50% increase**
Full	1990s WQ	10	90
Full	Current	20	80
Full	BAU	15	85
Full	New Water	60	40
None	1990s WQ	80	20
None	Current	100	0
None	BAU	80	20
None	New Water	100	0

Table K3: Conditional probabilities describing effects of background clarity at CH1 and tributary clarity on the node 'CH2 Clarity OK'

Parent node states		State % probabilities	
CH1 Clarity	**Trib Clarity**	**True**	**False**
No change	No change	45	55
No change	50% increase	60	40
30% increase	No change	65	35
30% increase	50% increase	70	30

L. Pathogen indicator *E. coli*

The measured *E. coli* levels monitored at the NRWQN sites at CH1 and CH2 since 2005 are summarised in Table L1. The corresponding tributary *E. coli* levels calculated by using a simple mass balance (i.e., with no die-off) are also included. These Tributary levels are likely to be underestimates as there is likely to be die-off between the inputs and CH2, although the calculated tributary median *E. coli* is similar to the levels in Ausseil (2010) for 2005-2008 of 410/100 ml in Dry Stream, 125 in Waitohi River, 225 in the Pahau at SH 70and 440 in St. Leonards Drain.

Table L1: *E. coli* (number100 ml^{-1}) in Hurunui and calculated values in average tributary inputs (by simple mass balance)

E. coli **(No 100 ml^{-1})**	**CH1**	**Calc tribs**	**CH2**
median	9	353	77
mean	21	2123	168
max	193	62352	1986
%>550	0	28	6
%>130	3	79	27

In the absence of any model predictions for the effects of scenarios on *E. coli*, it was assumed that the predicted % changes in TP (80-104% of current losses; Table F3) would also apply to *E. coli* (as they are both influenced by largely by surface runoff processes). The effects of these changes in inputs were applied to the predicted *E. coli* levels at CH2 for the average tributary inflow for each observation over 2005-2010 and summary statistics were recalculated. This gave the conditional probabilities in Table L2 for *E coli* levels in relation to the MFE/MOH (2003) guidelines for green (<130 100 ml^{-1}), amber (130-550) and red (>550 100 ml^{-1}) alert levels.

Reducing the low flow limit at CH1 would also increase *E. coli* levels at CH2, by reducing the quality of higher quality upstream water available to dilute the inflows from the Culverden Basin tributaries. The effects of this influence, in combination with the changes in tributary *E. coli* levels with land scenarios and mitigation (as indexed by 'P Loss', described above) were applied to the measured *E. coli* levels at CH2 and predicted levels for the average tributary inflow for each observation over 2005-2010 and summary statistics were recalculated. This gave the conditional probabilities in Table L3 for *E coli* levels in relation to the MFE/MOH guidelines (2003) for Green (<130 100 ml^{-1}), amber (130-550 100 ml^{-1}) and red (>550 100 ml^{-1}) alert levels.

Table L2: Conditional probabilities describing effects of 'PLoss' on the node 'Trib Ecoli Risk'

Parent node states	State % probabilities		
P loss	**green**	**amber**	**red**
80% current	21	54	25
104% current	21	48	31

Table L3: Conditional probabilities describing effects of the states of 'PLoss' and 'Low Flow Limit' on the BBN node 'CH2 Ecoli Risk'

Parent node states		State % probabilities		
P loss	**Low Flow Limit**	**green**	**amber**	**red**
80% current	Reduced 23%	62	31	7
80% current	Current	87	10	3
104% current	Reduced 23%	56	34	10
104% current	Current	72	21	7

M. Swimming

Water storage infrastructure to support irrigation and land use change have the potential to influence the suitability of downstream river sites for swimming/contact recreation via effects on water clarity, pathogen risk (as indicated by *E. coli* concentrations) and periphyton cover (through its negative effects on visual aesthetics, odour generation and making wading hazardous, Biggs (2000)). The CTP summarising these influences on suitability for swimming downstream of the Culverden Basin tributary inflows and at CH2 (Table M1) was developed with reference to New Zealand's national guidelines for periphyton cover (Biggs, 2000), water clarity (MFE, 1994) and *E. coli* (MFE/MOH, 2003). for contact recreation/swimming. The influence of *E. coli* was weighted more strongly that of algal cover that was weighted more strongly than that of clarity (Table M).

Table M: Conditional probabilities describing effects of the states of ‘CH2 Ecoli Risk’, ‘CH2 Algae OK’ and ‘CH2 Clarity OK on the BBN node ‘CH2 Swim OK’

Parent node states			State % probabilities	
CH2 *E.coli* Risk	**CH2 Algae OK**	**CH2 Clarity OK**	**True**	**False**
green	true	true	100	0
green	true	false	75	25
green	false	true	50	50
green	false	false	25	75
amber	true	true	75	25
amber	true	false	50	50
amber	false	true	35	65
amber	false	false	15	85
red	true	true	5	95
red	true	false	3	97
red	false	true	3	97
red	false	false	0	100

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