Lindis Catchment

Hydrological analysis to support an economic assessment of the potential impact of a minimum flow regime for the Lindis River

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Contents

1 Background

The Otago Regional Council (ORC) is preparing a change to the provisions in the *Regional Plan: Water for Otago (Water Plan)*. These changes seek to set a primary allocation limit and minimum flow, along with a supplementary minimum flow to manage supplementary allocation, for the Lindis catchment. An alluvial ribbon aquifer exists within the catchment. It is proposed that groundwater within this aquifer will be managed as surface water. The changes will make additions to Schedule 2 of the Water Plan.

The changes are being developed in consultation with a wide range of stakeholders. To meet the evaluation requirements of Section 32 of the RMA, and to provide stakeholders with an impartial assessment of the economic effects of any changes, the ORC has commissioned an independent economic assessment of the potential impact of any change.

Parts of Central Otago have the lowest rainfall in New Zealand. Areas of low elevation experience approximately 350mm per annum, and there is a large area of semi-arid land. Areas in the ranges, however, can receive in excess of 1400mm of rainfall per annum.

A change is being considered to the Otago Regional Plan would introduce minimum flows for particular rivers and streams. All water permits, both existing and new, will be made subject to the minimum flow. Existing resource consents to take water will be reviewed, and a new minimum flow condition will be added to the consents. Deemed permits/mining privileges are exempt from the minimum flow, but their replacement consents will be subject to the minimum flow. It is argued that restricting water allocations will result in significant environmental benefits without necessarily having a significant negative impact on economic activity. Such a management regime is likely to be even more effective following the expiration of a large number of "mining privileges" in 2021.

It is proposed to introduce *"A primary allocation limit on the volume of water that can be taken from the Lindis catchment under primary allocation consents. The primary allocation limit is set to maintain recharge of the shallow groundwater while enabling, and potentially enhancing, socio-economic and cultural well-being, and ensuring reliable access to the resource."*

Abstraction from the primary allocation will be linked to a minimum surface flow i.e., *"When river levels drop below the minimum flow any permits to abstract water under primary allocation consents will have to cease."*

The minimum flows and primary allocation limits for the catchment will be determined through a community consultation process and consideration of their potential environmental, socio-economic and cultural impacts.

When there is no further primary allocation available any additional water will only be able to be taken as a supplementary allocation. Supplementary allocations will allow the abstraction of water when river flows are much higher; typically during winter and spring. Any supplementary allocation will be subject to a higher minimum flow limit. Abstraction of water under the supplementary allocation will therefore cease much sooner, and more often, than water takes that operate under a primary allocation. Access to water under the supplementary allocation will consequently have lower reliability and greater inherent risk.

Given the strong hydraulic connection between the rivers and adjacent shallow unconfined aquifers, both the surface flows and groundwater system will be considered as a single interacting and integrated system. The maximum allocation limit will therefore also be set to maintain long-term groundwater levels.

Currently, Schedule 2A of the Regional Plan does not include a primary allocation limit, or a minimum flow for the Lindis River. However, the catchment is considered over-allocated. The sum of consented maximum instantaneous water takes has been estimated to be 4,134L/s.

It has been argued that the setting of allocation limits and minimum flows will result in increased efficiency, as well as increased environmental benefits and services. For example, community feedback suggested that in 2011 approximately 2,300L/s of water was taken to irrigate up to 2,000ha. Analysis has shown that the actual agricultural need for water is only about 1,000L/s. Questions, however, still remain over the relationships between actual water use, water need, water demand, and allocation.

2 Introduction

The Lindis River is situated in Central Otago, has a catchment area of 1,055km², and flows into the Clutha River/Mata-Au, about 6km upstream of Lake Dunstan. The lower Lindis catchment is one of the driest areas in New Zealand, with very little rainfall occurring throughout the summer months. The upper Lindis catchment, however, contributes significantly more water through a combination of its higher altitude and the presence of high-yielding vegetation such as snow tussock.

Average low flows of 1,550L/s have been measured in the upper Lindis catchment at Lindis Peak, while flows in the lower catchment at Ardgour Road drop below 250L/s most years. Because of moderate losses to groundwater and heavy water abstraction, the Lindis River generally flows intermittently upstream of the Ardgour Road flow recorder, and is completely dry between the SH8 Bridge and the Clutha confluence from January through to the end of April. Historically, flows at Lindis Peak has been used as a proxy for 'natural' flows within the entire catchment.

The lower Lindis is a very dynamic, braided alluvial channel and there is a direct hydraulic connection between the contemporary channel and the adjacent groundwater system. Consequently, some reaches of the lower Lindis River gain water from the groundwater system while other reaches lose flow to groundwater. It is also possible that the behaviour of any particular reach can change in response to differences in head and water level between the river and connected groundwater system.

A minimum flow at the Ardgour flow site therefore does not mean that flows in every section of the river will be the same. However, it is recognised that the river below Lindis Cross Bridge and upstream of the Ardgour Bridge are significant losing reaches, with net flow into the adjacent groundwater system.

Losses of water to the groundwater system in the lower river can vary from year to year and tend to be linked to the time since the last flood event large enough to mobilise the river bed. Immediately following a large flood losses tend to be highest because of greater infiltration through the porous river bed. Between flood events the bed tends to 'clog' with finer material reducing infiltration. However, there is always some natural loss over these reaches to the adjacent groundwater.

The direct connection between the lower Lindis River and the adjacent groundwater means that they must be considered two elements of a single interacting water resource. As a result the hydrological assessment in this report has considered only the naturalised flows in the Lindis River and not the storage and abstraction from the shallow groundwater system. As a consequence the analysis is likely to be slightly conservative. However, the difficulty in separating 'surface water' from 'groundwater' within the lower catchments means that such an approach is considered appropriate.

3 Hydrometric data

3.1 Naturalised flow series

The current flow regime of the Lindis River is affected by spatially and temporally discontinuous abstractions from both surface water and groundwater. Therefore, fundamental to any assessment of the likely impact of establishing a minimum flow regime, and a primary abstraction limit, is the development of a robust 'naturalised' flow series for the Lindis River. A 'naturalised' flow series represents what the natural flow of the river would be without any abstractions from either the surface water or groundwater.

To inform discussion of a minimum flow regime and abstraction limits the ORC installed six temporary flow recorders on various tributaries in the Lindis catchment. All of the tributary flow recorders were located either upstream of known water takes, or in the case of Coal Creek and Cluden Stream, in a location that captured all flow before any was diverted from the sub-catchments. Using the flow records from these tributaries, monitored from 2012 to 2014, a naturalised flow has been estimated for the Lindis River at the Ardgour Road flow recorder.

The flow sites used in the study covered about 70% of the catchment above the Ardgour Road flow recorder. However, much of the area from which flows were not monitored is relatively low yielding and does not contribute significantly to base flows i.e. the minimum flow regime.

The naturalised Ardgour Road flow was calculated by adding 50L/s to the flow at Lindis Peak, to account for upstream takes, and then summing together the flows from the six monitored tributaries. Although this is an improvement on historic mean annual low flow (i.e. MALF) calculations, it still has several limitations. It does not account for water yields downstream of the tributary flow recorders; nor does it account for several small un-monitored tributaries. While this may lead to a slight under-estimation of natural flows, any bias is offset by loss of some surface flow to the shallow groundwater aquifer in the reach immediately above the Ardgour Road flow recorder.

The resulting ‘naturalised’ flow series has been provided for use in the economic impact assessment. Constraints of that project meant that the ‘naturalised’ flow series was adopted and accepted as ‘correct’. No independent audit or quality assurance was undertaken specific to the economic study. While this may introduce an unquantifiable element of uncertainty, the adoption of the ‘naturalised’ flow series ensures consistency across all other studies relating to minimum flows and abstraction limits within the Lindis catchment.

Any minimum flow regime is likely to be based on mean daily flow, rather than instantaneous flow, to minimise uncertainty and to avoid potential ‘bounce’ in the hydrological system as various irrigation systems are turned on and off repeatedly. Consequently, all the analysis in this report has been undertaken using the ‘naturalised’ mean daily flow (Figure 3.1). Flows in the Lindis River is highly variable both throughout any year, and from year to year.

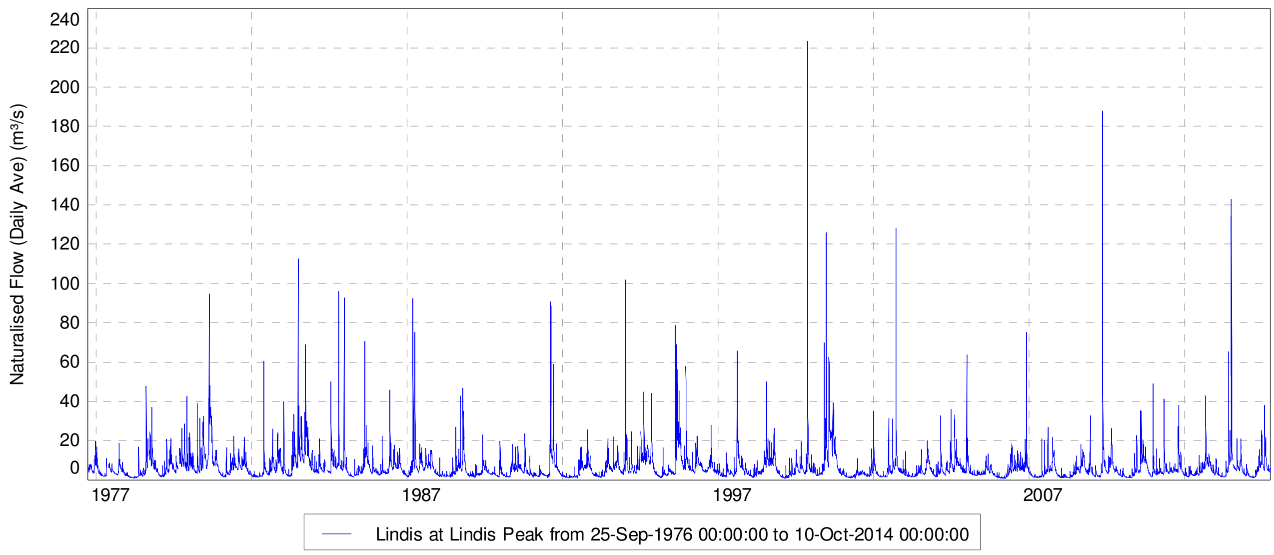

Figure 3.1: Naturalised mean daily flow in the Lindis River.

Figure 3.2 highlights both the annual and inter-annual variability and the generally long periods of low flow interspersed by occasional, random flood events.

The naturalised mean daily flow regime of the Lindis River is summarised in Table 3.1 & Table 3.2. The key feature of the flow regime are the extended periods of low flow. This is highlighted by the mean daily flow (i.e. 6.3m³/s) being 50% larger than the median daily flow (i.e. 4.4m³/s). Also, while the largest naturalised mean daily flow is 224m³/s, 90% of flows are actually less than 12m³/s.

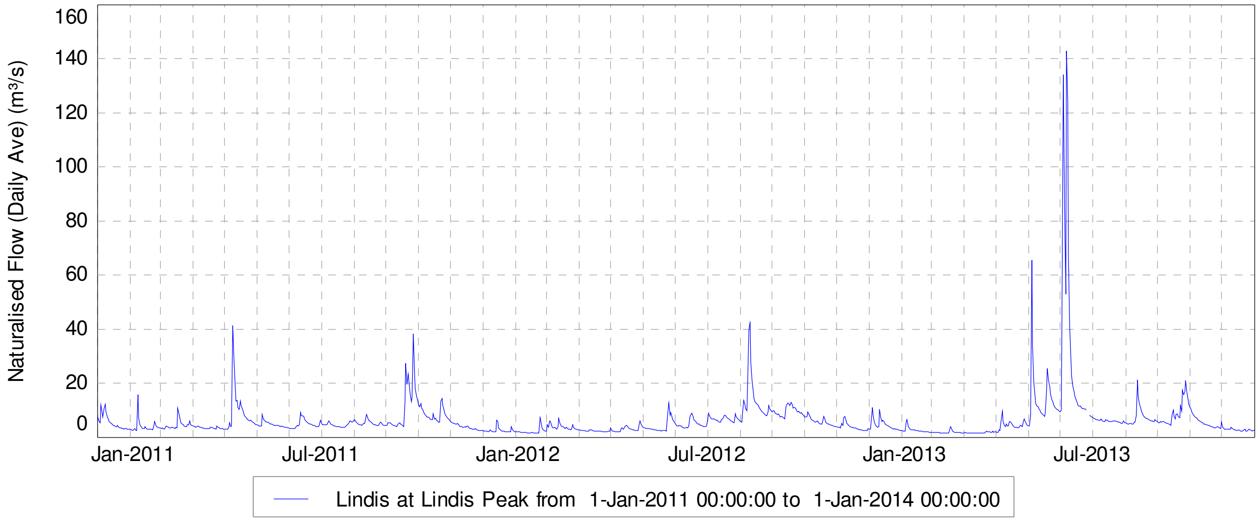

Figure 3.2: Naturalised flow in the Lindis River over a three year period highlighting both the annual and inter-annual.

Table 3.1: Summary statistics for the naturalised mean daily flow in the Lindis River.

	Min	Max	Mean	Std Dev	LQ	Median	UQ
Naturalised flow (m^3/s)	0.8	223.5	6.3	7.4	2.7	4.4	7.5

Table 3.2: Distribution of naturalised mean daily flows in the Lindis River.

	0	1	2	3	4	5	6	7	8	9
0	223.5	33.9	25.3	21.6	18.9	16.7	15.3	14.2	13.4	12.7
10	12.1	11.6	11.1	10.7	10.3	9.9	9.6	9.2	9.0	8.7
20	8.5	8.2	8.0	7.8	7.6	7.5	7.3	7.1	6.9	6.8
30	6.6	6.5	6.3	6.2	6.1	5.9	5.8	5.7	5.6	5.5
40	5.4	5.3	5.2	5.1	5.0	4.9	4.8	4.7	4.6	4.5
50	4.4	4.3	4.3	4.2	4.1	4.0	4.0	3.9	3.8	3.8
60	3.7	3.6	3.5	3.5	3.4	3.3	3.2	3.2	3.1	3.0
70	3.0	2.9	2.8	2.8	2.7	2.7	2.6	2.5	2.5	2.4
80	2.3	2.3	2.2	2.2	2.1	2.0	2.0	1.9	1.9	1.8
90	1.8	1.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.1
100	0.8									

3.2 Irrigation time series

Aqualinc (2006) provides the water requirements for all potentially irrigable areas in Otago. Irrigation demand was based on the amount of water needed to irrigate efficiently a range of crops under different climatic and soil conditions.

The key inputs to the process were the location of demand areas, climate for 1975 to 2004 (daily rainfall and evapotranspiration), soil type (plant available water), crop type (root depth and crop factors), and irrigation system characteristics and management regimes.

Daily time series of irrigation demand were developed for each soil class in the different regions so that the demand can be compared to available water supply to determine excesses and shortfalls. This information was intended to be used for strategic water studies and water allocation purposes.

The daily time series consists of the depths of water application by a notional irrigator for each soil type. Since different soil types have different potentials to store water, each soil has a minimum return period between irrigation cycles. The daily time series therefore consists of the total depth of water applied over each irrigation cycle rather than the specific daily application of water.

To use the daily time series in the current study it was therefore necessary to convert the total water application over each irrigation cycle to a daily irrigation depth. Since the period between irrigation cycles depends on the soil type, it was first necessary to map the water holding capacities of the different soils within the Lindis catchment.

Soils' information was obtained from the New Zealand Fundamental Soils Layer provided by Landcare Research (Newsome *et al.*, 2008). The Profile Available Water (i.e. PAW) was obtained for all soils within three irrigation 'zones' (Figure 3.3). These zones were:

- Areas irrigated by water sourced from the Lindis River and adjacent groundwater;
- Command area 13.362, which is irrigated by either water from the Lindis catchment or from the Clutha River; and
- Command area 13.451, which is irrigated by either water from the Lindis catchment or from the Clutha River.

It should be noted therefore that some areas in the 'Lindis irrigation zone' may also be serviced by one of the two different command areas (i.e. 13.362 & 13.451). Consequently there may be some 'double accounting' in the initial analysis resulting in a conservative assessment of water availability i.e. slightly greater apparent water demand.

The PAW of the various soils in the three irrigation 'zones' was therefore mapped and assigned to the classes developed in Aqualinc (2006). The relevant PAW classes are 45mm, 90mm and 155mm. There are no soils within the 175mm PAW class in the Lindis catchment. The distribution of PAW across the various zones is shown in Figure 3.4 & Figure 3.5. The areas of each PAW class, which affects both the irrigation depth and the inter-cycle period, within the three irrigation zones are summarised in Table 3.3.

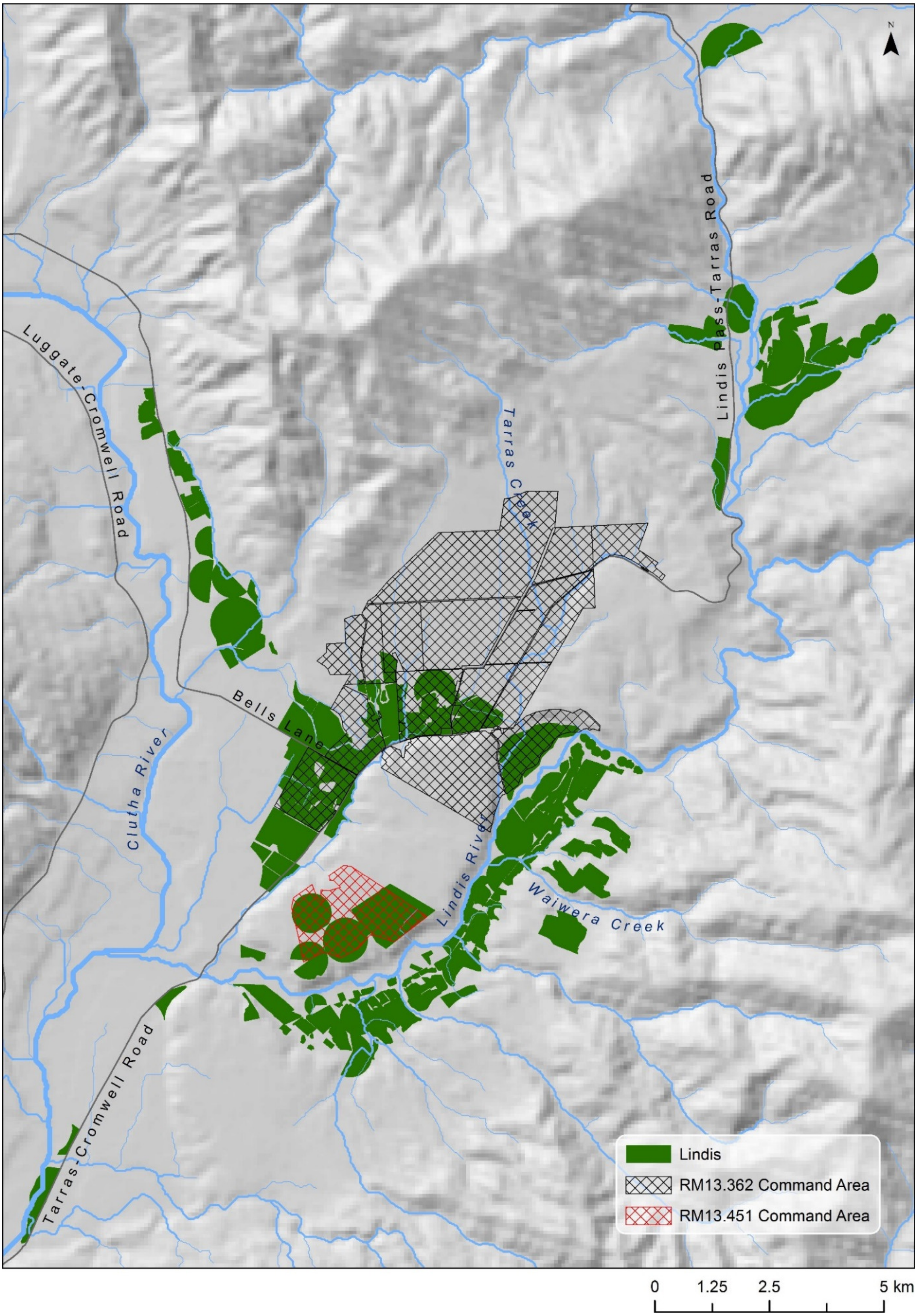

Figure 3.3: Three irrigation 'zones' initially considered in the analysis.

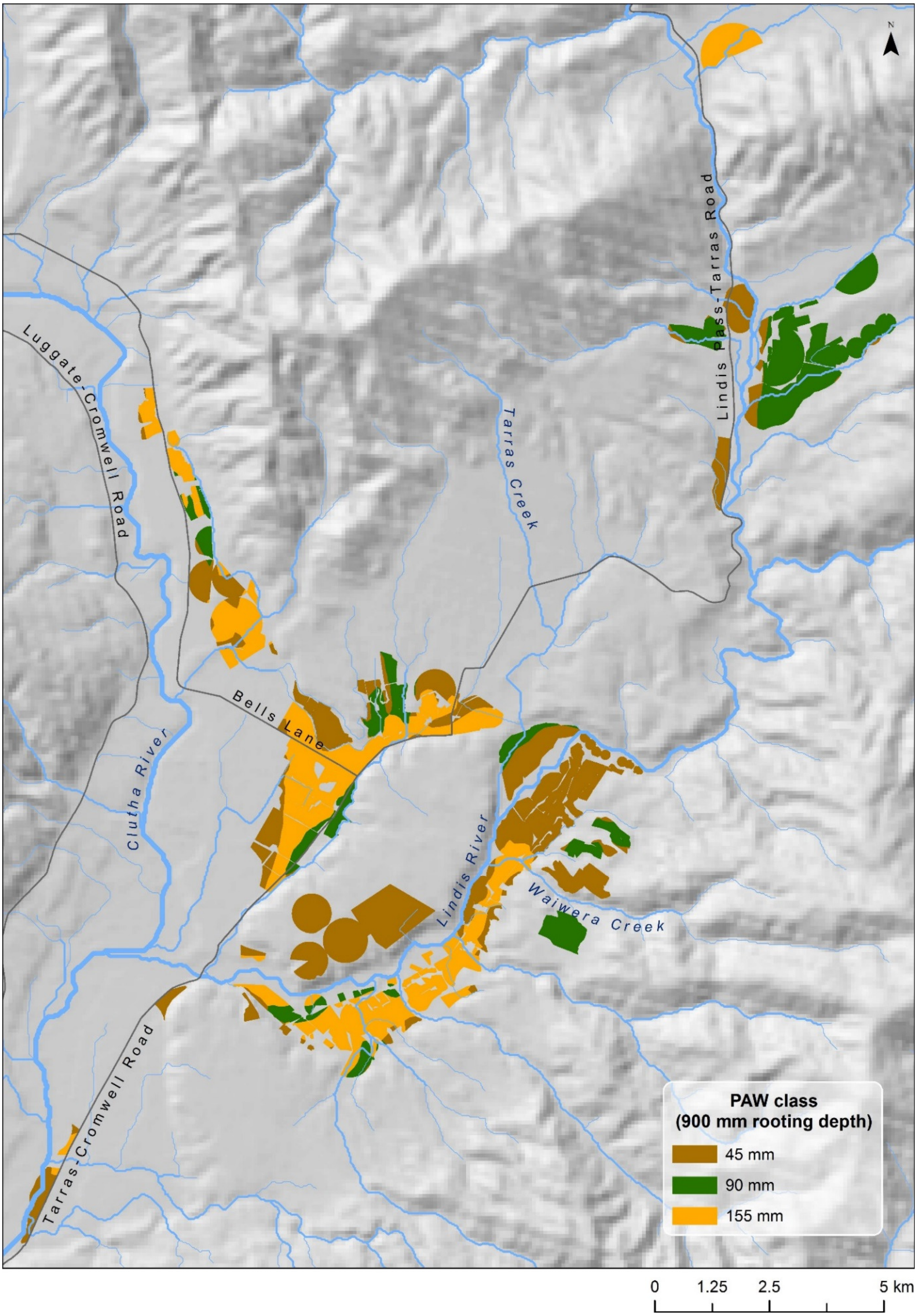

Figure 3.4: Distribution of PAW across the irrigation 'zone' serviced by water from the Lindis River.

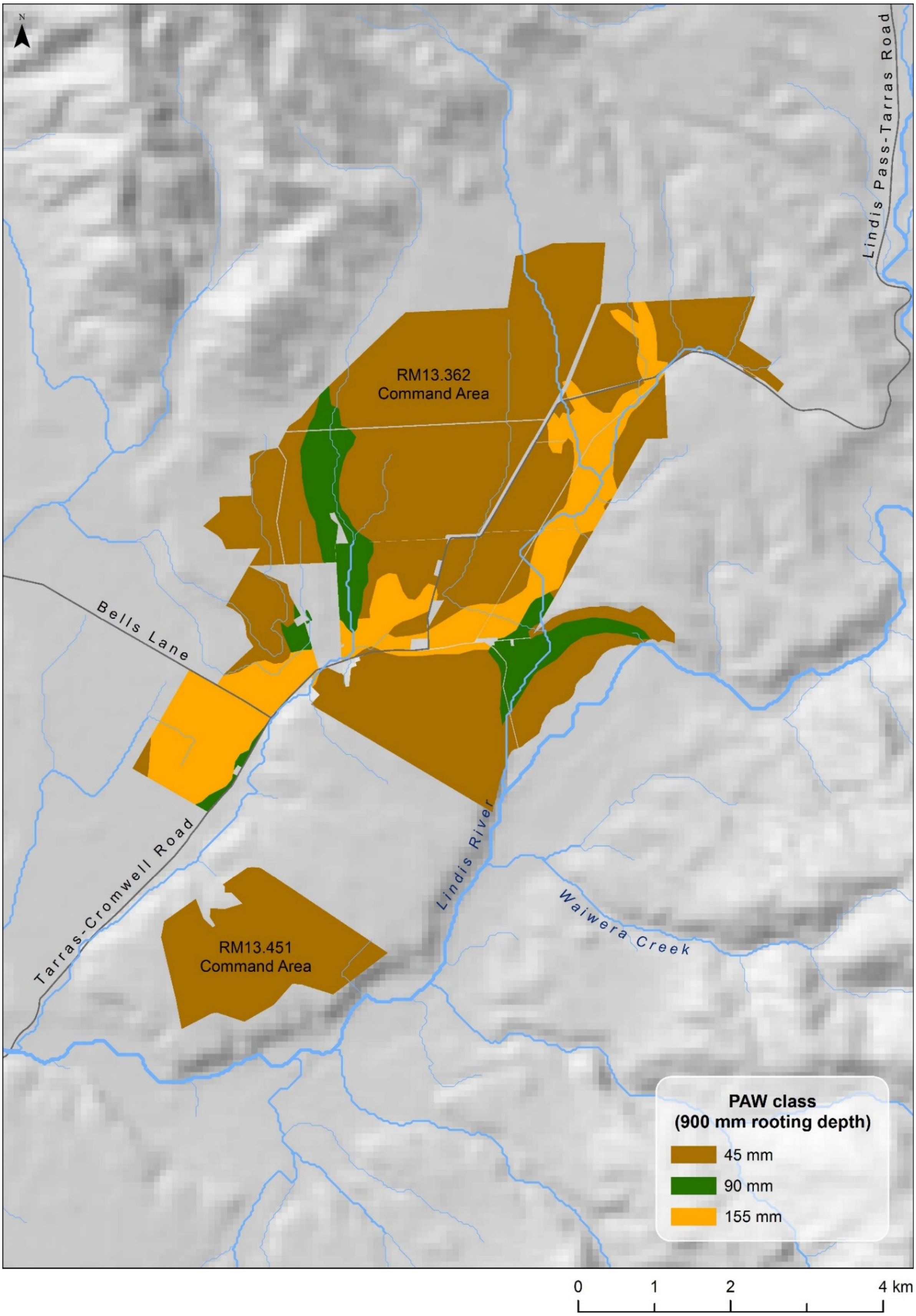

Figure 3.5: Distribution of PAW across the irrigation 'zone' serviced by water from either the Lindis River or the Clutha River.

Table 3.3: Distribution of the soils in each PAW classes in each of the irrigation zones.

	Lindis		CA RM13.362		CA RM13.451	
PAW Class	Area (ha)	%	Area (ha)	%	Area (ha)	%
45	1311.40	41.19	2011.11	71.96	378.76	100
90	748.22	23.50	240.42	8.60	0	0
155	124.13	35.31	543.35	19.44	0	0
175	0	0	0	0	0	0
Total	3183.75		2794.88		348.76	

The PAW classes in Table 3.3 are obtained directly from the New Zealand Fundamental Soils Layer provided by Landcare Research (Newsome *et al.*, 2008). However, for shallow rooting crops, where plants are unable to access water near the base of the soil profile, the PAW needs to be adjusted to allow for the depth of the roots. The procedure used in Aqualinc (2006), developed from the advice of Trevor Webb of Landcare Research Ltd, was used in the current study to provide PAW values appropriate for pasture (Table 3.4). These values were used in the modelling of irrigation and water demand. Since pasture has generally shallower roots, and a greater moisture demand, than other crops the analysis provided in this report is likely to be conservative.

Table 3.4: PAW classes assumed for different rooting depths.

PAW Class Assumed 600mm rooting depth (i.e. pasture)	PAW Class Assumed 900mm rooting depth (i.e. viticulture and stonefruit)
45mm	45mm
70mm	90mm
105mm	155mm
120mm	175mm

To derive a 'true' daily time series of irrigation demand the following process was adopted. The total application depths provided in Aqualinc (2006) were divided by the appropriate inter-cycle period and then the average irrigation application rate was applied to each day of the irrigation cycle.

Because the duration of the irrigation cycle is a function of the soil's PAW, this was done for each of the PAW classes found in the different irrigation 'zones'. The daily irrigation depth for each PAW class was then multiplied by the irrigable area of that particular soil. The total daily volume of irrigation applied to all PAW classes was then determined and converted to an average daily irrigation rate. The resulting irrigation demand time series is shown in Figure 3.6.

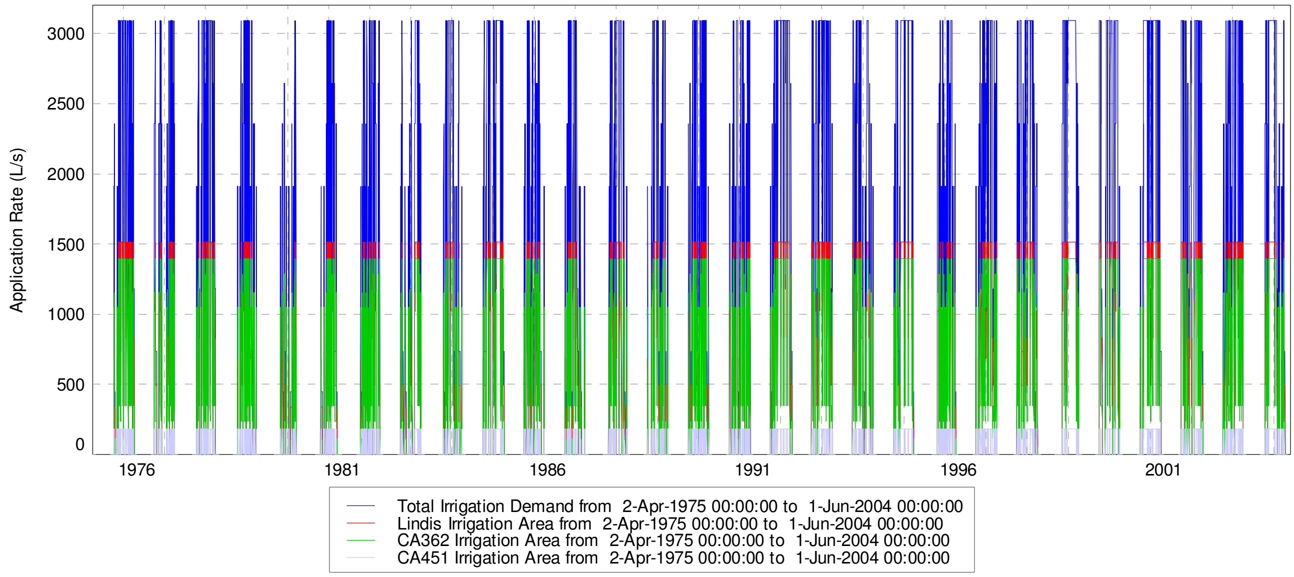

Figure 3.6: Irrigation demand time series based on Aqualinc (2006).

To irrigate the total irrigable area 'efficiently', as defined in Aqualinc (2006), would appear to require a maximum rate of abstraction of approximately 3100L/s. This compares to an existing allocation of 4,134L/s. It should be noted, however, that this maximum abstraction rate includes the capacity to potentially 'double irrigate' those areas which are included within both the 'command areas' and that area irrigated by water sourced from the Lindis catchment. The actual maximum abstraction rate from the Lindis River necessary to support the efficient irrigation of all irrigable land within the Lindis catchment is therefore likely to be significantly less than 3000L/s; assuming that the command areas source their water from the Clutha River and not from the Lindis. This is discussed in more detail later in this report.

The average daily abstraction rates needed to irrigate efficiently each of the 'zones' within the Lindis catchment between 1975 and 2004 are summarised in Table 3.5

Table 3.5: Average daily abstraction rates needed to irrigate efficiently different 'zones' of the Lindis catchment (L/s).

	Min	Max	Mean	Std Dev	LQ	Median	UQ
Lindis	0	1515	424	583	0.39	0.71	832
CA362	0	1395	387	559	0.40	0.70	1047
CA451	0	182	50	79	0.04	0.07	157
Total Area	0	3092	862	1207	0.83	1.47	1912

The distribution of the average daily abstraction rate for each of the three irrigation zones over the irrigation season from 1 September to 30 April are summarised in Table 3.6, Table 3.7 & Table 3.8.

Table 3.6: Distribution of average daily abstraction rates to support efficient irrigation of all areas supplied by water from the Lindis River (L/s).

	0	1	2	3	4	5	6	7	8	9
0	1515.00	1514.95	1514.90	1514.84	1514.79	1514.74	1514.68	1514.63	1514.58	1514.53
10	1514.47	1514.42	1514.37	1514.32	1514.26	1446.20	1338.32	1230.45	1176.78	1116.63
20	1021.08	1020.77	1020.47	954.71	858.73	832.33	832.05	831.78	715.35	683.14
30	682.91	682.69	638.25	521.94	494.51	494.27	494.03	397.71	338.42	338.06
40	232.47	48.75	0.82	0.80	0.79	0.78	0.76	0.75	0.74	0.73
50	0.71	0.70	0.69	0.67	0.66	0.65	0.64	0.62	0.61	0.60
60	0.58	0.57	0.56	0.55	0.53	0.52	0.51	0.49	0.48	0.47
70	0.46	0.44	0.43	0.42	0.40	0.39	0.38	0.37	0.35	0.34
80	0.33	0.31	0.30	0.29	0.27	0.26	0.25	0.24	0.22	0.21
90	0.20	0.18	0.17	0.16	0.15	0.13	0.12	0.11	0.09	0.08
100	0.00									

Table 3.7: Distribution of average daily abstraction rates to support efficient irrigation of Command area 13.362 (L/s).

	0	1	2	3	4	5	6	7	8	9
0	1395.00	1394.95	1394.90	1394.85	1394.81	1394.76	1394.71	1394.66	1394.61	1394.56
10	1394.52	1394.47	1394.42	1394.37	1394.32	1354.64	1291.36	1285.55	1185.96	1156.27
20	1155.99	1136.19	1051.50	1047.47	1047.27	1047.06	959.82	813.45	667.08	520.71
30	374.34	347.23	346.98	343.12	254.95	239.15	238.93	238.71	133.43	109.31
40	108.98	27.34	0.79	0.78	0.77	0.76	0.74	0.73	0.72	0.71
50	0.70	0.68	0.67	0.66	0.65	0.64	0.62	0.61	0.60	0.59
60	0.58	0.57	0.55	0.54	0.53	0.52	0.51	0.49	0.48	0.47
70	0.46	0.45	0.43	0.42	0.41	0.40	0.39	0.38	0.36	0.35
80	0.34	0.33	0.32	0.30	0.29	0.28	0.27	0.26	0.24	0.23
90	0.22	0.21	0.20	0.19	0.17	0.16	0.15	0.14	0.13	0.11
100	0.00									

Table 3.8: Distribution of average daily abstraction rates to support efficient irrigation of Command area 13.451 (L/s).

	0	1	2	3	4	5	6	7	8	9
0	182.000	181.996	181.992	181.989	181.985	181.981	181.977	181.973	181.970	181.966
10	181.962	181.958	181.955	181.951	181.947	181.943	181.939	181.936	181.932	181.928
20	181.924	181.920	181.917	181.913	181.909	156.927	131.550	106.172	80.795	55.417
30	30.040	4.662	0.097	0.096	0.095	0.093	0.092	0.091	0.089	0.088
40	0.087	0.085	0.084	0.083	0.081	0.080	0.079	0.077	0.076	0.075
50	0.073	0.072	0.071	0.069	0.068	0.067	0.065	0.064	0.063	0.061
60	0.060	0.059	0.058	0.056	0.055	0.054	0.052	0.051	0.050	0.048
70	0.047	0.046	0.044	0.043	0.042	0.040	0.039	0.038	0.036	0.035

80	0.034	0.032	0.031	0.030	0.028	0.027	0.026	0.024	0.023	0.022
90	0.020	0.019	0.018	0.017	0.015	0.014	0.013	0.011	0.010	0.009
100	0.000									

4 Analysis and results

The analysis provided below uses both the naturalised average daily flow series for the Lindis River (ORC, 2014) and the daily irrigation demand based on Aqualinc (2006). Abstraction and irrigation demand are only considered over the irrigation season which has been assumed to extend from 1 September to 30 April the following year.

Various minimum flow regimes have been proposed. This report, however, compares the potential impact of minimum flows of 450, 750 and 900L/s measured in the Lindis River at the Ardgour Road monitoring site.

Between 1976 and 2014 the naturalised flow in the Lindis River would never have dropped below 750L/s, and in only one year i.e. 2005, did the mean daily flow drop below 900L/s. During that particularly dry year flows were below the 900L/s for a total of 11 days (Figure 4.1).

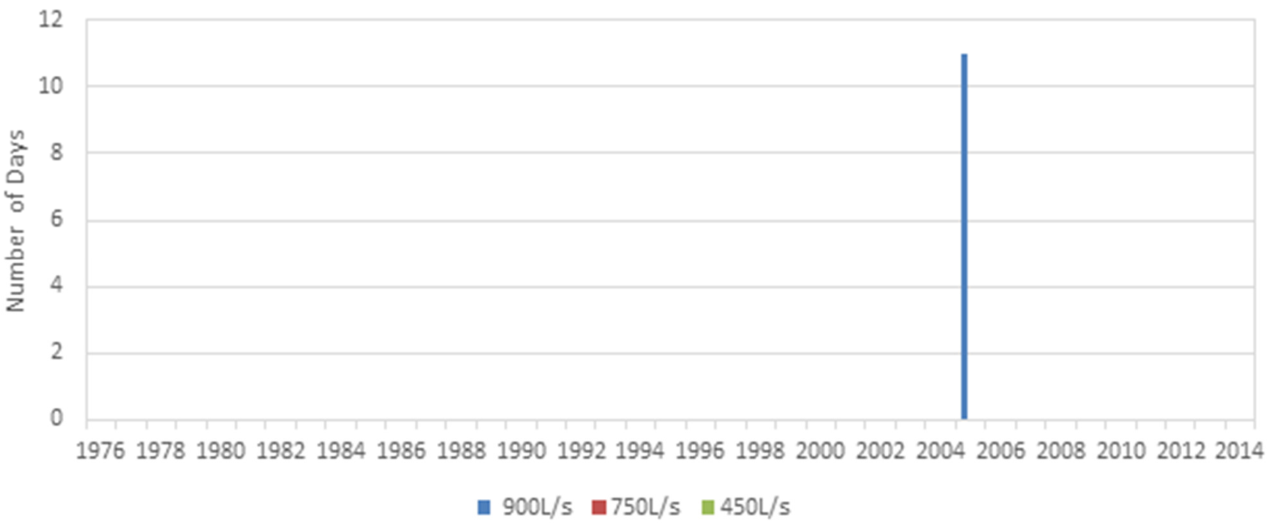

Figure 4.1: Number of days each irrigation season with a mean daily flow below various minimum flow thresholds.

4.1 Security of supply – existing situation

The security of irrigation supply under the current management regime was determined by comparing the daily naturalised flow to the existing allocation total of 4,134L/s. Assuming no minimum flow regime, as long as the mean daily naturalised flow is above 4,134L/s the total allocation could be met. As the naturalised flow drops below 4,134L/s proportionally less of the total allocation can be met until all abstraction would cease when the naturalised flow ceases. Since the naturalised flow never drops to '0' at least some of the total allocation can be met at all times (Figure 4.2).

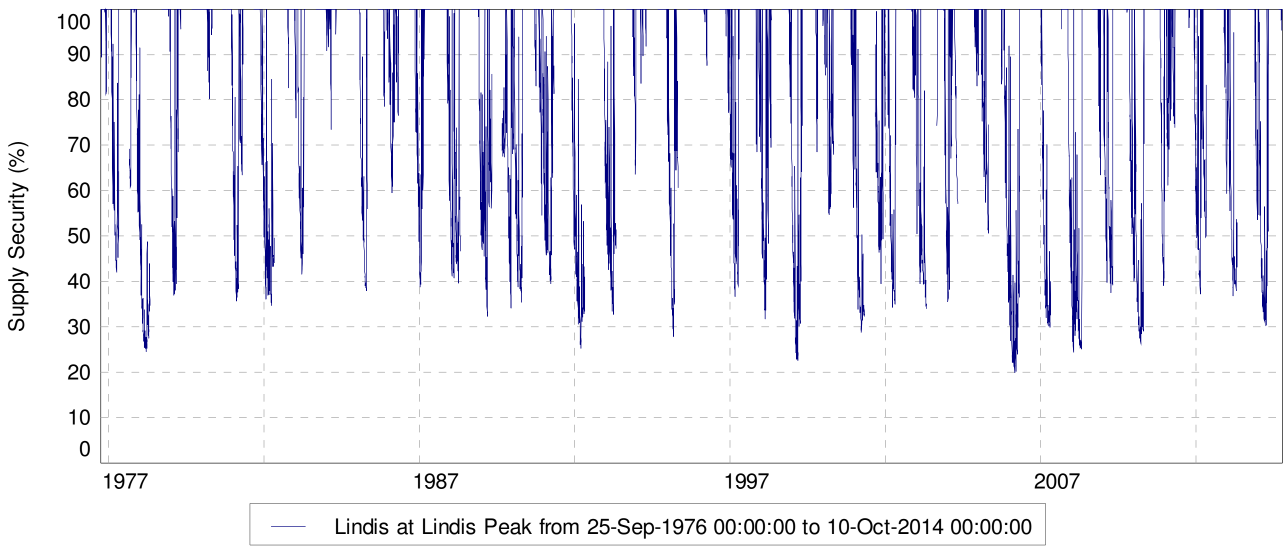

Figure 4.2: Security of supply assuming the mean daily naturalised flow and the current allocation of 4,134L/s.

During most irrigation seasons at least some of the existing allocation cannot be met, even assuming there is no minimum flow requirement. During the driest years, towards the end of the irrigation season, only about 70-80% of the existing allocation can be met.

Since it is often the duration of periods when no irrigation is possible which is critical, Figure 4.3 shows the duration of all consecutive periods when full existing allocation would not be possible, assuming the mean daily naturalised flow of the Lindis River.

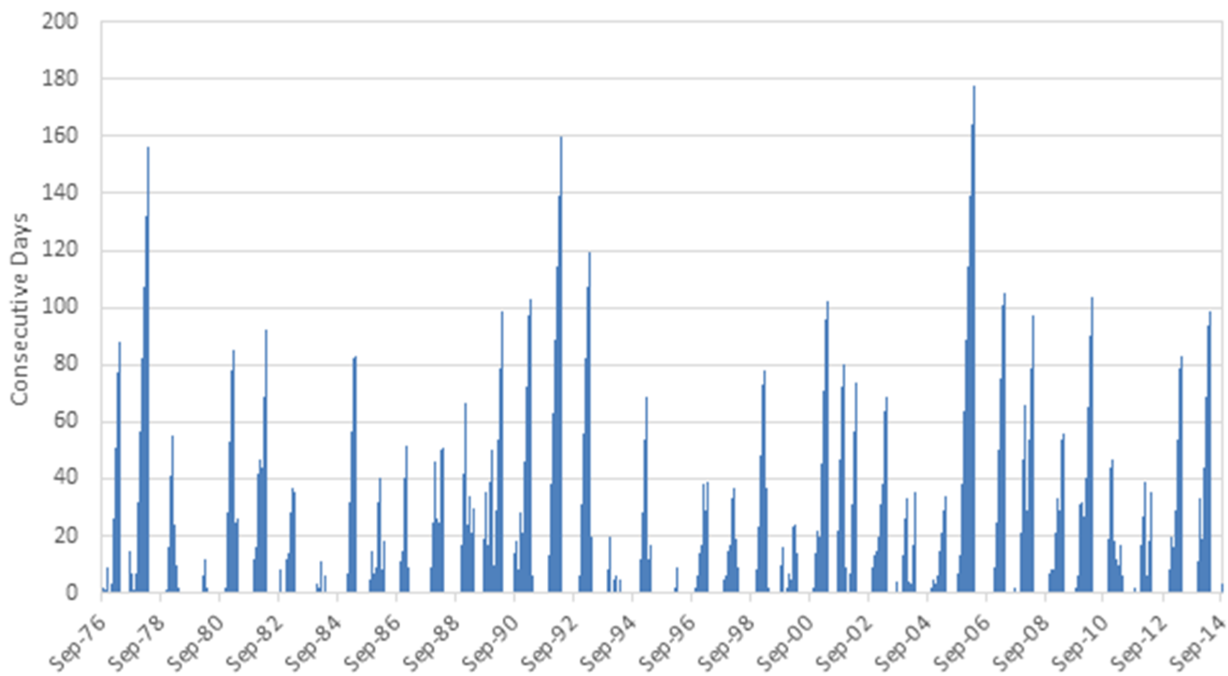

Figure 4.3: Periods of consecutive days when the full existing allocation could not be met from the mean daily naturalised flow of the Lindis River, assuming no minimum flow regime.

The above analysis was repeated, but assuming the various minimum low flow limits which have been proposed (Figure 4.4). It is apparent that the imposition of a minimum flow regime has some effect on the distribution of periods when full existing allocation would not be able to be met. A minimum flow regime also increases the duration of periods when full existing allocation would not be possible; generally by only about 10 days but can be up to 30 days. While any minimum flow has an effect on the duration of periods when full allocation is not possible, the actual magnitude of that minimum flow i.e. 450 or 900L/s, generally has a relatively minor impact.

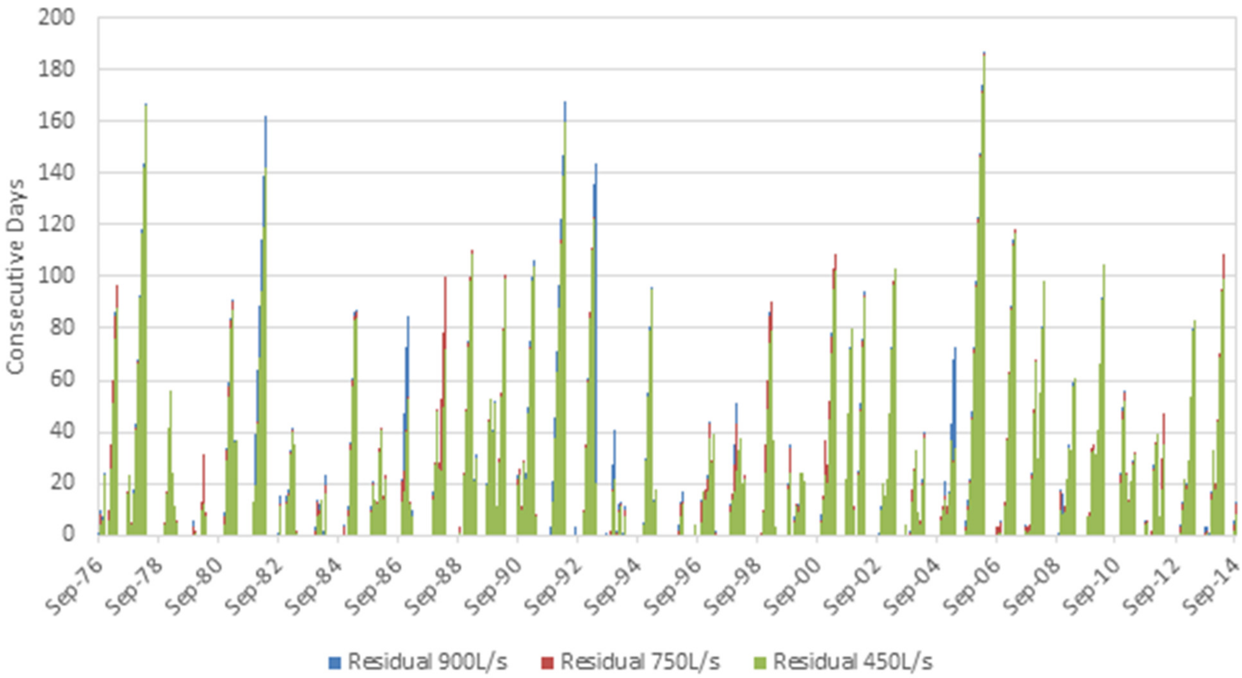

Figure 4.4: Consecutive days each year when full existing allocation could not be met from the mean daily naturalised flow of the Lindis River, assuming residual flows of 450, 750 and 900L/s.

The potential effect of a minimum flow on both the total number of days, and the maximum number of consecutive days, each year when full existing allocation would not be possible are summarised in Figure 4.5 & Figure 4.6. The actual data, and the potential effect of the various minimum flow regimes relative to the current situation are listed in Table 4.1.

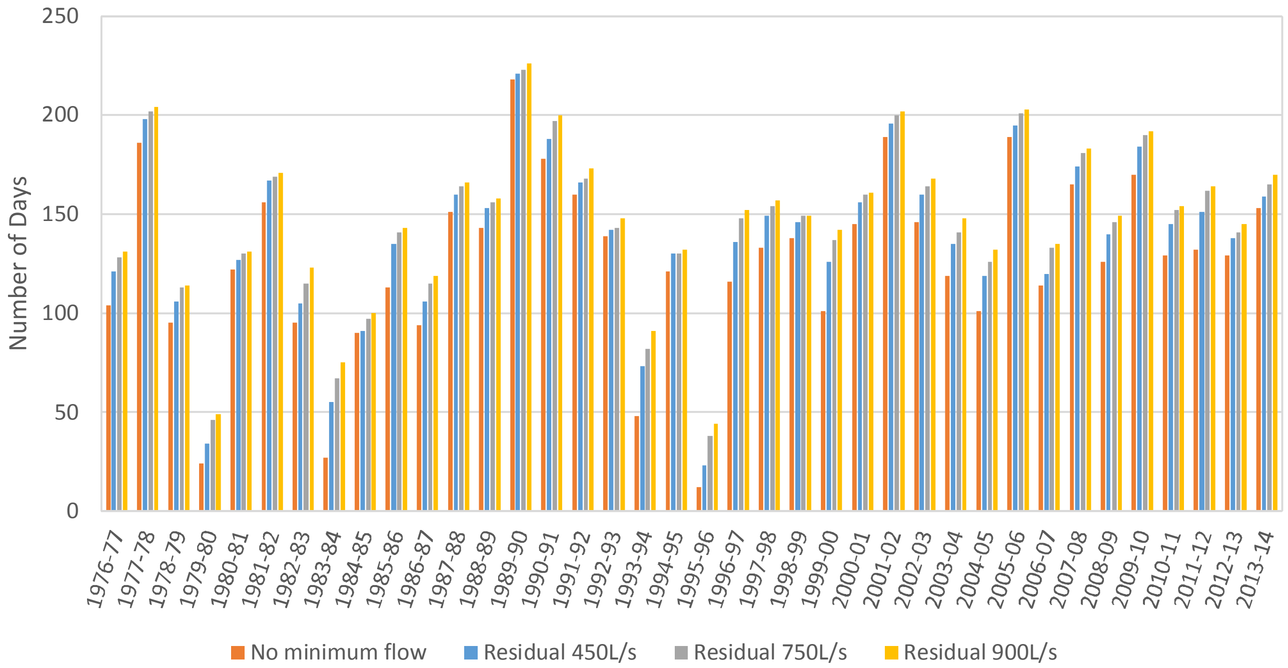

Figure 4.5: Total number of days when full existing allocation is not possible, under both the current situation and a range of minimum flow scenarios.

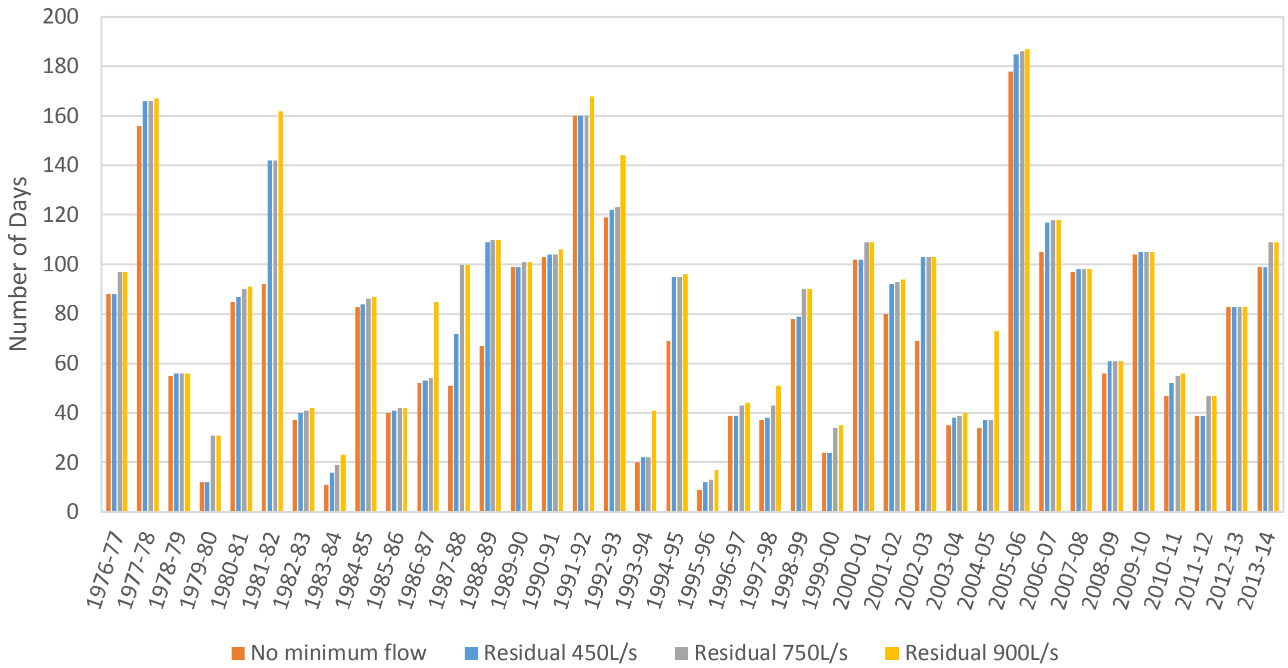

Figure 4.6: Maximum number of consecutive days when full existing allocation is not possible, under both the current situation and a range of minimum flow scenarios.

Table 4.1: Number of days and maximum number of consecutive days each year when full existing allocation cannot be met; under both the existing management and various minimum flow regimes.

	Total Days				Consecutive Days			
	Current	Residual 450L/s	Residual 750L/s	Residual 900L/s	Current	Residual 450L/s	Residual 750L/s	Residual 900L/s
1976-77	104	121	128	131	88	88	97	97
1977-78	186	198	202	204	156	166	166	167
1978-79	95	106	113	114	55	56	56	56
1979-80	24	34	46	49	12	12	31	31
1980-81	122	127	130	131	85	87	90	91
1981-82	156	167	169	171	92	142	142	162
1982-83	95	105	115	123	37	40	41	42
1983-84	27	55	67	75	11	16	19	23
1984-85	90	91	97	100	83	84	86	87
1985-86	113	135	141	143	40	41	42	42
1986-87	94	106	115	119	52	53	54	85
1987-88	151	160	164	166	51	72	100	100
1988-89	143	153	156	158	67	109	110	110
1989-90	218	221	223	226	99	99	101	101
1990-91	178	188	197	200	103	104	104	106
1991-92	160	166	168	173	160	160	160	168
1992-93	139	142	143	148	119	122	123	144
1993-94	48	73	82	91	20	22	22	41
1994-95	121	130	130	132	69	95	95	96
1995-96	12	23	38	44	9	12	13	17
1996-97	116	136	148	152	39	39	43	44
1997-98	133	149	154	157	37	38	43	51
1998-99	138	146	149	149	78	79	90	90
1999-00	101	126	137	142	24	24	34	35
2000-01	145	156	160	161	102	102	109	109
2001-02	189	196	200	202	80	92	93	94
2002-03	146	160	164	168	69	103	103	103
2003-04	119	135	141	148	35	38	39	40
2004-05	101	119	126	132	34	37	37	73
2005-06	189	195	201	203	178	185	186	187
2006-07	114	120	133	135	105	117	118	118
2007-08	165	174	181	183	97	98	98	98
2008-09	126	140	146	149	56	61	61	61
2009-10	170	184	190	192	104	105	105	105
2010-11	129	145	152	154	47	52	55	56
2011-12	132	151	162	164	39	39	47	47

2012-13	129	138	141	145	83	83	83	83
2013-14	153	159	165	170	99	99	109	109
Max.	**218**	**221**	**223**	**226**	**178**	**185**	**186**	**187**

4.2 Security of supply – Lindis only, existing allocation

As discussed previously, a considerable area of the lower Lindis catchment appears to be potentially irrigated, either using water from the Lindis River, or using water from the Clutha River. These areas are within Command Areas 13.362 and 13.451. Because some of these areas can apparently source water from two potential supplies, this results in an over-estimation of the total irrigation demand solely from the Lindis catchment.

To remove any potential effect of this 'double accounting', areas included in both the Lindis Irrigation Zone and either of the Command Area Irrigation Zones was allocated solely to the particular Command Area. Therefore, any area which occurs in both the Lindis and the Command areas was deemed not to require irrigation water from the existing allocation from the Lindis catchment. This reduces the amount of land which 'must' be irrigated from the Lindis catchment alone, and therefore the total irrigation demand.

Therefore, if land can be irrigated from an 'alternative' source of water, a minimum flow regime in the Lindis catchment is not considered relevant. Consequently potentially more 'Lindis water' is available for those who 'must' rely on this source alone (Figure 4.7).

Such an analysis obviously only takes a hydrological viewpoint. It ignores the political environment, any issues of social equity and justice, and the cost of water for irrigation. It simply assesses the ability of the water within the Lindis catchment to meet the irrigation demand which cannot at present be met from some other source e.g. the Clutha River.

The areas in each of the three distinct zones defined in the above manner are summarised in Table 4.2. It should be noted that such an approach reduces the area potentially irrigated by 'Lindis water' from 3,184ha to 2,420ha. Assuming that the existing allocation of Lindis water (i.e. 4,134L/s) is distributed 'evenly' across the entire area discussed in Section 4.1, then only 2,084L/s would be required to irrigate that area which must be serviced by the Lindis River.

Table 4.2: Areas and existing irrigation allocation for the three distinct irrigation zones.

Scenario	Area (ha)	% of irrigated area	Existing allocation
Lindis excluding command area overlap	2420	50.4	2084L/s
Command area 13.362 excluding Lindis	2267	47.2	1951L/s
Command area 13.451 excluding Lindis	113	2.3	95L/s
Total irrigated area	4799	100.0	(4134L/s)

The security of supply can then be assessed for that area which must currently be irrigated solely from water sourced from the Lindis River (Table 4.3).

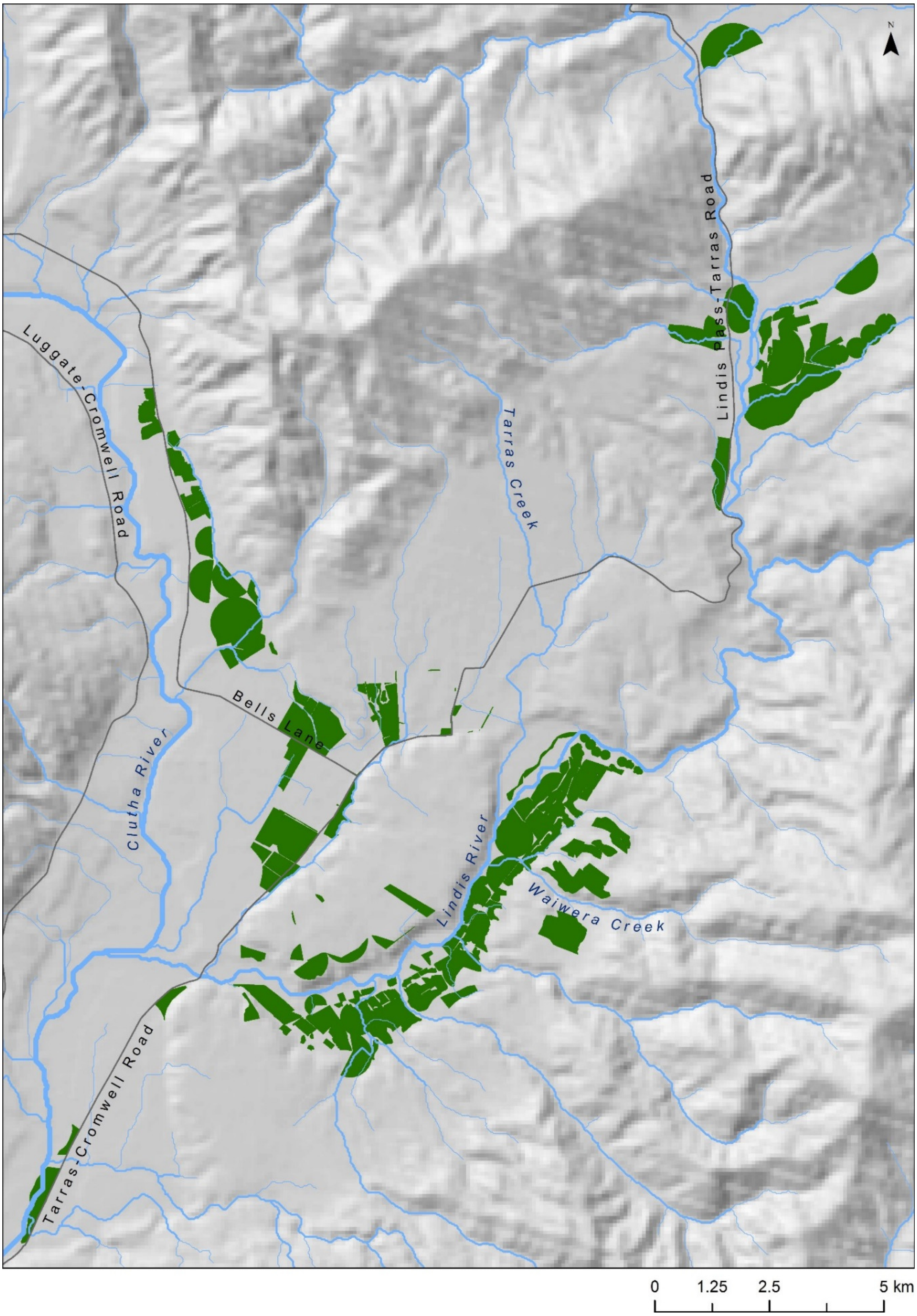

Figure 4.7: That area of the Lindis catchment which must be irrigated by 'Lindis water' as it currently has no alternative source of supply.

Table 4.3: Number of days and maximum number of consecutive days each year when existing full allocation cannot be met for that area which must obtain water from the Lindis catchment; under both the existing management and various minimum flow regimes.

	Total Days				Consecutive Days			
	Current	Residual 450L/s	Residual 750L/s	Residual 900L/s	Current	Residual 450L/s	Residual 750L/s	Residual 900L/s
1976-77	31	63	70	71	21	33	33	33
1977-78	114	137	155	161	100	118	119	119
1978-79	36	59	67	71	13	40	44	44
1979-80	0	0	0	0	0	0	0	0
1980-81	44	58	72	83	28	33	44	44
1981-82	95	120	129	133	29	54	63	63
1982-83	21	47	58	60	10	25	26	27
1983-84	0	0	0	0	0	0	0	0
1984-85	34	56	69	71	33	35	47	47
1985-86	0	4	18	23	0	3	14	20
1986-87	21	37	56	58	16	24	39	39
1987-88	63	101	116	120	13	24	24	24
1988-89	38	79	107	117	15	16	17	24
1989-90	78	111	134	156	37	39	42	45
1990-91	35	74	96	103	24	32	39	40
1991-92	113	130	134	139	32	74	74	74
1992-93	68	101	113	118	25	26	27	27
1993-94	0	0	5	7	0	0	5	7
1994-95	43	59	75	85	30	54	64	65
1995-96	0	0	0	0	0	0	0	0
1996-97	38	59	72	75	12	31	32	32
1997-98	38	61	70	80	24	35	36	36
1998-99	89	102	111	112	35	35	74	75
1999-00	0	22	34	43	0	11	16	19
2000-01	87	100	110	112	71	72	72	72
2001-02	68	110	136	143	21	55	56	72
2002-03	68	86	97	98	27	38	45	45
2003-04	30	48	61	68	11	24	25	25
2004-05	0	24	41	47	0	18	24	28
2005-06	134	146	157	160	66	85	86	86
2006-07	76	91	95	100	44	46	46	87
2007-08	121	141	150	152	38	58	74	74
2008-09	48	71	82	86	17	48	50	50
2009-10	103	125	142	149	56	92	95	96
2010-11	20	28	35	45	20	26	29	29

2011-12	31	74	90	97	24	25	31	32
2012-13	59	80	92	100	31	41	41	42
2013-14	76	104	117	125	46	80	81	81
Max.	**134**	**146**	**157**	**161**	**100**	**118**	**119**	**119**

Because only just over 50% of the total irrigable area of the lower Lindis catchment must be irrigated with water from the Lindis River, this scenario results in:

- A significant increase in the overall security of supply of irrigation water;
- A significant reduction in the number of days each year when full existing allocation could not be met (Figure 4.8); and
- A significant reduction in the duration of continuous periods when full existing allocation would not be possible (Figure 4.9).

It should be noted, however, that even under this scenario full existing allocation could not be met during the majority of irrigation seasons, even with no minimum flow requirement. The impact of a minimum flow on the number of days when full allocation is not possible is significantly less than the effect of the climate (Figure 4.8).

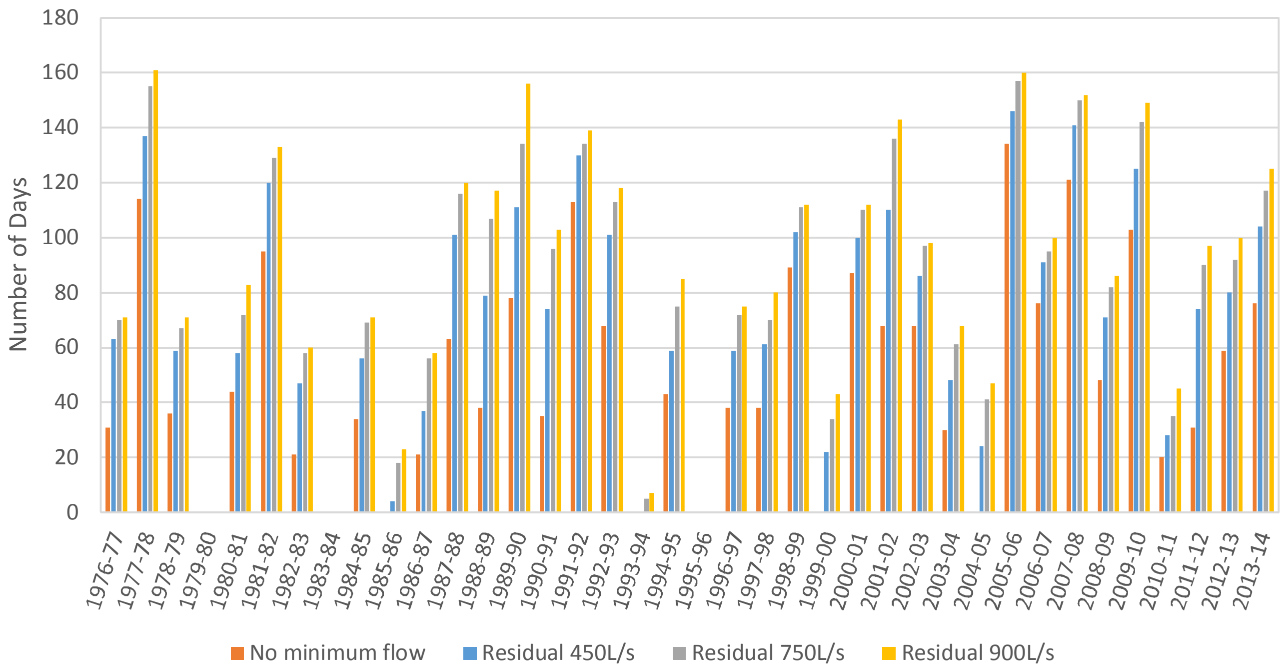

Figure 4.8: Total number of days when full existing allocation is not possible for that area which only has access to Lindis water; under both the current situation and a range of minimum flow scenarios.

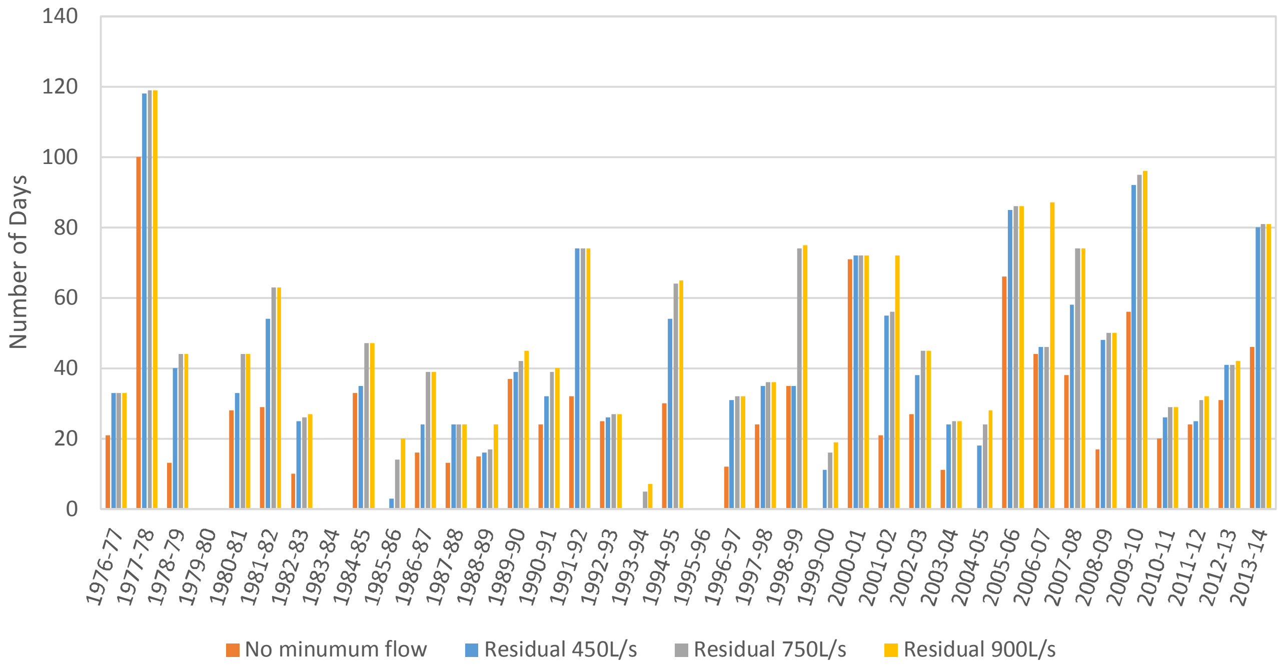

Figure 4.9: Maximum number of consecutive days when full existing allocation is not possible for that area which only has access to Lindis water, under both the current situation and a range of minimum flow scenarios.

4.3 Security of supply – with 'efficient' irrigation

The above analysis regarding the security of water supply was repeated but using the total daily irrigation demand discussed in Section 3.2 rather than the existing total allocation (i.e. 4,134L/s). The security of supply defined in this manner reflects more accurately the actual water demand required to produce pasture on the various soils in the Lindis catchment.

Considering only that 'zone' that must be irrigated by water from the Lindis River, it is apparent that even with no minimum flow threshold there are still years when there is insufficient water available to meet irrigation demand fully (Figure 4.10). For example, over the 28 years for which data are available 100% supply security was only available during approximately half of the irrigation seasons. However, supply security using efficient irrigation systems is certainly significantly greater than under the current primary allocation system.

The number of consecutive days each year when all the water required by an efficient irrigation system is not available, even without any minimum flow threshold, is shown in Figure 4.11. It is apparent that if efficient irrigation systems were installed, while there would still be periods when supply security would fall below 100% (i.e. there is insufficient water to meet irrigation demand), these periods are less common and of significantly shorter duration. For example, the longest period with insufficient water is only about 24 days under an efficient irrigation system. This compares to almost 180 days under the existing allocation regime.

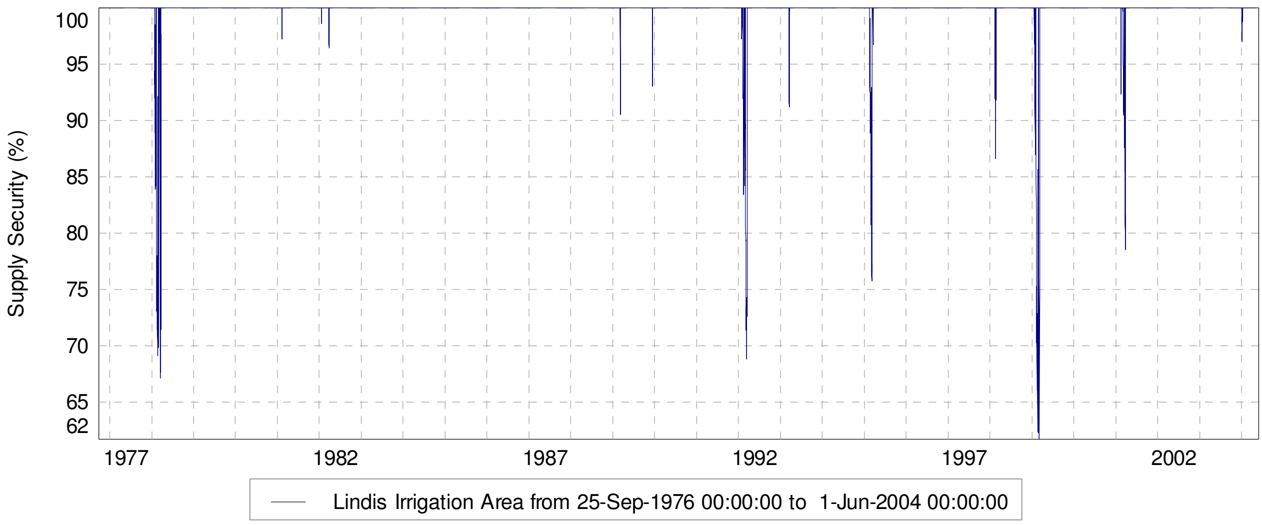

Figure 4.10: Irrigation supply security assuming efficient irrigation systems and no minimum flow requirement for the Lindis River.

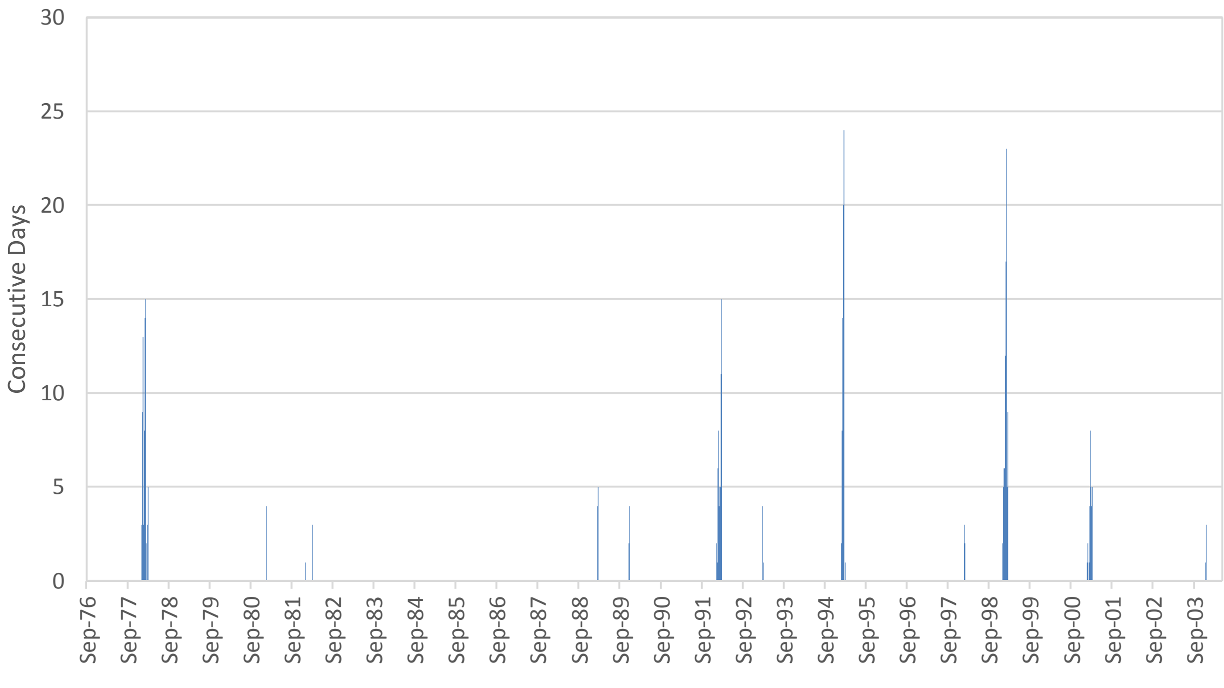

Figure 4.11: Number of consecutive days each irrigation season when 100% water supply security is not available even when using efficient irrigation systems.

The various minimum flows which have been suggested would have a significant effect on water supply security, even with the installation of efficient irrigation systems.

Water restrictions would apply in an additional 13 years i.e. in only 5 years between 1976 and 2004 would there have been 100% water supply security during the irrigation season. In all cases the number of days when 100% supply security is not available would more than double (Figure 4.12).

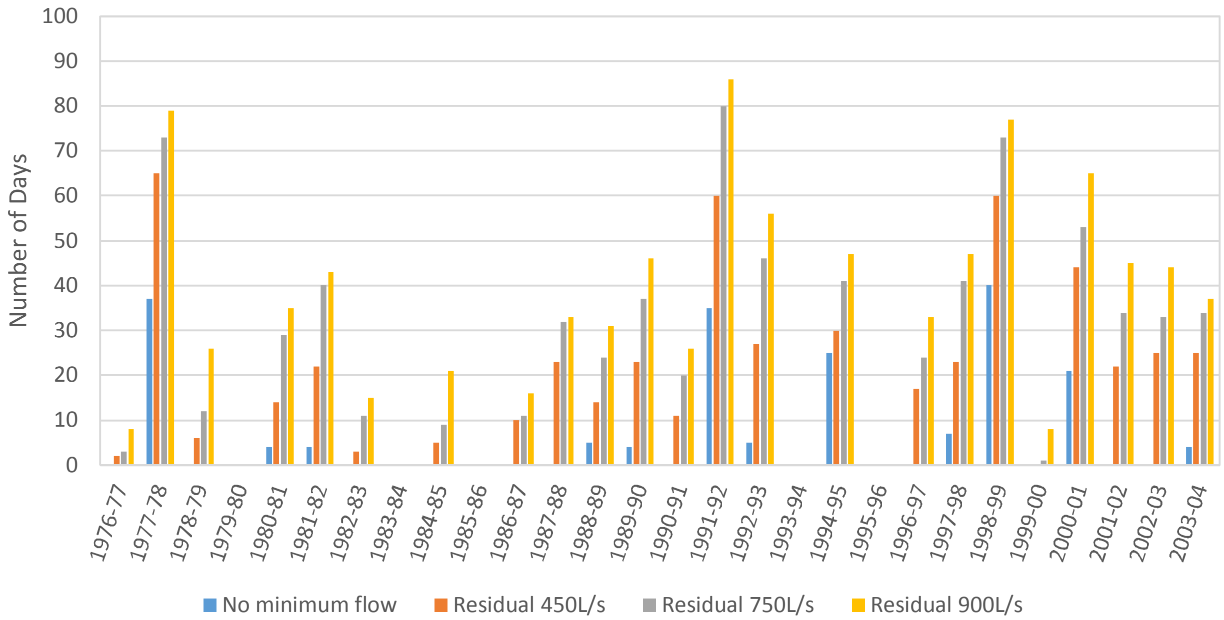

Figure 4.12: Number of days each irrigation season when 100% supply security is not available assuming efficient irrigation systems and various minimum flow regimes.

The imposition of a minimum flow regime would also significantly increase the duration of consecutive days when 100% irrigation supply security would not be available (Figure 4.13).

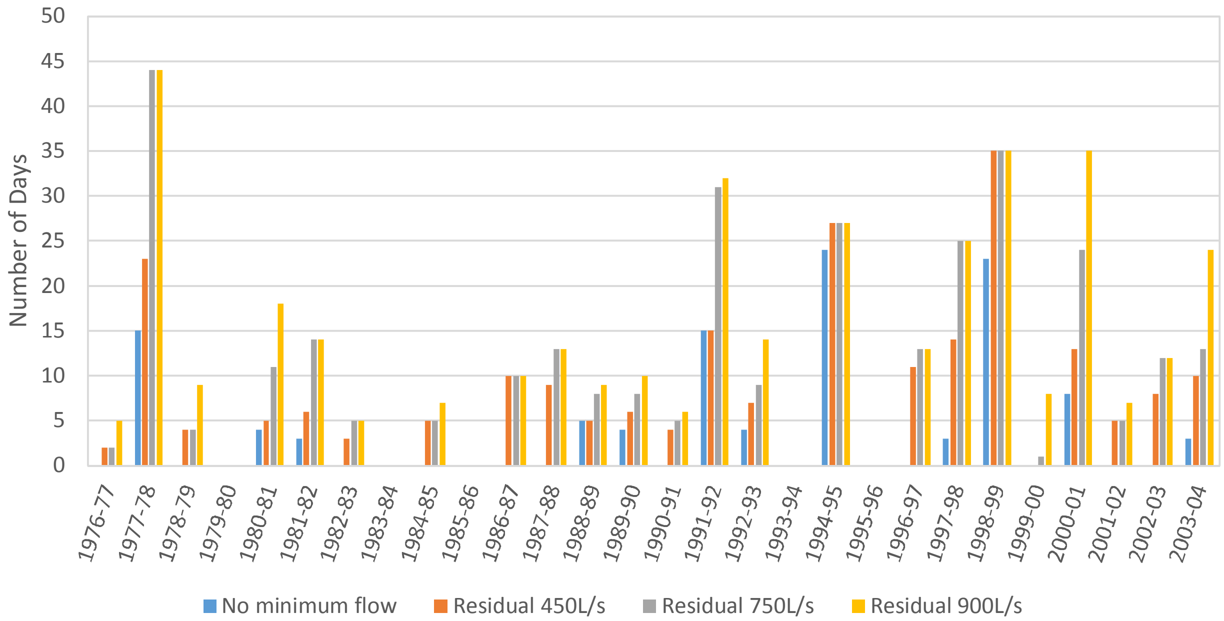

Figure 4.13: Number of consecutive days each irrigation season when 100% supply security is not available assuming efficient irrigation systems and various minimum flow regimes.

The above analysis, assuming efficient irrigation systems, was also undertaken with regard to the total irrigable area of the lower Lindis catchment i.e. including the Lindis and two Command Area irrigation zones. The inclusion of the two Command Areas, assuming that their irrigation demand must be met from the Lindis, even with efficient irrigation systems would increase both the frequency and duration of periods when 100% water supply security would not be available during the irrigation season (Figure 4.14 & Figure 4.15). The lack of security of water supply would occur even in the absence of any minimum flow regime i.e. the total flow in the Lindis could be abstracted.

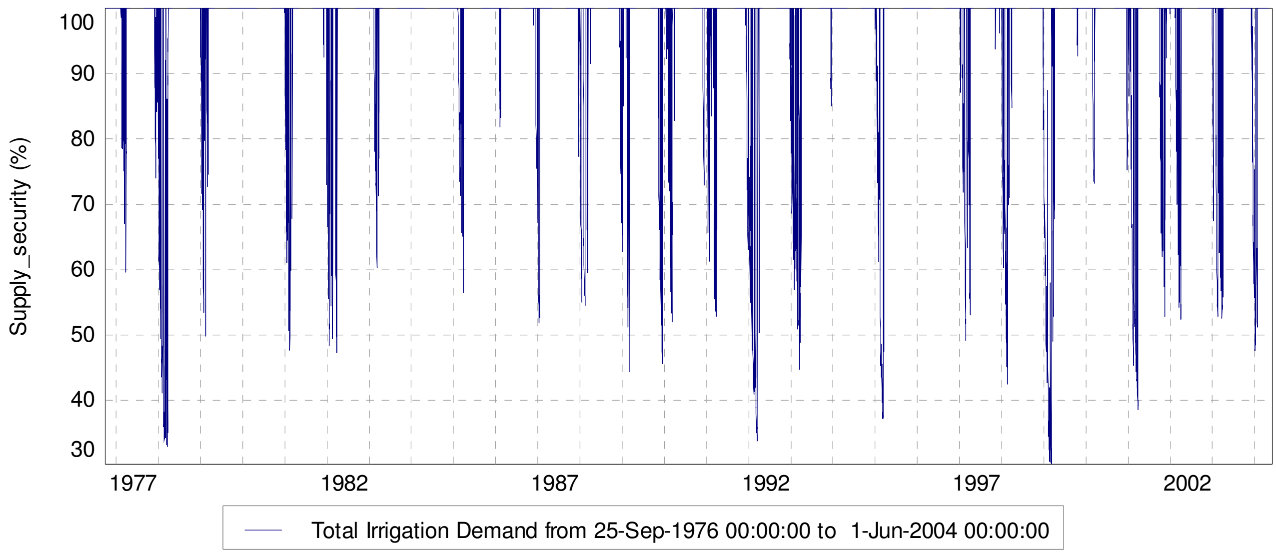

Figure 4.14: Number of days each irrigation season when 100% supply security is not available assuming all three irrigation zones and efficient irrigation systems.

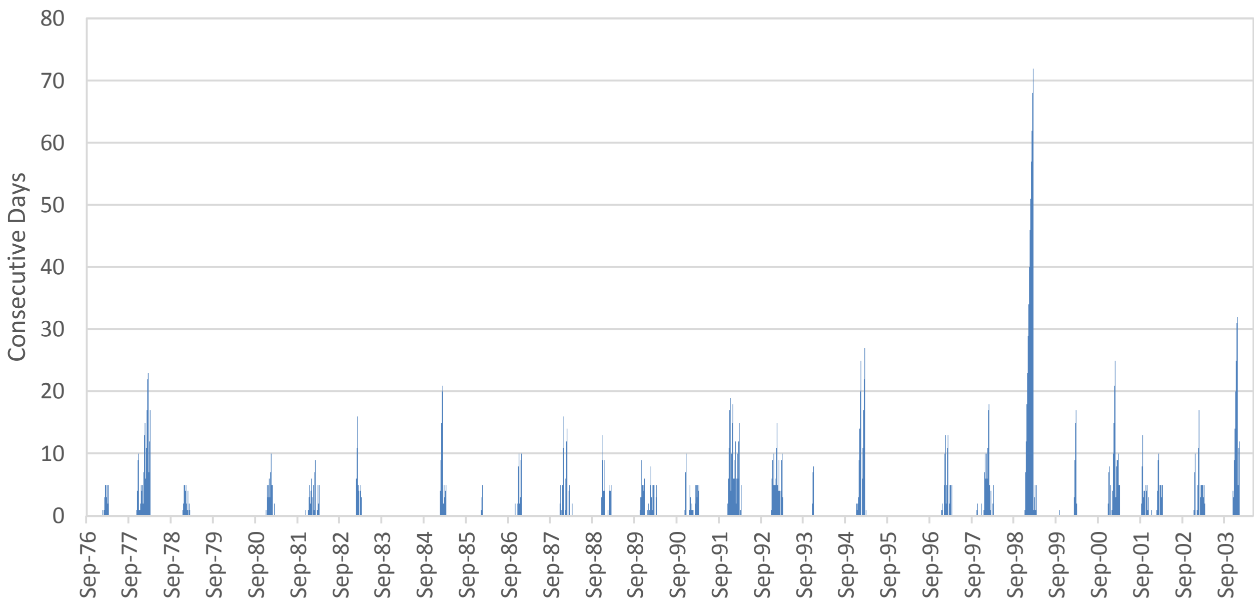

Figure 4.15: Duration of consecutive each irrigation season when 100% supply security is not available assuming all three irrigation zones and efficient irrigation systems.

The effect of a minimum flow regime on irrigation supply security, assuming efficient irrigation systems are installed, is not as significant as under the existing allocation regime. This is of course because of the reduced volume of water required to meet the irrigation demand.

The total number of days each irrigation season when total irrigation demand cannot be met increase slightly i.e. by about 25% or 10-20 days each season on average (Figure 4.16). Likewise the duration of periods when 100% water demand cannot be met also increases (Figure 4.17). It is significant that in most years the effect of the different low flow regimes is relatively small. In only about 4 years between 1976 and 2004 does the imposition of a minimum flow regime have a significant effect on the duration of periods when 100% supply security is not available.

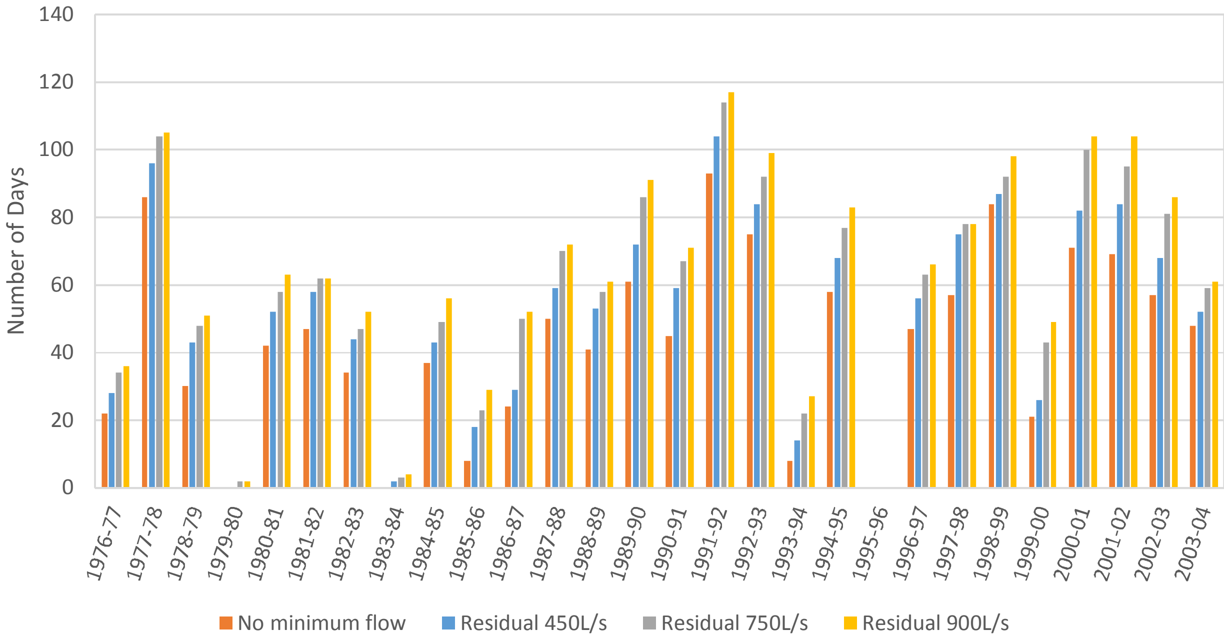

Figure 4.16: The effect of various low flow regimes on the number of days each irrigation season when full water demand cannot be met over the entire irrigable area.

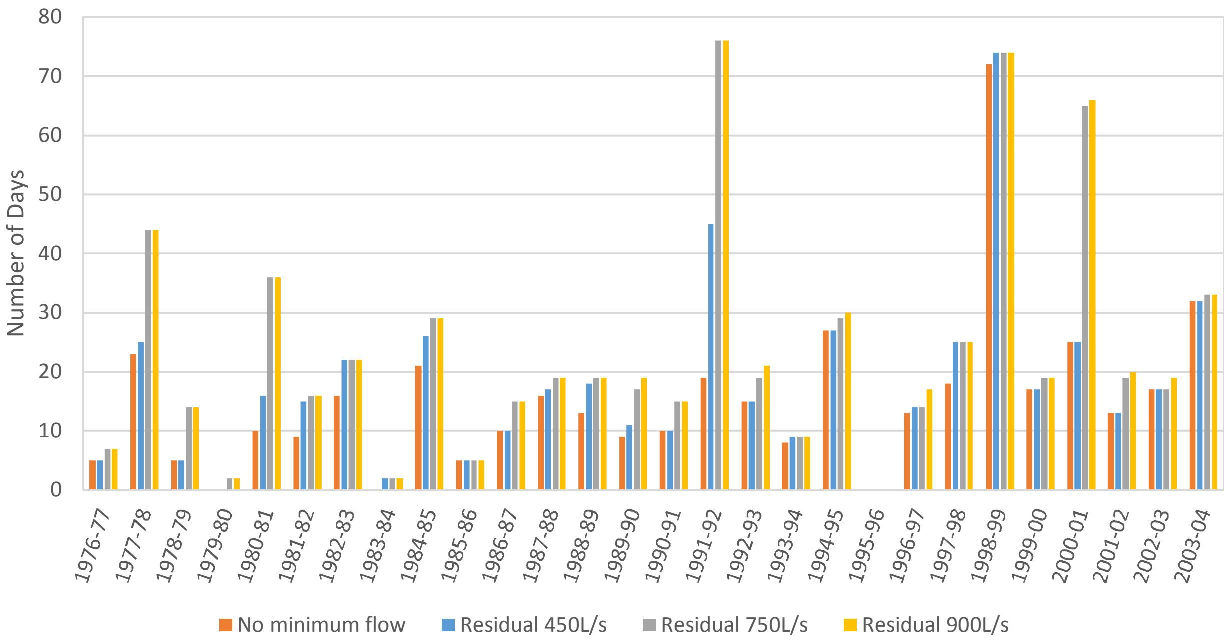

Figure 4.17: The effect of various low flow regimes on the duration of periods each irrigation season when full water demand cannot be met over the entire irrigable area.

4.4 Efficient irrigation – Lindis only

As discussed previously, the three irrigation zones actually include significant areas which are in both the 'Lindis Zone' and one of the two 'Command Area Zones'. Consequently, the remove the 'double-accounting' this causes, the previous analysis was repeated but for only that area which currently must meet its irrigation demand solely from the Lindis River i.e. there is currently no option to take water from the Clutha River or some other alternative supply.

The demand for irrigation, assuming efficient systems and the demand profiles from Aqualinc (2006), was determined in the same manner as discussed previously. The distribution of soils with different PAW classes is shown on Figure 4.19. The area of soils in various PAW classes which can currently be irrigated only with water from the Lindis River are summarised in Table 4.4.

Table 4.4: Distribution of the soils in each PAW class supplied by water from the Lindis River.

PAW Class	Area (ha)	%
45	908	37.5
90	673	27.8
155	839	34.7
175	0	0
Total	2420	100.0

The smaller area, and installation of efficient irrigation systems, results in a significantly smaller peak demand for water (i.e. 1146L/s) and therefore a high level of water supply security (Figure 4.18). In only three irrigation seasons between 1976 and 2004 was there insufficient water available from the Lindis catchment to meet irrigation demand defined in the above manner. This, however, assumes that there are no minimum flow regime for the Lindis River.

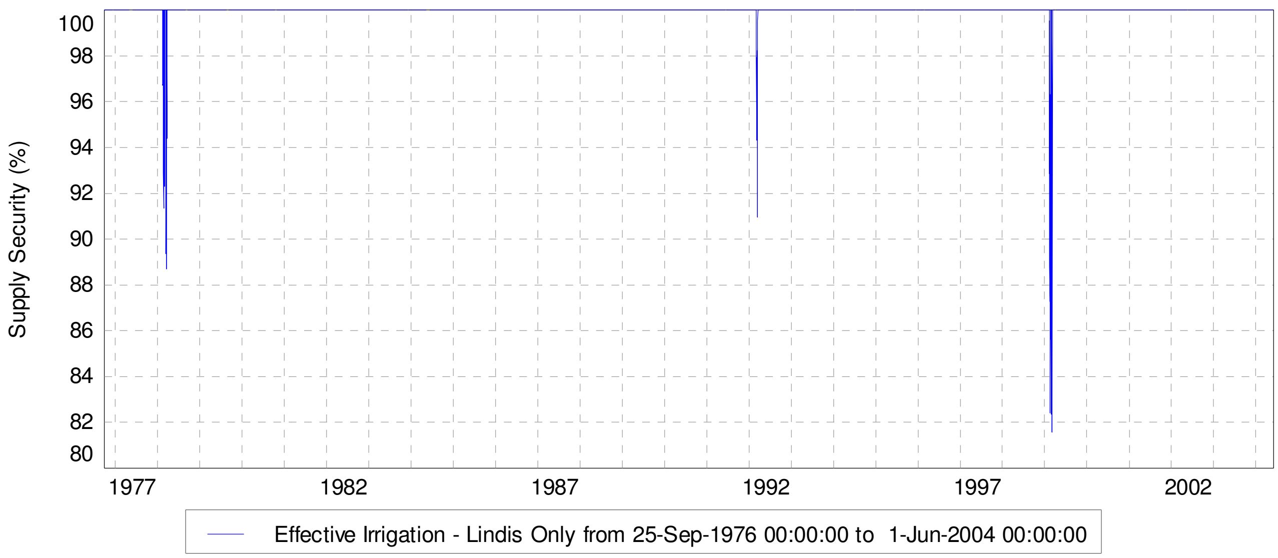

Figure 4.18: Number of days each irrigation season when 100% supply security is not available assuming efficient irrigation systems and only that area supplied solely from the Lindis River.

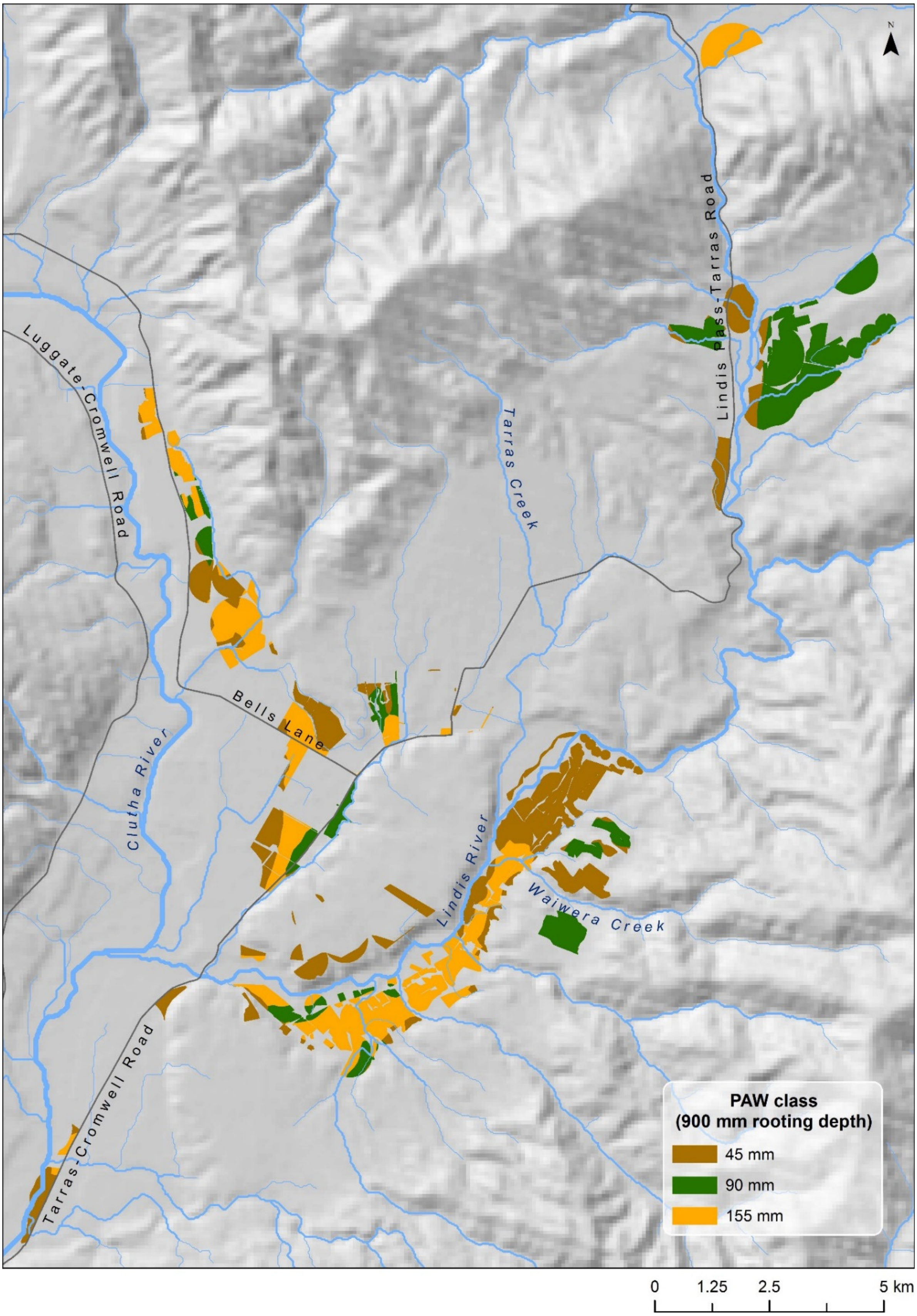

Figure 4.19: Distribution of soils with different PAW classes which are currently only irrigated with water from the Lindis River.

Likewise, the duration of periods when 100% irrigation supply security is not available during these three years tend to be very short i.e. no more than 11 days over the entire period considered (Figure 4.20).

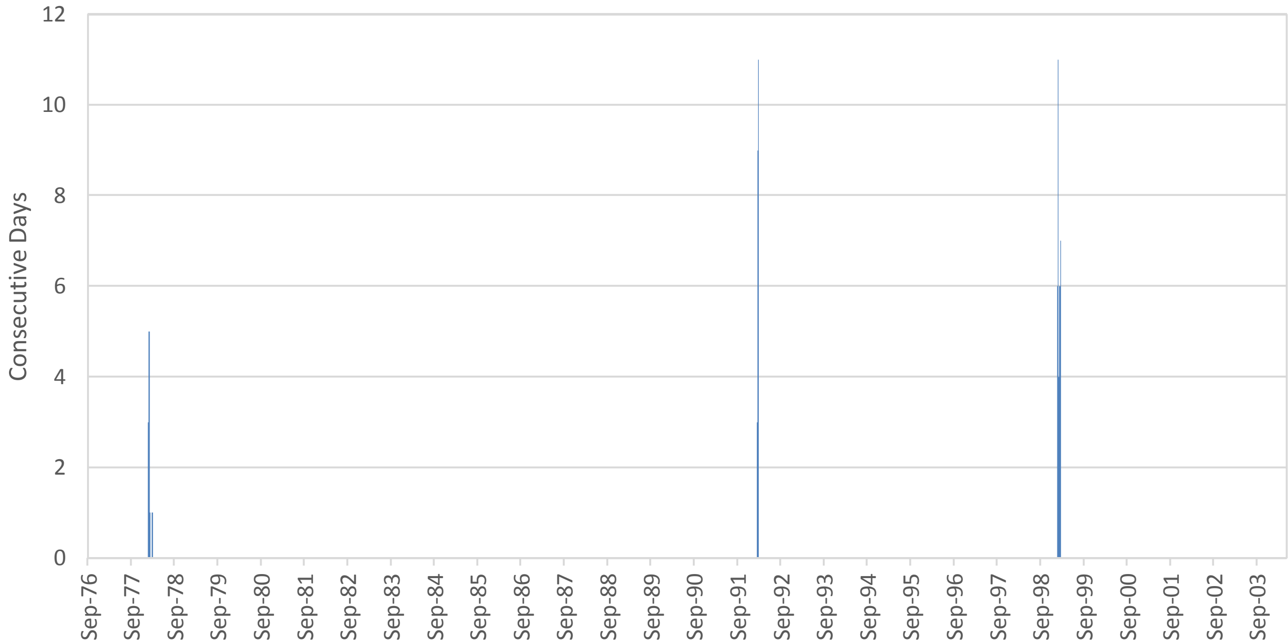

Figure 4.20: Duration of periods each irrigation season when 100% supply security is not available assuming efficient irrigation systems and only that area supplied solely from the Lindis River.

The above scenario assumes that there is no minimum flow regime for the Lindis River, and therefore that some abstraction can continue until there is zero flow.

The imposition of minimum flow regime would have a significant effect on both the number of days each irrigation season, and the duration of continuous periods when 100% supply security could not be met. The effect of any minimum flow requirement increases with the magnitude of that flow (Figure 4.21). For example, with no minimum flow the security of supply is impacted in only three years between 1976 and 2004. A minimum flow of 450L/s increases this to 13 years. A minimum flow of 900L/s would impact on irrigation supply security in all but seven years (Figure 4.21).

The adoption of a higher minimum flow also increases the duration of continuous periods when abstraction of water for irrigation would be restricted (Figure 4.22). The potential effect of a minimum flow of either 750L/s or 900L/s, however, is relatively small.

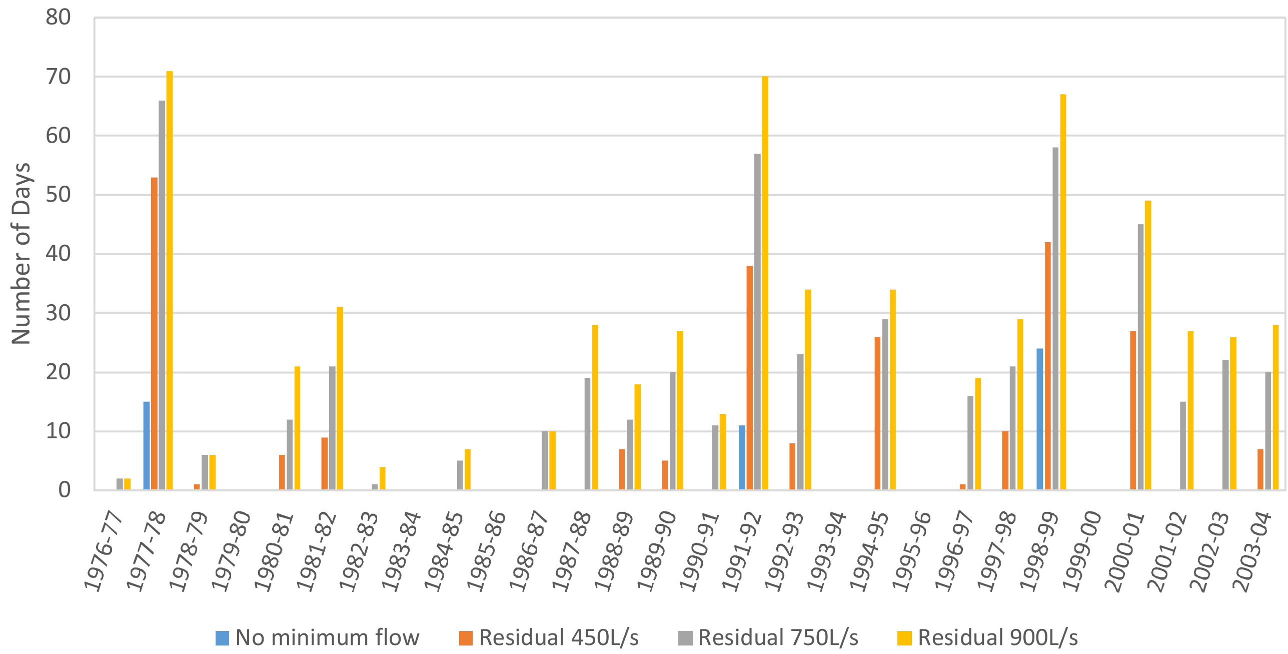

Figure 4.21: The effect of various low flow regimes on the number of days each irrigation season when full water demand cannot be met over the area currently serviced by only water from the Lindis catchment. This scenario assumes efficient irrigation systems.

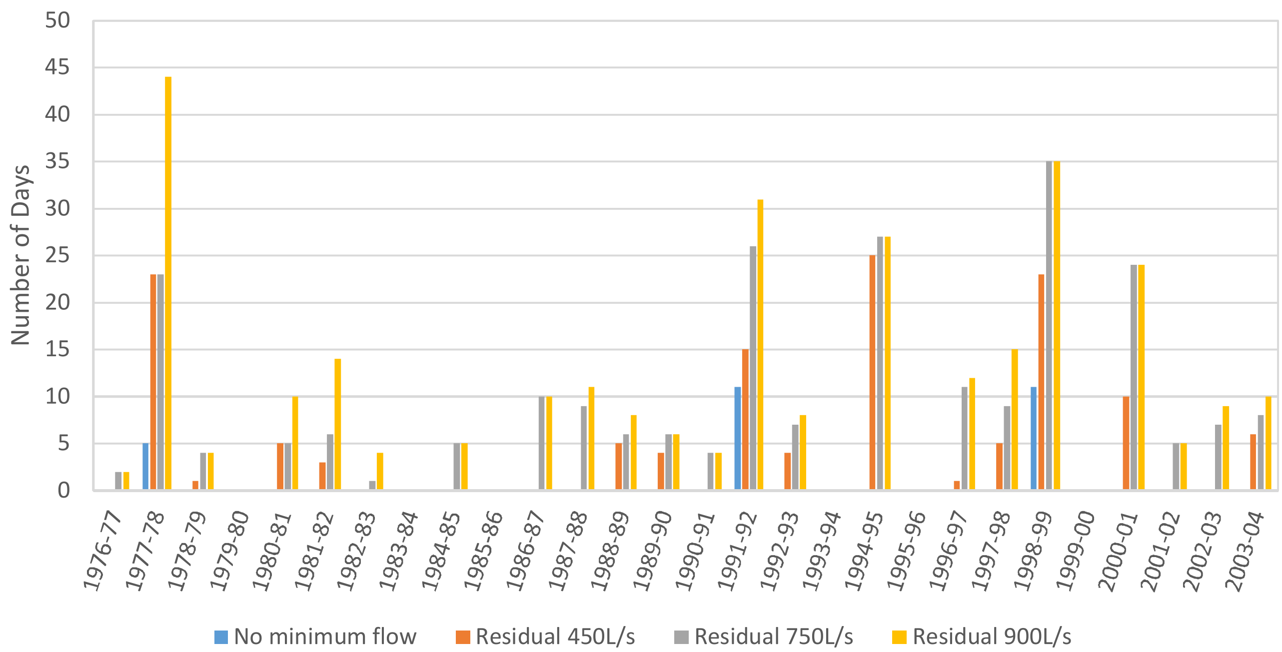

Figure 4.22: The effect of various low flow regimes on the duration of periods each irrigation season when full water demand cannot be met over the area currently serviced by only water from the Lindis catchment. This scenario assumes efficient irrigation systems.

4.5 Comparisons

The potential effect of various minimum flow regimes on the security of providing 100% of the water demand to various irrigable areas within the lower Lindis catchment are summarised below.

With reference to this discussion the following scenarios were compared:

- Current Existing Allocation: Assumes the current total water allocation from the Lindis catchment (Maximum average daily abstraction of 4,134L/s);
- Existing Allocation – Lindis Only: Assumes the existing allocation but apportioned over only that area which must currently get its irrigation water solely from the Lindis catchment i.e. it excludes the irrigable area which is also within either of the two command areas (Maximum average daily abstraction of 2,084/s);
- Efficient Irrigation – Lindis Only: Assumes that efficient irrigation systems are adopted throughout the area which currently must get water for irrigation solely from the Lindis catchment (Maximum average daily abstraction of 1,146L/s);
- Efficient Irrigation – Wider Lindis: Assumes the adoption of efficient irrigation systems throughout all areas which currently get water from the Lindis catchment i.e. includes portions of the two command areas which can get water from the Lindis catchment (Maximum average daily abstraction of 1,515L/s); and
- Efficient Irrigation – Total Area: Assumes the adoption of efficient irrigation systems throughout all irrigable areas, including the two command areas (Maximum average daily abstraction of 3,092L/s).

Assuming there is no minimum flow requirement (i.e. the total flow in the Lindis River can be abstracted) then the number of days where demand security is not 100% during each irrigation season is summarised in Figure 4.23; while the duration of periods of restricted abstraction are summarised in Figure 4.24.

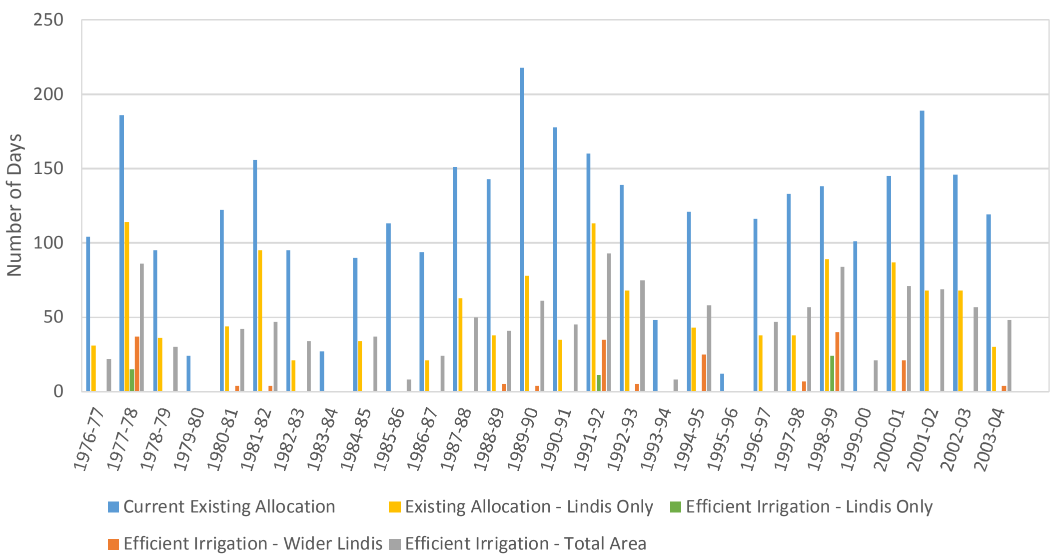

Figure 4.23: Number of days with reduced irrigation demand security for different irrigation zones and irrigation regimes assuming no minimum flow requirement in the Lindis River.

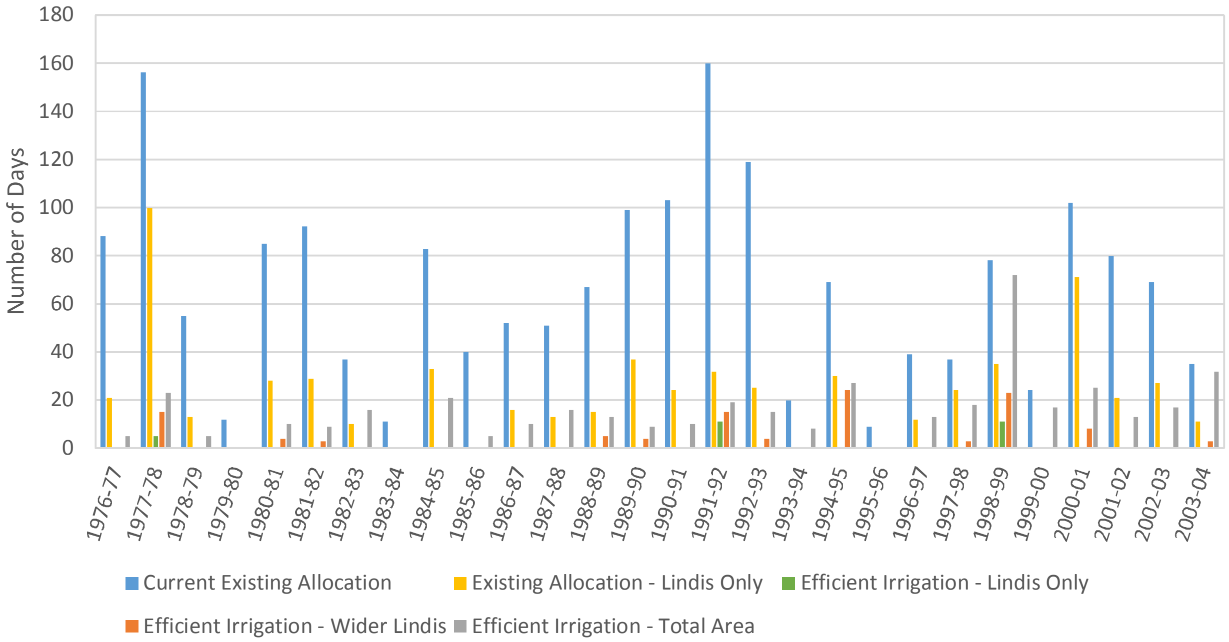

Figure 4.24: **Duration of periods with reduced irrigation demand security for different irrigation zones and irrigation regimes assuming no minimum flow requirement.**

Assuming that a 450L/s minimum flow requirement is imposed on the Lindis River then the number of days where demand security is not 100% during each irrigation season is summarised in Figure 4.25; while the duration of periods of restricted abstraction are summarised in Figure 4.26.

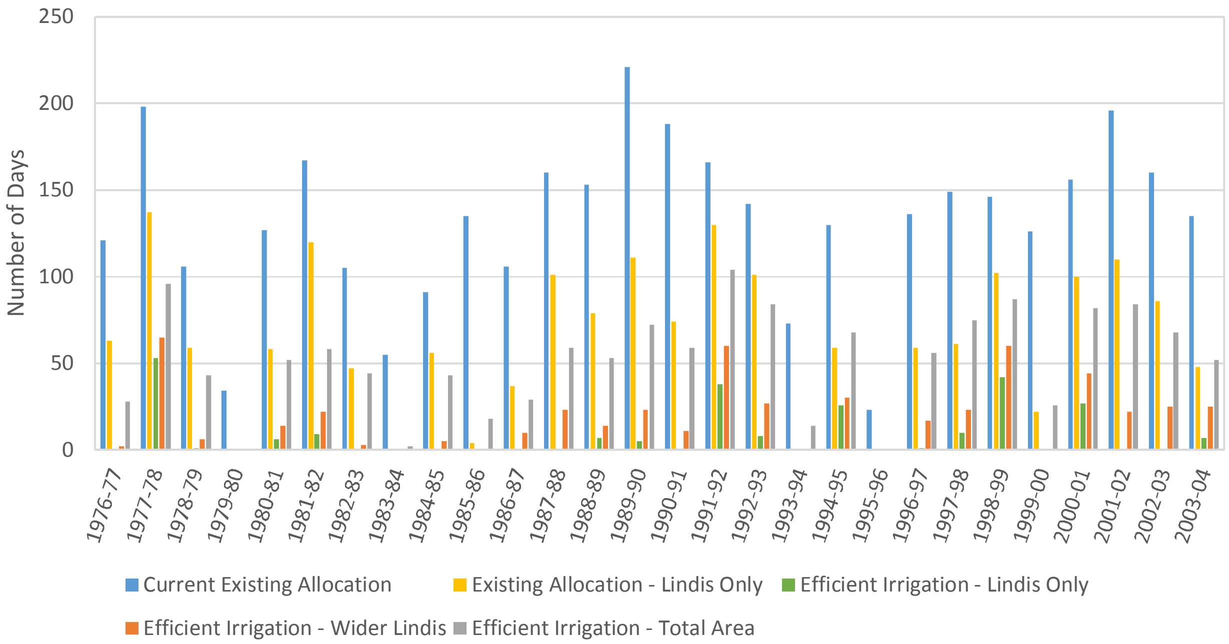

Figure 4.25: **Number of days with reduced irrigation demand security for different irrigation zones and irrigation regimes assuming a 450L/s minimum flow in the Lindis River.**

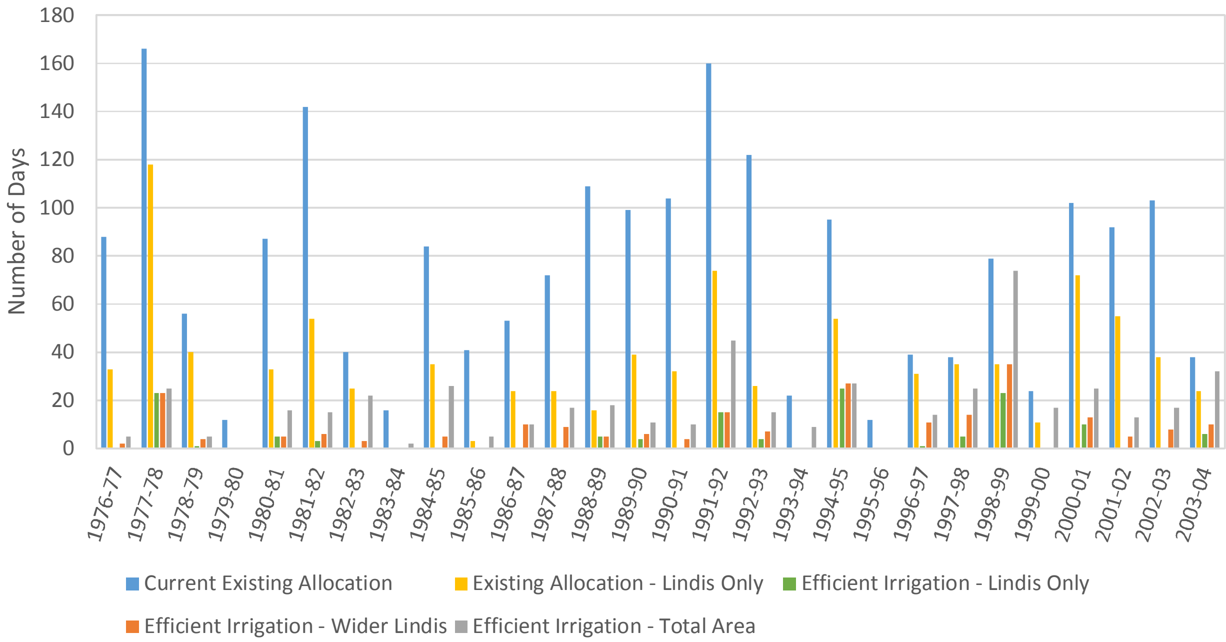

Figure 4.26: Duration of periods with reduced irrigation demand security for different irrigation zones and irrigation regimes assuming a 450L/s minimum flow in the Lindis River.

Assuming that a 750L/s minimum flow requirement is imposed on the Lindis River then the number of days where demand security is not 100% during each irrigation season is summarised in Figure 4.27; while the duration of periods of restricted abstraction are summarised in Figure 4.28.

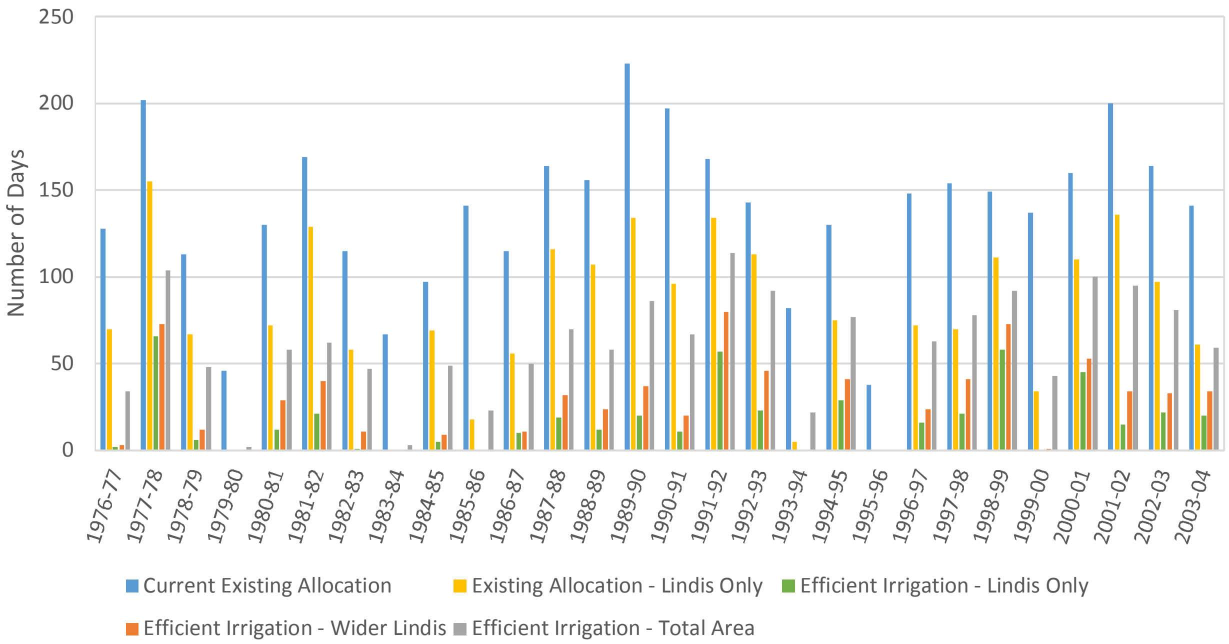

Figure 4.27: Number of days with reduced irrigation demand security for different irrigation zones and irrigation regimes assuming a 750L/s minimum flow in the Lindis River.

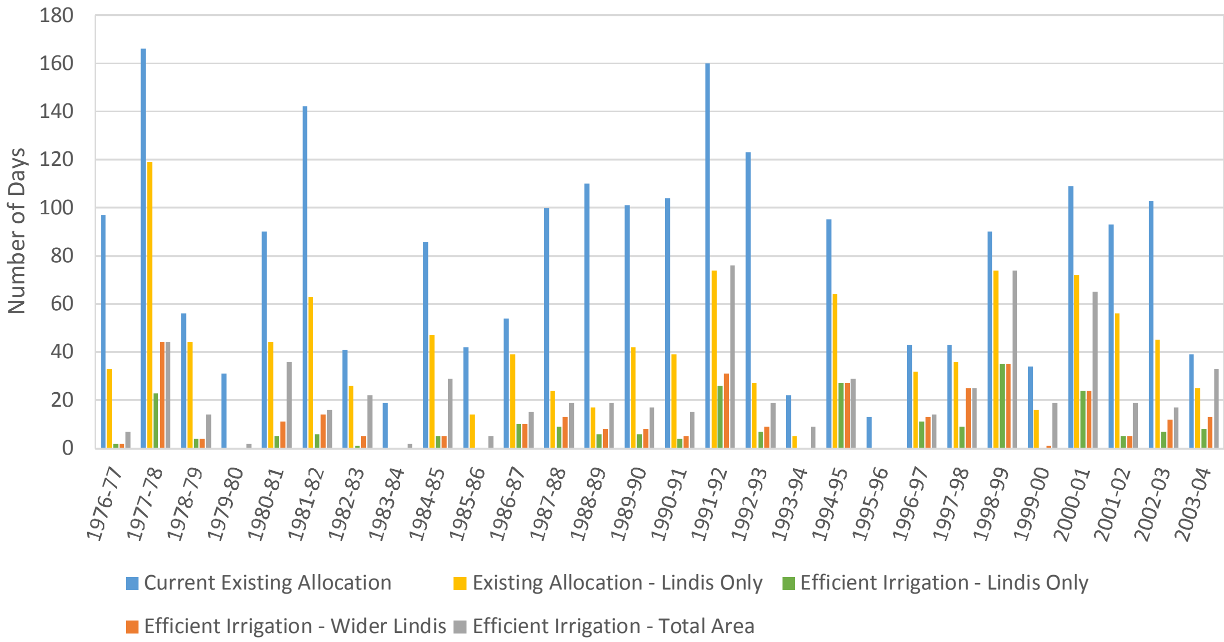

Figure 4.28: Duration of periods with reduced irrigation demand security for different irrigation zones and irrigation regimes assuming a 750L/s minimum flow in the Lindis River.

Assuming that a 900L/s minimum flow requirement is imposed on the Lindis River then the number of days where demand security is not 100% during each irrigation season is summarised in Figure 4.29; while the duration of periods of restricted abstraction are summarised in Figure 4.30.

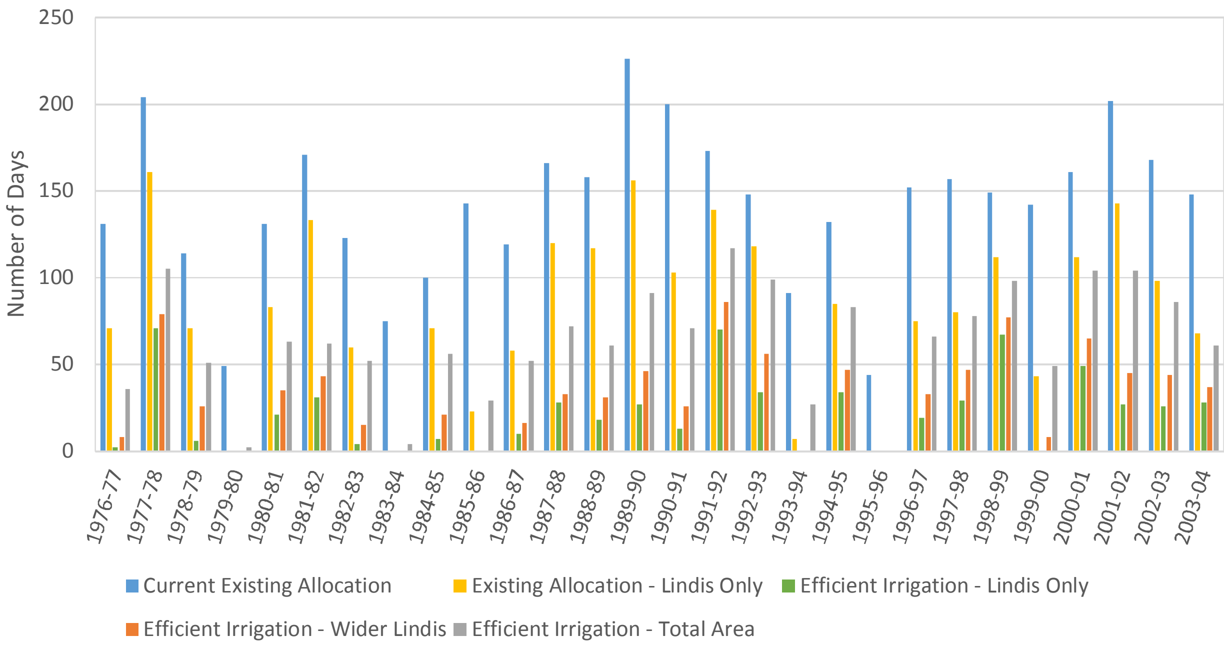

Figure 4.29: Number of days with reduced irrigation demand security for different irrigation zones and irrigation regimes assuming a 900L/s minimum flow in the Lindis River.

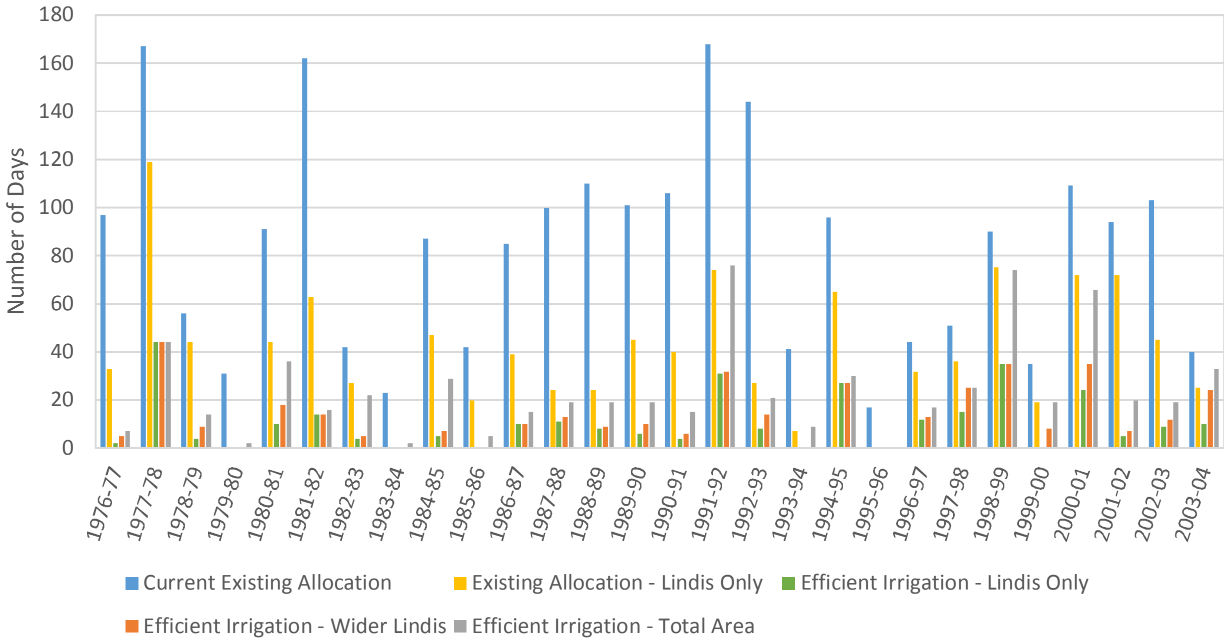

Figure 4.30: Duration of periods with reduced irrigation demand security for different irrigation zones and irrigation regimes assuming a 900L/s minimum flow in the Lindis River.

5 Conclusions

The principle controls on the availability of water to meet irrigation demand in the lower Lindis catchment are the climate and highly variable flow regime of the river. Natural climatic and flow variation means that restrictions on water availability are natural phenomena; although periods of low flow and restricted water availability are enhanced by water abstraction to meet the demand from irrigation.

Despite the highly variable flow regime, the security of water supply to meet irrigation demand is affected by:

- The area to be irrigated;
- The efficiency of irrigation; and
- Any minimum flow constraints on water abstraction from the Lindis River.

Improved irrigation efficiency, and the use of alternative water sources to irrigate some of the lower Lindis catchment, have a significant effect on the security of supply for the remaining areas which currently rely solely on water from the Lindis River.

While the implementation of a minimum flow regime would impact on water security, the potential effects of a minimum flow of 900L/s are generally not very different to those when the minimum flow is 450L/s.

The effects of a specific minimum flow are greatest when efficient irrigation systems are used to irrigate those areas of the Lindis catchment which currently do not have access to alternative water sources. This is because the volumes of water required for irrigation are minimised, and abstraction is more sensitive to the low flow regime. The demand for large volumes of irrigation water quickly exceeds the capacity of the low flow regime irrespective of the level of the minimum flow.

6 References

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