On-farm Water Storage Pre-feasibility Assessment

Cardrona Valley and Wanaka-Cardrona Flats

Report prepared for:

Otago Regional Council

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Table of Contents

1 Introduction

1.1 General

The Resource Management Act 1991 provides regional councils with the power to control the taking and use of water and control the quantity, level and flow of water bodies. The National Policy for Freshwater Management 2014 requires regional councils to set allocation limits and minimum water levels/flows for all freshwater management units and ensure efficient water use.

The Otago Regional Council (ORC) is preparing a proposed plan change to the Regional Plan: Water for Otago (Water Plan) which seeks to set allocation limits and minimum flows for the Cardrona catchment. ORC is required to undertake a Section 32 evaluation of the proposed plan change. This evaluation includes identifying and assessing the costs and benefits of the environmental, economic, social, and cultural effects that are anticipated, including economic growth and employment.

This pre-feasibility assessment of on-farm water storage will contribute to the information required to undertake the Section 32 evaluation. The assessment has been undertaken for ORC by GeoSolve Ltd and David Hamilton & Associates Ltd in accordance with GeoSolve's proposal dated 22 December 2016, which outlines the scope of work and conditions of engagement.

Under a future minimum flow regime, water storage may be utilised in two ways during low-flow periods to off-set the restrictions of the minimum flow requirement:

- Water stored in individual dams may be used to directly irrigate nearby land when abstraction is not permitted, or
- Stored water may be released back into the Cardrona River or tributaries to supplement the natural flows, allowing water to be abstracted for irrigation while still maintaining the required minimum flow.

The objective of this pre-feasibility assessment is to provide concept level identification and assessment of potential water storage sites within the study area, including indicative estimates of storage volumes & costs, and preliminary PIC assessments.

This has been a desk-top study at concept level. Sites have not been visited and property owners have not been consulted. Detailed site specific investigation needs to be undertaken to confirm the availability and viability of all proposals.

1.2 Study area

Background information in this section is adapted from the documents *Cardrona Catchment Information Sheet* (ORC, 2013), *Natural Hazards in the Cardrona Valley* (ORC, 2010), and *Integrated Water Resource Management for the Cardrona River* (ORC, 2011).

1.2.1 Location

Situated between Arrowtown and Wanaka, the Cardrona catchment (Figure 1) is located in the upper Clutha River/Mata-Au valley, east of Wanaka, west of Cromwell, north of Arrowtown and south of Albert Town. The catchment covers approximately 340 km^2 and is some 40 km long, bounded to the west and south by the Crown Range, to the east by the Criffel Range, and to the north by the Clutha River/Mata-Au.

The Cardrona River flows in a north-north-easterly direction down the Cardrona valley. Its headwaters originate at Mt Scott on the Crown Range, draining the western flanks of the Criffel Range, and from the eastern side of the Crown Range north to Mount Alpha. Cardrona tributaries include Boundary Creek, Little Meg Creek, Pringle Creek, Spotts Creek, Stoney Creek, and Timber Creek.

At the downstream (northern) end of the valley at 'The Larches' (otherwise known as Mt Barker), the river crosses about 7 km of relatively flat plains south-east of Wanaka, before discharging into the Clutha River/Mata-Au at Albert Town. The Wanaka-Cardrona flats (Figure 1) extend across the Cardrona delta area, bounded by Lake Wanaka in the west/northwest, the Clutha River to the north, Luggate to the east, and Mount Barker / The Larches in the south.

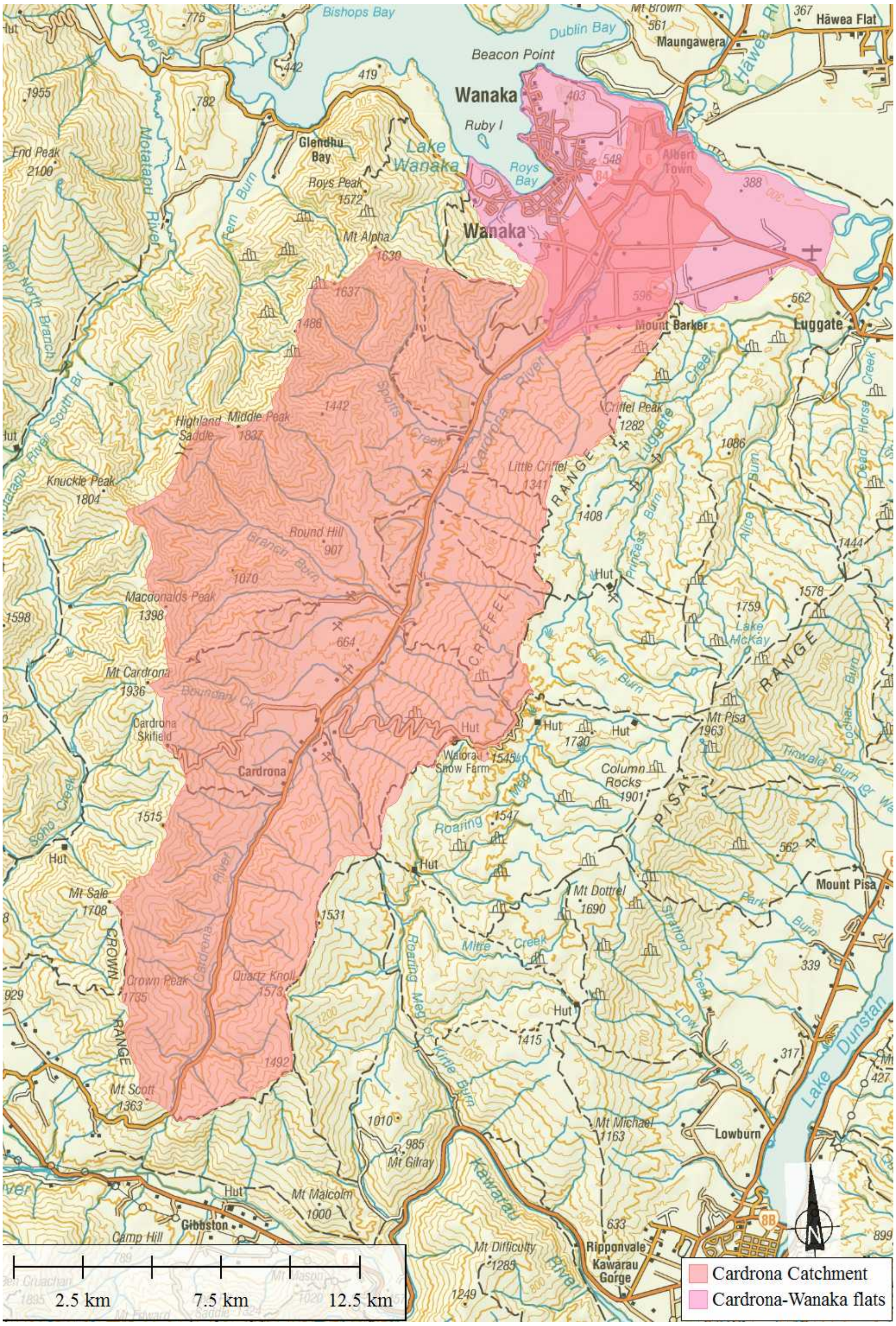

Figure 1: Study area location

1.2.2 Climate and rainfall

The climate within the catchment is characterised by cold winters and warm summers. Temperatures across the seasons range from an average of 6°C in winter to an average of 26°C in summer (depending on the altitude). Much of the moisture received in the higher areas during winter is in the form of snow, some of which can persist in shady areas through summer. Snow cover on the Criffel Range tends to be shallower and less frequent than the Pisa Range. The median annual rainfall ranges from 650-700 mm on the lower flats, to 1250-1500 mm on the tops of the Crown and Criffel Ranges. A severe rainfall deficit occurs during summer, with typical January - February rainfall totals approximately half of the potential evapotranspiration rate, leading to a high demand for irrigation water.

Rainfall within the study area is subject to trends which may vary according to the time frame. The Cardrona township, West Wanaka, and Wanaka Airport rainfall gauges show a downward trend in annual rainfall since the late 1990s. The five-year moving average at West Wanaka has fallen approximately 300 mm since 1995, while Wanaka Airport has dropped 120 mm since 1998. However the Ministry for the Environment (MfE, 2008) predicts that annual rainfall at Queenstown, 35 km to the southwest, will increase by approximately 12% by the end of the 21st century, with a significant increase in annual average rainfall predicted across western Otago (including the Cardrona catchment) by the end of this century.

1.2.3 Hydrology - surface flows and groundwater

Flows in the Cardrona River are generally higher in the spring due to snow melt, and reduced over the summer, although low flows can also occur during winter due to much of the catchment being locked up in ice. The lower Cardrona River can experience extreme low flows during summer with some tributaries running dry during this period, and the main river stem commonly dries up downstream of The Larches as surface flows are lost to groundwater and many abstractions occur. In the absence of abstraction the high-yielding upper catchment generally provides stable base flows in the main stem, although it is believed that the river may naturally dewater between The Larches and SH6 in an extremely dry year even in the absence of abstractions. Flow measurements either side of Ballantyne Road, undertaken between January and May 2010, suggested at the time an infiltration loss to the aquifer in the order of 700 l/s. Between SH6 and the Clutha confluence, the river regains approximately 300 l/s as groundwater re-enters the river. Relevant flow statistics for these locations on the lower Cardrona River are given in Table 1 (these are measured flows and therefore represent natural flows minus upstream abstractions):

Table 1: Flow statistics for the Cardrona River in litres per second

Site	Min (l/s)	Mean (l/s)	Median (l/s)	MALF (l/s)
Cardrona at The Larches	308	3,137	2,306	1,057
Cardrona at Clutha confluence	253	1,980	1,489	348

The Wanaka Basin-Cardrona gravel aquifer is located between Lake Wanaka, the Upper Clutha River/Mata-Au, the Criffel Range and Mount Roy. This aquifer is responsible for the flow of Bullock Creek through Wanaka township, and ensures the availability of groundwater in the rural areas. The aquifer also contributes to the periodic drying-up of sections of the Cardrona River during summer due to infiltration. The Cardrona alluvial ribbon aquifer comprises the river flats which extend from Little Meg Creek in the south to The Larches in the north.

1.2.4 Topography, geology and soils

Topography varies from river flats in the lower reaches, to the short steep slopes of the Criffel Range, to the higher undulating hills on the western side of the valley. The catchment has an elevation range from 273 m at the Clutha River confluence to 1,936 m at Mount Cardrona.

The Kaikoura Orogeny has formed the characteristic Central Otago basin and range topography over the past 5 million years. The Haast Schist bedrock of the Cardrona valley floor is overlain by Tertiary sediments including clays and sandstones. These are overlain by terraces of weathered Early Quaternary Gravels (Maori Bottom), and outwash gravels from later Pleistocene glacial advances.

The flanking ranges, composed of highly erodible schist, have been formed and uplifted by the active NW and SE Cardrona Faults. Landsliding has developed extensively on the steeply sloping valley sides.

The Cardrona River and its tributaries have deeply eroded into the basement schist and overlying formations forming the contemporary valley that exists today. On the valley's lower slopes, Early Quaternary and outwash gravel terraces, which pre-date the last glacial period by about 15,000 years, are being actively eroded and contributing sediment to the river. At the base of these terraces and at the confluence of many of the tributaries, alluvial fans have formed and act as temporary storage areas for sediment until a flood with sufficient energy can transport the material downstream.

The Wanaka Basin consists of Pleistocene glacial moraine deposits and outwash gravels which cover most of the underlying Tertiary sediments and schist basement rock. Soils in the valley are low-fertility pallic soils. On the lower plains, they are brown, melanic (darkened), and recent soils, with low-to-moderate fertility. The Wanaka-Cardrona Flats sit astride a sedimentary basin characterised by glacial moraine deposits and outwash gravels.

1.2.5 Land use

The upper catchment is dominated by sheep and beef farming, while deer are farmed in the lower catchment. Pastoral farming has been and continues to be an integral part of the fabric of the community. The availability of water for irrigation has been fundamental to this and ongoing development. Within the catchment are a number of past and present Crown pastoral leases, including Hillend, The Larches, Spotts Creek, Avalon, Branch Creek, Robrosa and Waiorau. Ski-fields and snow parks have been more recent additions to the landscape and are now dominant features providing recreational opportunities throughout the year. There has been a significant increase in the development of lifestyle blocks and residential use in both Cardrona Village, and the lower catchment toward Wanaka and Albert Town. The Pisa Ecological District (PED) covers 84.75 ha of land bounded in the north and east by the Clutha River/Mata-Au, in the west by Lake Wanaka and the Cardrona River, and in the south by the Kawarau River. The Cardrona River and tributaries support a range of agricultural, tourism and recreational uses, all of which play an important part in the overall character of the community and the region.

2 Methodology

2.1 Water supply and storage requirement

For the purposes of this assessment it is considered that, seasonal irrigation water requirements are generally in the range of 600 - 675 mm (or 6000 - 6750 m^3 per hectare) in this climate and soil environment. Additional allowance should be made for seepage and evaporation losses. It may be reasonable to assume that some inflows will be available during the irrigation season and so the full volume of seasonal water may not need to be stored at the start of the season; however at least 3-4 months' storage should be available and this is consistent with other irrigation schemes nearby.

The Cardrona River at The Larches has a mean flow of 3,137 litres/second (Table 1 above) from its 293 km^2 catchment area (ORC, 2011). This figure is derived from the recorded flow record, hence represents natural flows minus abstractions, and indicates a net long-term specific discharge of about 10.7 l/s/km^2. This equates to an annual mean runoff volume of 3,375 m^3/ha and a total catchment mean annual runoff of 99 Mm^3. This corresponds to about a third of an assumed average annual rainfall of 1000 mm over the entire catchment, which is consistent with known data and proven catchment yields in the drier areas of Otago.

Allowing for seepage, evaporation losses and minimum flow requirements, each 1 Mm^3 could comfortably irrigate some 100 ha; broadly indicating that overall there is enough available water to irrigate approximately 100 km^2 or about 25% of the total study area. Given that the majority of the upper catchment is too high and/or steep or otherwise unsuitable for irrigated land use, it is considered that rainfall is sufficient to support extensive storage-based irrigation for the wider Cardrona catchment and Wanaka-Cardrona flats.

The above range of water demand indicates that individual dams should be capable of capturing and storing about 120,000 m^3; i.e. sufficient when full to irrigate up to 20 ha without additional seasonal inflows. Smaller capacities may not be sufficient for seasonal storage, and will be expensive for the volume stored, but may be of some limited use for capturing freshes between irrigations. For the purposes of this study, a storage volume of 100,000 m^3 is adopted as the minimum for a significant site with reliable seasonal storage. The 100,000 m^3 minimum storage figure for 20 ha irrigated area is consistent with the findings of Aqualinc (2006), who recommend irrigation volumes of 5400 to 6525 m^3/ha for pastoral farming in the Upper Clutha area to cover 90% of seasonal crop requirements. Alternatively, because of the steep nature of some of the fans, a cascade of two or three dams one below the other may offer a solution at some locations, but again this option will be expensive per unit of water storage.

For potential dam sites, the criteria to meet this requirement are twofold:

- The contributing catchment must be capable of supplying the required volume of water, and
- The reservoir impounded by the dam must be large enough to store the required volume of water

These criteria were adopted as the basis for an initial desk-top research of existing digital information data sets, topographic maps, aerial and satellite photos to identify potential dam sites. Contributing catchment areas have been estimated using GIS computation based on the LINZ national 8 metre DEM (digital elevation model).

This scoping study is based on mean year and catchment-wide statistics, and has not investigated the reliability of supply for dry years without the normal winter-spring runoff, or for individual dams which may be in local rain shadow locations. Such studies should be conducted as part of further investigations and would be requisite for design.

2.2 Earthworks and Water Storage

This initial assessment is based on earth embankment type construction, which is often the most cost-effective for small, medium, and even quite large dams.

Earth dams are compatible with their local environment, being built mostly of locally sourced natural materials. Their lack of structural rigidity allows them to accommodate minor settlement and other movement, and they are readily repaired in the event of minor damage. With standard engineering provisions and monitoring programs they are robust against the normal range of natural hazards (see 3.4 below).

However it is recognised that for large gully dams some sites may be better suited to construction of concrete arch (like Idaburn and Butchers dams), rockfill with concrete membrane (like Falls and Loganburn dams), or roller compacted concrete (like Teviot). Future specific proposals should consider these options.

As well as sufficient water supply and storage capacity, a viable earth dam site must also offer a cost effective ratio of water storage capacity to dam earthworks. Really good sites can have ratios of greater than 10:1, while less viable sites can be as low as a 2:1 ratio if no artificial lining is required.

The earth embankment volume calculations have been based on upstream and downstream batter slopes of 3:1 and a crest width of 3.5 – 4.0 m. Assumed freeboard (height above spillway level) is 1.5 m for paddock dams and 2.0 m for gully dams. Lesser freeboard may suit some sites so the freeboard used translates to a level of conservatism in the estimates of earth fill required. A cutoff trench of 5 m^2 in cross sectional area (trapezoid 4 m wide and 1 m deep with 1:1 side slopes) has been used for the entire length of the embankment in calculating fill volumes.

Water volumes of natural storage reservoirs (gully dams) have been estimated using GIS computation based on LiDAR data. Total water storage has been assumed to include an allowance for ¾ of the fill for the dam wall to come from within the reservoir and below the maximum normal water level, thus increasing total storage. This proportion will vary depending on the suitability of earthfill on a given site.

2.3 Constraints

Sites identified as favourable under the storage/earthworks criteria were examined further to assess constraints including:

- underlying soils and geology (need for dam liner?);
- natural hazards - flooding, erosion, debris flow, seismicity;
- development and infrastructure - existing or potential;
- indicative costings;
- gravity irrigation command area (consistent with storage capacity);
- dambreak hazard - preliminary qualitative assessment, consistent with Potential Impact Classification (PIC) concept for large dams.

2.4 Water Allocation/Existing Consents

Currently the Cardrona River and its tributaries have 40 consented surface water takes. Of these, 16 are deemed permits and of the remaining 24 consented water takes, 18 are primary allocation, 1 is a non-consumptive take and 5 are supplementary allocation takes. The catchment has an overall consented primary instantaneous water take of 1904.69 l/s, which includes 1,894.28 l/s taken by surface water takes from the Cardrona River, as well as 10.41 l/s taken by two groundwater takes from the Cardrona Alluvial Ribbon Aquifer. Because 50% of MALF (as measured at the Larches flow monitoring site) equals 528.5 l/s, the catchment is over-allocated and no new primary allocation is currently available.

With no more water take able to be consented as primary allocation, new dams without pre-existing consents may still be feasible because further water may be allocated as supplementary allocation. Taking within supplementary allocation will be subject to a higher minimum flow and therefore stops much sooner than taking within primary allocation. Water taking within supplementary allocation typically occurs in winter and spring when river flows are much higher, or following substantial rainfall events.

2.5 Dam sites outside Cardrona catchment

There is potential to irrigate parts of the study area, specifically the Wanaka-Cardrona flats, from a dam(s) located in the adjacent Luggate Creek catchment. Possible sites have been identified and included in the summary.

The Luggate Creek catchment is also over allocated, therefore water taking for storage would need to occur under supplementary allocation at higher minimum flows.

2.6 Assumptions and Limitations

It is assumed that all gully dams will exceed the large dam threshold of 4 m height and 20,000 m^3 potential water storage and will therefore require a building consent and resource consent from the Otago Regional Council. Irrigation dams are not a permitted activity in the Queenstown Lakes District Council District Plan and thus the earthworks will normally require a resource consent from QLDC.

Surface water sources only have been considered in this assessment. There may be some additional opportunity for groundwater sourced water storage.

Reservoirs or dams with permeable foundations, as would be expected on alluvial fans or terraces, may require an artificial lining or treatment of the floor and walls of the reservoir to reduce seepage. No detail on spillway location or provision for diversion during construction has been made. In estimating approximate rough order costs, indicative figures of $14 and $21 +GST per cubic metre of embankment fill have been adopted for unlined and lined dams respectively. This figure is all inclusive of the works necessary to design, construct and commission the dams, including:

- investigation, design and consenting;
- topsoil stripping, cutoff trench and foundation preparation, reservoir excavations as necessary;
- handling, carting and compacting embankment fill, testing and certification of earthfill, placement of wave-lap protection and site tidy up on completion;
- main pipe conduit through the dam;
- bulk earthworks costs are increased by 50% if lining is required;
- land area cost for the dam and reservoir footprint allowed at $5,000 per ha.

Reliability of estimates is likely to be about plus or minus 30%, but may vary more depending on specific site constraints and the availability of suitably experienced contractors.

Ground truthing of the better sites with inspection and minor survey will be necessary to confirm site details and viability. This assessment has not covered detailed investigation and design that will require detailed site survey, geotechnical investigation of foundation, abutment and borrow areas, laboratory soil tests, and hydrology and structural design and preparation of construction drawings. Assessment of environmental factors associated with water takes and the construction of a dam are site specific and also need to be carried out to provide supporting information for consideration in processing of resource consents.

The full schedules attached are not an exhaustive set of all potential sites but was used to establish a representative sample of the types and costs of water storage opportunities available.

3 Site Assessments

3.1 Site locations

Figure 2 shows the sites investigated:

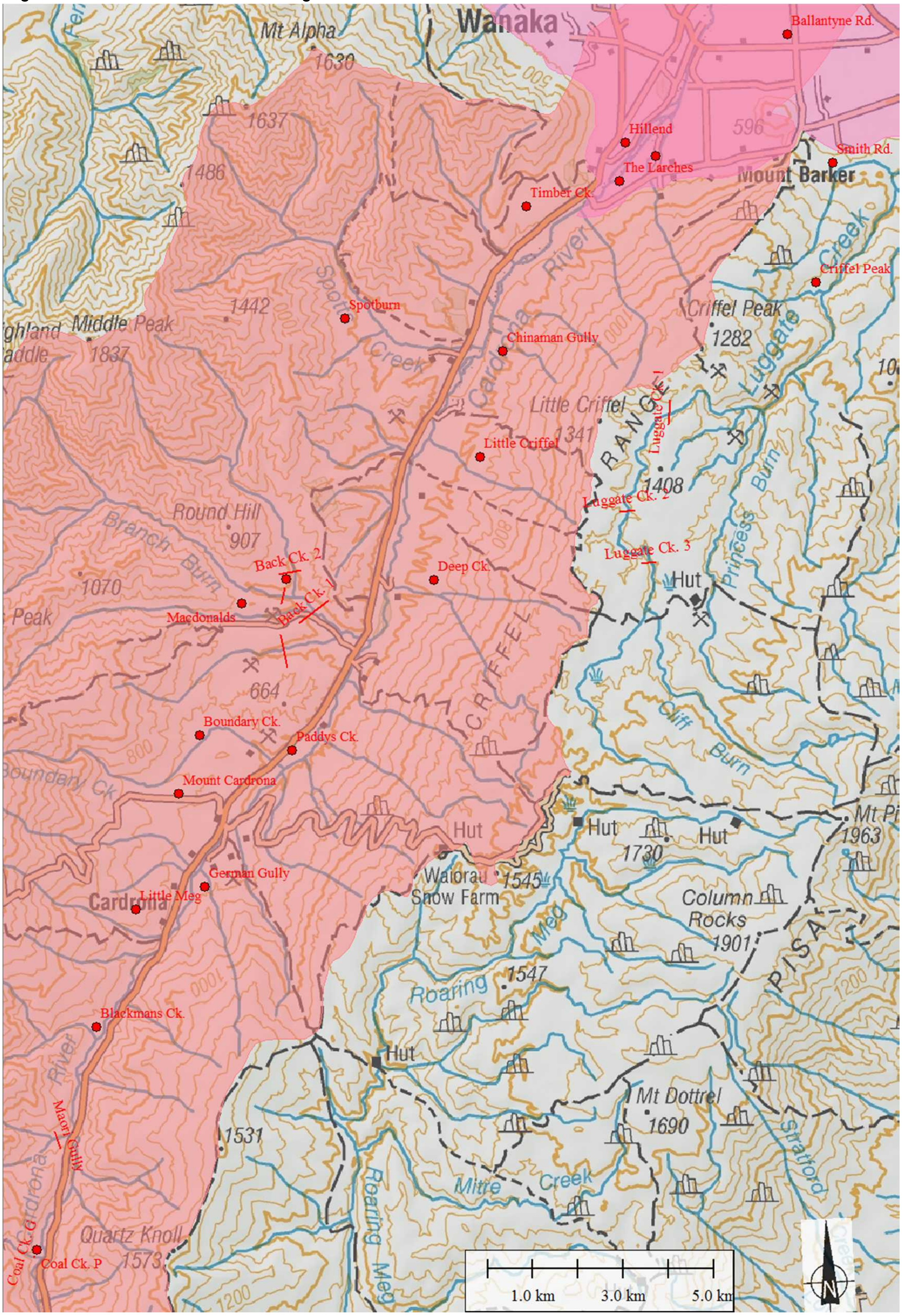

Figure 2: Potential dam sites assessed – red dots: paddock/'turkeys nest' dams; red lines: gully dams

3.2 Geology

The need for artificial lining (imported clay or synthetic material) to seal the reservoir floor against seepage is one of the major factors in the construction cost at a potential dam site. Consideration of the inferred site geology and soils suggests that many of the potential dam sites may be subject to high seepage losses and hence would need some form of lining.

Sediment loads are likely to be high in the Cardrona River tributaries and main stem, which mitigates in favour of off-channel impoundments rather than gully dams which may rapidly silt up reducing storage capacity.

Seismically, active Cardrona fault traces run close to several proposed sites and the Alpine Fault poses a regional seismic risk. Standard engineering solutions are available to mitigate seismic risk, which would be identified during geotechnical investigations and addressed by selecting dam types and design standards that offer greater seismic resilience.

3.3 Dam Safety

Preliminary assessment has been undertaken to determine the likely PIC (potential impact category) for the various potential dam sites. The PIC is a measure of the potential impacts on human life and infrastructure in the event of dam failure.

Based on our experience it is expected that having reached the Cardrona River main stem, any dam breach flow will create only a minor flood in the main river, hence the PIC is only likely to be an issue in the area between the dam and the Cardrona River (this assumption will need to be confirmed in formal PIC assessments). Further, for the most remotely located sites, the PIC is likely to be low owing to the absence of development in the downstream flood path and the capacity of downstream waterways to safely pass the breach flood.

It is likely that paddock dams can be sited such as to utilise existing terrain features to divert any breach flow away from dwellings, infrastructure etc.

However any large dams in the Luggate Creek catchment may have medium or high PIC owing to the downstream township of Luggate, State Highway 6, and other infrastructure.

3.4 Natural hazards

The study area is subject to a range of natural hazards as described by ORC (Natural Hazards in the Cardrona Valley, 2010) and mapped in the regional Natural Hazards Database (NHDB). These include river and alluvial fan hazards (flooding, debris flow, erosion & sedimentation), seismic action, and landslide. Based on the NHDB mapping, hazards potentially affecting proposed dam sites are shown in Table 2 and Table 3 below. It is expected that site-specific assessment will reduce the extent and significance of some of these hazards, as their identification is generally based on coarse regional-scale assessment.

Depending on their size and PIC (potential impact category), dams are subject to well established engineering design and regulated processes to withstand natural hazards. Consequently natural hazard triggered failures of properly engineered dams are extremely rare.

Paddock dams are remote from waterways and generally not exposed to significant flood or debris flow damage, but will still have spillways to provide a reasonable degree of freeboard against incoming flows, wave action and crest settlement. They may suffer seismic shaking, but are designed to resist this. Areas confirmed as liquefaction prone would preferably be avoided if possible.

Gully dams are likewise designed to resist seismic shaking, and will have spillways sized to safely pass extreme flood flows and wave action with a reasonable freeboard. However in this environment debris flows may pose additional hazard to gully dams, and careful consideration must be given to their siting and mitigation requirements.

Engineering measures to resist natural hazards are a normal part of dam design, construction and operation. As such, associated costs are covered within the indicative rough order estimates presented in this report. Individual dams would be subject to site-specific hazard assessment and mitigation as appropriate, however if the additional costs were inordinately high it is likely that more favourable sites would be selected.

3.5 Paddock dams

Also known as ring and turkey's nest dams, these are typically built off-stream on flatter or gently sloping land utilising material excavated from the reservoir footprint to construct an impounding embankment. Not being located in watercourses, resource consent to dam water is not usually required. These dams can be filled by pipe or canal from a natural stream, or by pumping from groundwater (however only surface water sources are considered in this study).

If there is no contributing natural catchment, the dam can receive only controlled supply inflows plus rain on the reservoir surface, therefore there is very low risk of flood-induced failure and only a nominal spillway is generally required.

A generic approach to these dams has been adopted, and a standardised design developed for pre-feasibility assessment purposes (see Appendix A). With a typical water depth of about 5 m, a reservoir footprint of some 5 ha is required to store a nominal 150,000 m^3. This can represent some 20% of the irrigable land and its loss may be a significant negative factor, and may interfere with the irrigation layout. Having large shallow reservoirs also means evaporation losses are comparably more than small deeper reservoirs.

A generic 150,000 m^3 ring dam design indicates a typical storage/fill ratio of around 2.6; i.e. marginal viability (even if un-lined) owing to the extensive earthworks required compared to water stored. Indicative total costs of the generic dam design are $800,000 if unlined and $1.2M if lined, with potential to reliably irrigate some 25 ha. These capital costs correspond to estimated water storage costs of around $5 and $8 /$m^3$ for unlined and lined dams respectively, and $30,000 - $50,000 per irrigated hectare, which may be attractive if justified by enhanced land use potential. The generic design is configured so as not to trigger Building and Resource consenting requirements. Any issues such as high consenting costs and/or land values are likely to adversely affect viability. Generally a larger dam will be more cost-effective, provided sufficient water is available to fill it and if the irrigable area commanded is sufficient to justify the increased storage.

Table 2 presents key parameters for a number of possible paddock dam sites. The estimated annual water yield is based on the average specific discharge over the upstream catchment area; water available for irrigation may be about half these figures when losses and minimum flow requirements are considered*.

Site name	Catchment area (ha)	*Annual water yield (m^3)	Lining required?	Prelim PIC	Natural hazard
Coal Ck. P	528	1,781,663	Probably	Low	Li
Blackmans Ck.	743	2,508,098	Probably	Low	Li, Af
Little Meg	416	1,404,169	Probably	Medium	Af
German Gully	159	537,705	Probably	Low	Li
Mount Cardrona	767	2,588,085	Probably	Low/Medium	
Boundary Ck.	933	3,149,381	Probably	Low/Medium	Af
Paddys Ck.	1000	3,375,000	Probably	Low	Li, Fl
Macdonalds	3437	11,601,225	Uncertain	Low	
Round Hill	4141	13,974,863	Uncertain	Low	
Deep Ck.	840	2,835,000	Probably	Low	Af
Little Criffel	11	36,140	Probably	Low	Af
Chinaman Gully	10	32,525	Probably	Low	
Spotburn	2053	6,927,525	Probably	Low	Li, Af
Timber Ck.	640	2,161,620	Yes	Low	
The Larches	191	645,705	Yes	Low	Li, Fl, Af
Criffel Deer	119	400,680	Yes	Low	Li, Af
Hillend		0	Yes	Low	Li, Fl
Criffel Peak	13	42,633	Uncertain	Low	La
Smith Rd.	327	1,103,389	Uncertain	Low	
Ballantyne Rd.		0	Probably not	Low	Li

Table 2: Potential paddock dam sites

Av = Avalanche
Af = Alluvial Fan
La = Landslide
Fl = Flooding
Sf = Seismic fault
Li = Liquefaction

3.6 Gully dams

Gully dams are in-channel storages formed by constructing an embankment across a natural watercourse to impound natural contributions from the catchment via stream flows and incidental runoff. Such dams require relatively smaller earthworks quantities compared to paddock dams and may therefore be cost-effective. However in steep terrain the reservoir volumes may be too small to support extensive irrigation, and this has been found to be the case at most potential locations within the Cardrona catchment.

presents key parameters for a number of possible gully dam sites. It can be seen that within the study area only one or two streams, Back Creek and possibly Branch Burn, offer potentially favourable storage/earthworks ratios of this magnitude. However geological considerations are less favourable; with active Cardrona Fault traces running close by, high seepage losses probable, and likely high sediment loads which may cause rapid silting up of the reservoirs.

More promising gully dam sites are located on upper Luggate Stream but this is outside the Cardrona catchment. See 3.6.1 below.

3.6.1 Luggate Creek

Potentially favourable sites have been identified on Luggate Creek. This stream is outside the Cardrona catchment and hence these dam sites are beyond the study area; however water stored in

Luggate Creek gully dams could be used to irrigate the Cardrona-Wanaka flats which are within the study area. Reservoirs at these sites could be utilised to supplement Luggate Creek low flows, or possibly conveyed around to supplement Cardrona River low flows.

The topography of the upper Luggate Creek valley is less steep than the Cardrona catchments, offering much greater storage volumes for similar dam sizes and therefore much better potential for cost-effective gully dams. Seepage losses are likely to be low at these sites, and sediment transport rates should be checked but the reservoir capacities are large and siltation may not be a major issue.

However being in steep sided valley, Luggate Creek storages may require higher spillway costs and construction diversion issues which may involve additional costs over standard earth embankments considered for other sites. A 20% cost premium has been added to allow for these factors.

With high dams, up to around 20 m water depth high, these sites offer the potential to store over a million cubic metres of water, possibly sufficient to service large irrigable areas on multiple farms. Roller-compacted, arch or mass concrete should be considered as an alternative to earth fill for such high dams.

Lower dams (up to 10 m high) at these sites may also be viable for irrigating smaller areas.

Wetland areas in the vicinity are not specifically mapped, but are higher than 800 m above sea level and as such are deemed to be Regionally Significant. Damming of water in this vicinity is therefore a non-complying activity (RPW rule 12.3.1A).

The Potential Impact Classification (PIC) of large dams on Luggate Creek is likely to be medium or high owing to the downstream township of Luggate, State Highway 6, and other infrastructure. Further analysis is required to assess this aspect.

Site name	Reservoir surface area (ha)	Water depth (m)	Total water storage (m^3)	Storage/ Earthworks ratio	Total cost	Storage cost $/$m^3$	Lining required?	Prelim PIC	Natural Hazard
Coal Ck. G	0.21	10.1	13,700	0.8	$228,340	16.67	Probably not	Low	Li
Maori Gully	1.52	14.0	88,012	1.4	$893,385	10.15	Probably not	Low	
Branch Burn	3.86	5.4	93,612	4.0	$509,635	5.44	Probably	Low	Sf, Af
Back Ck. 1 High	28.91	16.1	2,051,100	8.2	$5,396,755	2.63	Probably	Low	Sf, Li, Af
Back Ck. 1 Low	11.68	8	366,670	6.1	$1,312,205	3.58	Probably	Low	Sf, Li, Af
Back Ck. 2 High	8.20	15.0	568,600	5.0	$2,435,630	4.28	Probably	Low	Sf, Li, Af
Back Ck. 2 Low	3.80	9.5	146,950	4.4	$715,150	4.87	Probably	Low	Sf, Li, Af
Labrador	1.79	6.7	47,531	2.0	$502,125	10.56	Probably	Low	Li, Af
Luggate Ck. 1 High	16.63	20.8	1,883,031	23.4	$1,436,390	0.76	No	Medium	
Luggate Ck. 1 Low	8.11	6.0	319,419	42.9	$165,542	0.52	No	Medium	
Luggate Ck. 2 High	12.20	18.4	1,335,698	12.3	$1,883,212	1.41	No	Medium	
Luggate Ck. 2 Low	6.85	10.0	507,150	27.0	$350,342	0.69	No	Medium	
Luggate Ck. 3 High	38.96	16.5	4,281,900	26.0	$2,963,860	0.69	No	Medium	
Luggate Ck. 3 Low	30.38	13.0	2,325,951	30.6	$1,429,372	0.61	No	Medium	
Luggate Ck. 3 Low 2	24.07	8.5	1,090,024	34.0	$658,370	0.60	No	Medium	

Table 3: Potential gully dam sites

Av = Avalanche
Af = Alluvial Fan
La = Landslide
Fl = Flooding
Sf = Seismic fault
Li = Liquefaction

4 Conclusions and Recommendations

4.1 On-farm irrigation dams

There is some limited potential for farm dams which would allow individual land owners to directly irrigate their property during periods when abstractions were prohibited or rostered under a minimum flow regime. Viable gully dam sites in the Cardrona catchment are limited by the generally steep terrain and unfavourable geology. Some paddock dam sites have been identified; their viability is likely to be marginal and will depend on the economics of the enhanced land use potential.

4.2 Flow enhancement dams

There is greater opportunity for larger dams to be filled from the Cardrona River during high flow periods and used to supplement river flows during drier periods thus making water available for irrigation abstractions while still maintaining the minimum flow. This type of storage concept may be more suited to community dams, with the ability for a large dam to provide sufficient supplementary flow to allow a number of downstream abstractions.

The neighbouring Luggate Creek, with flatter terrain in the upper catchment, offers good viable gully dam sites (3.6.1 above) which likewise could supplement Luggate Creek low flows to irrigate parts of the study area in the lower Cardrona/Wanaka flats. It may also be possible to convey water over into the lower Cardrona River to supplement Cardrona River low flows.

A number of potentially suitable paddock dam sites have been identified (3.5 above) but further investigation is necessary to confirm viability. It may be that dams larger than the generic 150,000 m^3 design may prove more cost-effective for bulk community storage at these sites.

4.3 Alternative Option

It may be more economic to irrigate lower areas of the study area by direct pumping from the Clutha River, thus avoiding or reducing the need for expensive water storage facilities.

Capital costs of pumps and short-run pressure pipelines may be in the order of $5,000 to $7,000 per irrigated hectare, compared with some $30,000 or more per irrigated hectare for a paddock dam. However pipeline costs will increase substantially with distance from source.

Annual energy costs for a pumped system may be some $400 per irrigated hectare, compared to nil for a storage-based full gravity system.

Thus capital costs of short-run pumped supplies may be substantially lower than storage dams and gravity pipelines; however the on-going operating costs may be higher owing to pumping energy requirements.

It is considered likely that areas close to the Clutha River could be irrigated more economically by pumping from the river than by gravity from Cardrona-sourced storage dams. There will be threshold distance up the Cardrona valley, beyond which pumping will become uneconomic.

This alternative has significant potential and should be further investigated.

5 Applicability

This report has been prepared for the benefit of Otago Regional Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

This has been a broad-brush desk-top study at concept level. Sites have not been visited and property owners have not been consulted. Detailed site specific investigation needs to be undertaken to confirm the availability and viability of all proposals.

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Appendix A: Typical Ring Dam Cross-section