AQUALINC RESEARCH LIMITED

Lindis River Irrigation Reliability

Prepared for Lindis Catchment Group

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AQUALINC RESEARCH LIMITED

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1 Overview

Otago Regional Council is considering imposing a minimum flow on the Lindis River. This will affect existing irrigators, who collectively take up to 2,300 l/s from the river at various locations. The Lindis Catchment Group (LCG) has asked Aqualinc to assess how these changes may impact on their reliability based on the following scenarios.

Scenario 1: 200 l/s minimum flow [at the Ardgour flow recorder];
Scenario 2: 450 l/s minimum flow; and
Scenario 3: 750 l/s minimum flow.

For all scenarios, LCG have requested we assume that the Lindis Irrigation Company open races are decommissioned, and that a number of smaller intakes are established along the Lindis River. LCG have asked that we assume a primary allocation block size of 2,300 l/s, which equates to current abstraction by irrigators. This water would be sufficient to irrigate 4,000 ha at a rate of 5 mm per day.

For the three scenarios, average supply reliability for October to April for the full 2,300 l/s ranged from 93% to 85%. We would describe this as marginal to poor reliability. The low rainfall together with high summer evaporation rates means poor irrigation reliability can lead to significant production losses.

Irrigation restrictions have an impact on crop yields, which impact on stocking rates and land use options. Higher land use enterprises such as viticulture and dairying generally require higher reliability than sheep and beef, because the cost of lost production is higher. Water reliability can be improved with storage, but this comes at a cost. For Scenarios 1 to 3, to achieve good reliability for the entire 4,000 ha of potential irrigation would require between 60 and 1,100 m^3/ha of on-farm [i.e. 'turkey nest'] storage. On-farm storage typically costs in the order of \$3 to \$5 per m^3. Generally, we would expect that higher land use activities such as dairying and dairy support would be necessary to justify this expense. The alternative to constructing storage is to stop irrigating parts of the farm as water becomes unreliable, which requires either having a lower stocking rate or using supplementary feed during times of restrictions.

Depending on whether the minimum flow was 200 or 750 l/s, there is between 2,000 l/s to 1,200 l/s of reliable water (respectively). The remaining water is less reliable. Current practice is to use the most reliable water in efficient spray irrigation systems such as center pivots, and to use the less reliable water in less expensive and less efficient irrigation systems such as borderdyke and wild flooding.

The capital costs of infrastructure changes associated with closing the extensive system of open races and converting surface irrigation to efficient spray irrigation is likely to be in the order of \$2,000-\$3,000 per hectare off-farm and \$5,000 per hectare on-farm. Several farms have already converted a portion of their systems to efficient spray systems so for those hectares would primarily only incur the additional off-farm costs of \$2,000-\$3,000 per hectare.

2 Hydrology

The Lindis River has two main flow recorder sites: Lindis Peak and Ardgour Road (refer to Figure 1). There is very little water abstracted above Lindis Peak, which means that flows at this site are essentially unmodified. However, at the Ardgour Road site, flows are heavily modified by upstream irrigation abstraction. To estimate the naturalised flow at Ardgour Road we used the same relationship as ORC.

$$Ardgour\ Road_{Naturalised} = Lindis\ Peak \times 1.15944 + 50\ l/s$$

We have reviewed the raw flow data from which ORC derived this relationship, and agree that this is a reasonable estimate of the unmodified flow. Key flow statistics for these two sites are presented in Table 1.

Table 1: Lindis River flow recorder sites

Flow statistic[1]	Lindis Peaks	Ardgour Road (naturalised)
Average	6,149 l/s	7,179 l/s
Median	4,234 l/s	4,959 l/s
7DMALF	1,520 l/s	1,810 l/s
(1) Sep 1976-Jul 2015		

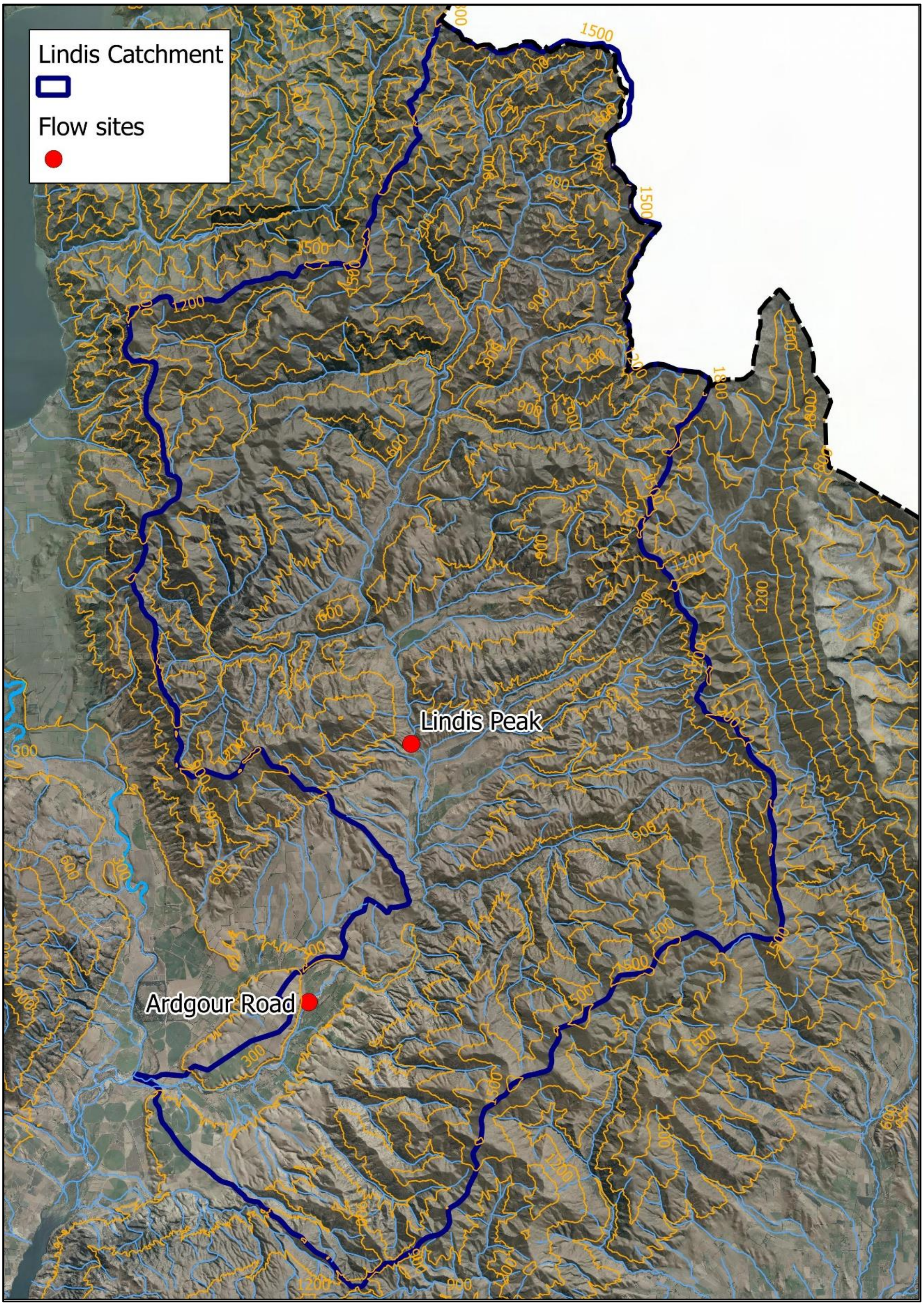


Figure 1: Lindis River flow recorder sites

3 Irrigation supply reliability

Supply reliability is the amount of water irrigators can actually take [once restrictions are imposed] as a proportion of their peak allocated flow. We have modeled supply reliability based on following scenarios.

Scenario 1: 200 l/s minimum flow [at the Ardgour flow recorder];
Scenario 2: 450 l/s minimum flow; and
Scenario 3: 750 l/s minimum flow.

For all scenarios, LCG have requested that we assume that the Lindis Irrigation Company's extensive network of open races are decommissioned, and that a number of smaller intakes have been constructed along the Lindis River. They have asked that we assume a primary allocation block size of 2,300 l/s, which equates to the current abstraction by existing irrigators. We were asked to model a total irrigated area of 4,000 ha, and to assume all irrigation was 80% efficient. We assumed distribution losses associated with the new pipe distribution would be minor (<50 l/s), and that 25% of irrigation losses [i.e. 5% of the water taken] will re-enter the Lindis River above the Ardgour flow recorder site, while the remaining 75% of losses will be either evaporation or will re-enter the Lindis River below the Ardgour recorder site. Results are presented in Table 2, Table 3, Figure 2, Figure 3, Figure 4 and Appendix A.

Table 2: Supply reliability from Oct to Mar, given a 2,300 l/s primary allocation

Season	Minimum flow		
	200 l/s	450 l/s	750 l/s
Average year	93.4%	90.3%	86.0%
1 year in 5 (average of 8 worst years in 39)	81%	76%	68%
1 year in 10 (average of 4 worst years in 39)	78%	71%	63%
Worst year (2005/06)	72%	64%	55%

Table 3: Supply reliability from Oct to Apr, given a 2,300 l/s primary allocation

Season	Minimum flow		
	200 l/s	450 l/s	750 l/s
Average year	92.5%	89.2%	84.5%
1 year in 5 (average of 8 worst years in 39)	80%	73%	65%
1 year in 10 (average of 4 worst years in 39)	76%	69%	60%
Worst year (2005/06)	73%	65%	56%

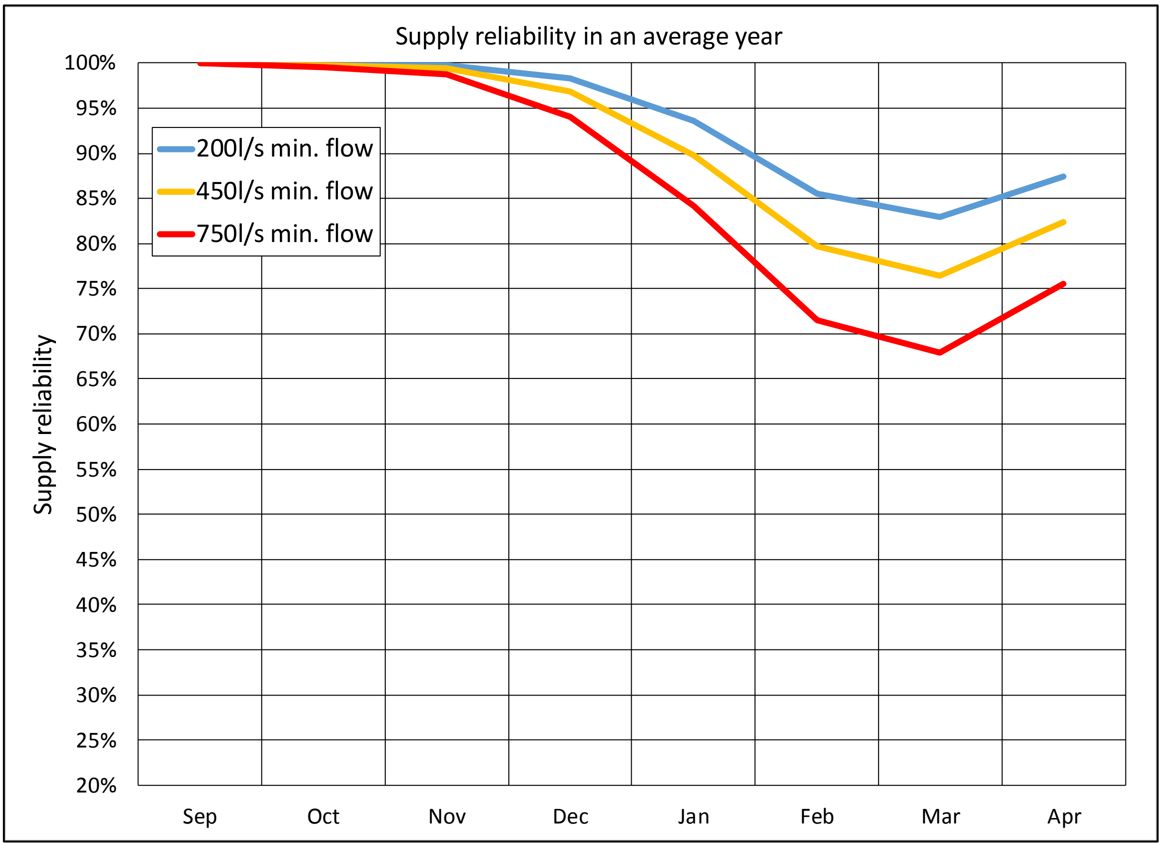


Figure 2: Supply reliability (average year)

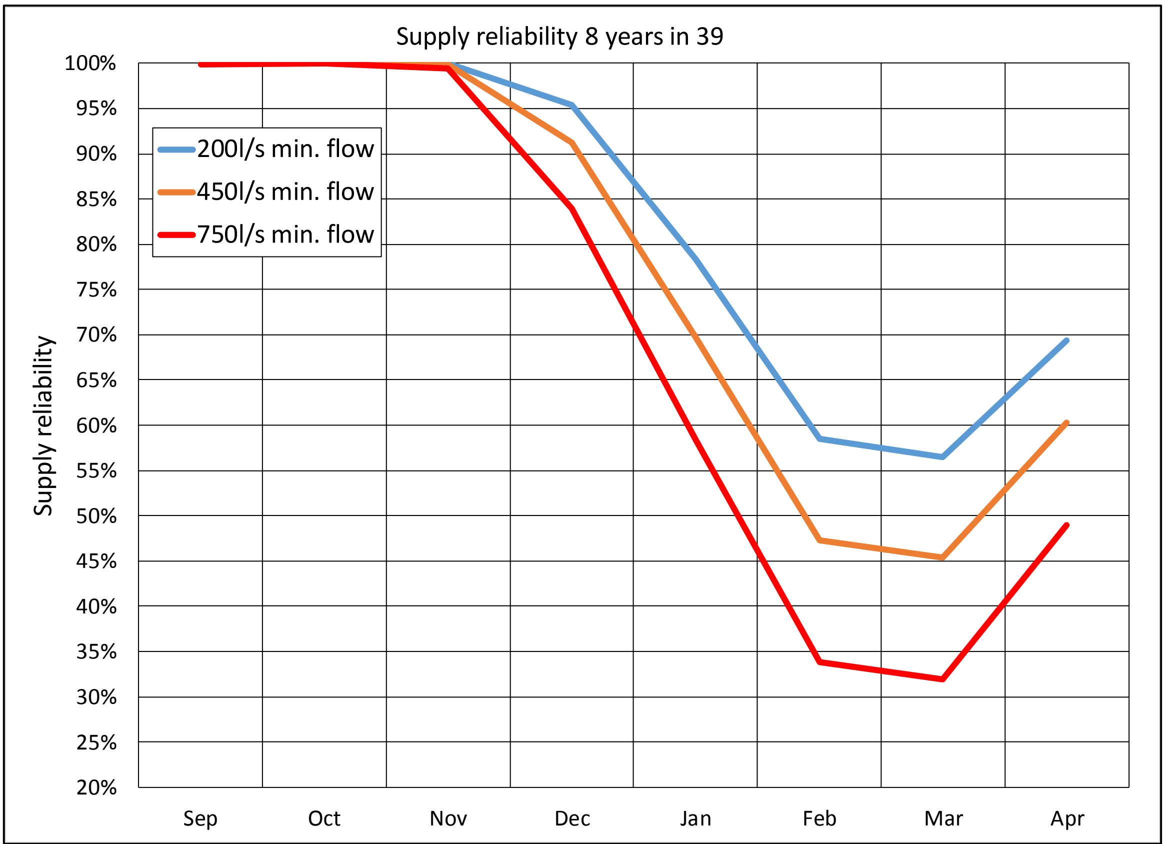


Figure 3: Supply reliability 1 year in 5 (average of 8 worst years)

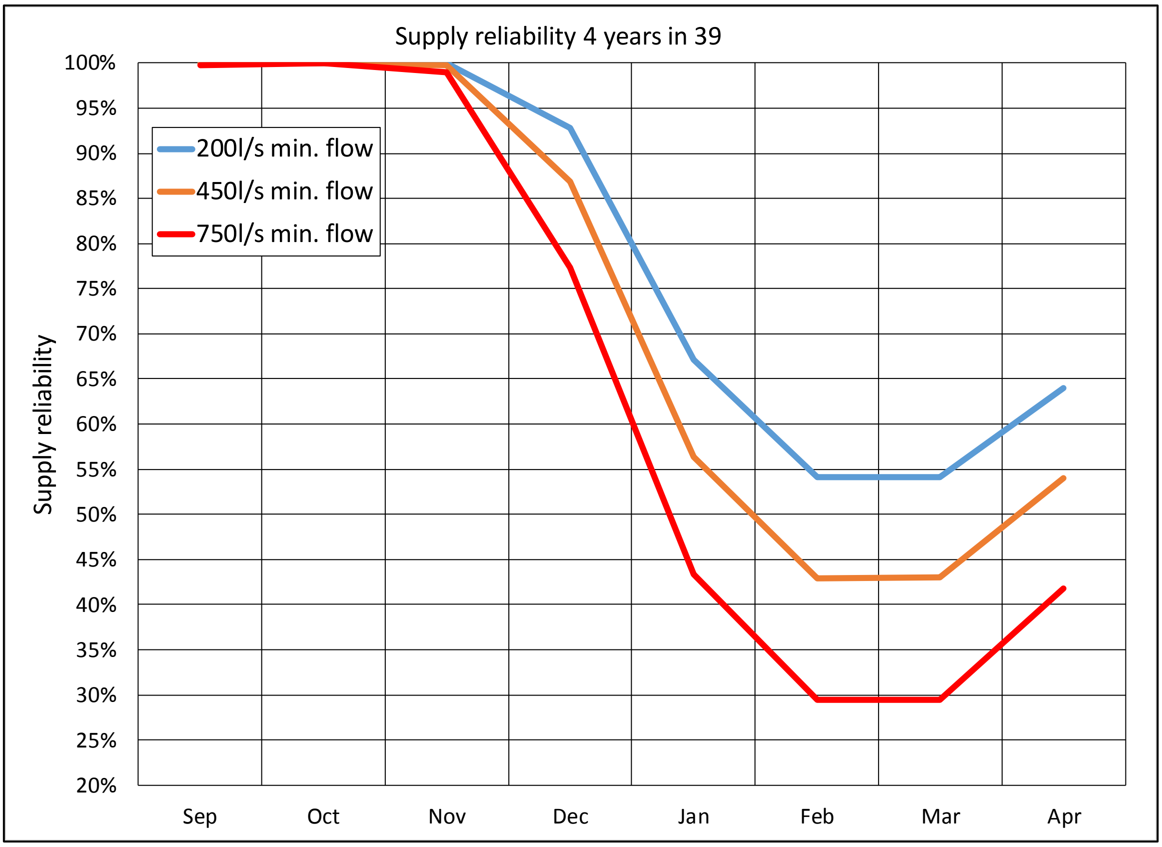


Figure 4: Supply reliability 1 year in 10 (average of 4 worst years)

For the three scenarios, average supply reliability for October to April for the full 2,300 l/s ranged from 85% to 93%. For Scenario 1, we would describe 93% reliability from October to April as 'marginal', while for Scenarios 2 and 3 we would consider 85 to 89% reliability as 'poor' (refer Brown 2015 for reliability definitions).

Depending on whether the minimum flow was 200 or 750 l/s, there is between 2,000 l/s to 1,200 l/s of good reliable water (respectively). By 'good' reliability we mean on average 95% supply reliability from October to April. The remaining water is less reliable. Current practice is to use the most reliable water in efficient spray irrigation systems such as center pivots, and to use the lower reliability water in less expensive and efficient irrigation systems such as borderdyke and wild flooding.

The closure of the Lindis Irrigation Company open races will have a significant impact on the hydrology of the Lindis River and the reliability of supply for existing irrigators. These changes mean that future reliability may be quite different than the historical experiences of irrigators supplied from the Scheme.

Reliability for Scenario 1 is 'marginal', reducing to 'poor' for Scenarios 2 and 3.

4 On-farm impact of irrigation restrictions

4.1 Overview

Reliability has a major impact on the economic value of water to farmers, primarily because of the impact on land use options and/or the cost of storage needed to improve reliability.

To understand the impact of reliability we have assessed the supply/demand ratio, with irrigation demands calculated using AusFarm.

Another approach to assessing the impact of reliability of supply is to calculate the cost of storage infrastructure that would be necessary to improve reliability to an acceptable level. This approach provides an upper bound on the economic value of reliable water. Generally more intensive land use activities such as dairying and dairy support would be necessary to justify the capital expense of constructing storage.

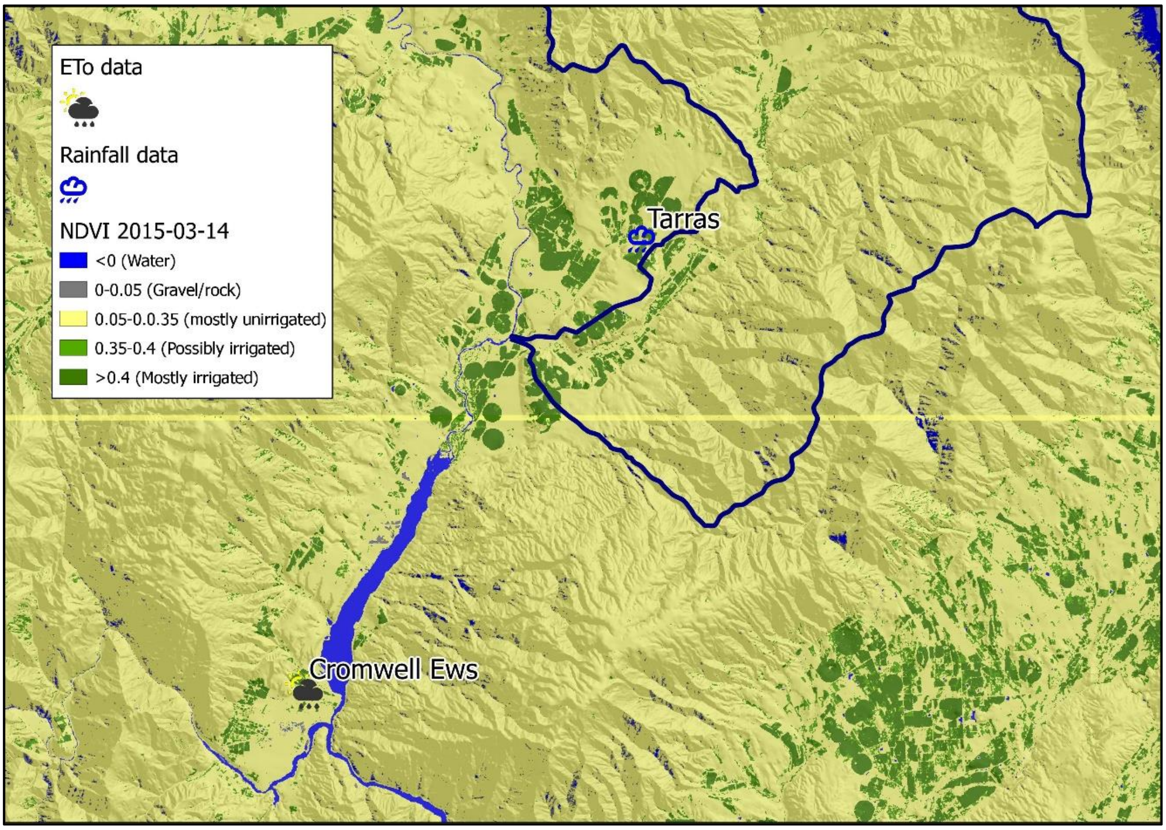
4.2 Irrigation demand

We calculated the irrigation demand using the AusFarm software package. AusFarm is a biophysical model of temperate pastoral systems, and is used through-out New Zealand for estimating irrigation requirements and the impact of water stress on production. The model was run using historical data from 1976 to 2015. Key modelling parameters are given in Table 4. Further details on the AusFarm model are provided in Appendix B.

Table 4: Key irrigation demand parameters

Parameter	Value
Daily rainfall data	Tarras (agent no. 5236). Mean annual rainfall (1976-2015)=476 mm
Daily evapotranspiration data	Cromwell EWS (agent no. 26381). Mean annual ETo (1976-2015)=995 mm
Plant available water	60 mm
Irrigation system capacity	5.0 mm/d
Irrigation application depth	20 mm
Irrigation return period	4 days
Application efficiency	80%
Trigger soil moisture deficit	20 mm
Crop type	Pasture

A soil plant available water (PAW) value of 60 mm is reasonably typical of most of the existing irrigated areas (refer to Figure 5 and Table 5). The evapotranspiration (ETo) data from Cromwell probably represent slightly drier than average climate conditions for the Lindis catchment, which means that irrigation demands will probably be at the higher end of what we would expect for efficient irrigation. An application efficiency of 80% is generally a challenging target, and will require both good irrigation design and management. Calculated average annual irrigation demand was 700 mm, while demand for a 1 in 10 dry year was 820 mm (refer Figure 6).



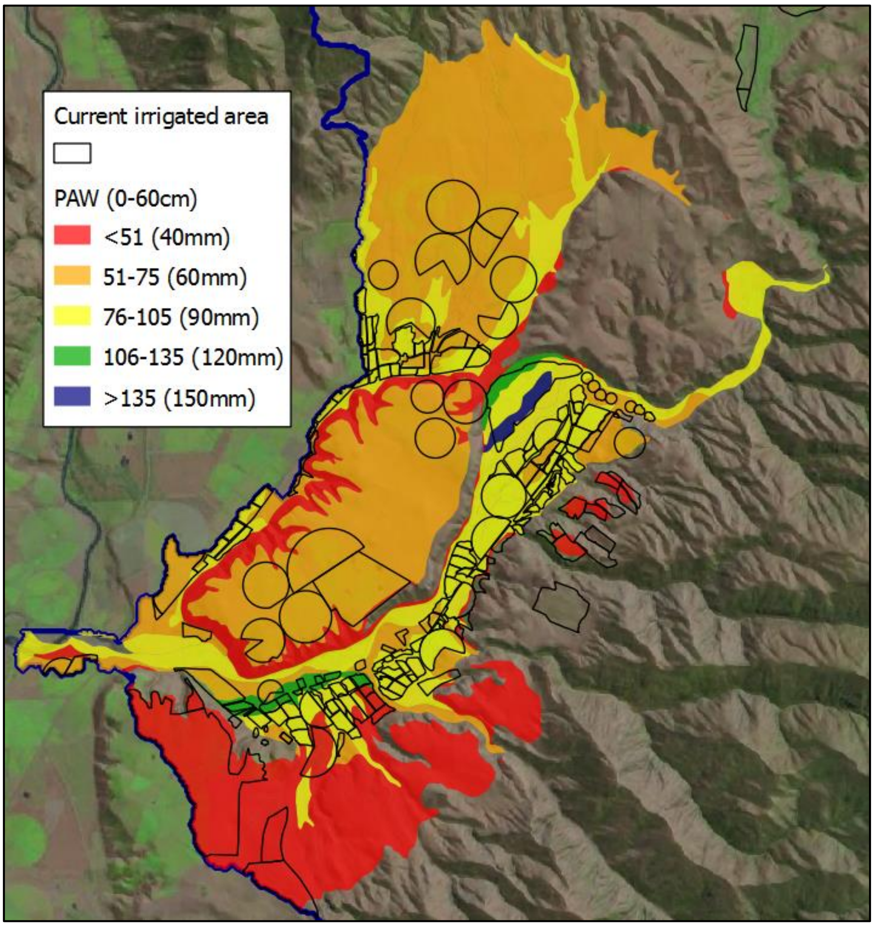


Figure 5: Soil PAW (source, SMap June 2014)

Table 5: Soil PAW (source, SMap June 2014)

Soil PAW (0-60cm)		% of area
Range	Class	
<51 mm	40 mm	25%
51-75 mm	60 mm	41%
76-105 mm	90 mm	31%
106-135 mm	120 mm	2%
>135 mm	150 mm	1%

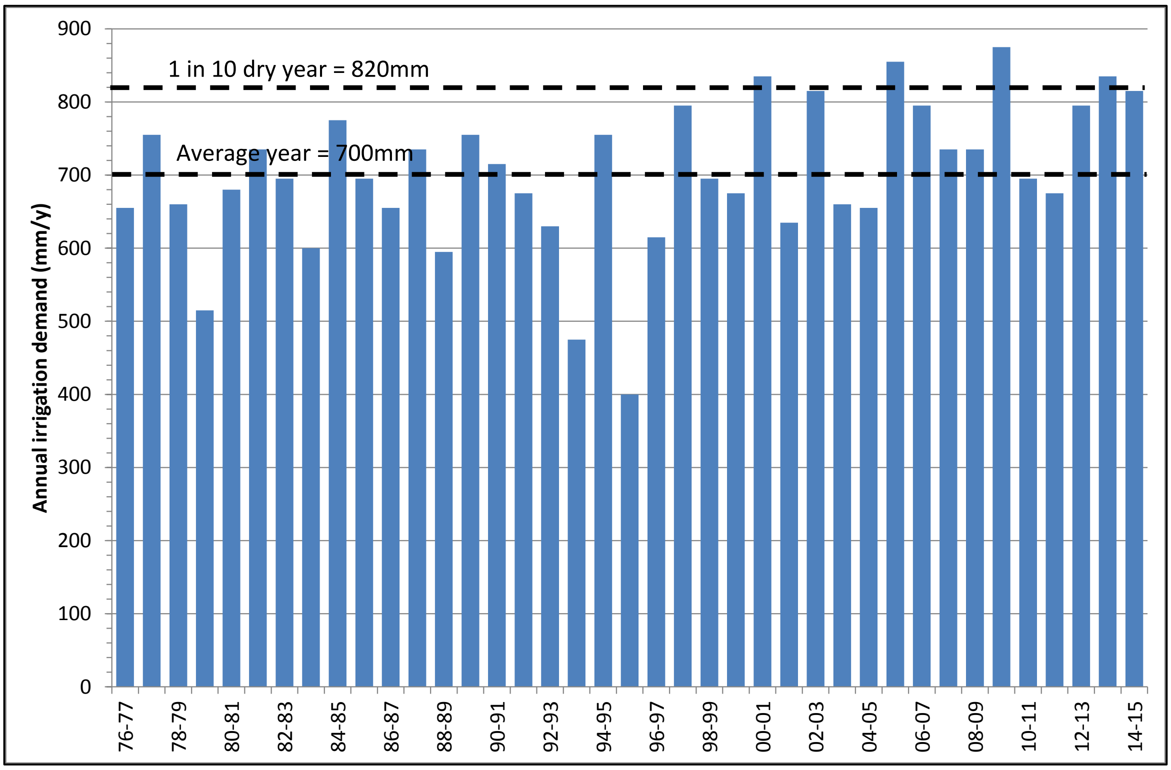


Figure 6: Estimated irrigation demand

4.3 Water supply vs demand

The supply/demand ratio is a measure of the amount of water available divided by the amount of water required for full irrigation. Alternatively expressed, it is a measure of how much you needed verses how much you got. It is a useful measure because it considers not only water availability, but whether the full water allocation was actually required on a particular day. The indicator can also be converted to mm per year of irrigation water shortfall, which is a useful indicator of production loss. Results are presented in Table 6, Table 7 and Appendix C. Results for Scenarios 1 to 3 show that in a 1 in 10 dry year, only 83 to 68% of the annual irrigation demand would be met. This shortfall will result in significant production losses.

Table 6: Supply/demand ratio

Parameter	200 l/s min. flow	450 l/s min. flow	750 l/s min. flow
Average year	94.2%	91.2%	86.6%
1 year in 10	82.9%	76.9%	68.3%
Worst year	78.9%	71.7%	61.8%

Table 7: Irrigation shortfall (mm/y)

Parameter	200 l/s min. flow	450 l/s min. flow	750 l/s min. flow
Average year	40	61	93
1 year in 10	133	181	248
Worst year	173	235	318

5 Storage requirements

Water reliability can be improved with storage, but this comes at a cost. For Scenarios 1 to 3, to achieve good reliability for the entire 4,000 ha of potential irrigation would require between 60 and 1,100 m^3/ha of on-farm [i.e. 'turkey nest'] storage (refer Table 8). Modelling assumes on-farm storage has either a clay or plastic liner to minimize leakage, and unused water from the primary allocation block is used to fill the pond. We modelled two reliability levels: 95% and 98% reliability. Most new irrigation schemes in New Zealand aim to deliver between 95% to 98% reliability. Reliability levels below 95% can limit land use options, which in turn impact on the financial viability of investing in new irrigation infrastructure. For the Lindis River, the cost of improving reliability to the more desirable 98% would probably be prohibitive of any land use other than viticulture. Consequently, 95% reliability would be a more economically optimum target level.

Table 8: On-farm storage requirements for pasture irrigation

Scenario	95% reliability (good reliability)	98% reliability (very good reliability)
1 (200 l/s min. flow)	56 m^3/ha	700 m^3/ha
2 (450 l/s min. flow)	420 m^3/ha	1,300 m^3/ha
3 (750 l/s min. flow)	1,140 m^3/ha	2,210 m^3/ha

On-farm storage typically costs in the order of \$3 to \$5 per m^3, which would mean it would cost roughly \$240-\$4,400 per hectare, depending on the scenario, to achieve 'good' reliability. Generally more intensive land use activities such as dairying and dairy support would be necessary to justify the capital expense of constructing storage.

6 Infrastructure costs

If the Lindis Irrigation Company's extensive open race system in the Lindis is closed, existing scheme irrigators will need to construct new infrastructure to get the water from the river to their farm. One option would be to move away from a few large takes to a number of smaller takes.

For smaller takes, a galley intake in the river bed may well be the best option. Galley intake costs vary significantly depending on how well the river gravels transmit water, and how much silt the river carries.

Indicatively, a galley for 60 l/s might cost in the order of $60,000, or $1000 per litre per second. 60 l/s would supply an irrigated area of about 100 ha. Other costs include a pump, a power supply, and a pipe in the order of 250 to 400 mm diameter to convey water from the river to the farm. Pumps, power, and off-farm pipes might indicatively cost $1,000 to $2,000 per ha, assuming an average distance of 500 m from the river to the farm boundary, and assuming power is generally available in the near vicinity of the river. Therefore, we estimate a total ball-park cost of off-farm infrastructure of $2,000-$3,000 per ha.

On-farm irrigation costs generally range from about $3,000 per ha for less efficient K-line irrigation systems, to $8,000 to $10,000 per ha for efficient solid set irrigation. Pivot irrigation would generally be in the range of $4,000 to $6,000 per hectare. Indicatively we would estimate the average cost for new efficient spray irrigation will be in the order of $5,000 per hectare.

Several farms have already converted portions of their water to efficient spray systems and these hectares would only incur the additional off-farm costs of $2,000-$3,000 per hectare.

7 References

Brown, P. 2015 “South Canterbury Coastal Streams (SCCS) limit setting process. Predicting consequences of future scenarios: Irrigation Reliability”. Report prepared for Environment Canterbury by Aqualinc Research Ltd. January 2015.

Appendix A: Supply reliability

200 l/s minimum flow and 2,300 l/s primary allocation

Season	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct-Mar
76-77	100%	100%	100%	100%	100%	100%	92%	93%	99%
77-78	100%	100%	100%	100%	78%	48%	48%	58%	79%
78-79	100%	100%	100%	100%	93%	83%	97%	100%	95%
79-80	100%	100%	100%	100%	100%	100%	100%	100%	100%
80-81	100%	100%	100%	100%	94%	75%	95%	100%	94%
81-82	100%	100%	100%	100%	88%	78%	73%	89%	90%
82-83	100%	100%	100%	100%	100%	100%	92%	99%	99%
83-84	100%	100%	100%	100%	100%	100%	100%	100%	100%
84-85	100%	100%	100%	100%	100%	100%	92%	83%	99%
85-86	100%	100%	100%	100%	100%	100%	100%	100%	100%
86-87	100%	100%	100%	100%	87%	100%	100%	100%	98%
87-88	100%	100%	100%	100%	94%	93%	89%	92%	96%
88-89	100%	100%	100%	100%	96%	89%	88%	100%	96%
89-90	100%	100%	96%	88%	100%	95%	84%	81%	94%
90-91	100%	100%	100%	100%	98%	99%	83%	100%	97%
91-92	100%	100%	100%	98%	84%	65%	56%	68%	84%
92-93	100%	100%	100%	100%	96%	88%	72%	96%	93%
93-94	100%	100%	100%	100%	100%	100%	100%	100%	100%
94-95	100%	100%	100%	100%	99%	74%	77%	100%	92%
95-96	100%	100%	100%	100%	100%	100%	100%	100%	100%
96-97	100%	100%	100%	100%	100%	90%	90%	95%	97%
97-98	100%	100%	100%	100%	97%	76%	96%	100%	95%
98-99	100%	100%	100%	100%	80%	50%	65%	86%	83%
99-00	100%	100%	100%	100%	100%	100%	100%	100%	100%
00-01	100%	100%	100%	100%	100%	78%	60%	61%	90%
01-02	100%	98%	95%	100%	100%	100%	82%	73%	96%
02-03	100%	100%	100%	100%	100%	91%	81%	75%	95%
03-04	100%	100%	100%	95%	85%	100%	100%	100%	97%
04-05	100%	100%	100%	100%	100%	100%	100%	100%	100%
05-06	100%	100%	100%	81%	61%	44%	43%	78%	72%
06-07	100%	100%	100%	100%	100%	83%	69%	58%	92%
07-08	100%	100%	100%	93%	61%	66%	66%	47%	81%
08-09	100%	100%	100%	100%	100%	94%	93%	83%	98%
09-10	100%	100%	100%	94%	95%	64%	52%	63%	84%
10-11	100%	100%	100%	88%	100%	100%	100%	100%	98%
11-12	100%	100%	100%	100%	98%	83%	100%	99%	97%
12-13	100%	100%	100%	100%	100%	97%	80%	79%	96%
13-14	100%	100%	100%	100%	100%	73%	61%	82%	89%
14-15	100%	100%	100%	97%	67%	58%	58%	51%	80%
Average	**100%**	**100%**	**100%**	**98%**	**94%**	**86%**	**83%**	**87%**	**93.3%**
8 in 39	**100%**	**100%**	**100%**	**95%**	**78%**	**58%**	**56%**	**67%**	**81.4%**
4 in 39	**100%**	**100%**	**100%**	**93%**	**67%**	**54%**	**54%**	**59%**	**77.9%**
Worst yr	**100%**	**100%**	**100%**	**81%**	**61%**	**44%**	**43%**	**78%**	**71.6%**

450 l/s minimum flow and 2,300 l/s primary allocation

Season	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct-Mar
76-77	100%	100%	100%	100%	100%	100%	84%	85%	97%
77-78	100%	100%	100%	98%	68%	37%	36%	46%	73%
78-79	100%	100%	100%	100%	86%	74%	94%	100%	92%
79-80	100%	100%	100%	100%	100%	100%	100%	100%	100%
80-81	100%	100%	100%	100%	87%	64%	93%	100%	91%
81-82	100%	100%	100%	99%	79%	67%	62%	79%	85%
82-83	100%	100%	100%	100%	100%	100%	83%	97%	97%
83-84	100%	100%	100%	100%	100%	100%	100%	100%	100%
84-85	100%	100%	100%	100%	100%	99%	84%	76%	97%
85-86	100%	100%	100%	100%	100%	100%	100%	100%	100%
86-87	100%	100%	100%	98%	79%	100%	100%	100%	96%
87-88	100%	100%	100%	100%	87%	87%	79%	85%	92%
88-89	100%	100%	100%	98%	90%	82%	83%	100%	92%
89-90	100%	100%	90%	84%	100%	89%	74%	72%	89%
90-91	100%	100%	100%	99%	93%	96%	73%	99%	94%
91-92	100%	100%	100%	96%	75%	54%	45%	56%	78%
92-93	100%	100%	100%	100%	90%	79%	63%	89%	89%
93-94	100%	100%	100%	100%	100%	100%	100%	100%	100%
94-95	100%	100%	100%	100%	96%	63%	70%	100%	88%
95-96	100%	100%	100%	100%	100%	100%	100%	100%	100%
96-97	100%	100%	100%	100%	100%	84%	82%	93%	94%
97-98	100%	100%	100%	100%	91%	67%	92%	100%	92%
98-99	100%	100%	100%	100%	69%	39%	55%	81%	77%
99-00	100%	100%	100%	100%	100%	100%	99%	100%	100%
00-01	100%	100%	100%	100%	98%	67%	49%	50%	86%
01-02	100%	93%	90%	99%	100%	99%	72%	63%	92%
02-03	100%	100%	100%	100%	99%	84%	69%	64%	92%
03-04	100%	100%	100%	89%	78%	100%	100%	100%	95%
04-05	100%	100%	100%	100%	100%	100%	100%	95%	100%
05-06	100%	100%	99%	71%	51%	33%	32%	70%	64%
06-07	100%	100%	100%	100%	100%	73%	59%	46%	89%
07-08	100%	100%	100%	86%	50%	56%	55%	36%	75%
08-09	100%	100%	100%	100%	100%	87%	86%	74%	96%
09-10	100%	100%	100%	87%	90%	52%	41%	54%	78%
10-11	100%	100%	99%	81%	100%	100%	100%	100%	97%
11-12	100%	100%	100%	100%	91%	74%	100%	95%	94%
12-13	100%	100%	100%	100%	100%	93%	69%	68%	94%
13-14	100%	100%	100%	99%	99%	61%	50%	74%	85%
14-15	100%	100%	100%	93%	57%	47%	49%	63%	74%
Average	**100%**	**100%**	**99%**	**97%**	**90%**	**80%**	**76%**	**82%**	**90.3%**
8 in 39	**100%**	**100%**	**100%**	**91%**	**70%**	**47%**	**45%**	**60%**	**76%**
4 in 39	**100%**	**100%**	**100%**	**87%**	**56%**	**43%**	**43%**	**54%**	**71%**
Worst yr	**100%**	**100%**	**99%**	**71%**	**51%**	**33%**	**32%**	**70%**	**64%**

750 l/s minimum flow and 2,300 l/s primary allocation

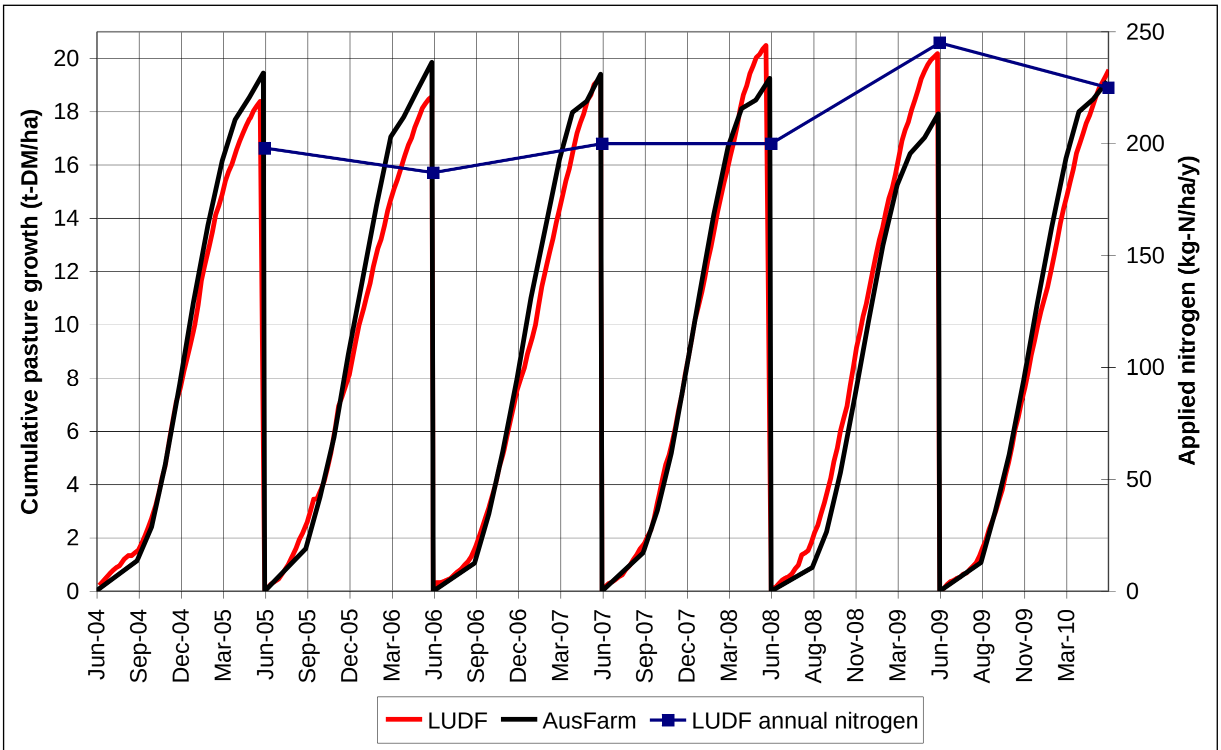
Season	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Oct-Mar
76-77	100%	100%	100%	100%	100%	96%	71%	74%	94%
77-78	99%	100%	100%	91%	55%	23%	22%	32%	65%
78-79	100%	100%	100%	100%	76%	62%	90%	100%	88%
79-80	100%	100%	100%	100%	100%	100%	100%	100%	100%
80-81	100%	100%	100%	100%	77%	50%	91%	100%	86%
81-82	100%	100%	100%	95%	67%	54%	48%	66%	78%
82-83	100%	100%	100%	100%	100%	95%	71%	93%	94%
83-84	100%	100%	100%	100%	100%	100%	100%	100%	100%
84-85	100%	100%	100%	100%	100%	95%	71%	66%	94%
85-86	100%	100%	100%	100%	100%	99%	100%	100%	100%
86-87	100%	100%	100%	92%	70%	99%	100%	100%	94%
87-88	100%	100%	100%	98%	76%	80%	67%	73%	87%
88-89	100%	100%	100%	92%	79%	72%	77%	97%	87%
89-90	100%	100%	80%	78%	100%	78%	62%	61%	83%
90-91	100%	100%	100%	97%	84%	88%	60%	99%	88%
91-92	100%	100%	100%	90%	62%	41%	32%	43%	71%
92-93	100%	100%	100%	100%	79%	66%	50%	79%	83%
93-94	100%	100%	100%	100%	100%	100%	100%	100%	100%
94-95	100%	100%	100%	100%	90%	49%	62%	100%	84%
95-96	100%	100%	100%	100%	100%	100%	100%	100%	100%
96-97	100%	100%	100%	100%	98%	75%	70%	89%	90%
97-98	100%	100%	100%	100%	80%	55%	87%	100%	87%
98-99	100%	100%	100%	99%	55%	26%	42%	75%	70%
99-00	100%	100%	100%	100%	100%	100%	90%	100%	98%
00-01	100%	100%	100%	98%	96%	54%	35%	36%	80%
01-02	100%	82%	82%	97%	100%	96%	60%	51%	86%
02-03	100%	100%	100%	100%	96%	72%	56%	52%	87%
03-04	100%	100%	100%	81%	68%	100%	100%	97%	92%
04-05	100%	100%	100%	100%	100%	100%	98%	87%	100%
05-06	100%	100%	96%	58%	38%	19%	18%	60%	55%
06-07	100%	100%	100%	100%	98%	60%	46%	33%	84%
07-08	100%	100%	100%	74%	38%	43%	42%	23%	66%
08-09	100%	100%	100%	100%	99%	78%	77%	63%	92%
09-10	100%	100%	99%	78%	82%	39%	27%	43%	71%
10-11	100%	100%	96%	72%	100%	100%	100%	100%	95%
11-12	100%	100%	100%	99%	81%	62%	100%	85%	90%
12-13	100%	100%	100%	99%	99%	84%	57%	54%	90%
13-14	100%	100%	100%	96%	95%	47%	36%	64%	79%
14-15	100%	100%	100%	86%	43%	33%	35%	51%	66%
Average	**100%**	**100%**	**99%**	**94%**	**84%**	**72%**	**68%**	**76%**	**86.0%**
8 in 39	**100%**	**100%**	**99%**	**84%**	**58%**	**34%**	**32%**	**49%**	**68%**
4 in 39	**100%**	**100%**	**99%**	**77%**	**43%**	**29%**	**29%**	**42%**	**63%**
Worst yr	**100%**	**100%**	**96%**	**58%**	**38%**	**19%**	**18%**	**60%**	**55%**

Appendix B: AusFarm – farm system modelling

Irrigation and soil water dynamics were modelled using AusFarm, coupled with Aqualinc's custom irrigation component. AusFarm is a biophysical model of temperate climate pastoral systems, developed by CSIRO Australia. This model is widely used in Australia and internationally by farm advisors and researchers. For further information about AusFarm, see http://www.grazplan.csiro.au/ . Details of the soil water and pasture models are given by Moore et al. (1997)[1]. A perennial rye-grass, white clover mix was modelled. In the model, pasture is periodically cut to simulate typical grazing management, with the amount of pasture cut used to calculate growth rates. Aqualinc has compared AusFarm model predictions to pasture growth data from Lincoln University Dairy Farm (LUDF) and from Winchmore Research Station irrigation trials, and has found that the model is suitable for use in Otago and Canterbury.

LUDF soil water balance, measured and predicted by AusFarm (June 2004-May 2010)

Parameter	Measured	Predicted
Average annual rainfall	639 mm/y	
Average annual irrigation	469 mm/y	487 mm/y
Average annual drainage	172 mm/y	159 mm/y
Average annual ET	936 mm/y(1)	945 mm/y
(1) Rainfall + irrigation - drainage		



LUDF pasture growth, measured and predicted by AusFarm

[1] Moore, A., Donnelly, J., Freer, M. (1997). "GRAZPLAN: Decision support systems for Australian grazing enterprises. III. Pasture growth and soil moisture submodels, and the GrassGro DSS". Agricultural Systems. 55(4): 535-582.

Appendix C: Water supply vs demand

Supply/demand ratio (m^3/m^3)

Season	200 l/s min. flow	450 l/s min. flow	750 l/s min. flow
76-77	99.1%	96.9%	92.9%
77-78	83.0%	76.9%	68.3%
78-79	98.9%	97.4%	94.9%
79-80	100.0%	100.0%	100.0%
80-81	99.4%	98.7%	96.7%
81-82	95.9%	91.6%	84.6%
82-83	100.0%	99.8%	98.8%
83-84	100.0%	100.0%	100.0%
84-85	98.8%	96.7%	92.3%
85-86	100.0%	100.0%	99.8%
86-87	100.0%	100.0%	100.0%
87-88	96.5%	91.6%	83.7%
88-89	97.8%	96.5%	94.0%
89-90	94.2%	90.2%	84.6%
90-91	98.7%	97.0%	93.7%
91-92	88.6%	81.1%	68.8%
92-93	92.7%	87.1%	78.8%
93-94	100.0%	100.0%	100.0%
94-95	95.3%	92.8%	88.3%
95-96	100.0%	100.0%	100.0%
96-97	98.2%	96.8%	93.5%
97-98	98.2%	96.4%	93.5%
98-99	92.2%	88.1%	82.0%
99-00	100.0%	100.0%	100.0%
00-01	80.8%	73.5%	64.2%
01-02	95.6%	92.3%	87.6%
02-03	92.8%	87.7%	80.3%
03-04	100.0%	99.8%	98.5%
04-05	100.0%	100.0%	99.9%
05-06	78.9%	72.8%	65.2%
06-07	88.5%	82.7%	73.8%
07-08	79.1%	71.7%	61.8%
08-09	97.9%	95.7%	91.7%
09-10	82.9%	76.6%	68.1%
10-11	100.0%	100.0%	100.0%
11-12	99.7%	98.0%	94.5%
12-13	93.3%	88.9%	82.9%
13-14	89.0%	84.7%	78.8%
14-15	87.1%	81.1%	73.6%
Average	**94.2%**	**91.2%**	**86.6%**
1 year in 10	**82.9%**	**76.9%**	**68.3%**
Worst year	**78.9%**	**71.7%**	**61.8%**

Irrigation demand shortfall (mm/y)

Season	200 l/s min. flow	450 l/s min. flow	750 l/s min. flow
76-77	5	16	37
77-78	131	178	244
78-79	8	20	39
79-80	0	0	0
80-81	4	9	21
81-82	27	56	102
82-83	0	1	9
83-84	0	0	0
84-85	8	22	51
85-86	0	0	2
86-87	0	0	0
87-88	23	54	107
88-89	15	23	40
89-90	39	66	103
90-91	10	23	49
91-92	72	119	196
92-93	47	84	137
93-94	0	0	0
94-95	33	50	81
95-96	0	0	0
96-97	11	19	38
97-98	13	27	49
98-99	55	84	127
99-00	0	0	0
00-01	145	200	270
01-02	29	51	82
02-03	59	101	162
03-04	0	2	12
04-05	0	0	1
05-06	171	220	282
06-07	88	133	201
07-08	173	235	318
08-09	14	30	58
09-10	140	192	262
10-11	0	0	0
11-12	2	13	37
12-13	46	76	117
13-14	91	127	175
14-15	110	161	226
Average	**40**	**61**	**93**
1 year in 10	**133**	**181**	**248**
Worst year	**173**	**235**	**318**