September 2015

PRE-FEASIBILITY ASSESSMENT

Managed Aquifer Recharge Wanaka-Cardrona

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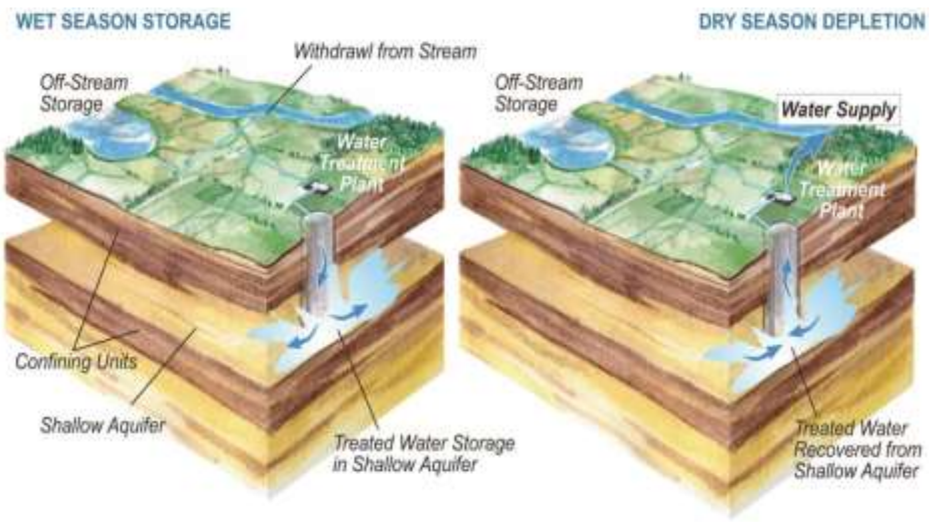

Report Number. 1534047-002

REPORT

Golder Associates

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List of Abbreviations and Units

Abbreviation/Unit	Name
µS/cm	Micro Siemens per centimetre – measure of electrical conductance
g	Grams
g/m^3	Grams per cubic metre
Golder	Golder Associates (NZ) Limited
GRS	Groundwater Replenishment Scheme
ha	Hectare
km	Kilometre
L/s	Litres per second
m	Metre
m^2/day	Metres squared per day
m^3/day	Cubic metres per day
MAR	Managed Aquifer Recharge
m bgl	Metres below ground level
Mm^3	Million cubic metres
NTU	Turbidity
ORC	Otago Regional Council
RL	Relative level

1.0 INTRODUCTION

1.1 Project Background

Otago Regional Council (ORC) has been carrying out hydrological and hydrogeological studies in the Wanaka-Cardrona area since 2003 to support improved water management planning for the area (ORC 2003, ORC 2007, ORC 2011). The Cardrona River loses flow once it leaves the narrow Cardrona Valley (at "The Larches") and regularly runs dry each summer upstream from State Highway 84. The river then gains flow from groundwater inflows downstream of the state highway. The flows in the Cardrona River are reduced and modified by surface water takes located at the southern edge of the Wanaka Basin, close to The Larches. The water races supplied by these takes are used to deliver irrigation water to significant areas of the Wanaka Basin.

ORC has contracted Golder Associates (NZ) Limited (Golder) to carry out an initial study to identify if there is potential to take water from the Cardrona River during higher flow periods and store this water in the underlying aquifer for use during the irrigation season. The objective is to reduce surface water take volumes during the irrigation period in order to improve continuity of flow of the Cardrona River downstream of The Larches.

Managed Aquifer Recharge (MAR) is a proven technology used throughout the world to actively manage the replenishment of groundwater systems. The term 'MAR' represents a wide range of physical and regulatory tools that are used to develop groundwater recharge schemes (GRS). These schemes are often most effective when MAR is integrated with other water management tools such as surface water storage, irrigation water conveyance systems and planning processes where surface and groundwater resources are evaluated as part of an overall sustainable water management framework.

Previous studies on which this MAR pre-feasibility assessment has been based include a groundwater study (supported by a groundwater model) (ORC 2011) and assessments on the Cardrona River hydrology (ORC 2013).

1.2 Scope

Questions regarding the feasibility of a local MAR project that ORC is seeking answered through this initial study include:

1) How much water would be required to be stored in the aquifer to replace current surface water takes?
2) Could stored water be pumped from the aquifer at a rate sufficient to provide for irrigation requirements?
3) Could the existing water races be utilised for MAR?
4) How permeable are the underlying sediments?
5) Would artificially recharged groundwater be stored for a sufficient period of time to support utilisation during the irrigation season?

In addressing the above questions at a high level, this pre-feasibility report presents:

- An initial assessment of the aquifer potential for recharge and storage.
- An initial assessment of source water suitability and availability for a GRS.
- An initial assessment of potential recharge areas.
- An assessment of potential fatal flaws to establishing a GRS in the Wanaka-Cardrona area.
- The methodology to support development of a GRS in the Wanaka-Cardrona area.
- An outline of a generic decision matrix that can be used to assess the viability of a GRS.

1.3 Hydrological Setting

The Cardrona River flows northwest for approximately 40 km, down the steep and narrow Cardrona Valley, before discharging into the Clutha River/Mata-Au at Albert Town. The Cardrona River has a catchment area of 337 km^2, which is bordered by the Crown Range to the south and west and the Criffel Range to the east (ORC 2007). The narrow Cardrona River valley opens onto the Wanaka Basin at The Larches.

The Wanaka-Cardrona Aquifer consists of glacial outwash gravels and sands that fill the Wanaka Basin. Water losses infiltrating through the bed of the Cardrona River over a 6 km reach downstream from The Larches are the primary source of recharge water to the Wanaka-Cardrona Aquifer. During winter, when there are no surface water abstractions from the river, an estimated 700 L/s of surface water is recharging the underlying aquifer (ORC 2011).

The lower reaches of Cardrona River to the east of Mt Iron are gaining reaches, in that they receive discharges from groundwater. Groundwater flows into the lower reaches of the Cardrona River at a rate of approximately 300 L/s (ORC 2011).

Bullock Creek is located on the north western edge of the Cardrona-Wanaka groundwater basin and flows through the Wanaka township. The creek is positioned along the base of a compacted moraine till area and gains flow from a series of springs. There are several prominent springs and numerous smaller springs that contribute to the total flow (ORC 2007). Most of the flow in Bullock Creek consists of seepage from the Wanaka-Cardrona Aquifer. Bullock Creek is the major groundwater discharge point from the aquifer. Groundwater discharge flows to Bullock have been linked to flow rates in the Cardrona River (GNS 1997; ORC 2003).

Flows at the Bullock Creek outlet to Lake Wanaka have been measured on a number of occasions and are generally in the order of 300 L/s to 600 L/s. Gaugings undertaken between 2001 and 2006 indicate base flows at the Bullock Creek outlet were between 300 L/s and 400 L/s (ORC 2007). Larger flows have been observed but were generally linked to rainfall run-off events.

Two of the major conclusions from the Integrated Water Resources Report (ORC 2011) are that the amount and timing of surface water takes for the water races has a significant influence on the annual volume of water available for natural infiltration into the aquifer. These takes are the primary influence on the habitat available for juvenile fish species and fish passage for the full length of the river.

1.4 Regulatory Setting

1.4.1 Deemed permits

In addition to resource consents to take surface and ground water, the Otago region has *deemed permits*. Deemed permits allowed for the taking, damming and discharging of water and were issued under early mining legislation, including the Mining Act 1926. As gold mining declined, this water was increasingly used for irrigation (ORC 2013). There are community irrigation groups who operate irrigation schemes under deemed permits.

The Cardrona River is used as a source of water for three large irrigation schemes in the Wanaka Basin. Up to 1,200 L/s is taken from the river at The Larches and transported via an open race network to the greater Wanaka Basin. In 1991, under the Resource Management Act (RMA), every mining privilege was deemed to become a water permit for the taking or damming of water on the same terms and conditions as the original mining privilege. Deemed permits expire on 1 October 2021 (RMA Section 413(3)), at which time water permits will need to be sought to replace the deemed permits if water is to continue to be taken or dammed after that time.

1.4.2 Consented takes

Eighty-one groundwater take consents have been issued in the Cardrona catchment under the RMA (ORC 2013). A further five non-consumptive groundwater take consents have been issued since 2006 for construction dewatering.

Groundwater takes can be divided into two groups:

- Groundwater takes from the Cardrona alluvial ribbon aquifer, which comprises the river flats extending from Little Meg Creek in the south to The Larches in the north.
- Groundwater takes from the much larger Wanaka-Cardrona gravel aquifer.

Groundwater takes from the ribbon aquifer are managed as surface water takes, subject to the surface water allocation regime and minimum flow criteria. There are currently two consented groundwater takes from this aquifer, with a total consented use of up to 0.21 Mm^3/year.

In 2013, groundwater from the Wanaka-Cardrona Aquifer was taken through approximately 290 registered bores. At that time there were 55 consented consumptive groundwater takes. The 2013 aquifer allocation of groundwater by resource consents was estimated to be around 4.2 million m^3/year (ORC 2013).

In 2013 there were 41 consented surface water takes from the Cardrona River and its tributaries (ORC 2013). Of these:

- Nineteen were deemed permits and 22 were consented water takes.
- Twenty are primary allocation with a further 2 being supplementary allocation takes.

The combined instantaneous flow rate of the total primary permits (deemed and primary allocations) in the catchment was approximately 2.4 m^3/s (ORC 2013).

2.0 SOURCE WATER SUITABILITY AND AVAILABILITY

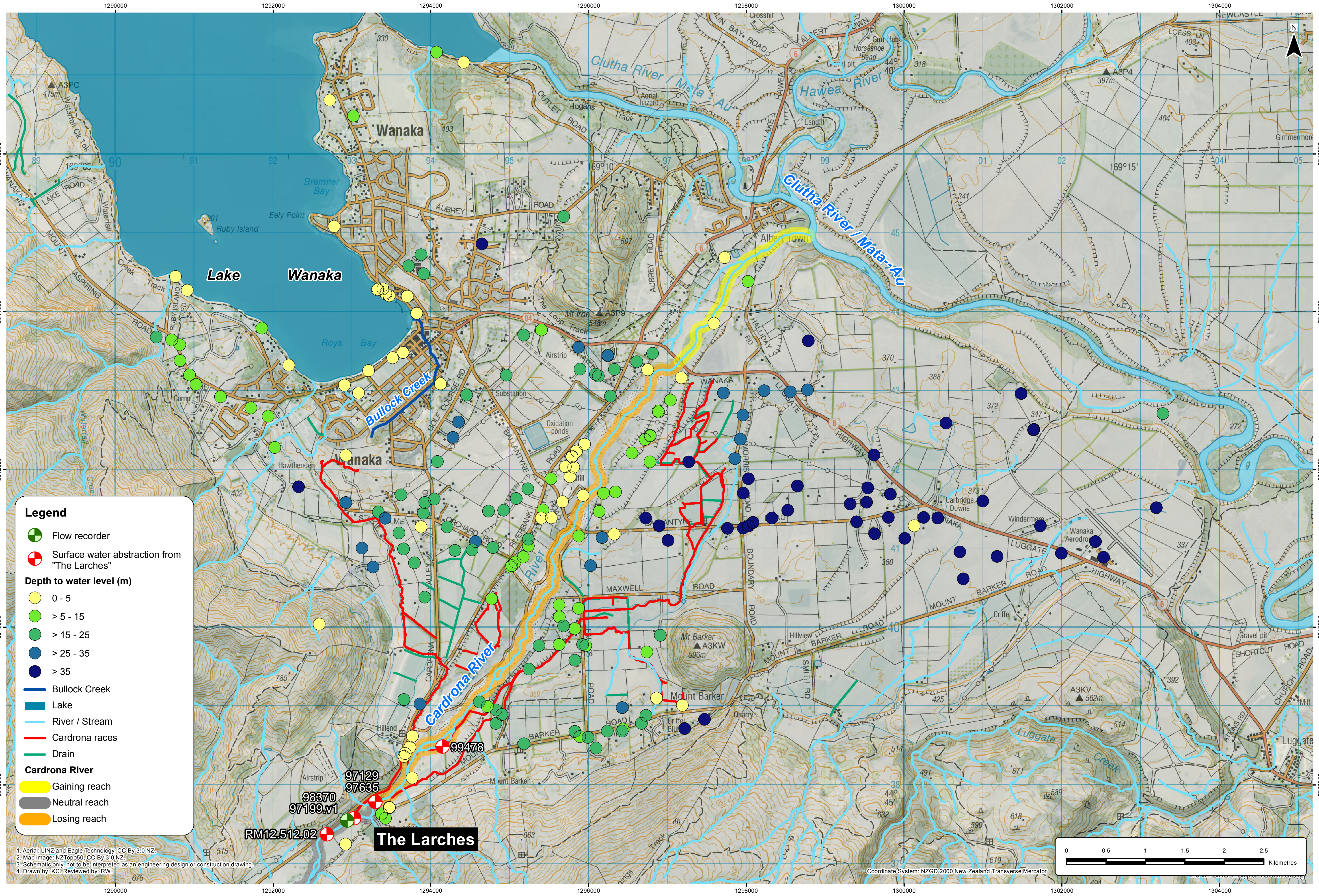
2.1 Cardrona River Flow Regime and Water Availability

The Larches flow monitoring site (also known as “Mt Barker” flow recorder) is located on the Cardrona River, approximately 8 km upstream of State Highway 6 (Figure 1). The site is currently operated by ORC and flow data is available from the mid-1970s.

Data derived from The Larches flow recorder is used to support the analysis of water availability in this section of the river. Water availability is not consistent in the Cardrona River downstream of The Larches site due to variable flows (refer Section 1.3). The river regularly dries out during the summer months below The Larches (ORC 2011). For this reason, water availability for any MAR project is based on the availability at The Larches only. It should also be noted that water is taken immediately upstream of the monitoring site at The Larches and this has not been accounted for in water availability calculations. This however this is considered a conservative approach in this context.

Water available from the Cardrona River during the irrigation off season (May to September inclusive) may be available to support additional recharge to the Wanaka-Cardrona Aquifer. The monthly average flow data from The Larches flow recorder provides an indication of what is potentially available at this location (Figure 2).

An in-stream habitat assessment undertaken on the Cardrona River (ORC 2011) suggested that minimum flows should be maintained at approximately 1.1 m^3/s (November to April) and 1.0 m^3/s (May to October) at The Larches to protect in-stream values along the lower Cardrona River (The Larches to the Clutha River/Mata-Au River). Currently the estimated minimum 7 day mean annual low flow (MALF) at The Larches is around 1 m^3/s (ORC 2011).



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TITLE WANAKA - CARDRONA GROUNDWATER BASIN

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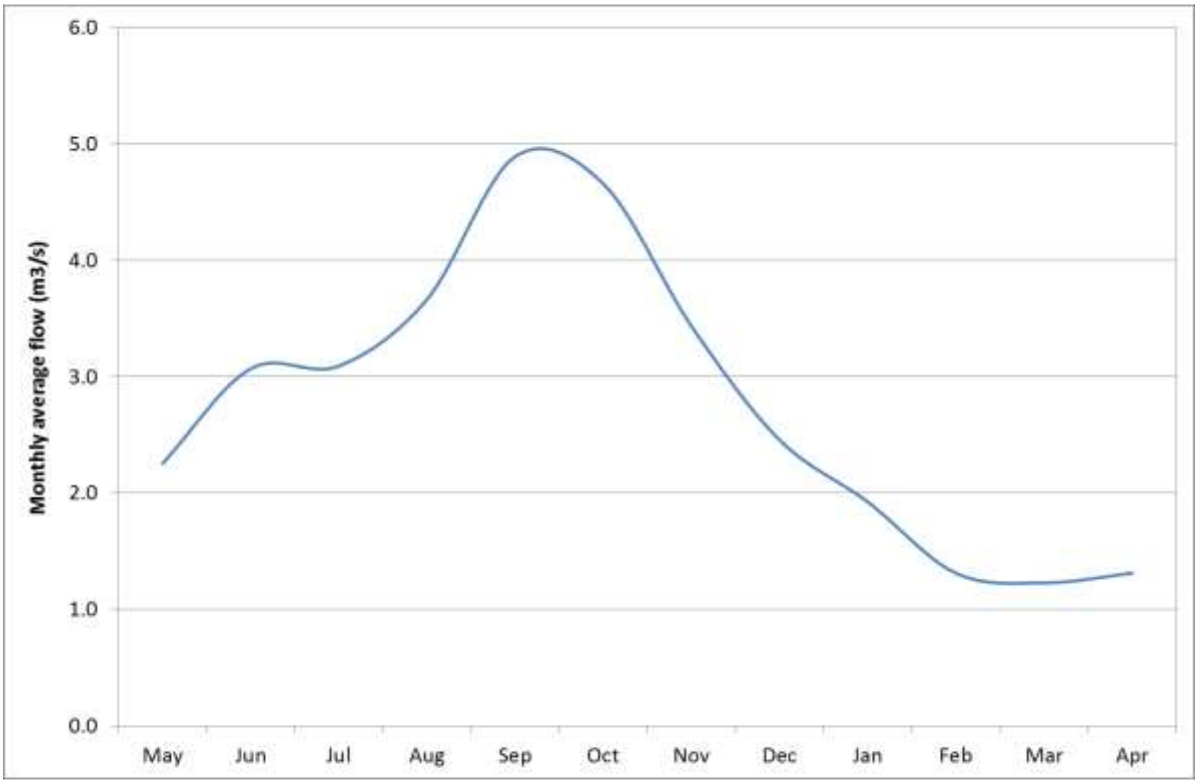


Figure 2: Cardrona River monthly average flow at The Larches.

Table 1 presents the monthly average flow data allowing for a minimum flow of around 1 m^3/s to be maintained within the river during water abstraction. The total available water volume during the irrigation off-season (May to November) would be around 48 Mm^3. Approximately 26 Mm^3 could be available on the shoulder of the irrigation season (September, October and November) when stream flows are elevated following snowmelt.

Table 1: Monthly average flow in the Cardrona River at The Larches

	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
	Irrigation Off Season							Irrigating				
The Larches average monthly flow (m^3/s)	2.3	3.1	3.1	3.7	4.9	4.7	3.4	2.5	1.9	1.3	1.2	1.3
Revised monthly flow(1) (m^3/s)	1.3	2.1	2.1	2.7	3.9	3.7	2.4	1.5	0.9	0.3	0.2	0.3
Total monthly volume(2) ($(Mm^3)^3$)	3.5	5.4	5.6	7.2	10.1	9.9	6.2	4.0	2.4	0.7	0.5	0.8
Total Available water (Mm^3)(3)	48							Not assessed				

Notes: (1)Assuming 1 m^3/s retained at The Larches for in-stream values. (2)Total discharge over the month. (3)1 Mm^3 = 1 million cubic metres.

2.2 Current Surface Water Usage

Three historic water race licences remain operative in the vicinity of The Larches flow recorder (Pers Comm. T De Pelsemaeker, ORC, 24 August 2015). These are called the “Wanaka Station race”, “Mt Barker race” and “Farrant race”. One additional active race has a true left bank off-take from Timber Creek, a left bank tributary of the Cardrona River in the vicinity of The Larches. These takes are associated with deemed water permits taking water from the Cardrona River (Table 2).

Table 2: Consent holders and water take limits for takes below The Larches.

Race ID	Consent no.	Consent holder	Consented take (L/s)	Comments
Mt Barker	97129/97635	Criffel Deer Ltd	138.9	No monitoring.
		Cochrane	138.9	No monitoring, limited to no use[1].
Farrant	99478	Dippie	250	Three properties share this race
		Cochrane		Has monitoring – irrigation race weir and logger.
		Farrant		
Wanaka	98370/97199.v1	JIT Hillend Investments Ltd	111	Two consents from same point of take. Has monitoring – irrigation race weir and logger.
		Orchard Road Holdings	500	Note 97199 has another (minor) point of take 5 km upstream of The Larches.
		South of Hillend		
		North Hillend		Further 18.2 ha flood/spray irrigated.
		Riverbank		
		North Orchard		
Other	99339	Hawthenden	55.5	Have a potential irrigable area of 200 ha but currently only irrigate 80 ha.
Total			**1,194.3**	

Notes: [1]Mt Barker properties predominantly irrigated with water from 99478 (Cochrane share).

The Mt Barker irrigation race originates on the true right bank of the Cardrona River just downstream of the Mount Barker road bridge at The Larches. No monitoring data exists for this take. It is understood that Criffel Deer (consent 97129) take most of the water from this race at a peak instantaneous rate of 138.9 L/s. Criffel Deer currently irrigate around 245.6 ha, the majority of which through spray irrigation.

The Farrant irrigation race (consent 99478) originates approximately 1 km downstream of the Mt Barker take, on the true left bank of the Cardrona River. No monitoring data exists for this take. The consented abstraction for this take is 250 L/s. It is understood that this take is the lowest priority take on the Cardrona River and as such there is rarely enough water during summer to fully supply the consented volume.

The Wanaka water race (consents 98370/9719) is by far the largest single water race by flow rate on the Cardrona River. The irrigation race off-take is located upstream of The Larches flow monitoring site on the true left bank. The combined consented abstraction for this take is 611 L/s. A short period of monitoring data exists for this take, from 13 November 2013 until 2 July 2015 (see Figure 3). Cumulative water abstraction for the 2014/2015 irrigation season varied between approximately 450,000 m^3/month and 550,000 m^3/month. Off-season takes were in the order of 100,000 m^3/month. The peak abstraction during the monitoring period was around 475 L/s. Total annual abstraction based on the monitoring data indicates that around 3 Mm^3 to 5 Mm^3 of water was abstracted over the 2013/2014 and 2014/2015 seasons.

The water race that abstracts water from Timber Creek (on the true left bank of the Cardrona River around 2 km upstream of The Larches) is currently un-named. The consented abstraction for this take is around 55 L/s. A short period of monitoring data (July 2014 to August 2015) is available. This data has not been analysed as there are several unresolved data validity issues.

Due to the general lack of monitoring data, an assessment of potential surface water usage has been made (refer Section 2.3). This assessment uses the existing irrigated areas and inferred irrigation rates (Aqualinc 2006).

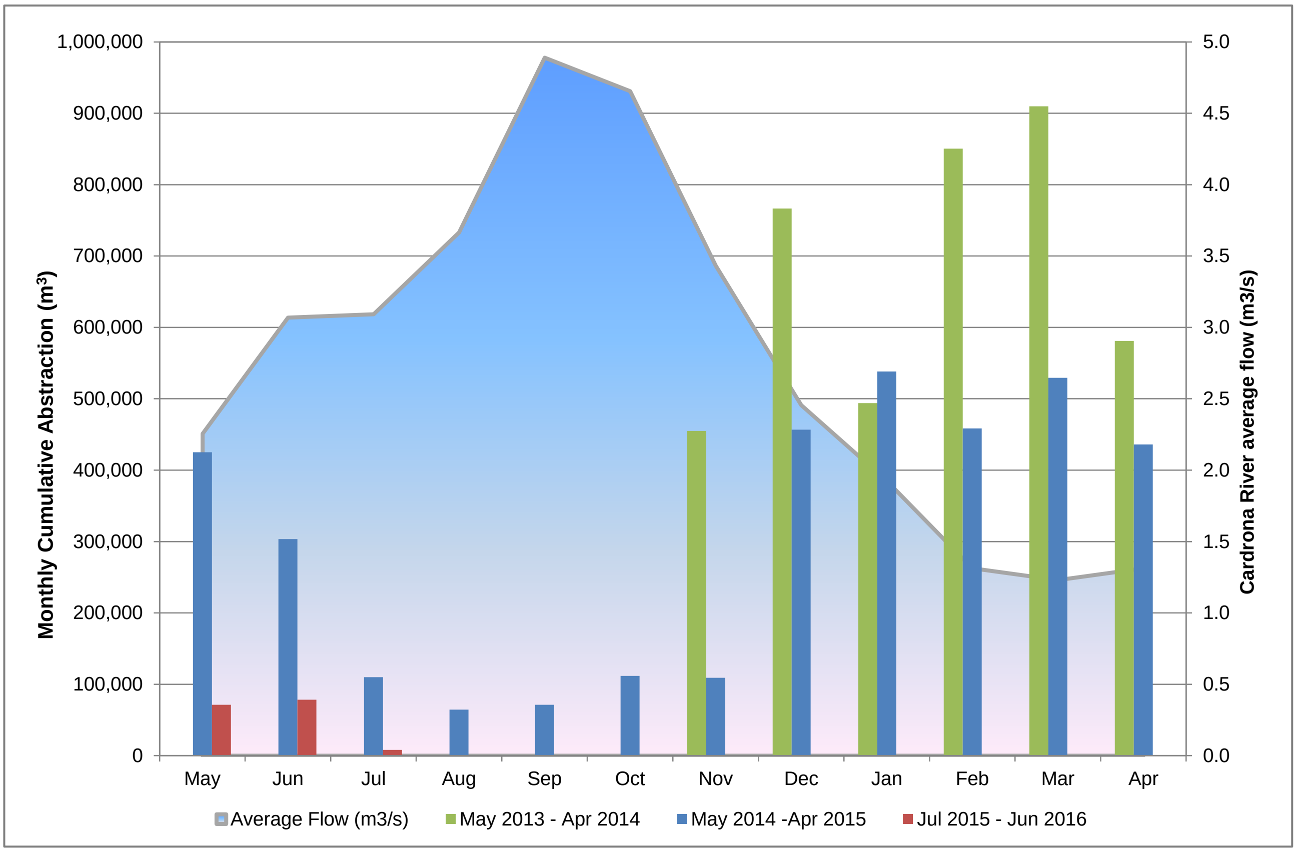
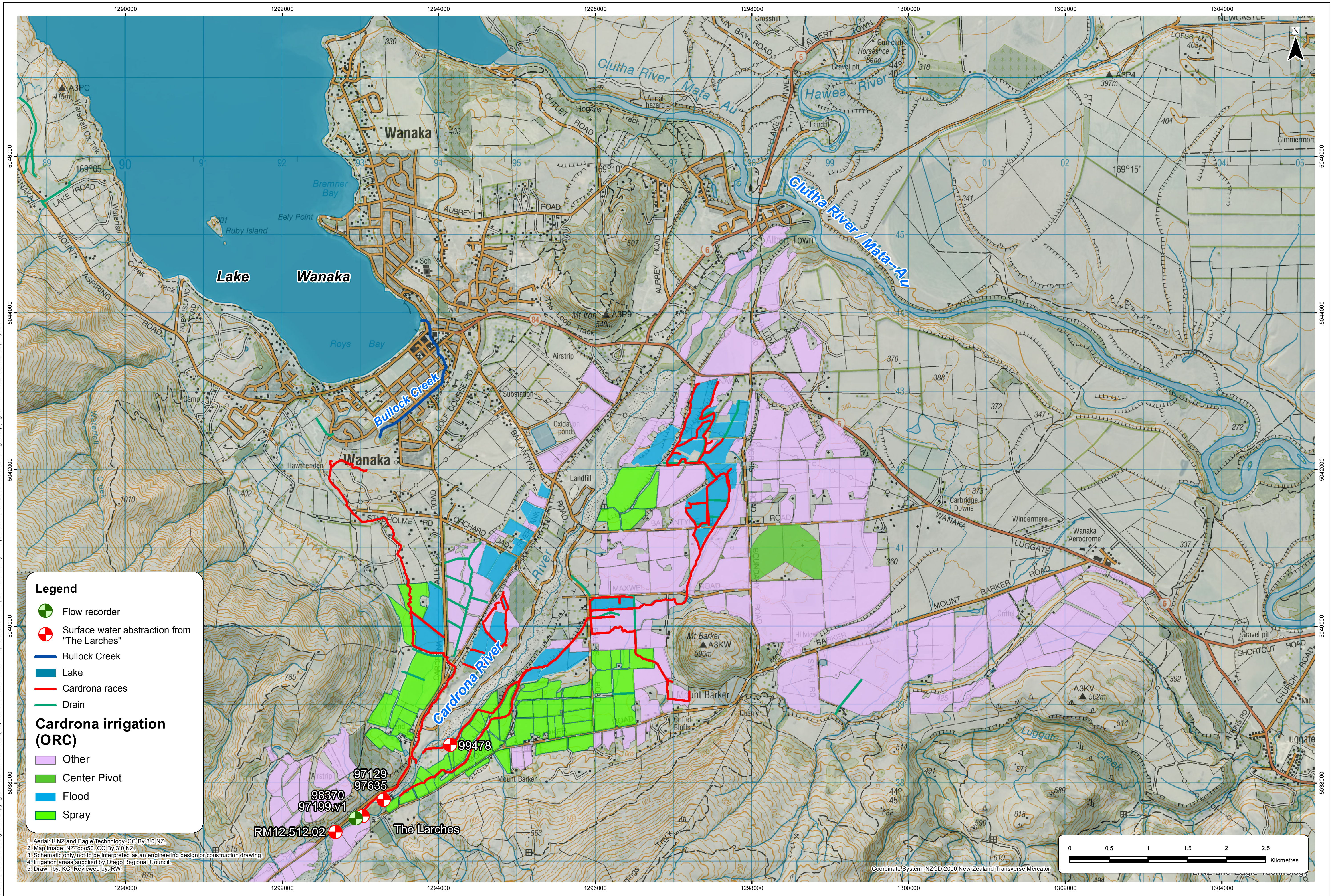


Figure 3: Wanaka water race monthly abstracted water volumes, November 2013-July 2015 and Cardrona River flows.

2.3 Annual Water Requirements for a MAR Project

A MAR project could look to offset current water requirements of the water races at The Larches and some additional groundwater replenishment to maintain and enhance the groundwater supply. Irrigated land in the Wanaka basin as recorded in the ORC database is shown in Figure 4.



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TITLE WANAKA WATER RACES AND IRRIGATION AREAS

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The area of land currently irrigated by water taken through the combined water races from The Larches is approximately 825 ha (data provided by ORC summarised in Table 3). An additional water race takes water from a tributary as outlined in Section 2.2. The irrigated area has not been included in these initial calculations. However, the additional area may be included at a later stage in a MAR project. This area has been used by Golder to calculate an initial assessment of the water requirements for efficient irrigation use. Based on the annual water irrigation requirements for the Upper Clutha area (Aqualinc 2006), the demand would be between 5,775 m^3/ha/year and 6,750 m^3/ha/year depending on soil conditions and irrigation return periods. This preliminary assessment implies the water requirements for irrigating 825 ha in the Wanaka Basin would be 4.8 Mm^3/year to 5.6 Mm^3/year.

The volume of water abstracted from the river through water races would require a greater volume due to evaporative and seepage losses from the races, and due to the use of flood irrigation techniques. For these reasons the estimated water requirement is similar to the recorded use for the Wanaka Race alone (Section 2.2).

Table 3: Land area currently irrigated by The Larches water races.

Consent no.	Race name	Property[1]	Flood area (ha)	Spray area (ha)	Flood/ Spray area (ha)	Approx. total (ha)	Comment
97129	Mt Barker	Criffel	20.6	225		245.6	
97635		Mt Barker (owner: Cochrane)					Limited to no use[2]
Mt Barker Race Total						**245.6**	
99478	Farrant	Dippie	44.5	27.9[3]		72.4	Three properties share this race
		Cochrane	52.9	50.8[3]		103.7	
		Farrant	38.7			38.7	
Farrant Race Total						**214.8**	
98370/97199	Wanaka	Hillend	15.2	97.2		112.4	Two consents from same point of take. Measured at one site
		South Hillend		9.2		9.2	
		North Hillend	13.6	60	18.2	91.8	
		Orchard Holdings	72.8			72.8	
		Riverbank	35.7			35.7	
		North Orchard	42.6			42.6	
Wanaka Race Total						**364.5**	
Total of three races			336.6	470.1[4]	18.2	**824.9**	

Notes: [1]Areas provided are approximate. [2]Mt Barker properties predominantly irrigated with water from 99478 (Cochrane share). [3]This area is currently not developed as irrigated pasture but has the potential to be put under irrigation. [4]Includes 78.7ha that is currently not irrigated but that could be developed into pasture in the future.

2.4 Current River Recharge

Locations and rates of natural recharge from the Cardrona River to the Wanaka-Cardrona aquifer have been derived through analysis of data from low flow gauging runs performed on the river (ORC 2007). Consecutive gauging runs were undertaken in 2001, 2002, 2004, 2005 and 2006. These runs start from Callaghan's Creek, some 20 km upstream of The Larches, and end at the Clutha River/Mata-Au confluence.

The highest flows recorded on the gauging runs were consistently observed at The Larches. Flow rates are reduced immediately downstream of The Larches, in part due to the large consented irrigation takes. Significant flow losses, not attributable to the water takes, also appear to occur between The Larches and Ballantyne Road (a 3 km reach). These flow losses are interpreted as being due to infiltration through the bed of the river to the Wanaka-Cardrona Aquifer. The reach between Ballantyne Road and SH6 is often at least partly dry during summer.

Initial estimates on losses from the Cardrona River to groundwater were estimated at 660 L/s to 900 L/s (ORC 2003). An aquifer water balance calculation (ORC 2011) used aquifer recharge of 22.1 Mm^3/year (from the Cadrona River between The Larches and SH6), which equates to 700 L/s (Section 3.2). Further research is required to more accurately quantify this recharge rate (ORC 2011).

2.5 Source Water Quality

Cardrona River water quality (Table 4) is of excellent quality with generally low levels of nutrients and sediment (ORC 2013). Water quality has shown an improvement in *Escherichia coli (E.coli)* concentrations and suspended solid concentrations between 2006 and 2011.

Water quality in the Cardrona River deteriorates after significant rainfall, with higher concentrations of bacteria, phosphorus, nitrogen and sediment being observed (ORC 2003; ORC 2006). These events occur naturally and presumably have the potential to influence the groundwater quality in the Wanaka-Cardrona Aquifer. On that basis, the groundwater quality in the Wanaka-Cardrona Aquifer already reflects the filtering capacity of the gravel aquifer and overlying unsaturated zone.

Depending on the site location, a MAR soakage basin has the potential to filter infiltrating water through a significant thickness of unsaturated gravel before it reaches the aquifer. The management of sediments in the water delivered to any MAR site will be an important factor in reducing the risk of clogging and maintaining the recharge efficiency at the site. Recharge efficiency is a factor that requires monitoring throughout the life of any MAR site.

Table 4: Median long-term water quality results, Cardrona River at Mt Barker monitoring site (ORC 2006).

	Turbidity (NTU)	*E.Coli* (n/100ml)	Ammonia-N (mg/L)	Nitrite Nitrate-N (mg/L)	Total N (mg/L)	Dissolved Reactive P (mg/L)	Total P (mg/L)
Long term median value at The Larches	1.9	86	0.005	0.041	0.105	0.0025	0.01

3.0 POTENTIAL FOR MANAGED AQUIFER RECHARGE

3.1 Aquifer Potential for Recharge and Storage

The Wanaka-Cardrona Aquifer consists of glacial outwash sands and gravels infilling the bedrock basin carved by glaciers. Generally these sediments have a high permeability, especially in the vicinity of Wanaka township, which is the location of the terminal moraine deposited by a glacier that flowed southeast through Wanaka. There are however areas of lower permeability silty deposits within the Wanaka basin, with remnants of the Manuherikia Formation identified during drilling close to Mt Barker and in Luggate (ORC 2011).

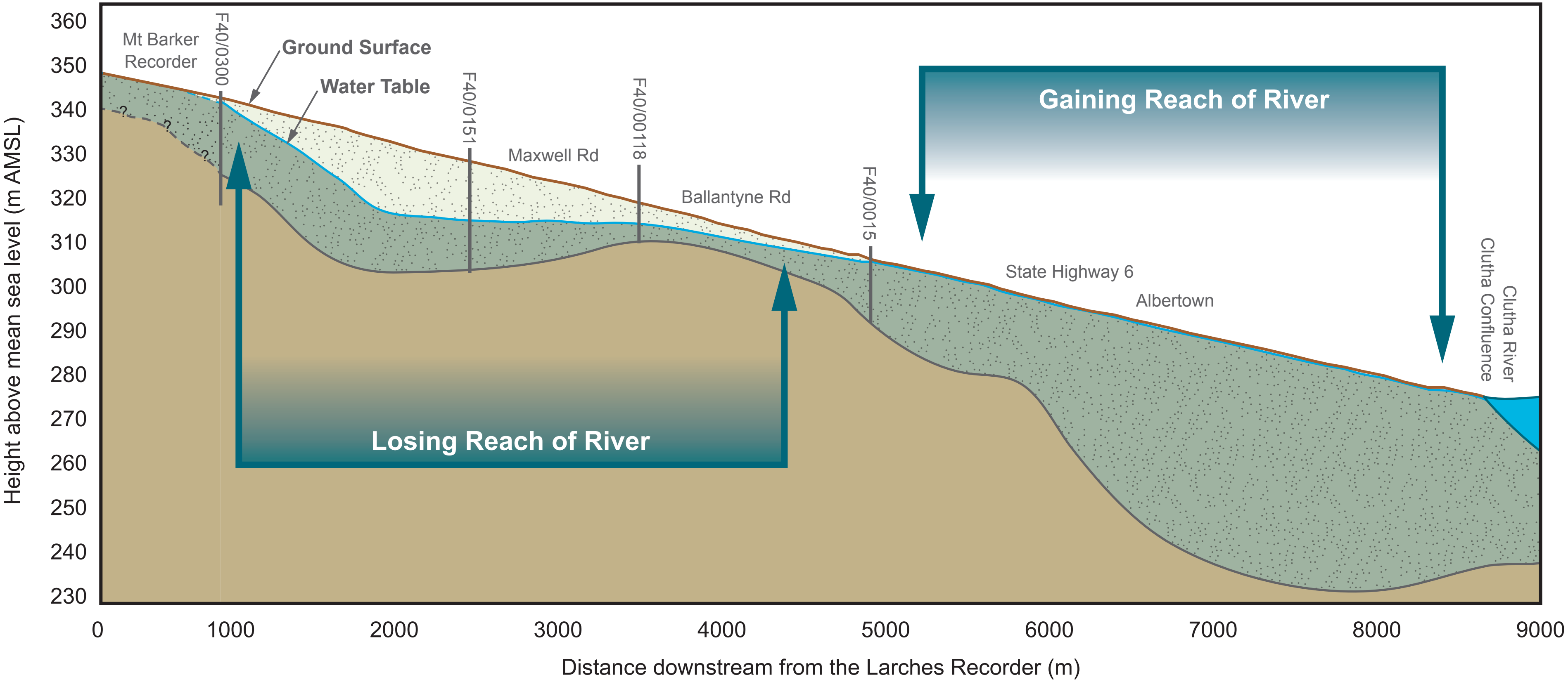
Evidence has also been found for two outwash deposits in the south west corner of the basin (ORC 2011). These two units consist of a younger alluvium of moderate permeability and older alluvium of low permeability, identified during drilling near the narrowing of the Cardrona Valley. The distinction between the two units was largely based on the presence of a silt/clay matrix, which formed a higher proportion in the older alluvium due to greater weathering. The results of a pumping test carried out on the younger unit indicated a transmissivity of 1,200 m^2/day. ORC 2011 concluded that hydraulic conductivity of the Wanaka-Cardrona Aquifer could be highly variable due to the heterogenous nature of an aquifer in outwash gravels mixed with melt-water deposits and glacial till. ORC 2011 used a median hydraulic conductivity of 35 m/day (range 10 m/day to 70 m/day).

There is a significant drop in both the basement and groundwater level (ORC 2011) within 1 km north-east of The Larches (Figure 5). This drop in groundwater level results in the groundwater system becoming hydraulically “disconnected” from the overlying river. There is substantial recharge to the underlying groundwater (refer Section 2.4) in this “disconnected” area during periods when the river is flowing. Up to 10 m of unsaturated gravel deposits remains beneath the river under average flow conditions. As outlined in Section 2.4 the river is losing 700 L/s in this disconnected section of the river. There may be some restriction to flow loss in the river due to clogging of the stream bed. This clogging was described in ORC (2003) following a flood event in the river. Groundwater recharge through the bed of the river is not expected to increase. For this reason there oportunity for enhancing groundwater replenishment through the establishment of targeted MAR sites.

A piezometric map for the Wanaka – Cardrona area (ORC 2011) indicates that recharge causes groundwater flows to radiate from the losing reach of the Cadrona River. Flow directions are either toward Lake Wanaka, with significant groundwater discharge through the springs in Wanaka township (Bullock Creek), or toward the lower Cardrona River and Clutha River/Mata-Au. Groundwater levels are within a couple of metres of the river level within the Cardrona Alluvial Ribbon Aquifer. Groundwater levels are generally highest in the spring as evidenced in the water level monitoring data (Appendix A).

A groundwater take application for the Criffel Deer farm (MWH 2008) documents a pumping test carried out on bore F40/0335, which is located close to the southwestern end of the Wanaka basin where the Cardrona River is disconnected. Groundwater level reponses to the test were recorded in three monitoring bores. This area of the aquifer consists of silty sands and gravel to more than 35 m below ground level (bgl) and has a static water level approximately 19 m bgl. Beneath the Cardrona river this is equivalent to approximately 12 m of unsaturated sands and gravels. Analysis of the pumping test results indicated the aquifer. Transmssivity at this location is between 1,200 m^2/day and 3,500 m^2/day. This translates to a hydraulic conductivity between 80 m/day and 230 m/day.

A calibrated groundwater model developed for Wanaka-Cardrona (ORC 2011) indicated this area is characterised by a hydraulic conductivity between 150 m/day and 250 m/day. In the model, this zone of high hydraulic conductivity covered an area between the losing reach of the Cardrona River and Bullock Creek in Wanaka. Another positive characteristic of this area for MAR is the thin layer of silty soil. Bore logs for the Criffel Deer Farm production bore and monitoring bores show a silty clay layer up to 1.4 m thick, underlain by unsaturated sandy gravels. So the area is considered to be relatively high permeability, with a substantial thickness of unsaturated gravels and a thin covering soil layer.



1. Note: Groundwater flows not necessarily parallel to this cross-section
2. Schematic only, not to be interpreted as an engineering design or construction drawing
3. DRAWN BY: ZM REVIEWED BY: RW

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TITLE CROSS-SECTION ALONG THE CARDRONA RIVER FROM THE LARCHES TO THE CLUTHA RIVER

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Groundwater levels in the aquifer to the northeast of Mt Barker, towards Luggate are deep (>30 m bgl). There are also several large groundwater abstractions in this area. The aquifer in this area is composed of sandy gravels. Two transmissivity results in the ORC database from pumping tests performed on bores in this area are relatively high and range from 600 m^2/day to 6,000 m^2/day. The groundwater model (ORC 2011) used a hydraulic conductivity of approximately 250 m/day for the area. Consented groundwater abstractions have been granted for takes up to 4,300 m^3/day (50 L/s) and there are nine consented takes for more than 850 m^3/day (10 L/s).

In terms of potential for the application of MAR to provide increased groundwater storage on a seasonal basis, there appears to be two areas of opportunity:

- The area of the Wanaka-Cardrona Aquifer to the south of Wanaka and west of Mt Barker has high permeability and a substantial thickness of unsaturated gravel above the groundwater table.
- The area of the Wanaka-Cardrona Aquifer to the northeast of Mt Barker has a substantial thickness of unsaturated gravel above the groundwater table and may require additional recharge to support the currently allocated groundwater takes as irrigation techniques shift from flood irrigation to spray irrigation.

The Integrated Water Resources report for Wanaka-Cardrona (ORC 2011) touched on aspects of utilising groundwater instead of water races for irrigation water supplies. This report also indicated that increased groundwater recharge through continuous river flows would allow greater use of the groundwater resource compared to water races. It was stated that this this would provide some offset to reduce reliance on water races. The report mentions one example of a deemed permit holder in the lower Cardrona River switching to groundwater supply. The original permit for 96 L/s was transferred to a groundwater take of 24 L/s. This allowed 100 % security of supply, to offset increased pumping and infrastructure costs. A MAR project could take this method a few steps further by utilising surface water resources during higher flows and the natural storage and distribution ability of the underlying aquifer.

3.2 Water Balance

An annual water balance for the Wanaka-Cardrona Aquifer developed by ORC (2011) is summarised in Table 5. In this model rainfall recharge was simulated on a daily time step based on soil and weather conditions. The total rainfall recharge to the aquifer was estimated to be 6.7 Mm^3/year. This is significantly less than the 22.1 Mm^3/year recharge from the Cardrona River.

The water balance suggests that the aquifer currently gains 9.7 Mm^3/year from irrigation loss. This may reduce with increasing efficiency in irrigation practices. In areas to the east of Mt Barker and towards Luggate where groundwater levels are relatively deep and the aquifer is more dependent on land surface recharge groundwater levels may start to drop.

Table 5: Wanaka-Cardrona Aquifer water balance (ORC 2011).

	Aquifer inflows (Mm^3/year)	Aquifer outflows (Mm^3/year)	Comments
Cardrona River (The Larches to SH6)	22.1		Assumes an average infiltration rate of around 700 L/s to the Wanaka-Cardrona Aquifer between The Larches and SH6.
Cardrona River (SH6 to confluence)		9.8	Assumes an average groundwater outflow from the Wanaka-Cardrona Aquifer to the Cardrona River between SH6 and the confluence with the Clutha River/Mata-Au of around 300 L/s.

	Aquifer inflows (Mm^3/year)	Aquifer outflows (Mm^3/year)	Comments
Rainfall recharge (natural)	6.7		Soil moisture balance modelling (ORC 2011).
Irrigation recharge (additional)	9.7		Assumed around 300 L/s. Currently estimated that around 1,200 L/s taken from Cardrona River through water races. This implies 25 % loss to groundwater.
Bullock Creek		12.6	Assumed 400 L/s outflow from the aquifer through springs contributing to Bullock Creek (300 L/s – 500 L/s) and other minor springs such as Ripponlea (approx. 100 L/s).
Clutha River/Mata-Au		8	Groundwater discharges to the Clutha River (estimated through groundwater modelling in ORC 2011).
Lake Wanaka		6.6	Groundwater discharges to Lake Wanaka (estimated through groundwater modelling in ORC 2011).
Groundwater takes		1.5	Assumed around 50 L/s abstracted from groundwater for irrigation and other purposes. Current allocation is more like 3.5 Mm^3/year – 4 Mm^3/year.
Total	**38.5**	**38.5**	

3.3 Potential Recharge Areas

To gain the most storage before groundwater flow losses to Bullock Creek it is recommended that an initial area of investigation be located as far south as possible while still being within the higher hydraulic conductivity zone.

A substantial thickness of unsaturated gravel appears to be present in this southern area of the Wanaka basin, within 3 km of The Larches (Section 3.1). These unsaturated gravels provide storage capacity for artificially recharged water. The observed river flow losses and diurnal responses of the groundwater levels close to the river during spring flow conditions are a positive sign that MAR systems can potentially be used to effectively increase seasonal recharge volumes in this area. The existing water races could be used to take surface water from the Cardrona River during periods of high flows for infiltration purposes. A range of methods could potentially be used to infiltrate water taken from the Cardrona River on a seasonal basis. These methods will however need to be assessed. More detailed investigations on the variability in vertical hydraulic conductivity would need to be carried out in more specific sites as thin silty layers may disturb vertical movement of recharge water.

The Wanaka-Cardrona Aquifer to the east of Mt Barker and towards Luggate has deep groundwater levels (>30 m bgl) and is predominantly dependent upon land surface recharge. The groundwater levels in this area may start to drop with less irrigation losses and water race losses. This area could be targeted for MAR for a separate purpose than river continuity. Supplementary recharge to this area would support current groundwater abstractions.

3.4 Potential Fatal Flaws

At this initial stage no potentially fatal flaws have been identified facing a Wanaka – Cardrona MAR project. There are a few gaps in available information required for a MAR project. These gaps can be addressed through further desk top assessment and field investigations (Section 3.6.2 and 5.0). From review of the information summarised in this report there are some aspects of the potential MAR project that would require careful management. These aspects include potential clogging of any infiltration basins and groundwater storage management to control flows in Bullock Creek. Groundwater modelling can be used to assess potential impacts on Bullock Creek flows.

3.5 Responses to ORC Questions

Responses to specific queries from ORC regarding MAR potential in the Wanaka – Cardrona area are presented below.

- ***How much water would be required to be stored in the aquifer to replace current surface water takes?***

Complete information on the annual abstraction from the Cardrona River at The Larches is not currently available. Based on the largest abstractions, the annual requirements are up to 5.6 Mm^3/year (Section 2.3). This amount of water appears to be available during winter and spring periods from the Cardrona River (Section 2.1). If this volume was to be infiltrated into the underlying aquifer over a period of 120 days, it would be equivalent to an artificial recharge rate of 540 L/s.

Infiltration rates through the bed of the Cardrona River are approximately 700 L/s. The Cardrona River is however disconnected, implying that there may be some restriction on the rate of infiltration through the bed of the river and this rate should be achievable with a well-managed infiltration basins. The current design for the Hinds MAR pilot project in Canterbury is for an infiltration basin of approximately 500 L/s.

The flow rate required for any replacement groundwater takes is likely to be significantly less than the rate taken with water races due to less flow losses and increased security of supply.

- ***Could stored water be pumped from the aquifer at a rate sufficient for irrigation requirements?***

The Wanaka-Cardrona Aquifer has a reasonably high hydraulic conductivity and other irrigation systems are operating from groundwater in this area (many taking 10 L/s to 50 L/s). Individual bores should be sufficient for abstracting water for irrigation purposes at suitable rates and the unconfined nature of the aquifer provides less interference than experienced in confined systems. There appears to be reasonable storage within the unsaturated gravels. More detailed modelling of the effects of increased groundwater storage on Bullock Creek flows will need to be investigated in the next stage of any MAR project.

- ***Could water races be utilised for managed aquifer recharge?***

There is a currently insufficient data on flow losses along the water races to accurately assess seepage losses. This is a data gap and could be simply investigated through field investigations (multiple flow measurements along the races and discussions with local operators). The races could certainly be used to distribute source water to MAR sites. And likely are providing a form of incidental recharge currently, however we will need to better understand their current loss rates and spatial coverage to better assess them as a viable MAR tool.

- **How permeable are the underlying sediments?**

In the aquifer underlying the disconnected Cardrona River area and extending towards Wanaka Township is the highest hydraulic conductivity (Section 3.1). This higher conductivity area (250 m/day) could be utilised for a MAR trial. There are some lower permeability areas along the edge of the basin.

- **Would artificially recharged groundwater be stored for a sufficient period of time to support utilisation in the irrigation season?**

Given the current recharge mechanisms and groundwater level responses it is expected that storage for a few months is possible. The balance between groundwater pressure responses to increased recharge and the distribution of abstracting bores to utilise the stored water will need some further investigation and modelling to ensure careful management of the flows in Bullock Creek. The existing model could be modified to achieve this. Management of the flows will aim to avoid excess flow in Bullock Creek during spring and limit abstraction pressure reducing the flows significantly during summer.

3.6 Methodology for Development

3.6.1 MAR assessment methodology

A MAR assessment methodology has been developed by Golder for New Zealand MAR projects through modification of Australia's assessment guidelines, which are specifically designed for the purpose of investigating, developing and commissioning MAR projects (MRMMC-EPHC-AHMC 2009, Dillon et al 2009). While the Australian guidelines provide a good basis with which to assess MAR, they do not include some factors relevant to the unique cultural, social and physical environments of New Zealand. Golder has therefore refined the guidelines to be more applicable to New Zealand conditions.

The guidelines generally describe MAR assessment as a four stage assessment process:

- Stage I – Conceptual model and desktop assessment.
- Stage II – Viability and risk assessment with field testing.
- Stage III – Further trials, validating conceptual models and viability of long term operations.
- Stage IV – Groundwater replenishment scheme development and verification, including development of further site(s), revenue and consenting structures, long term sustainable management goals.

This report covers part of Stage I as outlined above (Stage IA). Further desktop assessment (Stage IB) would cover specific issues related to the Wanaka –Cardrona site. For example these assessments could involve modelling flow effects on Bullock Creek, more detailed flow analysis of Mt Barker flow data, detailed analysis of clogging potential as outlined in the recommendations Section 5.0 of this report.

Fundamental questions to be addressed in a MAR assessment are set out below.

- **Conceptual MAR model** – Is there potential for a clear understanding and expectations to be developed for the MAR objectives and goals and whether these are realistically achievable based on Stage I available information?
- **Infrastructure/Physical settings/Logistics** – Are potential MAR test site(s) favourable for the capture, delivery, percolation or injection and operational management of a pilot project?
- **Source water** – Are data available or readily collected on the source water (to be recharged) with respect to quality, availability (timing/volumes), infrastructure (delivery), consenting and operations (e.g., willing water purveyors)?
- **Target aquifer(s)** – Are data available or readily collected on the target storage aquifer(s) for parameters such as storage capacity (e.g., freeboard), hydrogeological conditions (e.g., unconfined or confined, aquifer hydraulic parameters), geochemistry, existing water quality and any potential concerns, consenting?
- **Environmental/Economic –** Are data available or readily collected on the likely groundwater-dependent environmental influences of a MAR project(s) as well as an assessment of economic drivers (e.g., water demand exceeds supply) and cost-benefit analysis favouring project development?
- **Monitoring/Modelling –** Will existing and/or readily installed project-specific monitoring systems be sufficient to adequate data for the evaluation of the pilot test program? What kinds of modelling would be needed to help to evaluate and potentially manage the viability of a system-wide replenishment programme?

- **Collaboration/Partnerships –** Community, governmental, water management agencies, water purveyors and other stakeholders (e.g., iwi, environmental, etc.) will need to be informed and engaged regarding the development of MAR relative to their specific needs and regulatory requirements.
- **Regulatory/Consenting –** Are local, regional and/or national water plans and regulations favourable or can they be modified to provide for MAR pilot tests and eventually potential groundwater replenishment scheme development?

3.6.2 Decision matrix

The initial viability of a Wanaka-Cardrona MAR project can be assessed through the decision matrix presented in Table 6 and Table 7.

Table 6: Pre-feasibility viability assessment for the Wanaka – Cardrona MAR project.

Attribute	Question	Outcome of the assessment: Assessed as viable? Yes/No	
		Surface recharge to the aquifer	**Comments**
1. Intended water use	Is there is an ongoing local demand or clearly defined environmental benefit for recovered water (groundwater) that is compatible with local water management plans?	Yes	Groundwater supplies to replace surface water abstraction during December-April.
2. Source-water availability and right of access	Is adequate source water available, and is harvesting this volume compatible with catchment water management plans?	Yes Stage IB	Water appears to be available from prefeasibility level assessment (monthly average flow rates). Further detailed assessment on flows required.
3. Hydrogeological assessment	Is there at least one aquifer at the proposed managed aquifer recharge site capable of storing additional water?	Yes	Gravel aquifer infilling Wanaka Basin has significant depth of unsaturated gravels for potential storage.
	Is the project compatible with groundwater management plans?	Yes	Recharge will assist with any reduced recharge due to increased efficiencies in irrigation practices.
4. Space for water capture and treatment	Is there sufficient land available for capture and treatment of the water?	Stage IB	Source water generally good quality and low sediment. Amount of settlement required is to be further investigated in Stage IB.
5. Capability to design, construct and operate	Is there a capability to design, construct and operate a managed aquifer recharge project?	Stage IB	

The next stage of the pre-feasibility assessment has been conducted in Table 7. This is a list of 14 attributes with associated questions that rates the likely degree of difficulty.

Table 7: Prefeasibility assessment resultant degree of difficulty for a Wanaka-Cardrona MAR project.

Attribute	Question	Outcome of the PFA	Resultant degree of difficulty Surface infiltration to a constructed infiltration pond
1. Source-water quality with respect to groundwater environmental values	Does source water meet the water-quality requirements for the environmental value of ambient groundwater?	Yes Stage IB	Low Risk: Recharge water quality is same quality as currently recharging the aquifer. Further analysis of temporal changes and geochemical reactions. High rainfall events may need to be avoided for source water capture.
2. Source-water quality with respect to recovered water end-use environmental values	Does source water meet the water-quality requirements for the environmental values of the intended end uses of the water on recovery?	Yes	Low Risk: Recharge water quality is same quality as currently recharging the aquifer. Water for irrigation.
3. Source-water quality with respect to clogging	Does source water have low quality; for example: Total suspended solids (TSS) >10 mg/L; Total organic carbon >10 mg/L; or Total nitrogen >10 mg/L?	Stage IB Stage IB No	Low Risk: TSS- Values not analysed, likely to be variable depending on state of the Cardrona river. Needs further investigation in Stage IB.
	Is the soil or aquifer free of macro-pores?	Stage II	Low Risk: Aquifer is highly porous. Needs further site specific investigation once a site is chosen.
4. Groundwater quality with respect to recovered water end-use environmental values	Does ambient groundwater meet the water quality requirements for the environmental values of intended end uses of water on recovery?	Yes	Low Risk: as groundwater is currently used for irrigation in the area. Not an aquifer storage and recovery project.
5. Groundwater and drinking water quality	Is either drinking water supply, or protection of aquatic ecosystems with high conservation or ecological values, an environmental value of the target aquifer?	Stage IB	Low Risk: as source water quality is same as currently recharging aquifer. Proximity of water supply bores to potential sites to be investigated.
6. Groundwater salinity and recovery efficiency	Does the salinity of native groundwater exceed either of the following: 10,000 mg/L; or The salinity criterion for uses of recovered water?	No No	No Risk: Salinity a non-issue in New Zealand.

Attribute	Question	Outcome of the PFA	Resultant degree of difficulty
7. Reactions between source water and aquifer	Is redox status, pH, temperature, nutrient status and ionic strength of groundwater similar to that of source water?	Stage IB	Low Risk: as source water quality is same as currently recharging aquifer. Geochemical analysis to be carried out in Stage IB.
8. Proximity of nearest existing groundwater users, connected ecosystems and property boundaries	Are there other groundwater users, groundwater-connected ecosystems or a property boundary within 100 to 1,000 m of the MAR site?	Stage IB	Low Risk: Site to be determined Stage IB.
9. Aquifer capacity and groundwater levels	Is the aquifer/s: Confined and not artesian?; or Unconfined, with a water table deeper than 4 m in rural areas or 8 m in urban areas?	No Yes	Low Risk: Depth of unconfined aquifer appears adequate for surface infiltration to work. Stage IB modelling will help determine total available storage and the likely impacts on springs.
10. Protection of water quality in unconfined aquifers	Is the aquifer unconfined, with an intended use of recovered water that includes drinking water supplies?	Yes	Low Risk: as source water quality is same as currently recharging aquifer.
11. Fractured rock, karstic or reactive aquifers	Is the aquifer composed of fractured rock or karstic media?	Stage IB	Low Risk: The target gravels consist of sedimentary rock. Calcite from the Otago Schist has been noted in previous reports as controlling chemical composition of groundwater (GNS 1997).
	Is the aquifer known to contain reactive minerals?	Stage IB	Undetermined: Not likely, dissolution of aquifer matrix and potential for mobilisation of metals may warrant investigation in Stage IB.
12. Similarity to successful projects	Has another project in the same aquifer with similar source water been operating successfully for at least 12 months?	No	Low Risk: Aquifer has historical recharge through irrigation and natural recharge river recharge.
13. Management capability	Does the proponent have experience with operating managed aquifer recharge sites with the same or higher degree of difficulty, or with water treatment or water supply operations involving a structured approach to water-quality risk management?	Yes	Low Risk: Hinds Catchment Canterbury, Poverty Bay MAR project and other recharge sites in Oregon/Washington are fully operative (Bower & Lindsay 2010).

Attribute	Question	Outcome of the PFA	Resultant degree of difficulty
	Does the proposed project require development approval?	Yes	A development-approval process will require that each potential issue is assessed and managed. This may require additional information and steps in design which will be covered in Stage II of the project.
	Is it in a built up area; built on public, flood-prone or steep land; or close to a property boundary?	Stage IB	
	Does it contain open water storage or engineering structures; or is it likely to cause public health or safety issues (e.g., falling or drowning), nuisance from noise, dust, odour or insects (during construction or operation), or adverse environmental impacts (e.g., from waste products of treatment processes)?	Yes	
14. Cultural	Has consultation started with local iwi?	No Stage IB	As part of Stage IB, workshop with local iwi and environmental groups.
15. Social	Has consultation with community and general interested stakeholders started?	No Stage IB	Minimum flow consultation has started. As part of Stage IB, workshop with community and general interested stakeholders.

New Zealand has some specific areas that need considering in the development of a MAR project and can be further explored and discussed in the Stage IB part of the project. These include:

- Health and Safety and communication of activities and hazards to the public.
- Integration into regional planning processes including minimum low flow levels.

4.0 CONCLUSIONS

The Integrated Water Resources report for Wanaka-Cardrona (ORC 2011) touched on the potential to use groundwater for irrigation water supply instead of water races. The increased groundwater recharge through continuous river flows would allow greater use of the groundwater resource. This increased availability of groundwater would provide some offset to reducing reliance on supplies from water races. A MAR project could take this method a few steps further by utilising surface water resources available during higher flows and the natural storage and distribution ability of the underlying aquifer.

Current surface water abstractions from the Cardrona River are estimated to be up to 1,160 L/s (ORC 2003). Based on the irrigated land area supplied by the water races originating from The Larches, the annual irrigation water requirements are up to 5.6 Mm^3/year. If this volume was to be infiltrated into the underlying aquifer over a period of 120 days, the infiltration rate would be equivalent to 540 L/s. The current infiltration rate through the bed of the Cardrona River is approximately 700 L/s. A GRS for the Wanaka-Cardrona area should be able to achieve this rate of infiltration. For comparison, the design for the Hinds MAR pilot project in Canterbury incorporates a basin with an expected infiltration rate of approximately 500 L/s.

At this initial stage no fatal flaws in a potential Wanaka – Cardrona MAR project have been identified. Further assessments would however be required to confirm the viability of a GRS for the Wanaka-Cardrona area. These assessments could be incorporated into the next stage of developing a MAR project in this area.

5.0 RECOMMENDATIONS

Golder recommends further desk-top and field assessments be undertaken as part of the next stage of developing a MAR project for the Wanaka – Cardrona area. These assessments include:

- Groundwater modelling of the effects of a GRS on Bullock Creek. This would involve assessing both high flow (storage) and low flow effects (abstraction).
- A more detailed analysis of data from the Mt Barker flow recorder to confirm when flow is available for abstraction from Cardrona River and for how long.
- A detailed analysis of water quality effects and operational limitations. This would involve an investigation into temporal changes in source water quality and potential geochemical reactions with groundwater and aquifer materials.
- Field investigations into water race operations. This assessment would involve flow measurements to evaluate seepage losses from the water races. Consultation with the water race operators would also need to be undertaken to understand their current operations and requirements.
- Site options and recharge area selection. Work with community to identify a potential trial site for a pilot trial. Investigate local aquifer materials and local flow mechanisms.
- Hold a community workshop with water users, environmental, cultural and community interest. The workshop would be focused on the concepts of MAR and its application to the Wanaka – Cardrona area.

6.0 LIMITATIONS

Your attention is drawn to the document, “Report Limitations”, as attached in Appendix B. The statements presented in that document are intended to advise you of what your realistic expectations of this report should be, and to present you with recommendations on how to minimise the risks to which this report relates which are associated with this project. The document is not intended to exclude or otherwise limit the obligations necessarily imposed by law on Golder, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

7.0 REFERENCES

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APPENDIX A

Groundwater Level Monitoring Data

Groundwater level monitoring data for Wanaka-Cardrona Aquifer

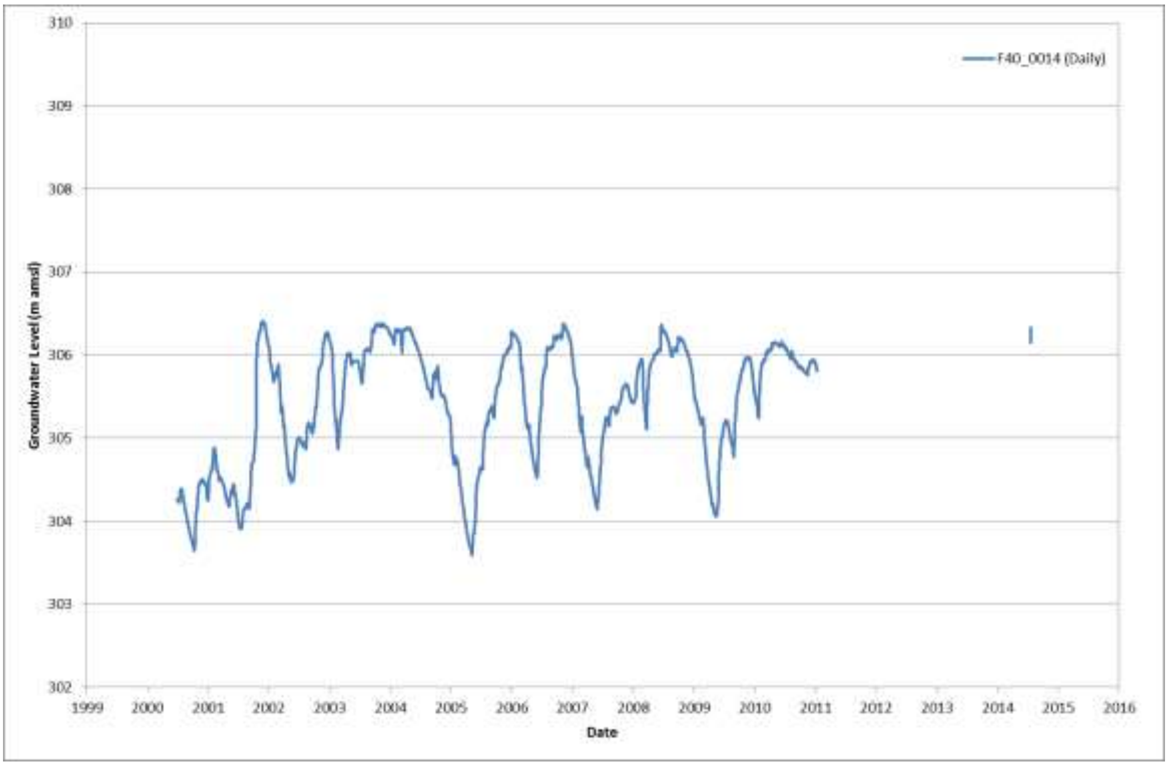

Figure A1: Automated groundwater level monitoring at Envirowaste bore F40/0014.

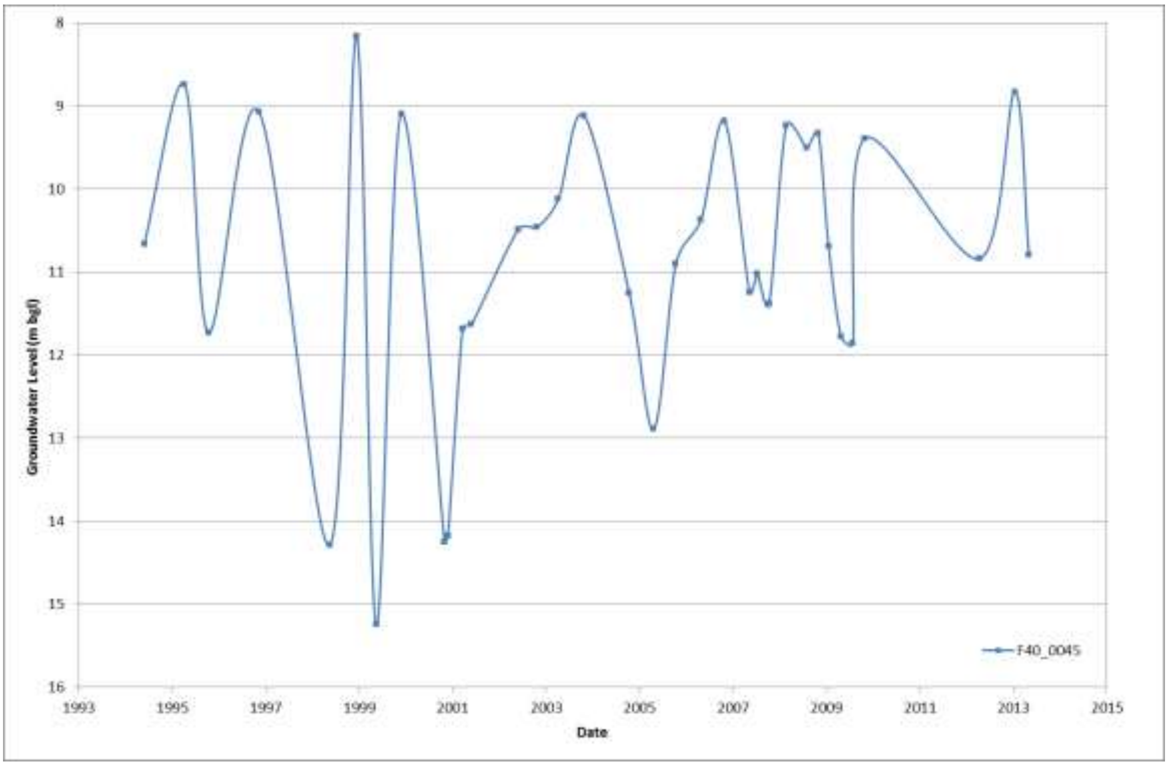

Figure A2: Manual groundwater level monitoring bore F40/0045.

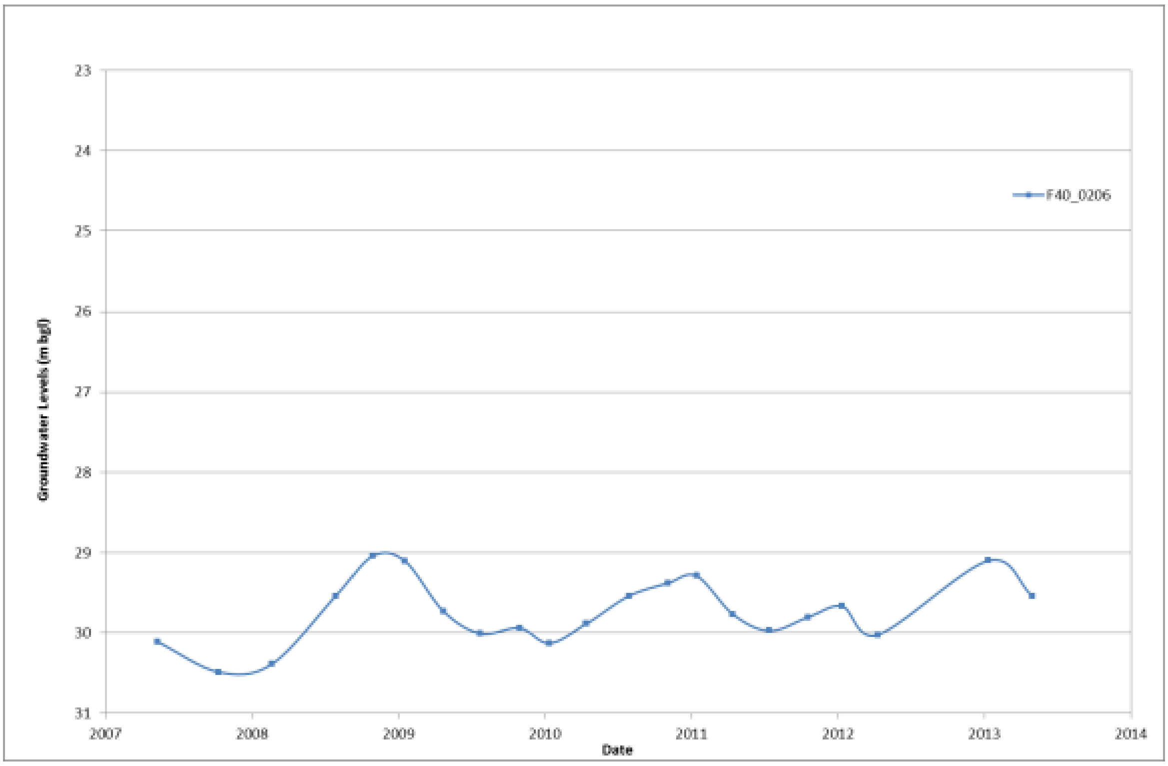

Figure A3: Manual groundwater level monitoring bore F40/0206.

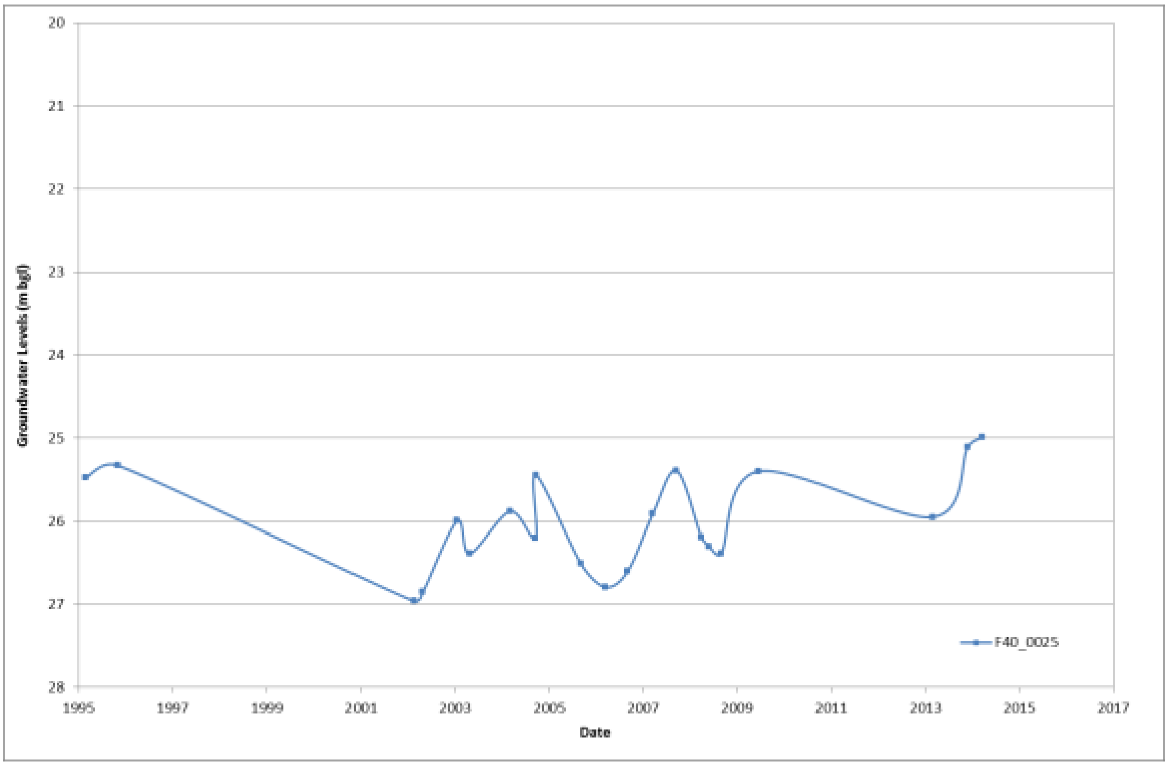

Figure A4: Manual groundwater level monitoring bore F40/0025.

APPENDIX B

Report Limitations

APPENDIX B
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