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CRITICAL WATER LEVELS FOR OPERATION OF IRRIGATION INFRASTRUCTURE IN THE LOWER MURRAY RECLAIMED IRRIGATION AREA (LMRIA)

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EXECUTIVE SUMMARY

The LMRIA is located on the historical floodplain of the Lower River Murray in South Australia that was reclaimed for agriculture in the early 1900s. The Millennium drought, from 2007-2010, had severe impacts on infrastructure, environment and the farming community due to low River Murray water levels and restricted water allocations. The heavy clay soils on the floodplain reacted severely in the drought, exhibiting drying, cracking, heaving, slumping, and acidification. This resulted in major damage to irrigation infrastructure and laser levelled land surfaces that had been rehabilitated across the LMRIA immediately prior to the drought. Given the predominant irrigation method in the LMRIA is gravity-fed, sufficient river water levels are required to provide sufficient hydraulic head needed to achieve suitable flow through the infrastructure (typically 600 mm diameter siphons). Due to the effects of the drought it was unclear whether the design parameters for the irrigation infrastructure, and hence critical river water levels for efficient operation, were still valid. This information was required to inform the *Variable Lower Lakes* Project that is currently being conducted by the Department for Water, Environment and Natural Resources (DEWNR).

The aim of this study was to undertake a survey of the LMRIA irrigation infrastructure and natural height of irrigation bays and to use this information to determine the critical minimum operating water level for the Lower Lakes and Lower River Murray channel (below Mannum).

Methods

A DGPS survey of LMRIA infrastructure and natural land surface levels was undertaken by DEWNR in April 2017. The 2017 survey data was compared to engineering design levels provided by DEWNR for infrastructure installed in the LMRIA rehabilitation project between 2005 and 2007 (pre-Millennium drought).

Water level data (daily and hourly average) for the Lower River Murray and Lower Lakes was obtained from DEWNR. Meteorological data (wind speed and direction at 15 minute intervals) at Narrung was obtained from the South Australian Murray-Darling Basin Natural Resources Management Board. The water level and wind data was analysed to assess patterns that might affect irrigation operations and determination of a critical minimum water level.

Key Findings

- Natural land surface levels in the vicinity of the irrigation inflow channels have sunk by a median of 0.17 m in the LMRIA following the 2007 to 2010 drought period, but up to 0.6 m at some sites. This is likely due to the slumping of the floodplain during the period.
- Irrigation infrastructure levels (lip of siphon) show little change in design levels, on average. This could be because the compacted clay levee banks, through which the siphons are located, were more resilient to drought effects than the floodplain.

Critical minimum water level

Based on the new survey data, a minimum water level of 0.5 m AHD would need to be maintained between Mannum and Wellington to enable the efficient operation of >95% of LMRIA irrigation infrastructure. This level is currently accepted by LMRIA irrigators and corresponds on average to a critical minimum water level of approximately 0.4 m AHD in the Lower Lakes.

Large fluctuations (positive and negative) in daily and sub-daily average water levels can occur due to wind but these temporary effects are not a primary consideration in setting critical minimum water levels. In general, it is favourable for LMRIA irrigators to irrigate during W-SW wind conditions when water is pushing up from the Lower Lakes, and less favourable in N-NE wind conditions. However, high salinity levels in the Lower Lakes may need to be taken into consideration when irrigating during W-SW conditions, particularly in the lower reaches of the LMRIA.

If water levels fall to 0 m AHD, then approximately 80% of irrigators will be negatively impacted and have to use alternative irrigation strategies. Alternative irrigation strategies are possible in extreme low river level situations but may require government support to be implemented regionally. These alternative strategies include low head-high volume pumps out of the siphon well (typically -1 m below level of siphon lip) or travelling irrigators.

The LMRIA irrigation season generally extends from September to April. Low water levels between May to August are unlikely to cause significant impacts on LMRIA irrigation operations due to the lack irrigation at this time.

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1 INTRODUCTION

1.1 BACKGROUND ON LMRIA

The LMRIA comprises approximately 5 200 ha of land, with over 20 separate irrigation areas, on the historical floodplain of the lower River Murray in South Australia (Figure 1). Historically, this floodplain contained patches of reed growth and standing water that changed according to river levels and local climatic conditions. Pre-European settlement, the area was used by the Ngarrindjeri indigenous people approximately 8 400 years before present (Wilson et al. 2012). The region commenced agricultural development in the late 1890s. Between 1900-1930 agricultural developments intensified with the construction of levee banks near the river edge, pumping out of standing water, and development of a drainage system to maintain the water-table at a sufficiently low level to grow pasture (Taylor and Poole, 1931).

Since the completion of barrages to prevent seawater ingress at the Murray Mouth in 1940, the water level in the reclaimed area has been 1.0 to 1.5 m below the river level, enabling consistent gravity fed irrigation from the River Murray. Dairy farming has been the predominant land use with smaller areas used for beef cattle, fodder production, horticulture and lifestyle farming. To enable sufficient soil quality for agricultural production, the rising saline water tables in the LMRIA are maintained below the pasture root zone via a drainage network and pumps. Large volumes of drainage water containing pollutants such as nutrients and pathogens have historically been returned to the river, which has impacted water quality in the main river channel (Murray and Philcox, 1995; Mosley and Fleming, 2010). A major LMRIA rehabilitation project was undertaken by the irrigators, State and Commonwealth Governments from 2003–2007 to improve irrigation efficiency and reduce drainage volumes returned to the River Murray.

Due to the Millennium drought, the LMRIA has faced severe challenges over the past ten years (2007-2017). River and groundwater levels fell to their lowest in over 100 years between 2007 and 2010 (Mosley et al., 2014). During this period, there were restricted irrigation water allocations, which meant that there was very little irrigation water applied to the land. These two factors led to severe soil cracking to depths of up to 4 m, salinisation and acidification (Mosley et al., 2014) and severe socio-economic impacts. The result of this was that many irrigators ceased or down-scaled their operations in the LMRIA, with a pronounced loss of dairy farming activities (Philcox and Scown, 2012). Seven years after the drought ended (in terms of river levels) LMRIA soil, water and irrigation infrastructure are still impacted (Mosley et al., 2017). There is an increased risk of negative drought effects becoming more prevalent in the future, given climate change projections for this region.

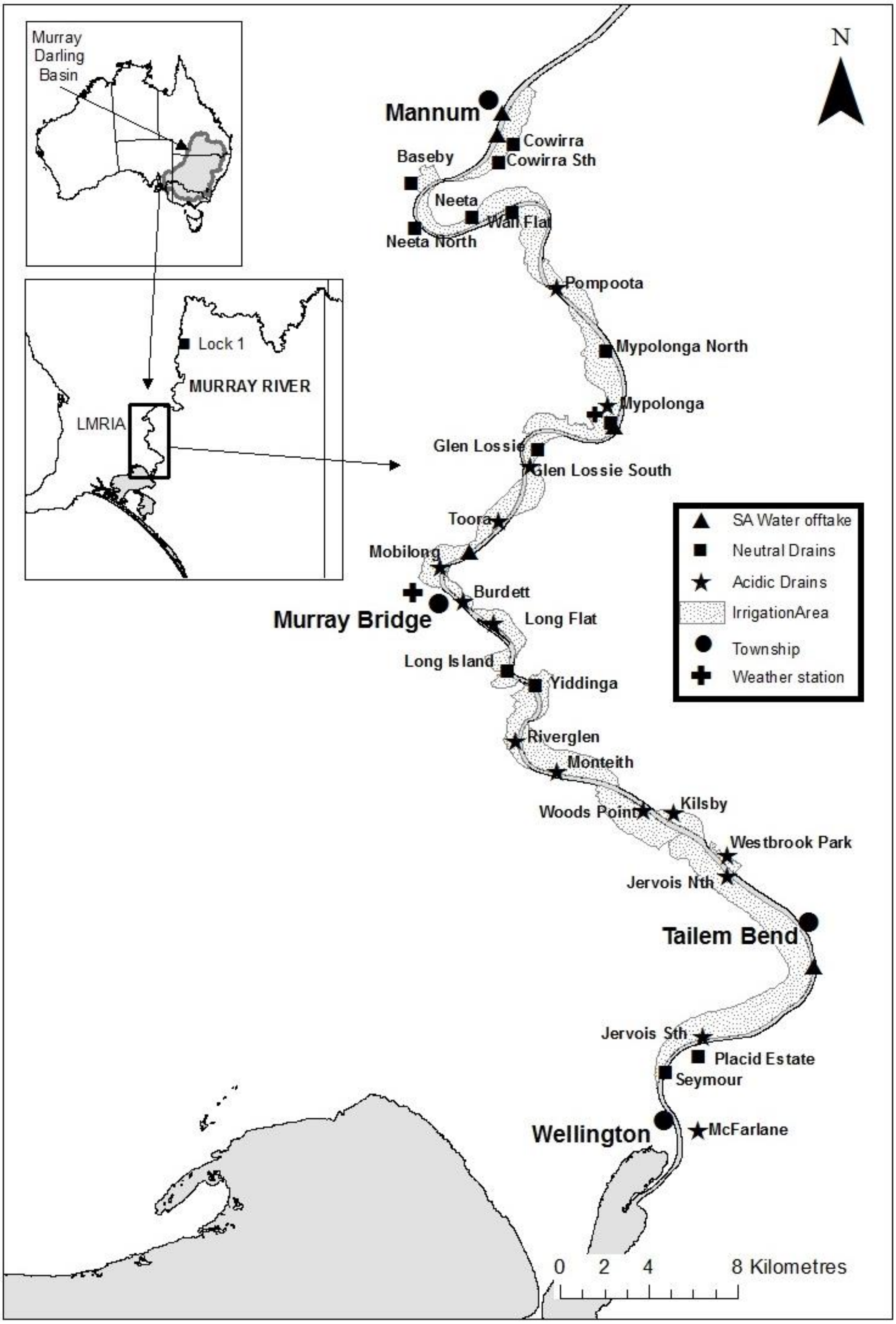

Figure 1. Locality map showing the general LMRIA location in the Lower River Murray region of South Australia. The individual irrigation areas comprising the LMRIA are shown (listed in Table 1).

The main areas comprising the LMRIA region are shown in Figure 1 and listed in Table 1. Historically, the land in the LMRIA was almost exclusively used for dairy production. In 1990, the LMRIA was estimated to provide about 40% of Adelaide's fresh milk supply (Philcox and Douglas, 1990). From 2003–2008 approximately 4 200 ha of land was rehabilitated under the LMRIA rehabilitation project with approximately 1 000 ha of land retired from farming and not rehabilitated (EPA, 2009). This includes the SA Water owned land at Mobilong and Toora. Post-Millennium drought (in 2012), the total area of productive farms remaining in the LMRIA was estimated to be 3 192 ha, dairy production has reduced from approximately 5 000 ha to 1 866 ha, a reduction of approximately 63% (Philcox and Scown, 2012). There has been a decided switch to beef production during and post drought, with this land use covering an estimated 735 ha of the LMRIA (Philcox and Scown, 2012).

Table 1. List of key irrigation areas in the LMRIA with their size in ha. In addition, some smaller retired areas also exist, which contribute to the total LMRIA area of 5 200 ha.

Irrigation area	Size (ha)
Cowirra	259
Baseby	67
Neeta	303
Wall Flat	243
Pompoota	160
Mypolonga	557
Glen Lossie	150
Toora	143
Mobilong	207
Burdett	42
Long Flat	129
Long Island	72
Yiddinga	65
River Glen	163
Westbrook Park	40
Kilsby	42
Monteith	386
Woods Pt	262
Jervois	1 490
McFarlanes	113
Total	**4 893**

1.2 VARIABLE LAKES PROJECT

The Department for Water, Environment and Natural Resources (DEWNR) and SA Water currently manage the water level in Lake Alexandrina and Lake Albert (Lower Lakes) for multiple purposes. There are a number of strategies and processes that guide Lower Lake water levels and barrage operations. However, there is no formalised, integrated and specific policy or strategy to manage water levels and barrage operations. To better manage water levels in the Lower Lakes, the *Variable Lakes Project* has been undertaken by DEWNR. The project will include a policy to guide water levels and barrage operations and a Barrage Operating Strategy to support the implementation of the policy.

Lock 1 down to (and including) the Lower Lakes is one connected weir pool. The LMRIA lies within this connected weir pool with its lower areas within close proximity to the northern edge of Lake Alexandrina. The proximity to, and connection of, LMRIA to the Lower Lakes means that a sufficient water level in the River Murray channel downstream of Lock 1 and in the Lower Lakes is critical to enable the LMRIA irrigation infrastructure to operate effectively. Previous reports have indicated that for LMRIA irrigation bays to operate effectively, a water level below Lock 1 of +0.6 m AHD must be maintained (absolute minimum of +0.55 m AHD) (Lamontagne et al., 2004). However, little investigation has been undertaken to verify this critical operating water level or to determine how this translates to Lower Lakes operating water levels.

1.3 STUDY AIMS

The aim of the *Critical water levels for operation of irrigation infrastructure in the Lower Murray Reclaimed Irrigation Area (LMRIA*) project was to determine the critical operating limits for the irrigation infrastructure in the LMRIA. The following activities were conducted:

1. LMRIA site visit to guide the irrigation infrastructure survey
2. collation and assessment of the relevant data sets to inform analysis of irrigation infrastructure operating limits (specifically design drawings, land surface elevation data, and river levels under different wind conditions)
3. assessment of the infrastructure survey data against river levels and previous as-constructed design drawings
4. determination of the minimum river levels for the efficient operation of the LMRIA irrigation infrastructure in various areas based on the consideration of the above.

2 METHODS

2.1 INFRASTRUCTURE SURVEY

A DGPS Survey was undertaken by DEWNR in April 2017. Natural land surface and sluice/syphon outlet locations and heights were determined using a global navigation satellite system (GNSS) that uses DPGS to give sub 10 mm vertical accuracy (Figure 2). A Hemisphere S321 Survey Smart Antenna connected via Bluetooth to a Hemisphere XF3 hand held unit using Carlson SurvCE operating system was utilized. At each irrigation zone a static base station was established with a minimum runtime of 1 hour, this increased the accuracy of the static positions. A network of 'rover' Hemisphere S321 units on 2m poles were connected and received positioning information from the base station via UHF operating under the Geocentric Datum of Australia (GDA) 94 projection. At each syphon or sluice, a rover was used to take a measurement of the elevations of the siphon outlet lip (see Figure 3) and of the adjacent natural land surface of the adjoining irrigation bay. Post-processing of the raw data was undertaken using the AUSPOS Online GPS Processing Service provided by Geoscience Australia. AUSPOS corrects the raw data for Australian Height Datum (AHD) and GRS80 Ellipsoid. The post process data provides easting and northing locations as well as the correct heights/levels for each surveyed point.

These levels, with consideration of the head required for sufficient flow, relate to the critical river water levels to enable gravity-fed flood irrigation. Several irrigation areas were resurveyed during 2017 (Jervois, Monteith, Long Flat, Wall Flat, Mypolonga, Pompoota, Cowirra, and Neeta). There were problems with establishing the DGPS datum at Cowirra and Neeta so reliable survey data was obtained and was omitted from this report. The raw survey data supplied by DEWNR is provided in Appendix 1. The 2017 survey data was compared with previous "as built" engineering design drawings provided by DEWNR for infrastructure installed in the LMRIA rehabilitation project between 2005 and 2007.

Figure 2. DGPS surveys undertaken by DEWNR staff to obtain the heights of irrigation infrastructure outlets (left) and the natural land height within irrigation bays (right).

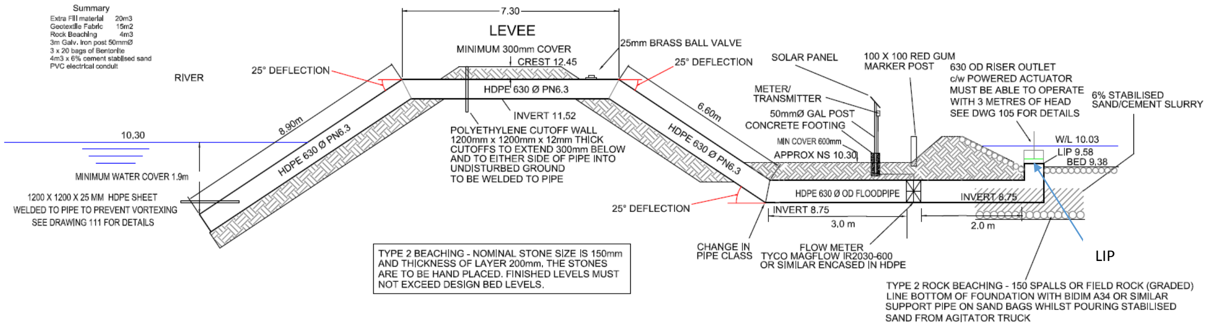

Figure 3. Design drawing of a typical irrigation siphon in the LMRIA showing the LIP (survey point) on the right hand side (extract of original design supplied by DEWNR, formerly DWLBC). Note 10 m needs to be subtracted from levels on diagram to correct to m AHD (artefact of engineering design program not being able to handle negative AHD numbers).

2.2 HYDROLOGICAL DATA

Average water level data (daily and hourly) was obtained from DEWNR for Goolwa Barrage (Upstream) (Site ID A4261034), Wellington (A4261159), Murray Bridge (A4261162) and Mannum (A4261161).

Meteorological data, including wind speed and direction at 15 minute intervals was obtained from the SAMDB NRM Board, where names identify the station, e.g. Narrung (http://aws.naturalresources.sa.gov.au/). Assessments using meteorological data are found in Section 3.2 below.

2.3 HYDRAULIC ENGINEERING CALCULATIONS

LMRIA siphons were designed to have a minimum 0.20 m of head above the highest bay on each property serviced by a siphon/sluice, to enable an adequate depth of flow to irrigate. Critical operating levels are determined by using a typical siphon (600 mm diameter, 27 m long) supplying 20 ML/day with 0.10 m head loss through the siphon. Details of the calculations and flows at different head losses are shown in Appendix 2.

3 RESULTS AND DISCUSSION

3.1 IRRIGATION INFRASTRUCTURE ELEVATIONS

The 2017 survey, comprising data from 89 irrigation siphons, was compared to the previous design and survey levels (pre-drought) (Table 2). The level of the siphon lip has shown minimal change since installation (pre-drought) in a majority of cases, although at a few siphons there were changes of up to ±0.4 m. The natural surface level (NSL) has shown a much larger regional change, sinking on average 0.17 m per irrigation bay, and up to 0.6 m at a few sites. This appears to be due to the drying and slumping of the LMRIA floodplain during the extreme drought, where the soil desiccated deeply due to lack of irrigation (Mosley et al., 2014). There is a wide range of infrastructure critical operating levels (-0.98 to +0.65 m AHD), with a median of ±0.2 m AHD. A proposed critical water level to protect the entire LMRIA region is discussed below.

Table 2. Irrigation infrastructure survey data and calculations comparing the pre-drought and 2017 (post-drought) periods. The key survey points were the lip of the siphon outlet (LIP), the Natural Surface Level (NSL) and the Design Water Level (DWL) on the irrigation bay immediately adjacent to the outlet (see Methods and Figure 2 for more details). The Critical Operating Level is based on a typical irrigation siphon (600 mm diameter, 27 m long) supplying 20 ML/day, with a 0.10 m loss in head through the siphon.

	ORIGINAL DESIGN ABS SURVEY DATA						2017 SURVEY DATA					FINAL LEVEL CALCULATIONS	
Irrigation Area	**Sluice**	**Siphon**	**DWL**	**Meter Inv**	**LIP**	**NSL**	**NEW LIP**	***LIP DIFF***	**NEW NSL**	***NSL DIFF***	**LEVEL SINKAGE ASSUMPTION**	**NEW DWL**	**Critical Operating Level**
Wellington													
		600	-0.04	-1.45							ASSUME 0.15m	-0.19	-0.09
		600	-0.13	-1.50							ASSUME 0.15m	-0.28	-0.18
Jervois													
		600	0.00	-1.38	-0.60	-0.04					ASSUME 0.15m	-0.15	-0.05
		600	-0.49	-1.83	-1.00	-0.63					ASSUME 0.15m	-0.64	-0.54
		600	-0.41	-1.80	-0.97	-0.63	-0.81	*0.16*	-1.05	*-0.42*	ADOPT NS DIFF.	-0.83	-0.73
		600	-0.36	-1.80	-0.97	-0.55			-1.01	*-0.46*	ADOPT NS DIFF.	-0.82	-0.72
		600	-0.23	-1.75	-0.92	-0.60	-1.00	*-0.08*	-1.01	*-0.41*	ADOPT NS DIFF.	-0.64	-0.54
		450	-0.50	-1.80	-1.15				-0.86		ADOPT NS DIFF.	-0.50	-0.40
		600	-0.37	-1.57	-0.62	-0.58	-1.01	*-0.39*	-1.10	*-0.52*	ADOPT NS DIFF.	-0.89	-0.79
		600	-0.51	-1.83	-0.88	-0.67	-0.94	*-0.06*	-0.86	*-0.19*	ADOPT NS DIFF.	-0.70	-0.60
		600	-0.44	-1.72	-0.77	-0.70			-0.73	*-0.22*	ADOPT NS DIFF.	-0.66	-0.56
		600	-0.56	-1.84	-0.89	-0.66	-0.79	*0.10*	-0.97	*-0.31*	ADOPT NS DIFF.	-0.87	-0.77
		600	-0.50	-1.57	-0.72	-0.30	-0.62	*0.10*	-0.88	*-0.58*	ADOPT NS DIFF.	-1.08	-0.98
		600	-0.22	-1.58	-0.75	-0.71	-0.69	*0.06*	-0.73	*-0.02*	ADOPT NS DIFF.	-0.24	-0.14
		600	-0.32	-1.58	-0.75	-0.75			-0.88	*-0.15*	ADOPT NS DIFF.	-0.47	-0.37
		600	-0.20	-1.30	-0.50	-0.76	-0.87	*-0.37*	-1.01	*-0.25*	ADOPT NS DIFF.	-0.45	-0.35
		600	-0.02	-1.30	-0.27	-0.38	-0.23	*0.04*	-0.88	*-0.50*	ADOPT NS DIFF.	-0.52	-0.42
		600					-0.55		-0.05	*-0.3*	ADOPT NS DIFF.		
		600	0.23	-1.25	-0.42	0.01	-0.38	*0.04*	-0.10	*-0.11*	ADOPT NS DIFF.	0.12	0.22
		600	0.03	-1.25	-0.42	-0.27	-0.49	*-0.07*	-0.65	*-0.38*	ADOPT NS DIFF.	-0.35	-0.25

	ORIGINAL DESIGN ABS SURVEY DATA						2017 SURVEY DATA					FINAL LEVEL CALCULATIONS	
Irrigation Area	**Sluice**	**Siphon**	**DWL**	**Meter Inv**	**LIP**	**NSL**	**NEW LIP**	***LIP DIFF***	**NEW NSL**	***NSL DIFF***	**LEVEL SINKAGE ASSUMPTION**	**NEW DWL**	**Critical Operating Level**
		600					-0.38		-0.44	*-0.37*	ADOPT NS DIFF.		
		600	0.01	-1.36	-0.53	-0.32	-0.65	*-0.12*	-0.68	*-0.36*	ADOPT NS DIFF.	-0.35	-0.25
		600	0.12	-1.26	-0.31	-0.67	-0.18	*0.13*	-0.84	*-0.17*	ADOPT NS DIFF.	-0.05	0.05
		600	0.12	-1.26	-0.31	-0.55	-0.28	*0.03*	-0.46	*0.09*	ADOPT NS DIFF.	0.21	0.31
		600	0.09	-1.06	-0.25				-0.46		ADOPT NS DIFF.	0.09	0.19
		600	0.20	-1.23	-0.40	-0.08	-0.18	*0.22*	-0.09	*-0.01*	ADOPT NS DIFF.	0.19	0.29
		600	0.24	-1.04	-0.31	-0.18	-0.09		-0.34	*-0.16*	ADOPT NS DIFF.	0.08	0.18
		600	0.23	-1.15	-0.32	-0.12	-0.22	*0.10*	-0.13	*-0.01*	ADOPT NS DIFF.	0.22	0.32
		600	0.23	-1.15	-0.37	0.00	-0.26	*0.11*	0.01	*0.01*	ADOPT NS DIFF.	0.24	0.34
		600	0.23	-1.15	-0.37	-0.10				*0*	ADOPT NS DIFF.	0.23	0.33
		600	0.23	-1.25	-0.30	-0.02	0.09	*0.39*	0.05	*0.07*	ADOPT NS DIFF.	0.30	0.40
		600	0.16	-1.31	-0.50	-0.11	-0.42	*0.08*	-0.16	*-0.05*	ADOPT NS DIFF.	0.11	0.21
		600	0.02	-1.46	-0.51	-0.09	-0.27	*0.24*	-0.09	*0.00*	ADOPT NS DIFF.	0.02	0.12
		600	0.11	-1.37	-0.42	0.05	-0.24	*0.18*	-0.33	*-0.38*	ADOPT NS DIFF.	-0.27	-0.17
		600	0.36	-1.17	-0.22	0.20	-0.22	*0.00*	0.07	*-0.13*	ADOPT NS DIFF.	0.23	0.33
Woods Pt													
		600	0.30	-1.20	-0.25				-0.35		ASSUME 0.15m	0.15	0.25
		450	0.01	-1.20	-0.54				0.14		ASSUME 0.15m	-0.14	-0.04
		600	0.28	-1.20	-0.27				-0.03		ASSUME 0.15m	0.13	0.23
		600	0.27	-1.20	-0.28				-0.09		ASSUME 0.15m	0.12	0.22
		600	0.17	-1.20	-0.38				0		ASSUME 0.15m	0.02	0.12
Westbrook													
		450	0.13	-1.02	-0.37				0.03		ASSUME 0.15m	-0.02	0.08
		450	0.30	-1.00	-0.30				0.01		ASSUME 0.15m	0.15	0.25
Kilsby													
		450	0.41	-0.89	-0.24						ASSUME 0.15m	0.26	0.36

	ORIGINAL DESIGN ABS SURVEY DATA						2017 SURVEY DATA					FINAL LEVEL CALCULATIONS	
Irrigation Area	**Sluice**	**Siphon**	**DWL**	**Meter Inv**	**LIP**	**NSL**	**NEW LIP**	***LIP DIFF***	**NEW NSL**	***NSL DIFF***	**LEVEL SINKAGE ASSUMPTION**	**NEW DWL**	**Critical Operating Level**
		450	0.35	-0.99	-0.34						ASSUME 0.15m	0.20	0.30
Monteith													
	600		0.53	-0.80	-0.02	0.18	-0.03	*-0.01*	0.02	*-0.16*	ADOPT NS DIFF.	0.37	0.47
		600	0.50	-1.00	0.00	0.07							
	600		0.35	-0.91	-0.30	0.35	-0.41	*-0.11*	0.02	*-0.33*	ADOPT NS DIFF.	0.02	0.12
		600	0.40	-1.15	-0.20	0.30	-0.28	*-0.08*	0.15	*-0.15*	ADOPT NS DIFF.	0.25	0.35
		600	0.34	-0.76	-0.26	0.07	-0.24	*0.02*	-0.20	*-0.27*	ADOPT NS DIFF.	0.07	0.17
	600		0.37	-1.00	-0.22	0.07	-0.37	*-0.15*	-0.16	*-0.23*	ADOPT NS DIFF.	0.14	0.24
	600		0.50	-0.94	-0.10	0.23	-0.09	*0.01*	0.12	*-0.11*	ADOPT NS DIFF.	0.39	0.49
	600		0.38	-1.00	-0.22	0.07	-0.43	*-0.21*	-0.03	*-0.10*	ADOPT NS DIFF.	0.28	0.38
	600		0.22	-0.95	-0.38	-0.10	-0.39	*-0.01*	-0.35	*-0.25*	ADOPT NS DIFF.	-0.03	0.07
Yiddinga													
		450	0.36	-0.82	-0.17						ASSUME 0.15m	0.21	0.31
		450	0.16	-1.00	-0.35						ASSUME 0.15m	0.01	0.11
		450	0.28	-1.00	-0.32						ASSUME 0.15m	0.13	0.23
		450	0.36	-1.00	-0.19						ASSUME 0.15m	0.21	0.31
		450	0.39	-1.00	-0.16						ASSUME 0.15m	0.24	0.34
Riverglen													
		600	0.15	-1.33	-0.50						ASSUME 0.15m	0.00	0.10
		600	0.31	-1.17	-0.34						ASSUME 0.15m	0.16	0.26
		600	0.70	-1.04	-0.21						ASSUME 0.15m	0.55	**0.65**
		600	0.40	-1.04	-0.21						ASSUME 0.15m	0.25	0.35
		600	0.60	-1.00	-0.15						ASSUME 0.15m	0.45	**0.55**
Long Island													
		600	0.30	-1.13	-0.25						ASSUME 0.15m	0.15	0.25
	500/598		0.25	-0.90	-0.22	0.10					ASSUME 0.15m	0.10	0.20

	ORIGINAL DESIGN ABS SURVEY DATA						2017 SURVEY DATA					FINAL LEVEL CALCULATIONS	
Irrigation Area	**Sluice**	**Siphon**	**DWL**	**Meter Inv**	**LIP**	**NSL**	**NEW LIP**	***LIP DIFF***	**NEW NSL**	***NSL DIFF***	**LEVEL SINKAGE ASSUMPTION**	**NEW DWL**	**Critical Operating Level**
		600	0.30	-1.13	-0.30						ASSUME 0.15m	0.15	0.25
	500/600		0.25	-1.03	-0.20	0.10					ASSUME 0.15m	0.10	0.20
Long Flat													
		600	0.39						0.14		ASSUME 0.15m	0.24	0.34
		600	0.22						-0.03		ASSUME 0.15m	0.07	0.17
		600	0.16				-1.31		-0.09		ASSUME 0.15m	0.01	0.11
		600	0.25				-0.90		0.00		ASSUME 0.15m	0.10	0.20
Mypolonga													
	600		0.39	-0.87	-0.26	0.15	-0.43		0.14	*-0.01*	ASSUME 0.08m	0.31	0.41
	600		0.39	-0.87	-0.27	0.15	-0.65		0.07	*-0.08*	ASSUME 0.08m	0.31	0.41
	600		0.45	-0.87	-0.25		-0.44		0.03		ASSUME 0.08m	0.37	0.47
	600		0.46	-0.87	-0.25						ASSUME 0.08m	0.38	0.48
	600		0.37	-0.87	-0.23						ASSUME 0.08m	0.29	0.39
	600		0.39	-0.87	-0.27	0.15	-0.30		0.01	*-0.14*	ASSUME 0.08m	0.31	0.41
	600		0.39	-0.87	-0.26	0.15					ASSUME 0.08m	0.31	0.41
Neeta													
	600		0.24	-0.75	-0.31						ASSUME 0.15m	0.09	0.19
	600		0.25	-1.15	-0.30						ASSUME 0.15m	0.10	0.20
	600		0.41	-0.80	-0.20	-0.05					ASSUME 0.15m	0.26	0.36
	600		0.50	-1.11	-0.23	0.17					ASSUME 0.15m	0.35	0.45
	600		0.47	-0.65	-0.15	0.26					ASSUME 0.15m	0.32	0.42
	600		0.36	-1.13	-0.24						ASSUME 0.15m	0.21	0.31
	600		0.43	-0.72	-0.15	0.35					ASSUME 0.15m	0.28	0.38
	600		0.50	-1.00	-0.15	0.24					ASSUME 0.15m	0.35	0.45
Cowirra													
	600		0.38	-0.80	-0.24						ASSUME 0.15m	0.23	0.33

	ORIGINAL DESIGN ABS SURVEY DATA						2017 SURVEY DATA					FINAL LEVEL CALCULATIONS	
Irrigation Area	**Sluice**	**Siphon**	**DWL**	**Meter Inv**	**LIP**	**NSL**	**NEW LIP**	***LIP DIFF***	**NEW NSL**	***NSL DIFF***	**LEVEL SINKAGE ASSUMPTION**	**NEW DWL**	**Critical Operating Level**
	600		0.54	-0.80	-0.22						ASSUME 0.15m	0.39	0.49
	600		0.44	-0.81	-0.21						ASSUME 0.15m	0.29	0.39
	600		0.25	-0.79	-0.30						ASSUME 0.15m	0.10	0.20
	600		0.37	-0.89	-0.28	0.10					ASSUME 0.15m	0.22	0.32
	800/600		0.38	-1.00	-0.20						ASSUME 0.15m	0.23	0.33
MEDIAN			**0.25**	**-1.12**	**-0.30**	**-0.04**	**-0.39**	**0.03**	**-0.13**	**-0.17**		**0.13**	**0.23**
MIN			**-0.56**	**-1.84**	**-1.15**	**-0.76**	**-1.31**	***-0.39***	**-1.10**	***-0.58***		**-1.08**	**-0.98**
MAX			**0.70**	**-0.65**	**0.00**	**0.35**	**0.09**	***0.39***	**0.15**	***0.09***		**0.55**	**0.65**

3.2 LOWER RIVER MURRAY WATER LEVELS AND THEIR RELATIONSHIP TO WIND

3.2.1 LONG TERM WATER LEVELS BELOW LOCK 1

Long term water levels in the River Murray between 2002 and 2017 are shown in Figure 4 for Goolwa Barrage, Murray Bridge and immediately downstream of Lock 1, with daily average flow over Lock 1 shown for context. The extreme period of the Millennium Drought (2007 to 2010) saw record low water levels throughout the Murray-Darling Basin, with areas at the very end of the system (such as the Lower Lakes, upstream of Goolwa Barrage) suffering the greatest. High rainfall throughout the catchment leads to large flow pulses, with almost immediate impact on water levels below Lock 1. Flow pulse examples include the drought-breaking flow event during 2010, 2012, 2013 and 2016 (Figure 4). Immediately below Lock 1, higher water levels in the River Murray channel during high river flows are reflective of the relatively narrow nature of the River Murray channel and less influence of water extraction.

Past Wellington, the River Murray enters the wide and shallow Lower Lakes (821.7km^2 total surface area) which dissipates the effects of high river flows on water levels. Water levels in the Lower Lakes are regulated using a series of barrages.

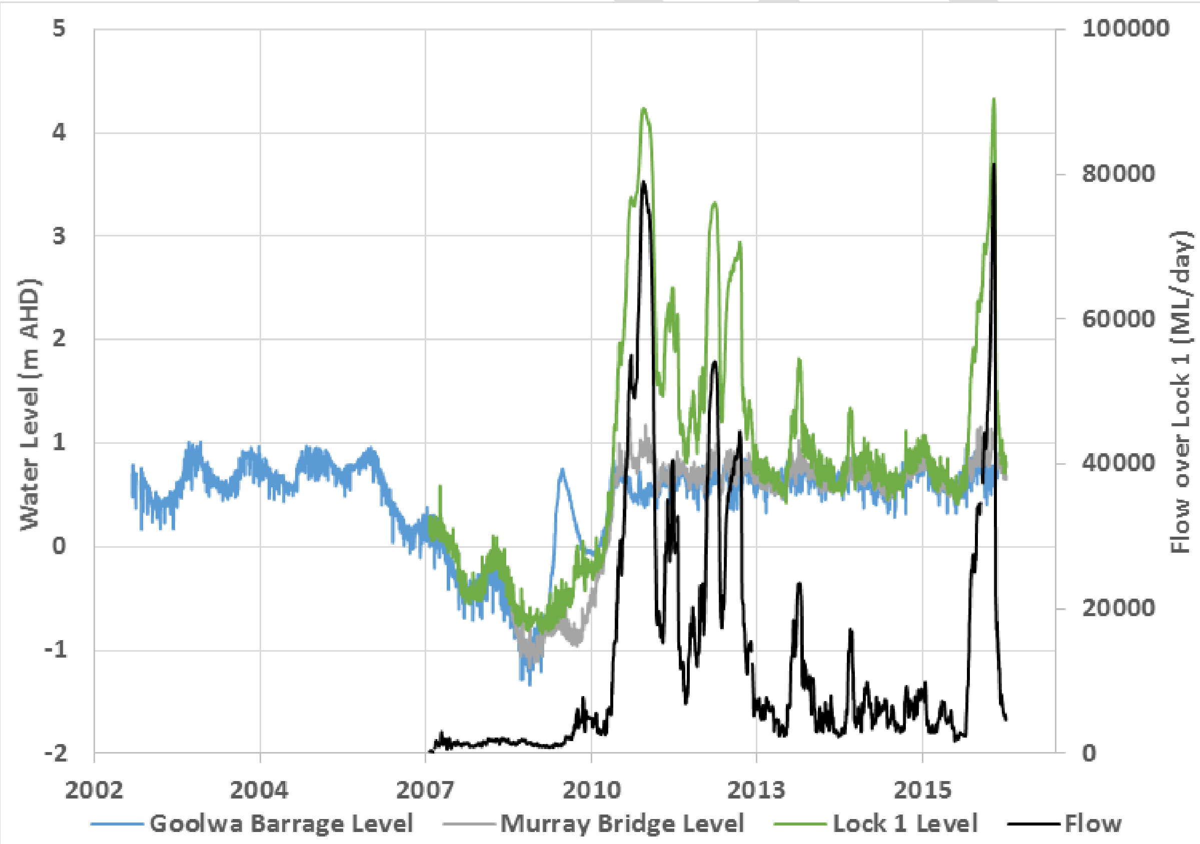

Figure 4. Long term daily average water level and flow over Lock 1 in the Lower Murray.

3.2.2 AVERAGE DIFFERENCE BETWEEN WATER LEVELS AT MANNUM, MURRAY BRIDGE AND WELLINGTON AND THE GOOLWA BARRAGE

In 2016, the average difference between water levels from the Goolwa Barrage and three sites upstream were compared. Differences ranged from 6cm at Wellington, 6 cm at Murray Bridge and 14 cm at Mannum (Figure 5). This supports the current understanding of water levels being approximately 10 cm higher in the Lower River Murray compared to the Lower Lakes. For example, a water level of 0.4 m AHD in the Lower Lakes translates on average to a water level of 0.5 m AHD in the River Murray. There is a lot of variability around this average level difference however due to the influence of wind (see below).

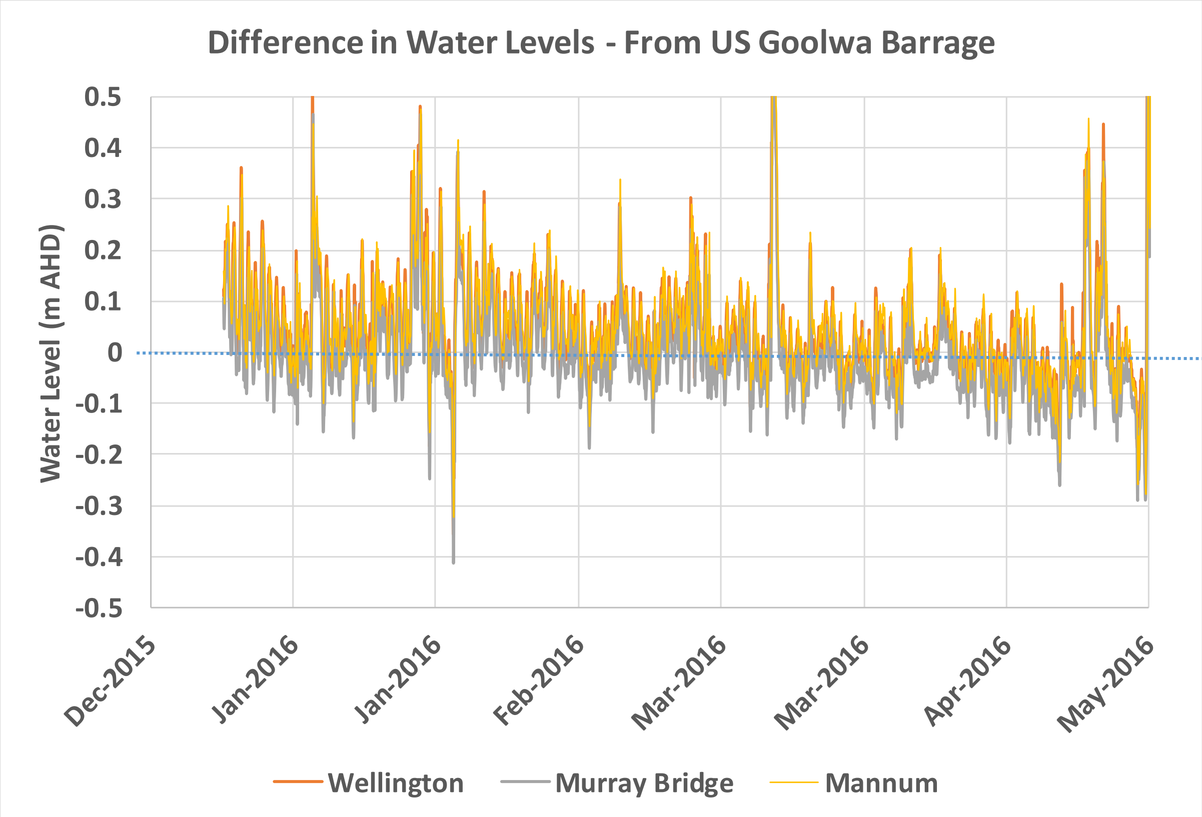

Figure 5. Differences in hourly water levels from Goolwa Barrage (Upstream) to Wellington, Murray Bridge and Mannum.

3.2.3 DIFFERENCE BETWEEN WATER LEVELS AT LOCK 1 AND AT THE GOOLWA BARRAGE

Differences in water levels at Wellington, Murray Bridge and Mannum compared to the Lower Lakes (measured upstream of Goolwa barrage) are shown in relation to wind speed and strength in Figure 6, Figure 7 and Figure 8 respectively. Similar patterns are observed across all sites. During strong W-SW winds (approx. 250-300 degrees), water levels become elevated (up to 0.75 m) compared to the Lower Lakes. In contrast, during strong N-NE winds (approx. 0 to 90 degrees) water levels decrease compared to the Lower Lakes. This is the effect of wind-seiching, moving water up or down the river respectively.

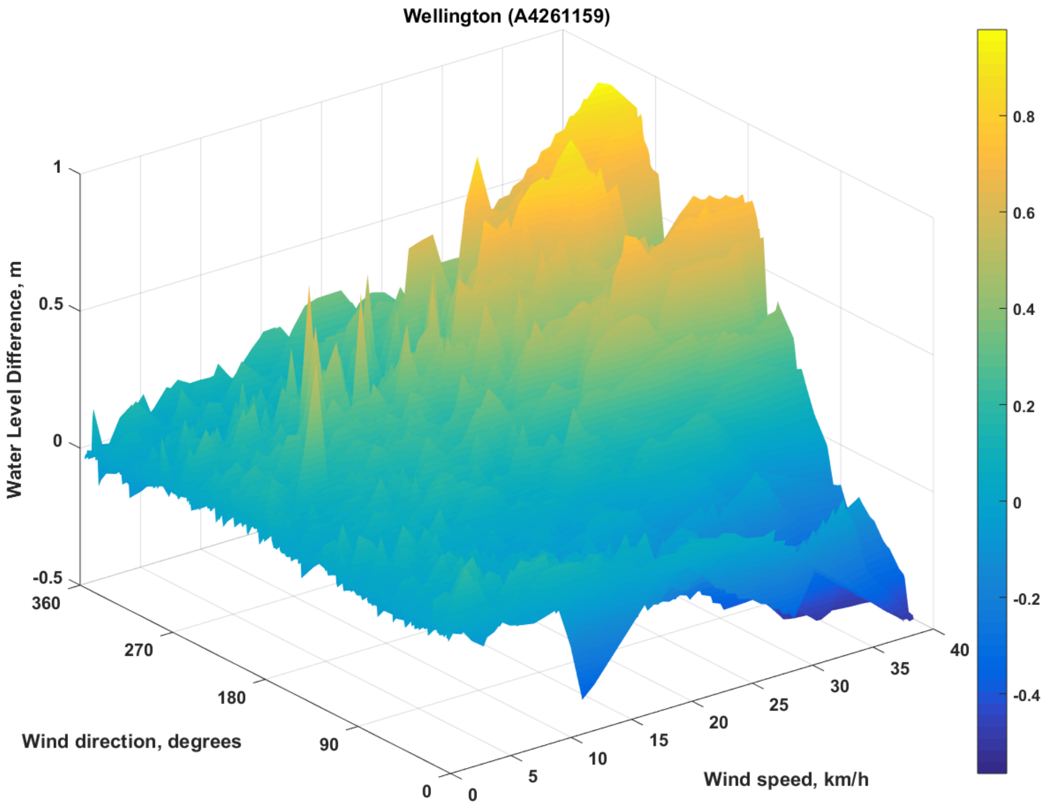

Figure 6. Difference in hourly water levels between Wellington and Goolwa Barrage (Upstream) versus wind direction (degrees) and speed (km/h) in 2016.

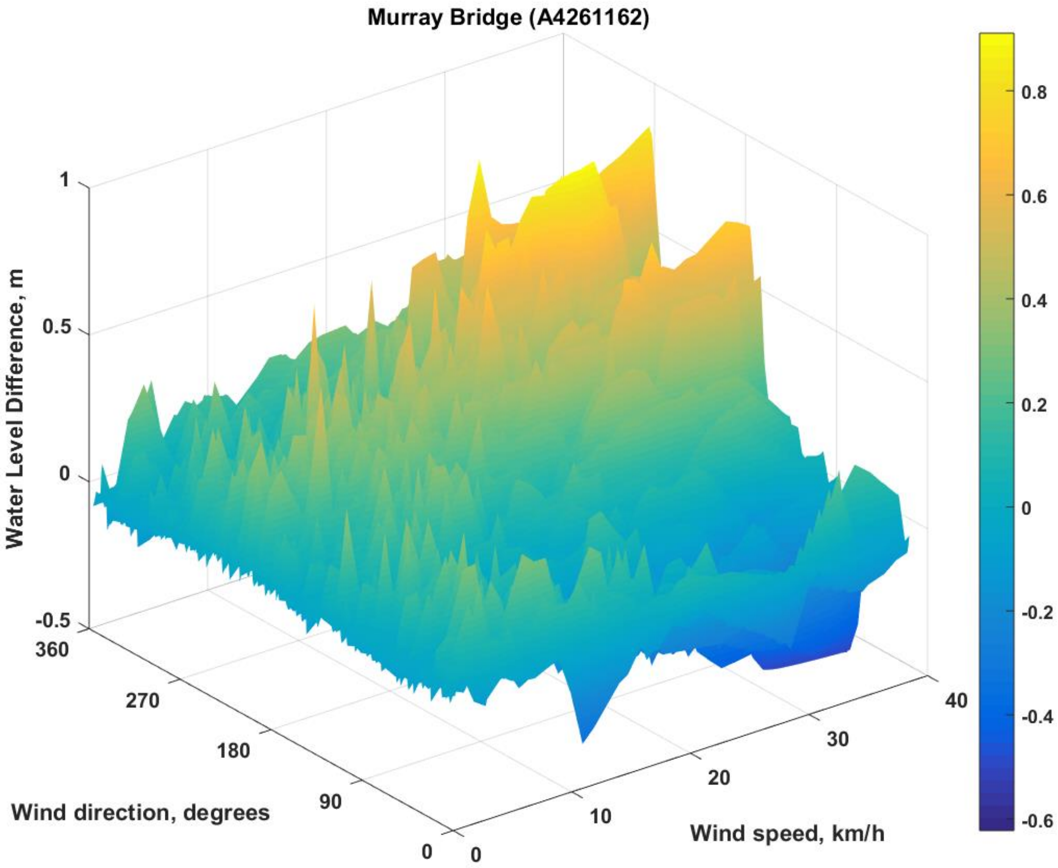

Figure 7. Difference in hourly water levels between Murray Bridge and Goolwa Barrage (Upstream) versus wind direction (degrees) and speed (km/h) in 2016.

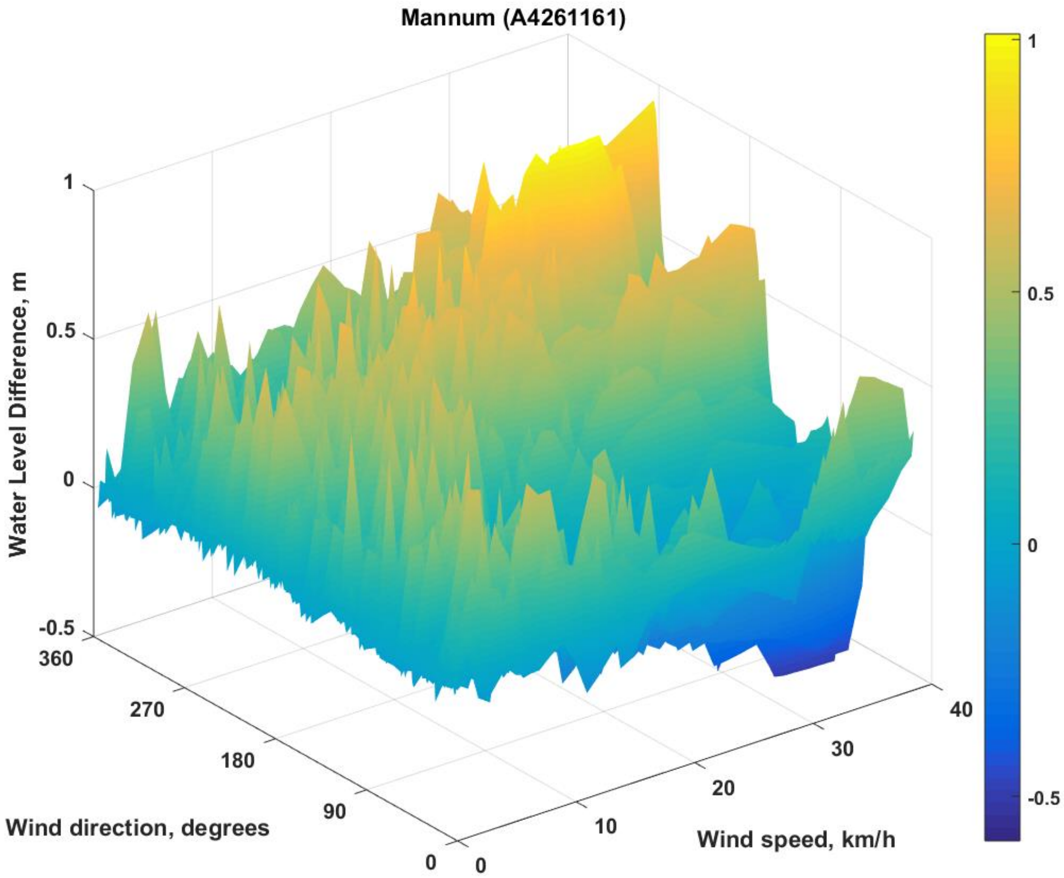

Figure 8. Difference in hourly water levels between Mannum and Goolwa Barrage (Upstream) versus wind direction (degrees) and speed (km/h) in 2016.

Predominant winds come from the W, WSW and NE directions (Figure 9) at Narrung, corresponding with the changes in water levels (positive and negative) in the River Murray (Figure 6, Figure 7 and Figure 8). Irrigating during W-SW wind conditions is likely to be beneficial for irrigators.

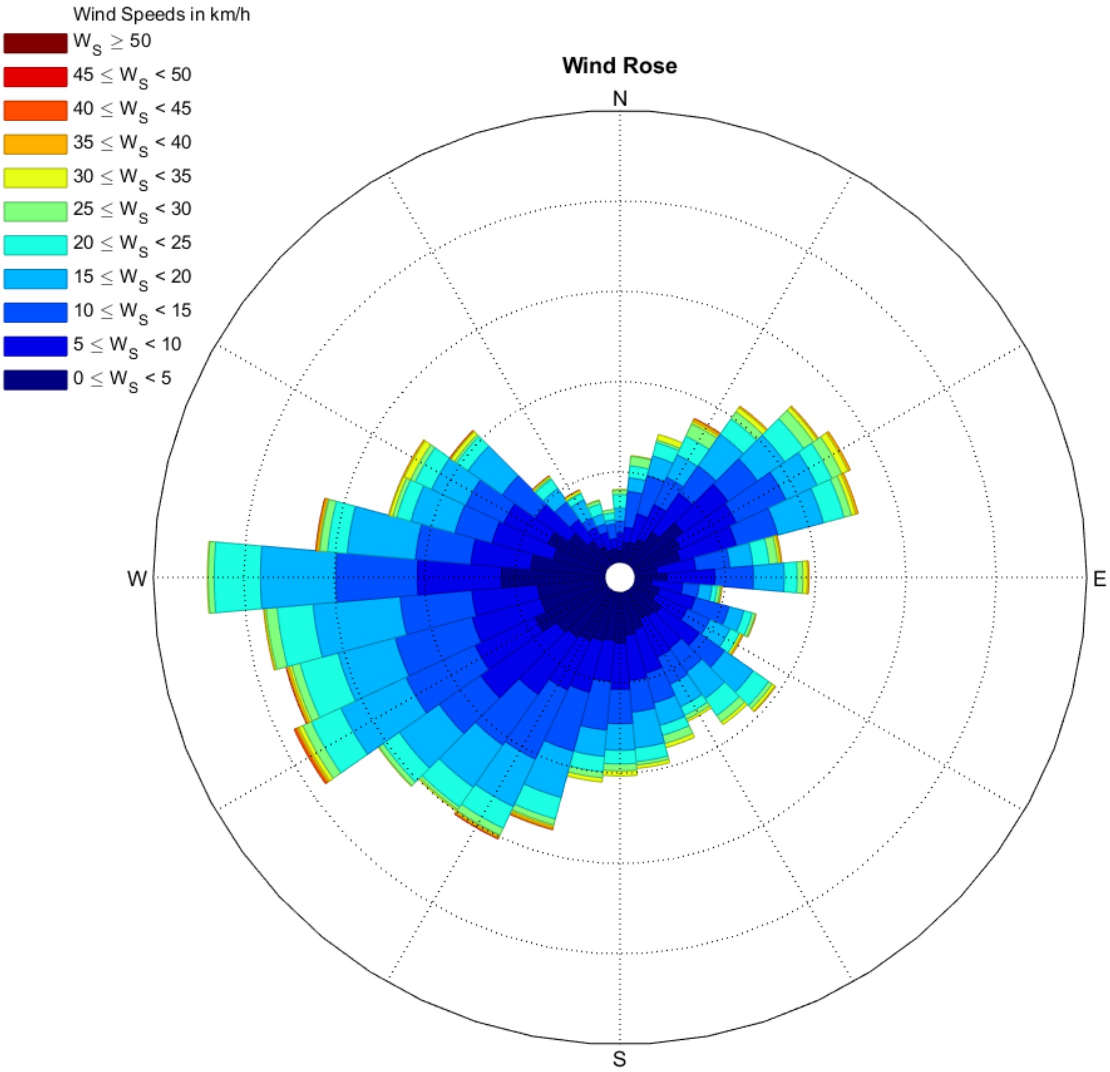

Figure 9. Wind Rose showing wind speeds (in km/h) and direction from the Narrung meteorological station (data recorded every 15 minutes) of the South Australian Murray-Darling Basin Natural Resources Management Board.

3.3 CRITICAL WATER LEVELS TO PROTECT IRRIGATION IN THE LMRIA

The critical water levels for operating individual siphons are shown in Table 2. A cumulative frequency plot of this data is shown in Figure 10. To protect the LMRIA during water level manipulation in the Lower lakes:

- The critical water levels for almost complete (>95%) protection of the LMRIA irrigation infrastructure corresponds to +0.5 m AHD between Mannum and Wellington, the value currently accepted by LMRIA irrigators.
- This corresponds to a critical water level average of approximately +0.4 m AHD in the Lower Lakes, as measured upstream of the Goolwa barrage.
- Daily and sub-daily water level fluctuations (+ve and –ve) occur due to wind seiching, but short term dynamics are not a primary consideration in setting critical levels for irrigation. This is because irrigation can be deferred a day or two if wind conditions are really unfavourable. In general, it should be favourable if irrigation occurs during W-SW wind conditions when water

is pushed up from the Lower Lakes, and less favourable in N-NE wind conditions. However, salinity of the Lower Lakes should also be taken into consideration for irrigating during W-SW conditions, particularly in the lower reaches of the LMRIA.

- The timing of any lowering of water levels below +0.4 m AHD in the Lower Lakes is important. The LMRIA irrigation season generally extends from September to April. Lowering water levels between May-August is unlikely to significantly impact the LMRIA due to the lack of irrigation at this time.
- If water levels fall to 0 m AHD (lower limit in the Basin Plan), approximately 80% of irrigators will be impacted and have to use alternative irrigation strategies.
- One irrigator with critical infrastructure levels higher than 0.5 m AHD is currently trying to secure funding to convert to a Pumped Pipe and Riser Irrigation delivery system, and one other irrigator with a siphon above the proposed critical level rarely irrigates.
- Alternative irrigation strategies involving low head-high volume pumps out of the siphon well (extended to approx. -1 m AHD, below level of siphon lip, see Figure 3) or travelling irrigators are possible in extreme low river level situations (Mosley et al., 2017b) but would require government support to be implemented regionally.

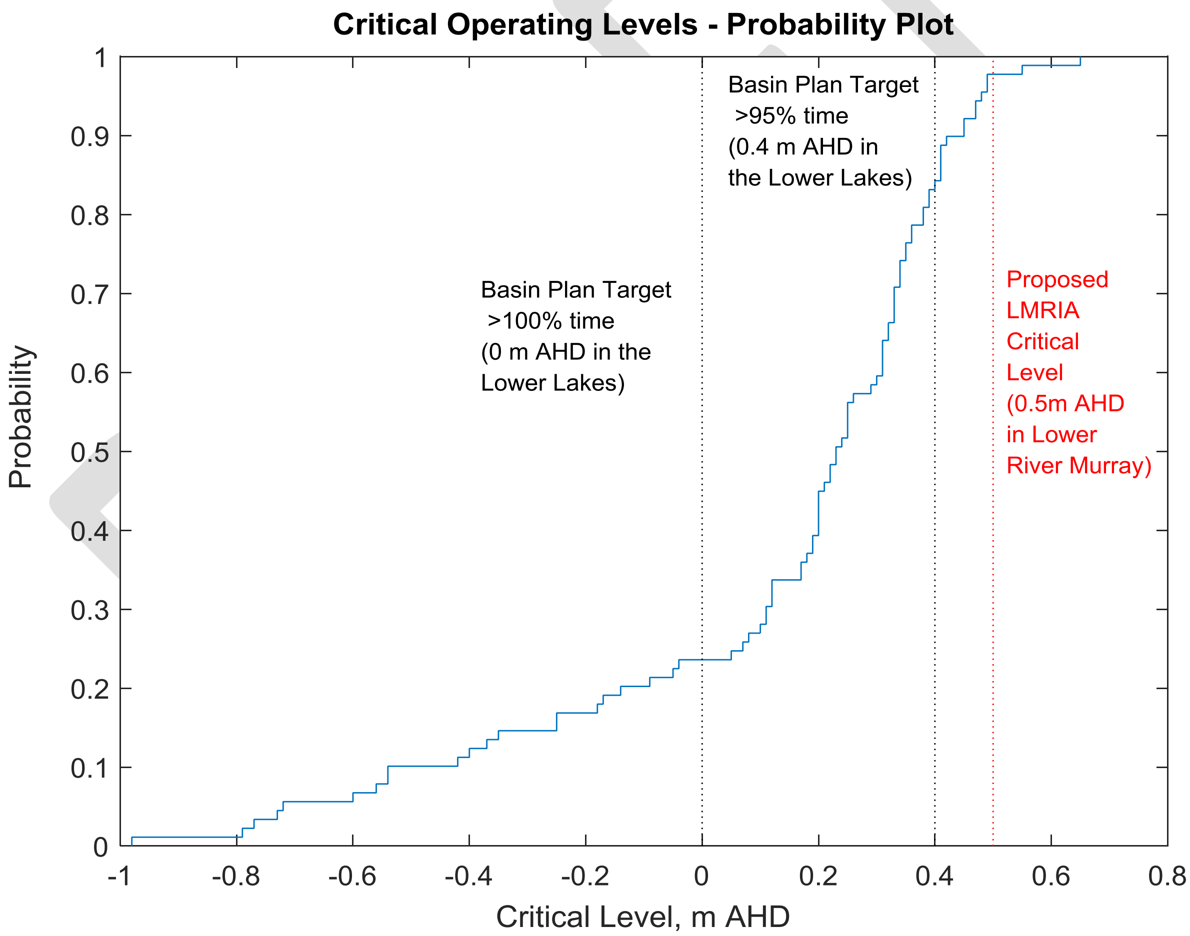

Figure 10. Cumulative frequency plot of the critical levels of individual LMRIA irrigation infrastructure (n=89). The vertical red dashed line at 0.5 m AHD is the proposed critical minimum water level in the Lower River Murray for regional protection of irrigation in the LMRIA. The black dotted lines are the Basin Plan targets to maintain the water level above 0.4 m AHD for 95% of the time and above 0 m AHD 100% of the time.

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5 APPENDIX 1

Survey points and irrigation infrastructure and natural land surface elevation data. Survey data collected by DEWNR using DGPS in April 2017. Datum is GDA 94 Zone 54, levels in m AHD. Data includes irrigation siphon lips and natural surface levels.

Irrigation Area	N	E	Level (m AHD)	Siphon ID
Jervois	6092662	354702.6	2.318	JBP1MARCH20
	6092609	354308.6	-1.0576	J2203
	6092617	354295.2	-1.0103	J2203
	6092614	354322.8	-0.9978	J2203
	6092632	354341.6	-1.0706	J2203
	6092072	353311.7	-0.8144	J18978
	6092086	353301.8	-1.0553	J18978
	6092711	354889.9	-1.0069	J17309
	6092728	354863	-1.105	J17309
	6092712	354897	-1.0692	J17309
	6092729	354903.3	-1.3021	J17309
	6092758	355639.6	-0.941	J17309
	6092758	355639.6	-0.9403	J17343
	6092783	355649	-0.8584	J17343
	6092779	355610.1	-0.92	J17343
	6092779	355610.1	-0.9191	J17343
	6092812	356031.9	-0.8673	J17342
	6092862	356367.7	-0.788	J17310
	6092884	356343.6	-0.9687	J17310
	6092889	356386.5	-1.1117	J17310
	6093207	357243.9	-0.6498	J18969
	6093216	357210.4	-0.8759	J18969
	6093236	357244.2	-0.9361	J18969
	6093211	357249.7	-0.6231	J18969
	6093388	357535.6	-1.147	J24085
	6093554	357750.9	-0.6836	J18165
	6093553	357729.3	-0.7751	J18165
	6093563	357761.9	-0.8789	J18165
	6093579	357761.9	-0.7335	J18165
	6093706	357951.3	-0.7687	J16932
	6093818	358087.4	-0.8717	J18986
	6093848	358082.2	-1.0155	J18986
	6094238	358712.2	-0.2303	J17900
	6094248	358676.9	-0.8796	J17900
	6094474	358980.7	-0.5508	J18974
	6094506	358995.6	-0.0481	J18974
	6094697	359163.1	-0.3847	J18976
	6094731	359167.1	-0.0986	J18976
	6095764	359500.7	-0.4939	J18980
	6095774	359470	-0.647	J18980

Irrigation Area	N	E	Level (m AHD)	Siphon ID
	6096276	359426.6	-0.3794	J18152
	6096283	359424.8	-0.4554	J18152
	6096297	359405.1	-0.4397	J18152
	6096857	359321.1	-0.6546	J18981
	6096842	359306.6	-0.6809	J18981
	6100007	355744.7	2.677	JWPBPMARCH21
	6100123	355607.2	-0.177	JWPR19929
	6100363	355374	0.0905	JWPR18286
	6100370	355343.6	0.045	JWPR18286
	6100806	354978.6	-0.4244	JWPR19875
	6100787	354978.9	-0.1611	JWPR19875
	6100813	354968.5	-0.4238	JWPR19872
	6100810	354938.3	-0.2125	JWPR19872
	6101055	354747.5	-0.2672	JWPR18271
	6101039	354743.7	-0.0935	JWPR18271
	6101466	354379.3	-0.237	JWPR18313
	6101445	354378.3	-0.3269	JWPR18313
	6101781	353855.5	-0.2233	JWPR18257
	6101762	353853.5	0.065	JWPR18257
	6097305	359116.5	-0.1831	JWPR17967
	6097338	359080.2	-0.8394	JWPR17967
	6097865	358693.4	-0.2817	JWPR17968
	6097865	358664.8	-0.4613	JWPR17968
	6098414	357917.5	-0.1776	JWPR20250
	6098410	357877.8	-0.0912	JWPR20250
	6098739	357411.3	-0.0874	JWPR18973
	6098716	357406.3	-0.3386	JWPR18973
	6099332	356541.6	-0.2173	JWPR19870
	6099301	356546.2	-0.1255	JWPR19870
	6099332	356494.4	-0.1298	JWPR19870
	6099341	356539.8	-0.105	JWPR19873
	6099807	355938.2	-0.2595	JWPR19876
	6099778	355946.3	0.0051	JWPR19876
	6099820	355896.3	-0.039	JWPR19876
	6099816	355937.3	-0.2204	JWPR19869
Long Flat	6111298	345298.7	2.173	LFBP1MARCH20
	6111262	345363	-0.861	LFR21848
	6111271	345379.6	0.3587	LFR21848
	6111112	345598.8	0.4197	LFR24081
	6110927	345795.4	0.5856	LFR1998
	6111462	345082.1	-0.4469	LFR24136
	6111492	345064.2	0.4484	LFR24136
Monteith	6104700	348051	2.826	MONTIETHRMARCH21
	6104665	348262.1	-0.1038	MR17796
	6104674	348289.6	0.1037	MR17796

Irrigation Area	N	E	Level (m AHD)	Siphon ID
	6104528	349199.5	0.1741	MR17815
	6104545	349202.2	0.3852	MR17815
	6104453	349639.9	-0.2052	MR17816
	6104471	349620.2	0.232	MR17816
	6104460	349683	0.1216	MR17816
	6104452	349650.8	-0.1688	MR17816
	6104246	350418.6	-0.1147	MR17876
	6104246	350418.7	-0.1269	MR17876
	6104267	350403.8	-0.0878	MR17876
	6106173	346535	0.2876	MR17818
	6106222	346532.3	0.2323	MR17818
	6105418	346694.7	0.1251	MR17797
	6105443	346698.2	0.557	MR17797
	6105400	346712.9	0.4955	MR17797
	6105114	346945.9	-0.1457	MR17795
	6105134	346940.1	0.2851	MR17795
	6104916	347287.1	-0.0139	MR17721
	6104935	347269.2	0.4179	MR17721
	6104803	347672.2	0.0242	MR17814
	6104821	347668	0.061	MR17814
Mypolonga	6120307	350533	4.042	MYPOBP1R
	6119794	349556	0.4799	MYPO18223
	6119817	349592.1	0.9551	MYPO18223
	6119824	349520	0.9389	MYPO18223
	6120132	348407.3	0.2687	MYPO17969
	6120150	348411.8	0.9913	MYPO17969
	6120172	348339.1	0.9664	MYPO17969
	6120279	347610.9	0.4961	MYPO18308
	6120300	347630	1.0641	MYPO18308
	6120295	347572.3	0.9225	MYPO18308
	6124843	349446.4	0.9913	MYPOSMART1
	6124603	349664.7	-2.8304	MYPOSMART2
	6124597	349650.3	0.8876	MYPOSMART2PADDOCK
	6124476	349777.3	1.2675	MYPOSMART3
	6124468	349766.3	1.1177	MYPOSMART3PADDOCK
	6124339	349884.4	1.264	MYPOSMART4
	6124334	349876.8	1.0884	MYPOSMART4PADDOCK
	6123823	350248.1	1.181	MYPOSMART5
	6123746	350280.5	0.9389	MYPOSMART6PADDOCK
	6123751	350291.6	1.201	MYPOSMART6A
	6123685	350330.7	1.1901	MYPOSMART7
	6123678	350318	0.9526	MYPOSMART7PAD
	6121075	350746.5	0.6228	MYPO18309
	6121112	350736.5	0.9346	MYPO18309
Pompoota	6126552	348033.4	3.845	POMR1MARCH21

Irrigation Area	N	E	Level (m AHD)	Siphon ID
	6126424	348225	1.2149	POMR15569
	6126395	348262.5	1.1089	POMR15569
	6126365	348295	1.1239	POMR15569
	6126335	348327.5	1	POMR15569
	6126306	348359.9	0.8242	POMR15569
	6126276	348392.9	0.8023	POMR15569
	6126245	348429.4	0.7784	POMR15569
	6126219	348463.8	0.8801	POMR15569
	6126991	347658.2	0.7849	POMR15577
	6127054	347639.9	0.7755	POMR15577
Wall Flat	6128518	347273.9	3.905	WALLFLATMARCH24R
	6128518	347273.9	3.905	WFRBPMARCH24
	6128518	347274.3	2.81	WALLFLATMARCH24R
	6128426	347209.8	0.4737	WFR15745
	6128465	347221	0.1742	WFR15745
	6128535	347248.7	0.1594	WFR15745
	6128827	347360	0.1759	WFR15768
	6128876	347376.5	0.2681	WFR15768
	6128923	347391.9	0.3054	WFR15768
	6129112	347460	0.1224	WFR15739
	6129067	347444.6	0.0936	WFR15739
	6129024	347432.9	0.1338	WFR15739
	6129650	347489.5	0.0158	WFR15703
	6129593	347516.1	-0.0606	WFR15703
	6129543	347552.1	0.2808	WFR15703
	6127859	347138	0.4386	WFR15778
	6127801	347140	0.3215	WFR15778
	6127728	347136.4	0.2992	WFR15778
	6127263	347187.7	-0.8555	WFR15750
	6127339	347153	-0.0575	WFR15750
	6127265	347167.2	-0.0549	WFR15750
	6127193	347182.4	-0.1165	WFR15750

6 APPENDIX 2

Siphon headloss calculations, based on a typical original (pre-drought rehabilitation project) design with a 600mm Nominal Diameter x 27m Long Siphon. The green shaded line is the 10 cm headloss value used in the critical level calculations. At this headloss a flood irrigation siphon can supply about 20 ML/day which is in the optimum range for this region.

Headloss	Flow Rate	Flow Rate	Velocity
(m)	ML/Day	(l/sec)	(m/sec)
0.01	6.5	75.2	0.28
0.02	9.2	106.5	0.4
0.03	11.3	130.8	0.49
0.04	13.1	151.6	0.57
0.05	14.7	170.1	0.64
0.06	16.1	186.3	0.70
0.07	17.4	201.4	0.76
0.08	18.7	216.4	0.81
0.09	19.8	229.2	0.86
0.10	20.9	241.9	0.91
0.11	22.0	254.6	0.96
0.12	22.9	265.0	1.00
0.13	23.9	276.6	1.04
0.14	24.8	287.0	1.08
0.15	25.7	297.5	1.12
0.16	26.6	307.9	1.16
0.17	27.4	317.1	1.19