Dunstan – Earnscleugh Groundwater Basin: Conceptual Model

Prepared for

Otago Regional Council

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1.0 Introduction

The Earnscleugh Flat and Dunstan Flats aquifers are located in the Alexandra Basin in Central Otago, on opposite sides of the Clutha River / Mata-Au (Figure 1). The area has a semi-arid climate, and direct rainfall infiltration comprises a relatively small proportion of recharge. Water losses relating to irrigation (both related to application of irrigation water, and losses from water transport and storage) comprise a significant proportion of recharge to both aquifers. Changes in abstraction pressure and associated surface water management practices in the last 10 years mean that reassessment of the existing water allocation settings is necessary.

Pattle Delamore Partners (PDP) have been engaged by Otago Regional Council (ORC) to build numerical groundwater models for the Earnscleugh Flat Aquifer and Dunstan Flats Aquifer that will provide a basis for allocating groundwater, for consultation and inclusion in the proposed Land & Water Regional Plan for Otago.

This report provides our conceptual understanding of the Earnscleugh Flat and Dunstan Flats aquifers, and a review of the existing literature, studies and investigations undertaken within the Alexandra Basin used to inform this. This report also outlines the proposed modelling approach, for consultation with ORC science staff.

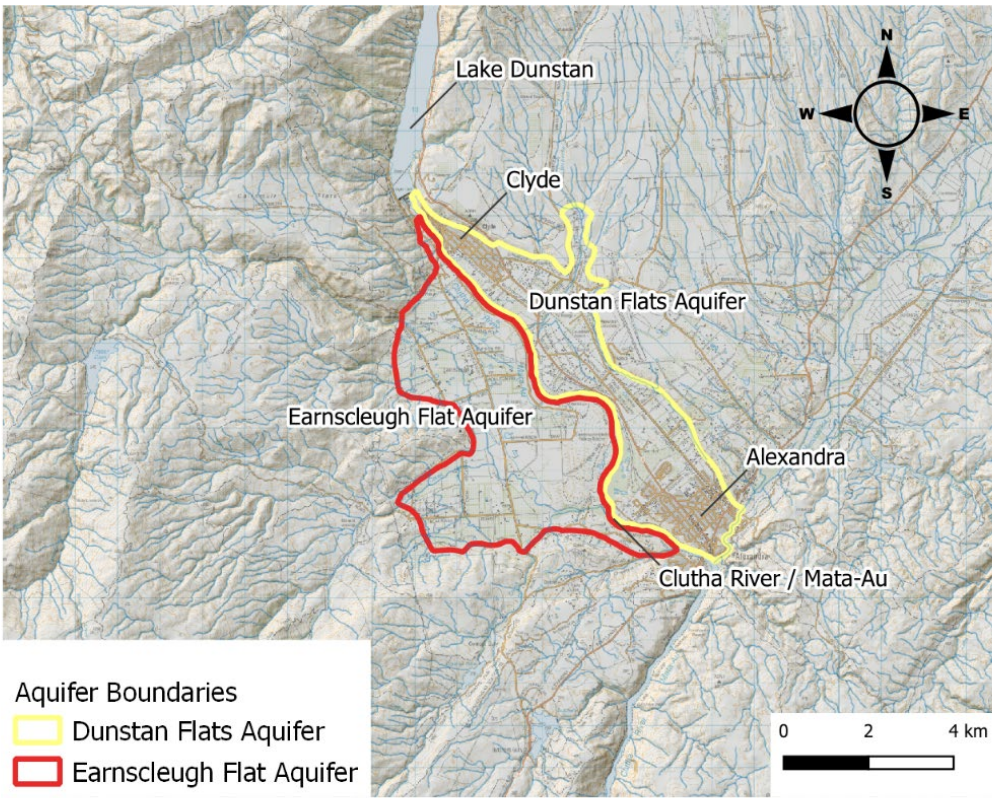

Figure 1: The study area, showing the approximate extent of the Earnscleugh Flat Aquifer (red) and Dunstan Flats Aquifer (yellow).

2.0 Earnscleugh Flat Aquifer

The Earnscleugh Flat Aquifer is on a terrace on the south - western side of the Clutha River / Mata-Au.

2.1 Topography

Earnscleugh Flat is a terrace that is elevated 20 – 30 m above the Clutha River / Mata-Au and bounded by the foothills of the Cairnmuir Mountains, Old Woman Range and Old Man Range to the north, west and south, respectively. LiDAR elevation data indicates that the Clutha River / Mata-Au is generally at an elevation of 132 – 134 m above mean sea level (amsl), while the surface of the Earnscleugh Flat terrace is at 155 – 165 m amsl.

The terrace is extensively irrigated and land use is predominantly pasture and viticulture (Figure 2). The Otago Irrigated Area GIS layer (dated 26 October 2021) indicates that the predominant irrigation type on the terrace is drip/micro. Significant areas are also irrigated using border dyke, pivot, wild flooding and k-line/long lateral methods. The Alexandra Groundwater Basin Allocation Study (ORC, 2012) indicated that most irrigation at that time was of wild flood and border dyke type, which suggests that irrigation methods are shifting to more efficient types over time.

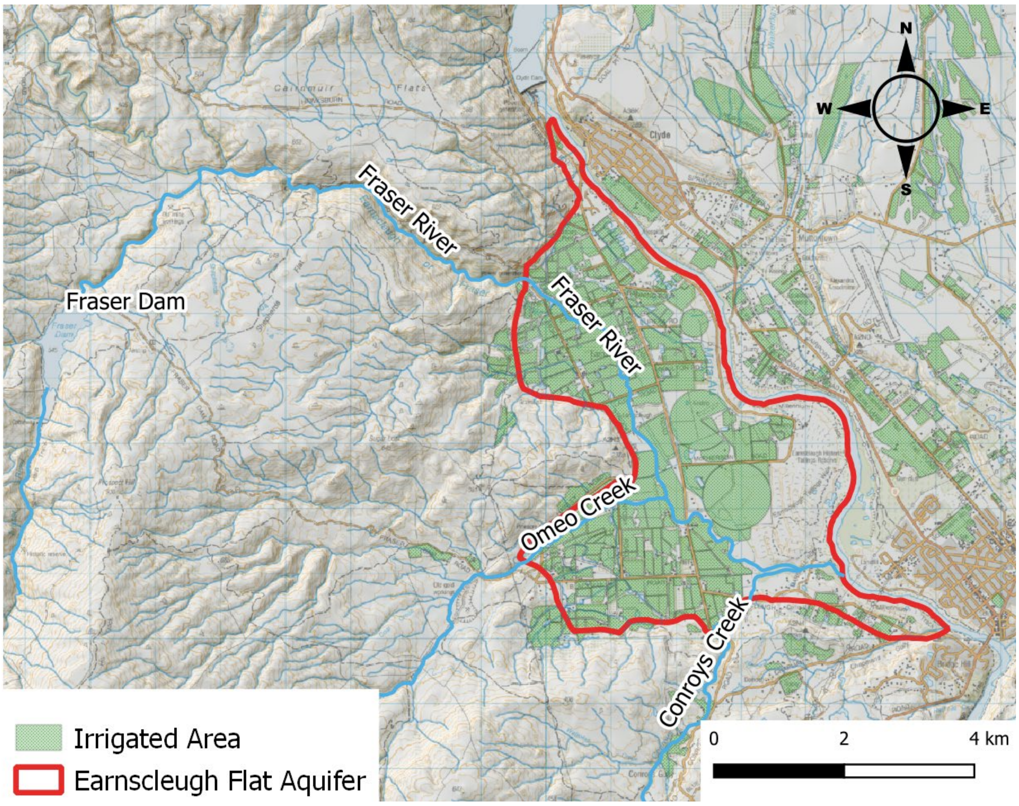

Figure 2: The Earnscleugh Terrace, with the approximate extent of the Earnscleugh Flat Aquifer outlined in red. Areas of irrigation are shown in green.

The largest surface waterbody that crosses Earnscleugh Flat is the Fraser River, which drains the eastern slopes of the Old Woman Range and exits a steep bedrock gorge onto the northern end of the Flat. The river crosses the flat and drains into the Clutha River / Mata-Au near the southern end of the Flat. Fraser Creek has a dam and associated lake in the upper catchment (at approximately 545 m amsl) and a weir in the gorge below, at approximately 440 m amsl. The water stored by the dam is used for power generation and irrigation.

The other main streams that cross the Flat are Omeo Creek at the central part of the terrace and Conroys Creek at the southern end of the terrace (Figure 2).

According to the ORC GIS mapping system, there are no regionally significant wetlands mapped across the Earnscleugh Aquifer.

2.2 Geology

The Earnscleugh Terrace consists largely of glacial outwash of Pleistocene age, associated with the Albert Town and Luggate glacial advances (AquaFirma, 1997). This outwash consists primarily of sandy gravels and is on average 24 m thick, though up to 38 m in places (AquaFirma, 1997). The depth of this outwash across the terrace is well constrained by over 1000 boreholes drilled for gold exploration (AquaFirma, 1997). The base of the Earnscleugh Flat Aquifer consists of Miocene to Pliocene silt, mudstone and sandstone of the Manuherikia Group, which is expected to have a low permeability. The Manuherikia Group is underlain by basement schist of the Torlesse Supergroup and Caples Group. A geological map of the area is shown in Figure 3. A map showing the thickness of the gravels is shown in Figure 4.

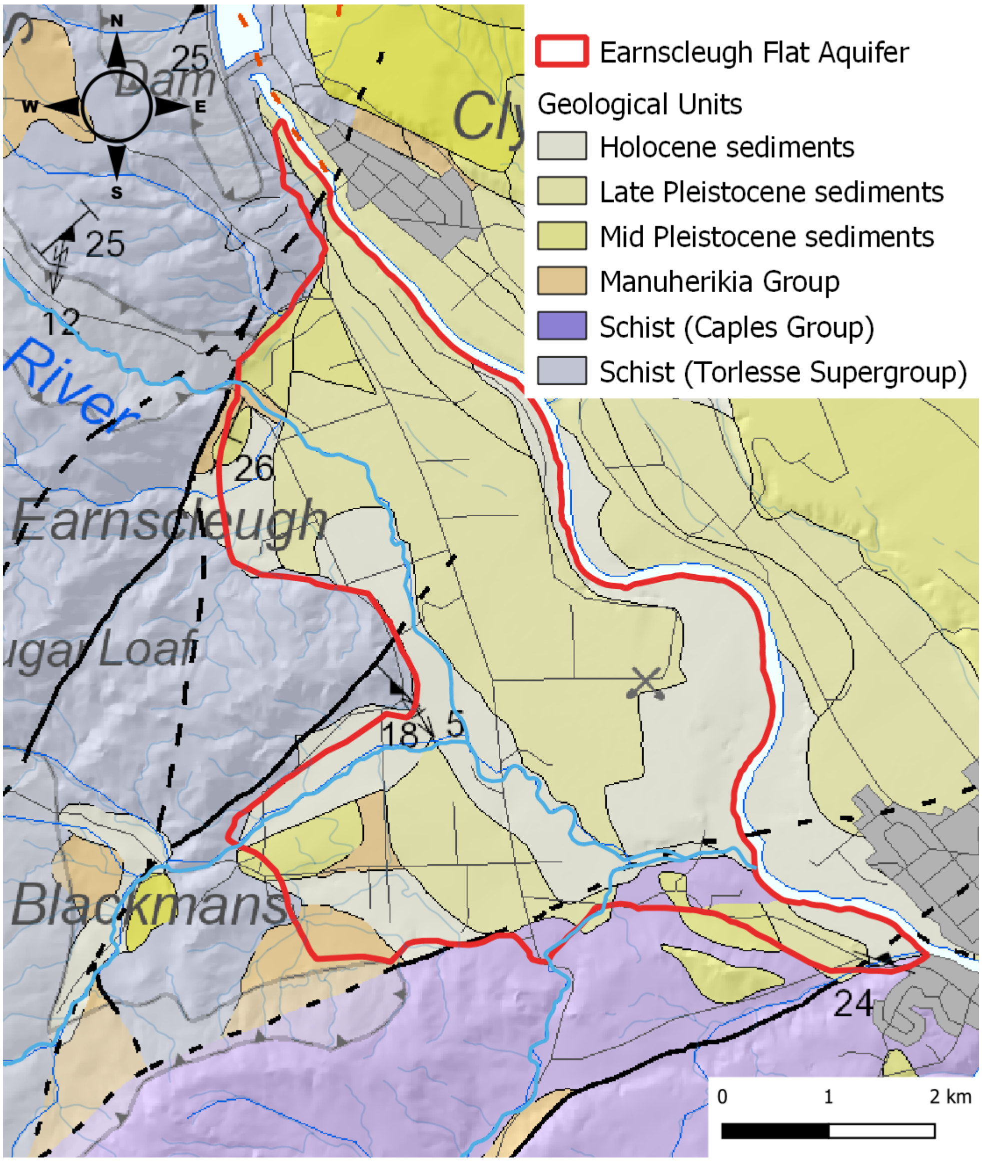

Figure 3: Geological map of the area surrounding the Earnscleugh Aquifer (Turnbull, 2000).

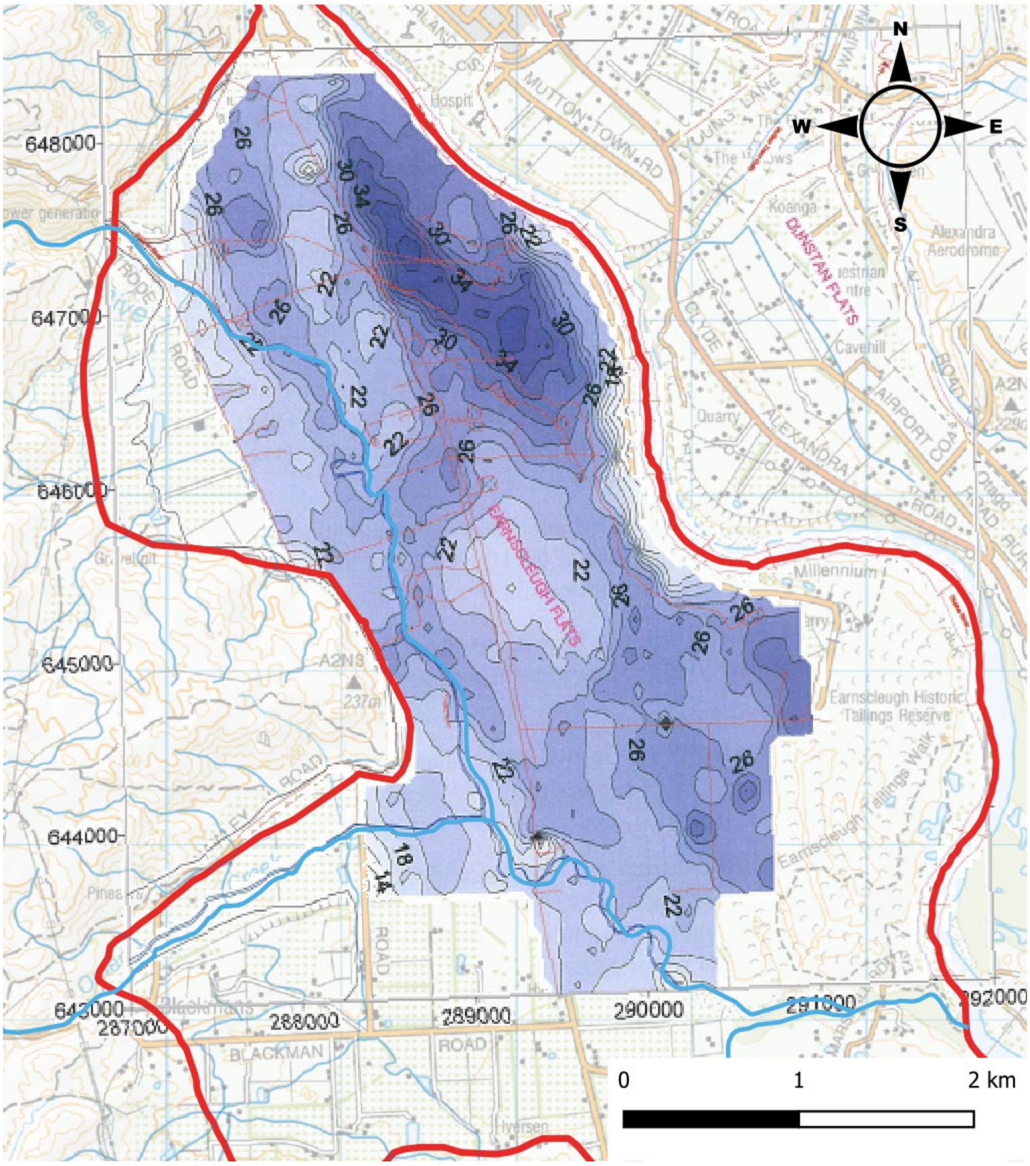

Figure 4: Contour map of the thickness of Quaternary gravels (in metres) across Earnscleugh Flat (after AquaFirma, 1997). The boundary of the aquifer is shown in red.

Earnscleugh Terrace and Dunstan Flats occupy the western end of the wider Alexandra Basin, which is a fault-bound basin between basement ranges of the Dunstan Mountains to north and the Raggedy Range to the south. Uplift of these basement ranges postdates deposition of the Manuherikia Group. The Alexandra Basin is one of a series of subparallel fault-bound basins in Central Otago.

2.3 Hydrogeology

2.3.1 Groundwater use and aquifer properties

The Earnscleugh Flat Aquifer is hosted in the outwash gravels described in section 2.2 above. Groundwater generally flows in an eastward direction, towards the Clutha River / Mata-Au (Figure 5). There are 189 bores recorded on Earnscleugh Flat, and they range in depth from 2 – 54.4 m below ground level (bgl), though many of the bores are of unknown depth (Figure 6).

Aquifer tests conducted in the Earnscleugh Flat Aquifer have estimated transmissivities of 1,100 to 8,900 m^2/day, based on three tests near the centre of Earnscleugh Flat.

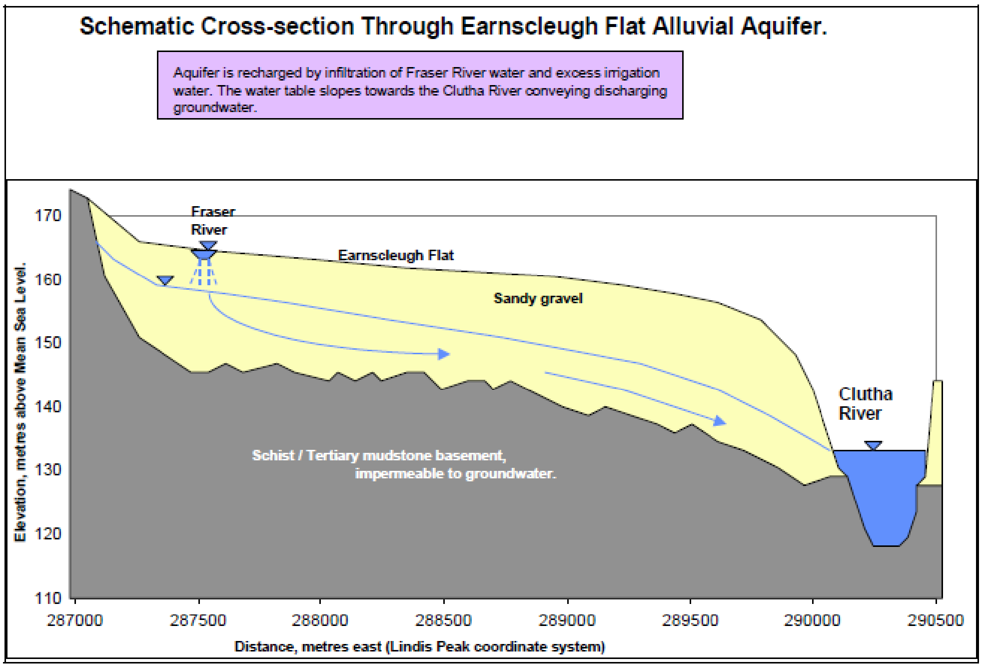

Figure 5: Conceptual cross-section through the Earnscleugh Flat Aquifer (after AquaFirma, 1997).

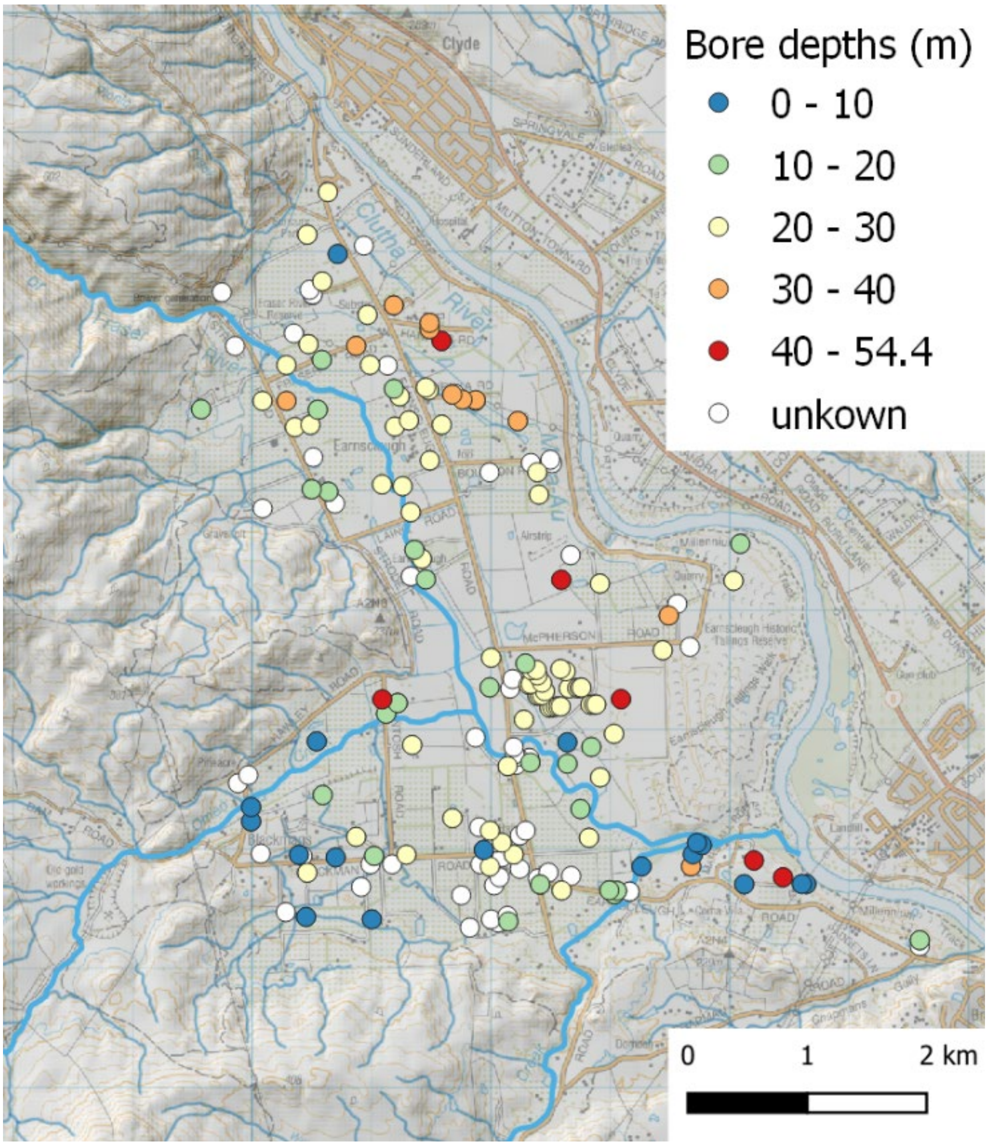

Figure 6: Map of known bores on Earnscleugh Flat, and their depths where known.

2.3.2 Groundwater Levels

Static water level records in bores on Earnscleugh Flat show that the groundwater table is generally deeper towards the Clutha River / Mata-Au across most of the terrace (Figure 7). At the southern end of the terrace groundwater levels are closer to the surface where the Fraser River has incised into the terrace. This coincides with the gaining reach of the Fraser River, as discussed further in the sections below. Mean piezometric contours derived from monitoring of groundwater levels across Earnscleugh Flat by AquaFirma from 1993 to 1997 indicated a similar pattern (AquaFirma, 1997) (Figure 8).

There are relatively few long-term records of groundwater levels available for the Earnscleugh Flat Aquifer. Bore G42/0190, near where Earnscleugh Road crosses the Fraser River in the southern central part of the terrace (shown on Figure 7 below), has a sporadic monitoring record, with one to five measurements per year since 2015. This bore is 21.3 m deep, and the groundwater level record shows that seasonal fluctuations of up to approximately 2.6 m per year are common (9.7 – 12.3 m bgl), though there have been at least two periods, in March 2017 and December 2020, when levels were much lower than usual at 17.6 and 18.4 m bgl, respectively. It is noted that this bore is close to the site of mining operations that PDP understands occurred from approximately 2009 to 2015 and involved significant dewatering (Consent 2000.410).

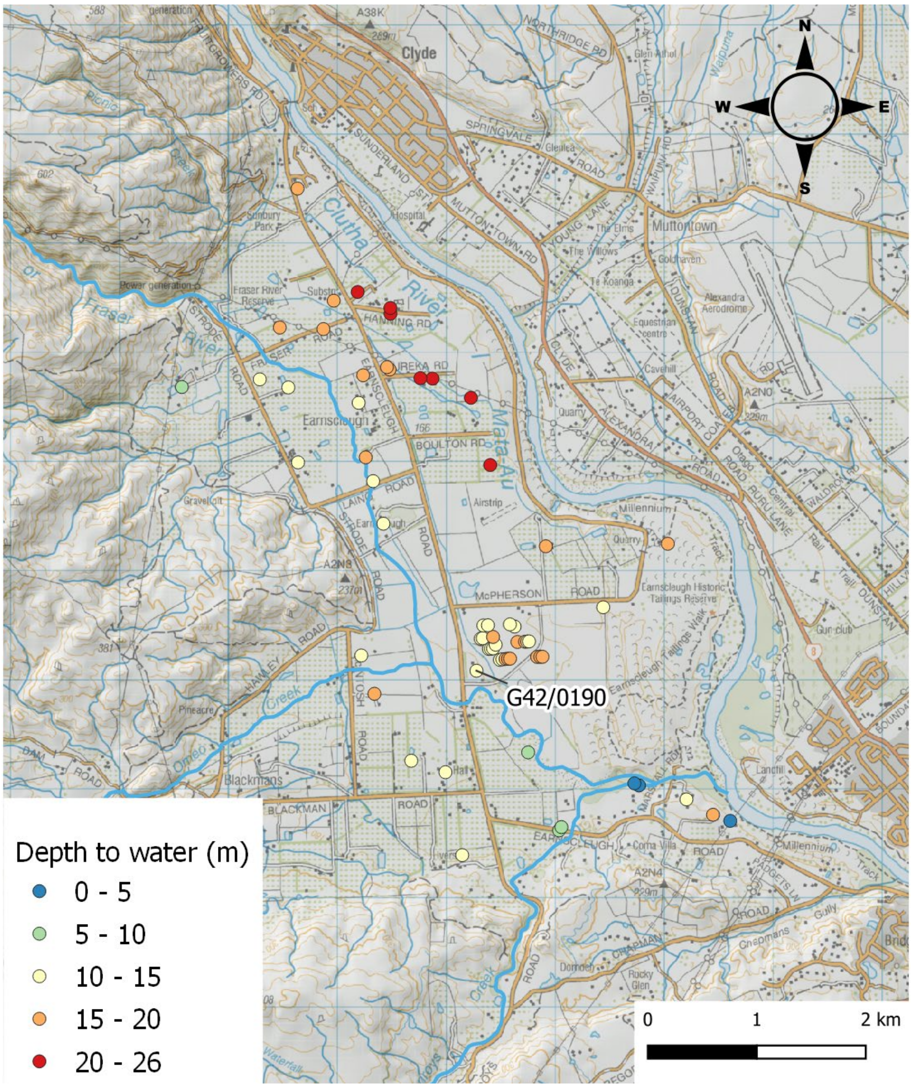

Figure 7: Recorded depth to water (at the time of drilling) in bores on Earnscleugh Flat.

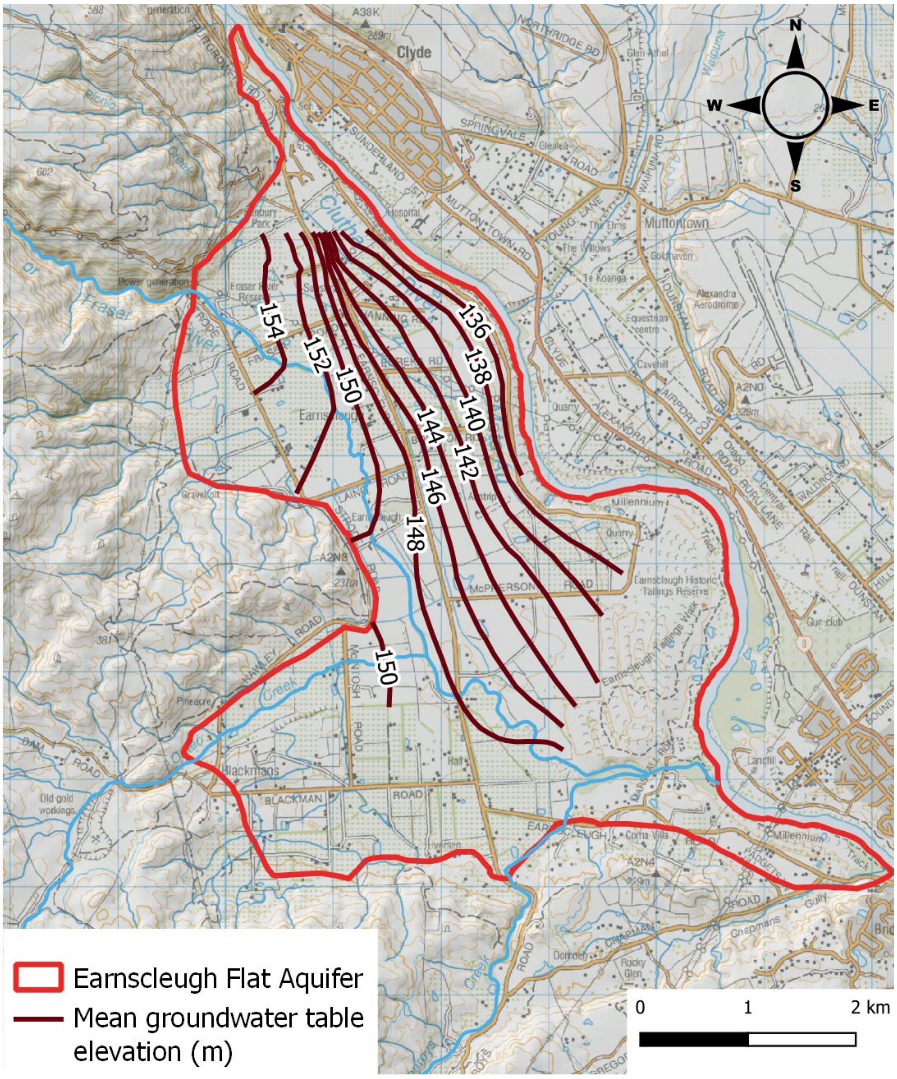

Figure 8: Contour plot of the mean groundwater table elevation across Earnscleugh Flat, in metres above mean sea level, based on monitoring from 1993 to 1997 (after AquaFirma, 1997). The Clutha River / Mata-Au is reported to have a mean water elevation of 134 m amsl.

2.3.3 Recharge

Earnscleugh Flat has a semi-arid climate; the floor of the Alexandra Basin has a typical annual rainfall of 350 mm per year (mm/y), while rainfall is significantly higher at higher elevations (ORC, 2012). The mean annual pan evaporation is just over 1000 mm and typically a small soil moisture excess, totalling on average 38 mm/yr for June – August, recharges groundwater from rainfall under natural conditions (ORC, 2005).

The most significant source of recharge for the Earnscleugh Flat Aquifer is losses from the Fraser River. Smaller losses also occur from Omeo Creek. Flow gauging studies indicate that the Fraser River loses water from where it exits the bedrock gorge at the northern end of Earnscleugh Flat to approximately where Earnscleugh Road crosses the Fraser River, in the southern central part of the Flat. Downstream of this crossing the river incises down into the terrace as it flows towards the Clutha River, and the Fraser River gains from groundwater in its lower reaches, approximately 2 km above the confluence with the Clutha River / Mata-Au (AquaFirma, 1998; ORC, 2012). The 2012 allocation study estimated that 25 Mm^3 of water infiltrates through the bed of the Fraser River per year (an average of around 790 L/s), and 16 Mm^3/yr is gained to the lower portion of the river from groundwater (ORC, 2012).

Flows in the Fraser River are partially controlled by a dam in the upper catchment, which stores water for irrigation and electricity generation (Landpro, 2020). Water is also taken from the river for irrigation purposes, with most of the surface water takes occurring near where the river exits the bedrock gorge. Losses from Omeo Creek have been estimated at 6 Mm^3/yr, but are not well constrained (ORC, 2005). Little data is available for Conroys Creek, but its location on the margin of the terrace makes it unlikely to be a major contributor to the overall water balance of the aquifer.

Irrigation provides a significant source of groundwater recharge on Earnscleugh Flat, both as a result of direct application to ground and via losses from water races and storage ponds. Irrigation methods are becoming more efficient over time, with most irrigation reported to be occurring via border dyke and wild flooding methods in 2012 (ORC, 2012), while the 2021 irrigated area GIS layer indicates that micro drip is now the most common method. Recharge due to irrigation is therefore likely to be reducing over time as further areas transition from wild flooding and border dyke methods, and irrigation recharge will be assessed as part of the PDP modelling work.

PDP understands that irrigation water is primarily sourced from surface water takes from the Fraser River, with other sources including diversions from Lake Dunstan/Clyde Dam and from groundwater bores (Figure 9 and Figure 10). The diversion from the Clutha River is directed into the Fraser River where it exits the gorge, from where irrigation race offtakes occur.

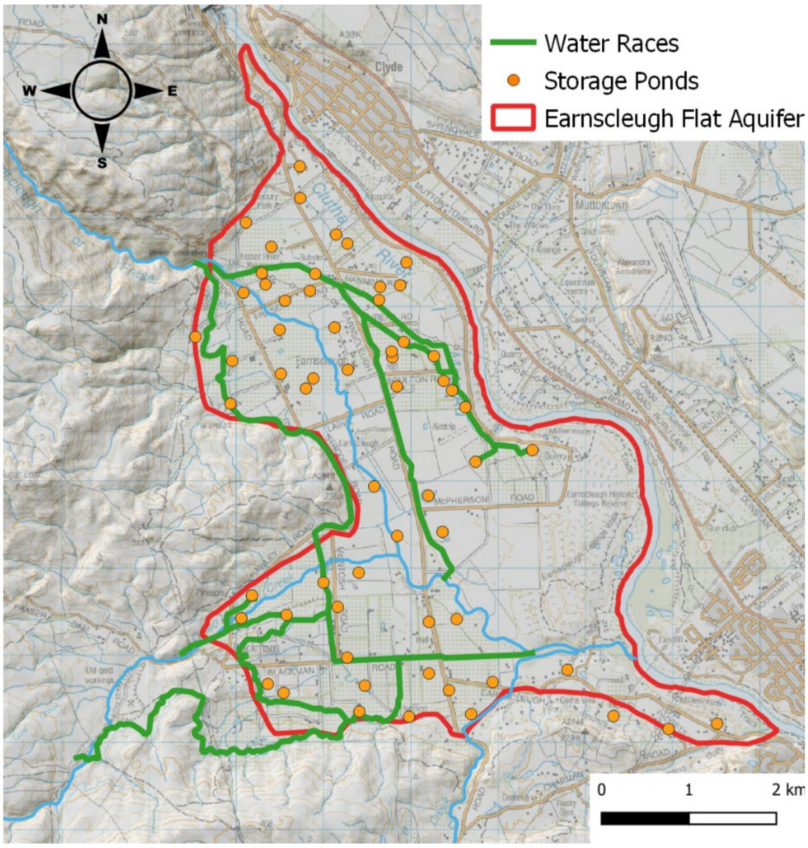

Figure 9: Map of water races and water storage ponds/reservoirs on Earnscleugh Flat, as identified from consent documents and aerial photography.

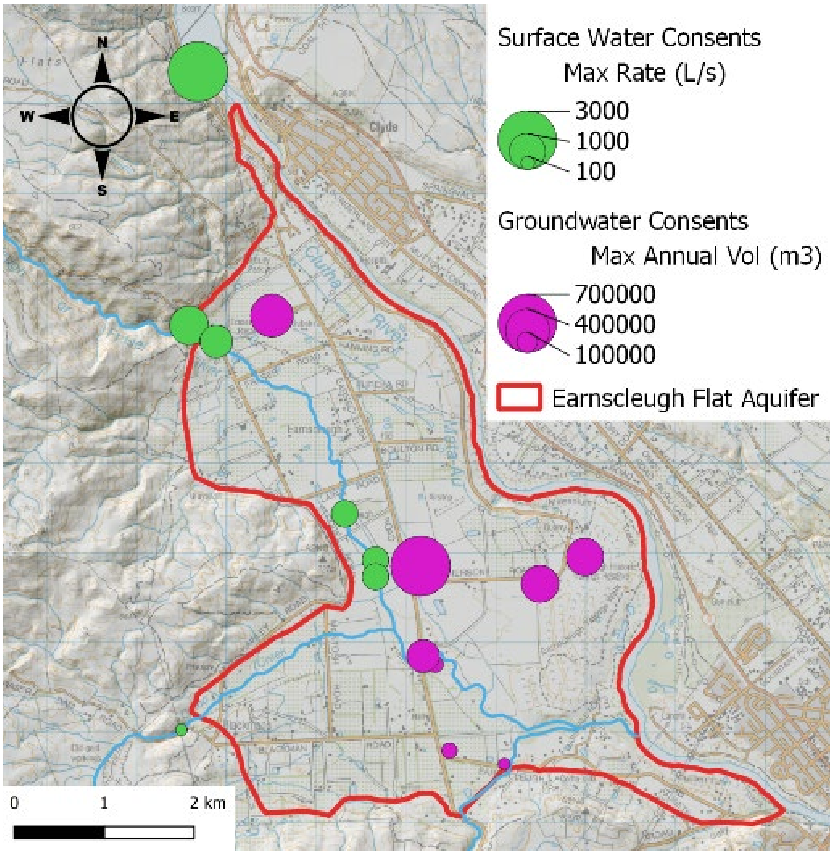

Figure 10: Map showing consented surface water and groundwater takes on Earnscleugh Flat. The surface water take from Clyde Dam to the north of Earnscleugh Flat diverts water (via pipe) into the Fraser River.

2.3.4 Outflow

All outflow from the Earnscleugh Flat Aquifer occurs either as groundwater abstractions, flow to the lower Fraser River and thence to the Clutha River / Mata-Au, seepage directly into the Clutha River / Mata-Au, or else as springs along the bank of the Clutha River / Mata-Au.

As stated in section 2.3.2 above, outflow to the lower 2 km of the Fraser River has been estimated at 16 Mm^3/yr, which in 2012 was estimated as 56% of the total outflow from the aquifer (ORC, 2012).

It has been observed that at times of low water levels in the Clutha River / Mata-Au groundwater can be seen to discharge from springs along the upper contact of Manuherikia Group sediments along the bank of the Clutha River / Mata-Au (AquaFirma, 1997). Spring discharge along the margin of the terrace is a major source of outflow from the Earnscleugh Flat Aquifer, and in 2012 was estimated as 14% of total outflow (ORC, 2012).

Groundwater seeps directly into the Clutha River / Mata-Au where the river is not incised into the impermeable Manuherikia Group sediments or schist basement. These seepages are mostly along the margin of the southern portion of Earnscleugh Flat (AquaFirma, 1997), and were estimated to comprise 29% of total outflow in 2012 (ORC, 2012).

Most irrigation water on Earnscleugh Flat is sourced from surface water takes, however there are groundwater abstractions from the Earnscleugh Aquifer. In 2012 these abstractions were estimated to total 0.15 Mm^3/yr, or 1% of the total outflow from the aquifer (ORC, 2012).

2.4 Surface Water – Groundwater Interaction

The major surface water – groundwater interactions that occur are significant losses from the Fraser River and Omeo Creek, losses from irrigation-related water races and storage ponds, gains from groundwater to the lower Fraser River and discharge (via springs and direct seepage) to the Clutha River / Mata-Au. Losses from the Fraser River are the most significant source of recharge to the Earnscleugh Flat Aquifer.

The Earnscleugh Flat Aquifer may be directly connected to the Clutha River / Mata-Au along the southern half of the Earnscleugh terrace, e.g. in the vicinity of the Fraser River confluence. However, no correlation between water levels in the Clutha River / Mata-Au and the Earnscleugh Flat Aquifer have been noted during past monitoring, unlike the correlations observed in the Dunstan Flats Aquifer (AquaFirma, 1997). Theoretically, changes in the stage height of the Clutha River / Mata-Au could affect the hydraulic gradient in the Earnscleugh Flat Aquifer, however due to the lack of observed connection (and therefore the lack of calibration data) this is not considered necessary to represent for the purposes of this groundwater model.

2.5 Water Balance

The overall water balance of the Earnscleugh Flat Aquifer as estimated by ORC in 2012 is provided in Table 1 below. It is noted that aspects of this water balance, in particular inflow due to irrigation and outflow from groundwater abstraction, may have changed since 2012 and will be refined during the modelling process. However, this water balance is considered a useful starting point for the conceptual model of the aquifer.

Table 1: Water balance of the Earnscleugh Flat Aquifer (after ORC, 2012)

Water balance component	Mean annual inflow (Mm^3/y)	Mean annual outflow (Mm^3/y)
Rainfall recharge	0.35	
Excess soil drainage related to Fraser Irrigation Scheme	0.55	
Infiltration of water from Fraser River to the aquifer	24.60	
Water race losses to the aquifer	3.40	
Seepage into the lower Fraser River		16.20
Pumping from the Earnscleugh Flat Aquifer[1]		0.15
Seepage into springs cascading into the Clutha River / Mata-Au		4.00
Seepage directly into the Clutha River / Mata-Au		8.5
Total	28.9	28.9

Notes:

1. *Actual pumping estimated as 30% of groundwater take consent allocation for the aquifer.*

3.0 Dunstan Flats Aquifer

The Dunstan Flats Aquifer is beneath Dunstan Flats, on the eastern side of the Clutha River / Mata-Au between the towns of Alexandra and Clyde.

3.1 Topography

Dunstan Flats is a terrace that is elevated 20 - 30 m above the Clutha River / Mata-Au. LiDAR elevation data indicates that the Clutha River / Mata-Au is generally at an elevation of 132 – 134 m amsl, while the terrace surface is mostly at 150 – 170 m amsl. The terrace is bounded by the alluvial fan of the Waikerikeri Creek to the northeast, a higher elevated terrace (called ‘Airport Terrace’) to the east (which is approximately 60 m higher than Dunstan Flats, at an elevation of approximately 225 m amsl), and the Manukerikia River to the southeast. The Waikerikeri Creek alluvial fan extends southwards from the base of the Dunstan Mountains.

The Dunstan Flats are extensively irrigated, and consist of pasture, viticulture, residential and commercial land use. The Otago Irrigated Area GIS layer (dated 26 October 2021) indicates that the irrigation type on the terrace is roughly evenly split between drip/micro, K-line/long lateral and border dyke methods, with smaller areas of wild flooding type irrigation. As with the Earnscleugh terrace, it is likely that less efficient border dyke and wild flooding methods are transitioning to drip/micro and K-line/long lateral methods over time. Irrigation on the Waikerikeri alluvial fan and Airport Terrace (as shown on Figure 11) is important for understanding the water balance of the Dunstan Flats Aquifer, as discussed further in section 3.3 below.

Waikerikeri Creek is the only significant stream that crosses Dunstan Flats, and it is reported to be intermittent in its lower reaches (ORC, 2005). Waikerikeri Creek drains the southern slopes of the Dunstan Mountains and is a significant source of recharge to the Manuherikia Claybound Aquifer, as discussed further in section 3.3 below.

According to the ORC GIS mapping system, there are no regional significant wetlands located across the Dunstan Flats aquifer.

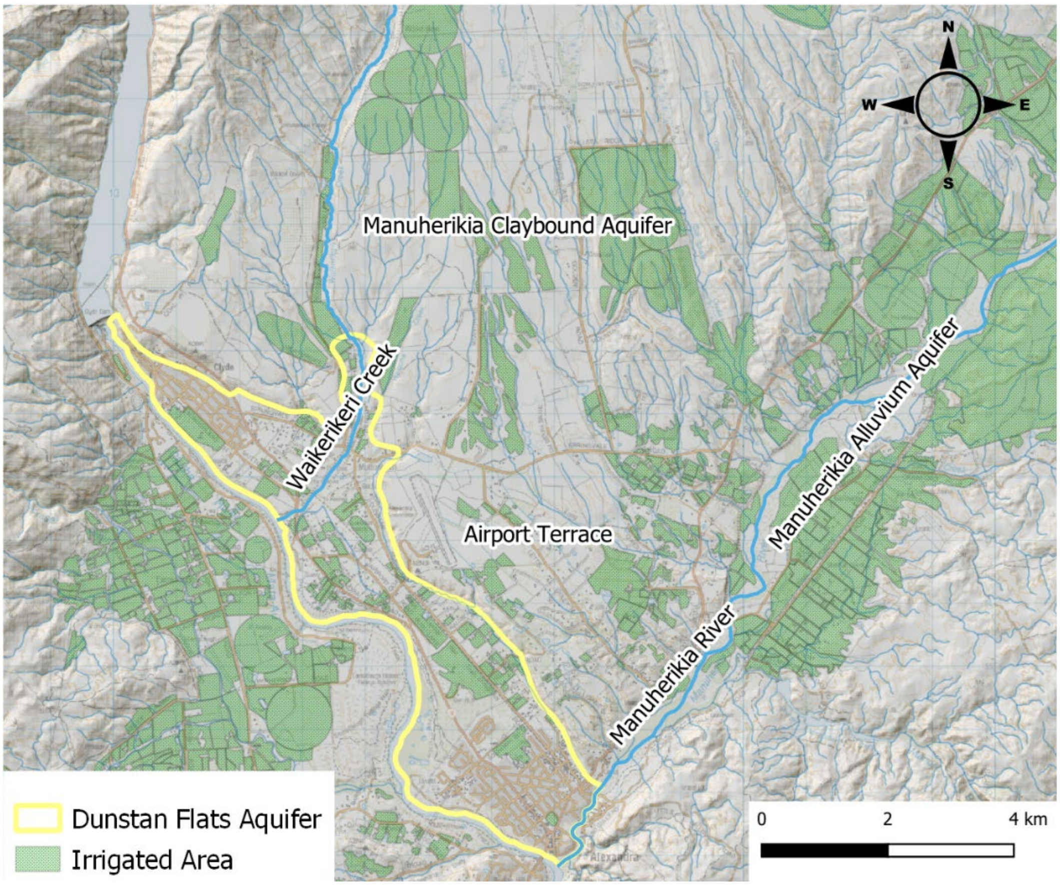

Figure 11: The Dunstan Flats, with the approximate extent of the Dunstan Flats Aquifer outlined in yellow. Areas of irrigation are shown in green.

3.2 Geology

The geology of the Dunstan Flats Aquifer is similar to that of the Earnscleugh Aquifer as described in section 2.2 above. The Dunstan Flats consist largely of glacial outwash of Pleistocene age, associated with the Albert Town and Luggate glacial advances (AquaFirma, 1998). This outwash consists primarily of sandy gravels and rests on low permeability sediments of the Manuherikia Group. The Manuherikia Group is underlain by basement schist of the Torlesse Supergroup and Caples Group. A geological map of the area is shown in Figure 12.

The adjacent Airport Terrace and Manuherikia Claybound Aquifer generally consist of outwash from the Lindis glacial advance. This outwash is described as a silty sandy gravel with occasional “clay-bound gravel” more accurately described as silty or weathered gravel (AquaFirma, 1998).

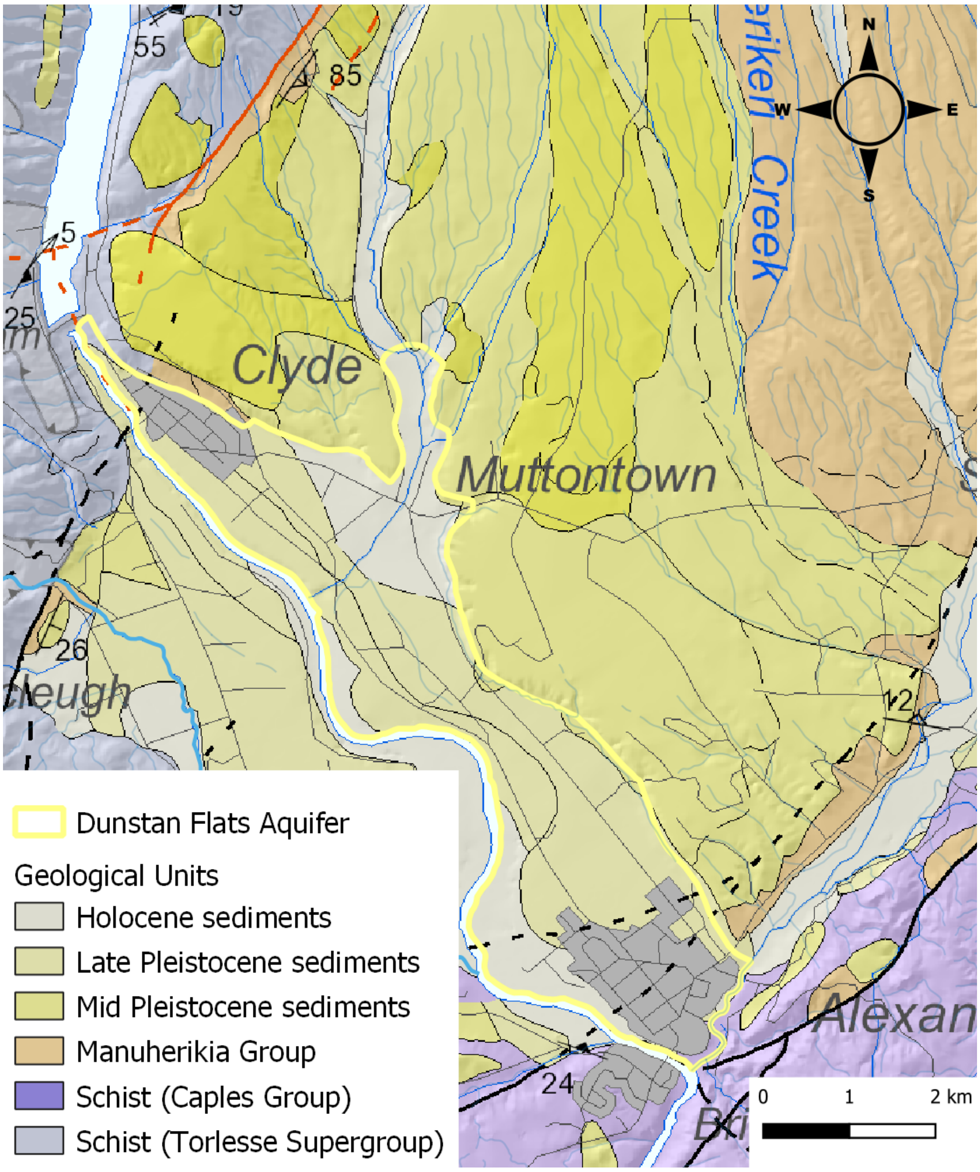

Figure 12: Geological map of the Dunstan Flats area. Grey and purple depict basement schist of the Torlesse and Caples Groups, respectively. Orange depicts Manuherikia Group sediments, while yellow and beige depict Pleistocene and Holocene sediments, respectively (Turnbull, 2000).

3.3 Hydrogeology

3.3.1 Groundwater use and aquifer properties

The Dunstan Flats Aquifer is hosted in the outwash gravels described in section 3.2 above. Groundwater generally flows in a westward direction, towards the Clutha River / Mata-Au. There are 289 bores recorded on Dunstan Flats, and they range in depth from 6 – 204 m below ground level (bgl), though many of the bores are of unknown depth (Figure 13). Most bores are up to 39 m deep and used for domestic supply, with irrigation and stockwater the other most common bore usages.

Aquifer tests conducted in the Dunstan Flats Aquifer have estimated transmissivities of 1,200 to 7,000 m^2/day based on three tests in the central Dunstan Flats.

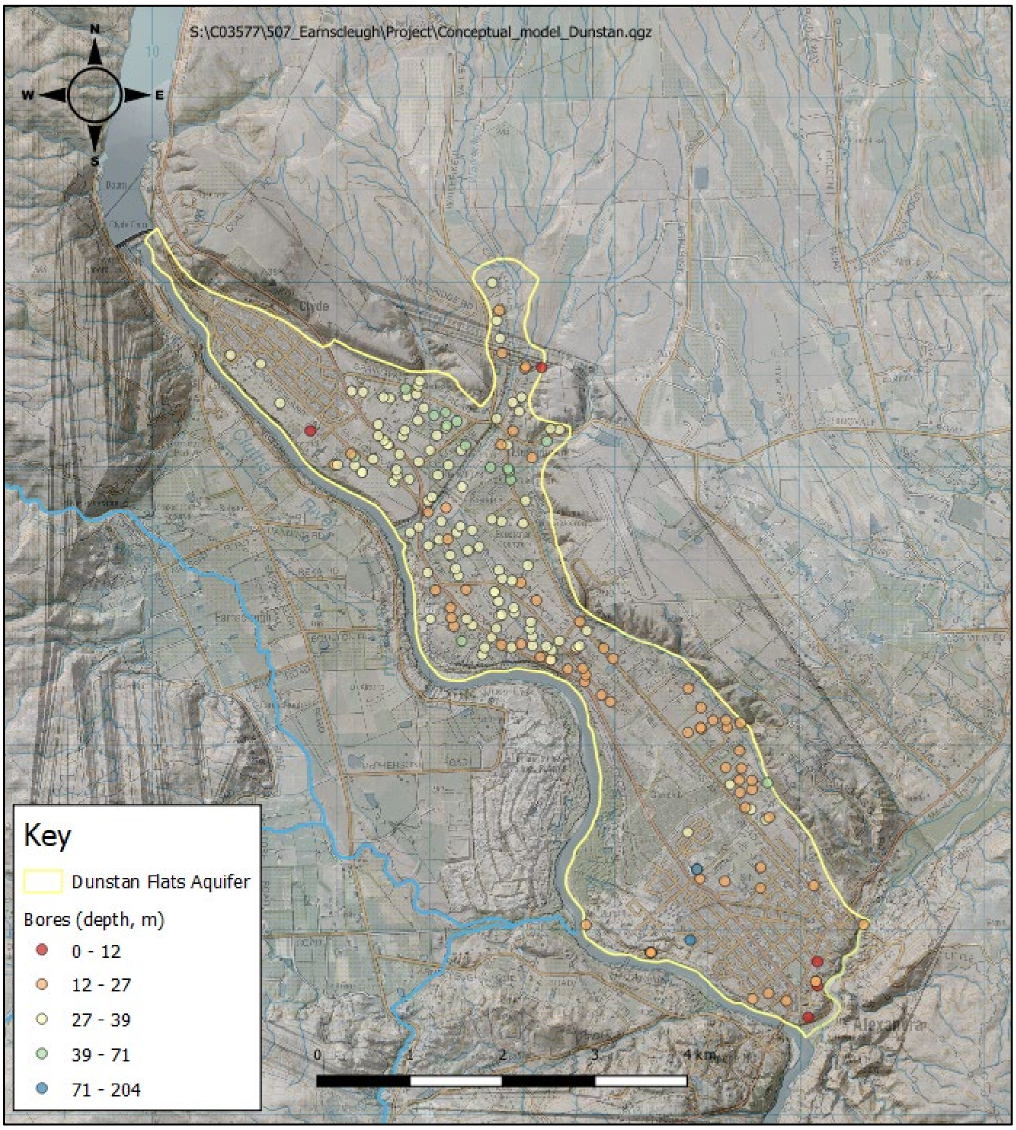

Figure 13: Map of known bores on Dunstan Flats and their depths where known.

3.3.2 Groundwater Levels

Static water level records in bores on Dunstan Flats show that the groundwater table is shallowest both at the upper margins of the terrace near Waikerikeri

Creek and on the lower margins of the terrace near the Clutha River / Mata-Au (Figure 14).

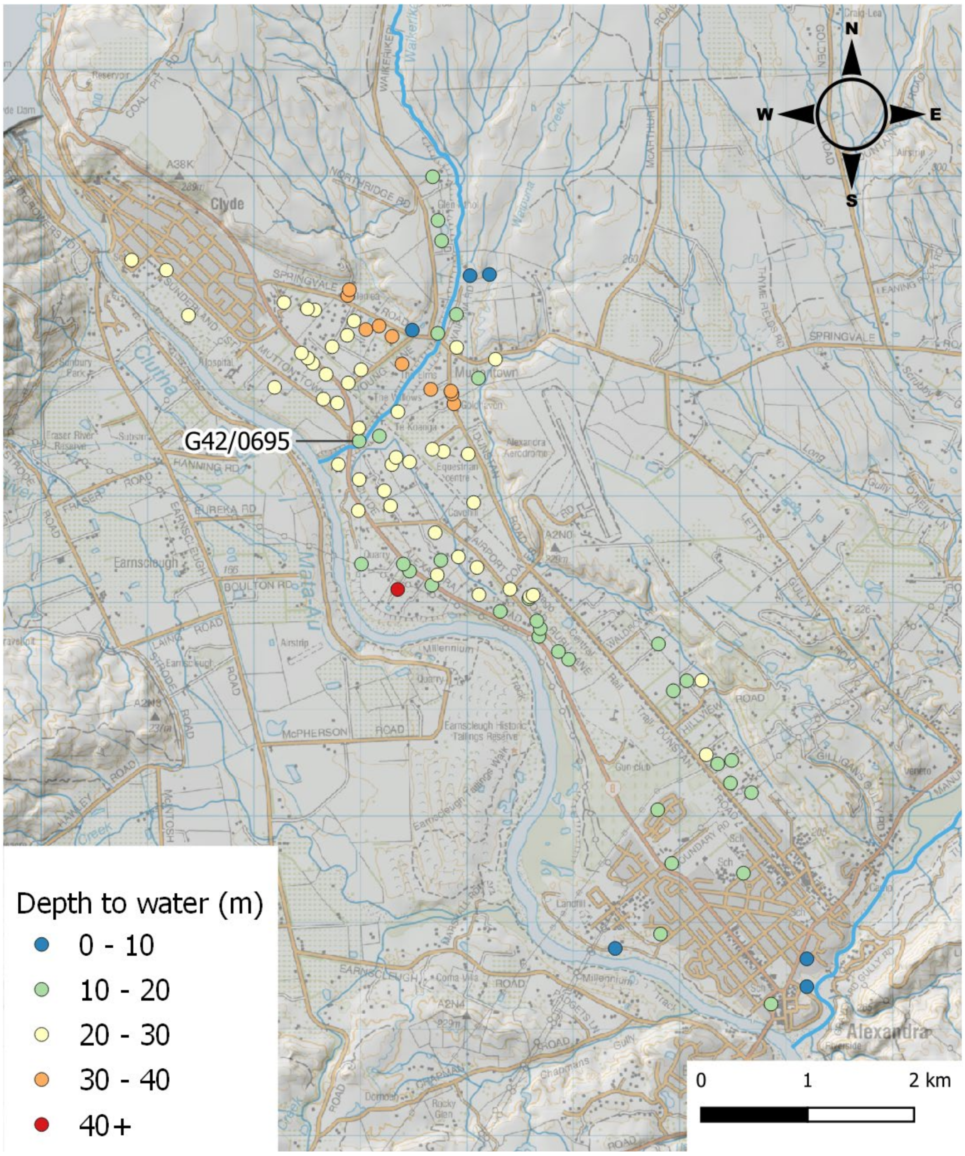

Figure 14: Recorded depth to water (at the time of drilling) in bores on Dunstan Flats.

Long-term groundwater level records are available from bore G42/0695 (shown on Figure 14), which is located on the northwestern side of Dunstan Flats, near where Clyde – Alexandra Road crosses Waikerikeri Creek. This bore is 17.8 m deep, at an elevation of approximately 189 m amsl and has a record from April 1986 to present. Groundwater level data is currently recorded at 5-minute intervals.

The record (shown in Figure 15) shows that seasonal fluctuations are generally on the order of 2 metres. Comparisons of groundwater level records with the flow in the Clutha River / Mata-Au (Figure 16) show that generally there is not a strong correlation between the two, except for times when floods in the Clutha River / Mata-Au mean that the river stage exceeds the adjacent groundwater level, and the groundwater table rises in response (AquaFirma, 1998). This pattern has been observed in several bores in the Dunstan Flats Aquifer, with the bores closest to the river showing the strongest correlation with river stage (AquaFirma, 1998).

This occasional relationship suggests that, on average, groundwater in the Dunstan Flats is not directly connected to the Clutha River at least in the area around the monitoring bore G42/0695.

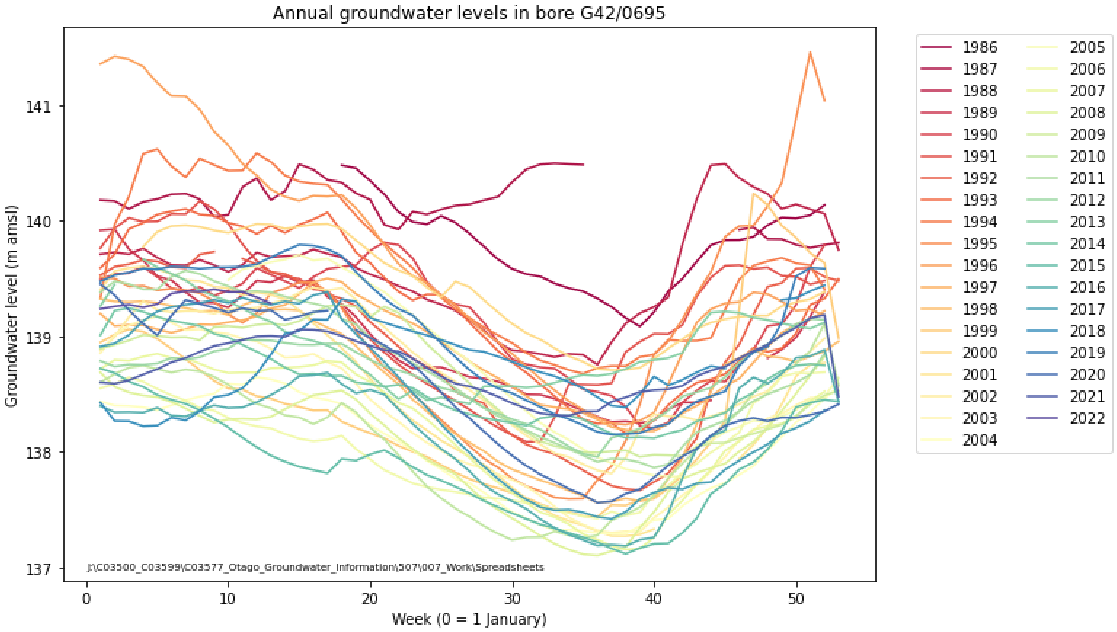

Figure 15: Annual groundwater level record from bore G42/0695, located on Dunstan Flats near Waikerikeri Creek.

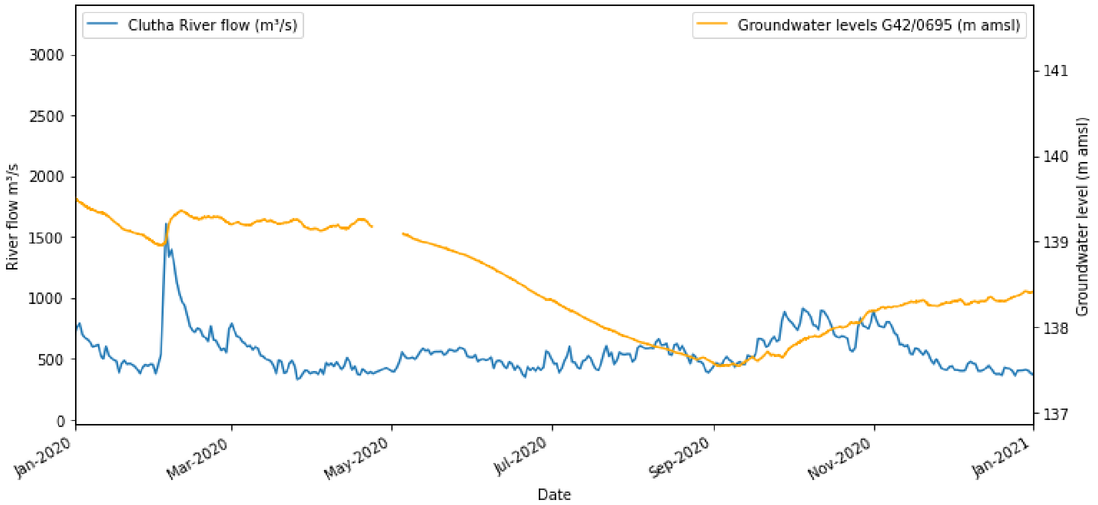

Figure 16: Groundwater levels in G42/0695 and Clutha River levels for 2020.

Based on the data from bore G42/0695, groundwater levels are typically highest in late summer and lowest in spring, which correlates with the pattern of irrigation and reflects irrigation losses contributing to groundwater recharge in the area.

3.3.3 Recharge

As with Earnscleugh Flat, direct rainfall recharge is expected to be minor on Dunstan Flats due to the semi-arid climate (350 mm/yr annual rainfall), however the soils generally have a lower field capacity than those of Earnscleugh Flat (ORC, 2012). In 2012, rainfall recharge was estimated to comprise 4% (0.48 Mm^3/yr) of the total annual recharge to the Dunstan Flats Aquifer (ORC 2012).

A small amount of water infiltrates to the Dunstan Flats Aquifer from Waikerikeri Creek, which was estimated in 2012 to be 3% of total recharge (0.3 Mm^3/yr) (ORC, 2012). Waikerikeri Creek loses most of its flow upstream of Dunstan Flats, via infiltration into the Manuherikia Claybound Aquifer and from surface water abstractions, though it gains some flow across the lower Waikerikeri alluvial fan through either seepage from groundwater or irrigation by-wash discharges (ORC, 2012). Waikerikeri Creek is ephemeral, at least in its lower reaches (ORC, 2005).

Past estimates of losses from irrigation on Airport Terrace and the Manuherikia Claybound Aquifer have indicated that groundwater flow from the Manuherikia Claybound Aquifer is a significant source of recharge for the Dunstan Flats Aquifer (ORC, 2012). These studies have also indicated that irrigation losses, both from direct application of irrigation water and losses from water races and storage ponds, are the primary recharge source for the Manuherikia Claybound Aquifer (ORC, 2012).

Irrigation water for Airport Terrace and Manuherikia Claybound aquifer is primarily sourced from the Manuherikia River via the extensive Manuherikia and Galloway water races (Figure 18, as well as from Waikerikeri Creek. In 2012 it was estimated that 21% of recharge to the Dunstan Flats Aquifer was from subsurface through-flow from the Manuherikia Claybound Aquifer (ORC, 2012).

Irrigation water from the Manuherikia Irrigation Scheme water race is stored in reservoirs on Airport Terrace and is fed to Dunstan Flats at a rate of up to 400 L/s via a drop structure, and then delivered to irrigators on Dunstan Flats via water races. Water race losses to the Dunstan Flats Aquifer were estimated to comprise 65% of total recharge in 2012, while irrigation excess soil drainage losses related to the Manuherikia Irrigation Scheme were estimated to comprise 7% of total recharge (ORC, 2012). As discussed in section 3.1 above, it is likely that irrigation use and water transport is becoming more efficient over time, potentially resulting in reduced recharge.

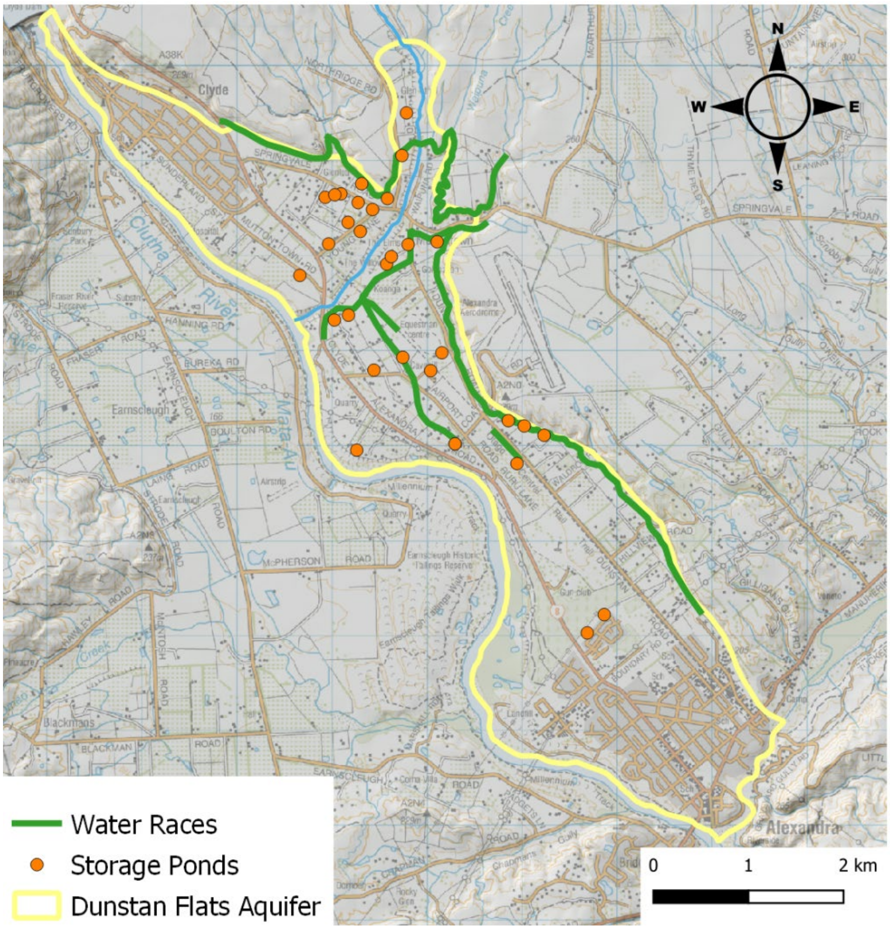

Figure 17: Map showing water races and water storage ponds/reservoirs, as identified from aerial photography.

The relationship between flood events in the Clutha River / Mata-Au and groundwater levels discussed in section 3.3.2 above suggest that the Clutha River / Mata-Au may act as a source of recharge at times to the Dunstan Flats Aquifer. However, this is expected to occur only during transient flood events, with most of the recharge seeping back into the Clutha River / Mata-Au as river levels drop.

Therefore, the water balance for the aquifer is heavily reliant on irrigation losses as well as seepage from irrigation races. Changes to the patterns of irrigation, both in terms of volumes as well as spatial changes are likely to have significant bearing on the possible groundwater allocation from the Dunstan Flats aquifer.

3.3.4 Outflow

All groundwater that is not abstracted from bores ultimately discharges to the Clutha River / Mata-Au via groundwater seepage. In 2012 groundwater abstractions were estimated to total 0.43 Mm^3/yr or 4% of total outflow, with discharge to the Clutha River / Mata-Au comprising the other 96%. A map showing the location of consented takes across the aquifer is shown in Figure 19.

The largest water takes are surface water abstractions from the Clutha River, with groundwater takes generally occurring in the north and centre of the aquifer. Most of the groundwater takes are small scale stockwater and domestic supplies with only four larger takes up to 291,600 m^3/year. Based on the pattern of consents, groundwater use is not extensive across the aquifer, reflecting the presence of the irrigation race network.

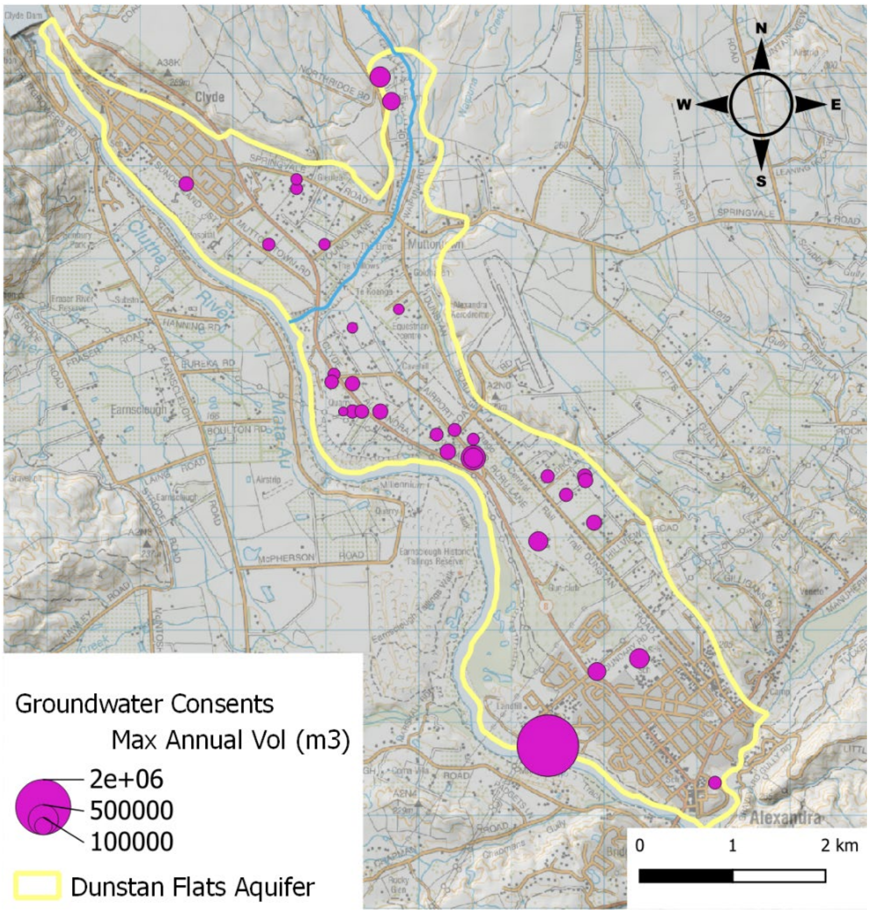

Figure 18: Map showing groundwater take consents on Dunstan Flats. There are no active surface water take consents on Dunstan Flats

3.4 Surface Water – Groundwater Interaction

As described in section 3.3.3, losses from surface waterways (Waikerikeri Creek and irrigation water races) are significant sources of recharge for the Dunstan Flats Aquifer. Recharge from the Clutha River / Mata-Au may occur at times of large flood events, however these events are not likely to be consistent enough to be appropriate to consider in a steady-state groundwater model.

3.5 Water Balance

The overall water balance of the Dunstan Flats Aquifer as estimated by ORC in 2012 is provided in Table 2 below. It is noted that aspects of this water balance may have changed since 2012, in particular inflow due to irrigation, inflow from the Manuherikia Claybound Aquifer and outflow from groundwater abstraction. Some of these aspects will be refined during the modelling process. However, this water balance is considered a useful starting point for the conceptual model of the aquifer.

Table 2: Water balance of the Dunstan Flats Aquifer (after ORC, 2012)

Water balance component	Mean annual inflow (Mm^3/y)	Mean annual outflow (Mm^3/y)
Rainfall recharge	0.48	
Excess soil drainage related to the Manuherikia irrigation scheme	0.70	
Subsurface through-flow from the Manuherikia Claybound Aquifer	2.20	
Infiltration of water from Waikerikeri Creek into the Dunstan Flats Aquifer	0.30	
Water race losses to the aquifer	7.00	
Pumping from the Dunstan Flats Aquifer[1]		0.43
Seepage directly into the Clutha River / Mata-Au		10.20
Totals	10.7	10.6

Notes:

1. *Actual pumping estimated as 30% of groundwater take consent allocation for the aquifer.*

4.0 Proposed Modelling Approach

The Earnscleugh Flat and Dunstan Flats Aquifers are separated by the Clutha River / Mata-Au, and there is no evidence of a direct connection between them. Therefore we consider it most appropriate to model the two aquifers separately. The following sections outline our proposed modelling approach, in light of the conceptual setting described in the sections above.

4.1 Modelling code

The groundwater models will be developed using the USGS MODFLOW 6 code (version 6.3). The MODFLOW family of codes are the industry standard groundwater modelling codes and the latest release (MODFLOW 6) allows a wide range of flexibility in terms of both the model grid design as well as interaction between different model packages.

4.2 Earnscleugh Aquifer

4.2.1 Model discretisation

Model extent

The extent of the groundwater model is shown in Figure 19. The overall extent of the active model area is based on surface water boundaries (the Clutha River / Mata-Au) and the extent of the Quaternary gravels of Earnscleugh Flat. The Manuherikia Group and basement schist that outcrop adjacent to the Quaternary gravels are assumed to be impermeable, therefore the other boundaries of Earnscleugh Flat will be modelled as no flow boundaries.

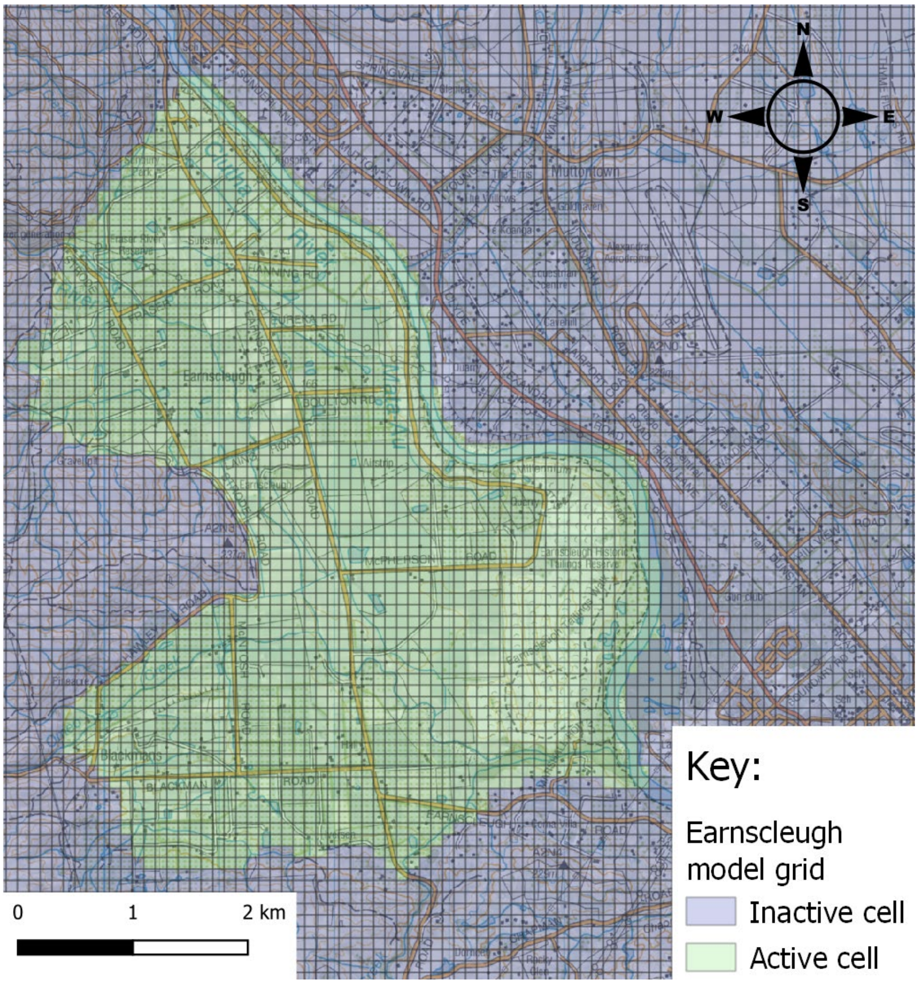

Figure 19: Earnscleugh model extent.

Model grid

The model cell size will be 100 x 100 m. This grid is expected to provide a reasonable balance between representing the model area with sufficient accuracy, whilst ensuring the model runs efficiently.

Model layering

It is proposed for the Quaternary gravels that host the Earnscleugh Aquifer to be modelled as two layers. Across most of the aquifer the map of the thickness of the gravels produced by AquaFirma (Figure 4) will be used to define the thickness of the cells. The upper cells will be 10 m thick, and the lower cells' thickness determined based on the AquaFirma map. Across the parts of the terrace not covered by the AquaFirma map the gravel thickness will be assumed to be 24 m, so layer 1 will be 10 m thick and layer 2 will be 14 m thick.

This approach enables some vertical anisotropy to be modelled in the aquifer where it is required and also allows surface waterways to be modelled in an upper aquifer.

Time frame

The model will be steady state with a single stress period representing average conditions. In this context, average conditions will represent average annual recharge, average groundwater levels and average stream flows between 2010 and 2020.

4.2.2 Model boundary conditions

There are a number of boundary conditions that will be required as part of the model, including surface water boundaries, recharge boundaries, abstraction boundaries and drain boundaries. These are discussed in more detail below.

Surface water boundary conditions

Surface water boundaries in the Earnscleugh Flat Aquifer include the Fraser River, Omeo Creek, Conroys Creek and the Clutha River / Mata-Au. The Fraser River, Omeo Creek and Conroys Creek will be modelled as stream cells using the MODFLOW stream package (SFR) as this ensures that only the available flow in the river can be lost to the underlying aquifer. The stage in these streams will be set based on LiDAR data for the stream and the flow at the top end of the streams where they enter the model area will be based on gauged flows in the streams where available (e.g. for the Fraser River), or from modelled stream flows sourced from the Ministry for the Environment (available at https://data.mfe.govt.nz/layer/53309-river-flows/).

The Clutha River / Mata-Au will be modelled using the MODFLOW River package (RIV). Again the stage of the river will be based on LiDAR elevation data, but no specified flow is required for the river package.

The stream bed conductance parameter for all streams and the Clutha River will be determined via calibration.

Abstractions

Groundwater abstractions in the model will be represented via the MODFLOW well package (WEL). Actual groundwater abstraction rates are not well defined for takes in the area and at this stage we will use an initial value of 30% of the annual volume as the abstraction rate. However, this may be altered during model calibration as required.

Recharge and Throughflow

Recharge to the groundwater system is based on a soil moisture model for the area, which will also incorporate irrigation losses. However, in addition to these losses we will allow for further losses from the irrigation race network. These losses are poorly defined, although it is likely that they represent a significant part of the Earnscleugh Flat aquifer water balance. The loss rates from the irrigation race network will be an important calibration factor.

Due to the impermeable nature of the strata surrounding the Earnscleugh Flat Aquifer, it will be assumed that there is no groundwater throughflow from upgradient of the aquifer.

4.2.3 Model calibration

The model will be calibrated to observed groundwater levels and, where available, surface water flow rates. We note that overall, there is limited data available to calibrate the model to and we expect to also use the water balance estimates from the 2012 study of the aquifer as general calibration targets. In addition, we will use the piezometric contours determined by AquaFirma during long term groundwater level monitoring in the 1990s (Figure 8) as calibration targets.

There are a number of different calibration variables discussed above, including the conductances of various model boundaries. However, the key variable for calibration will be the distribution of hydraulic conductivity across the model area. We expect to use a pilot-points based approach to determine how conductivity varies within the model area. This approach calculates the pattern of hydraulic conductivity based on interpolation between a number of discrete points that are specified across the model area.

4.3 Dunstan Aquifer

4.3.1 Model discretisation

Model extent

The extent of the groundwater model is shown in Figure 20. The overall extent of the active model area is based on surface water boundaries (the Clutha and Manuherikia Rivers) and the outcrop of the Manuherikia Claybound aquifer to the north-east. Both the surface water boundaries represent flow boundaries to the aquifer, however, the Dunstan Flats aquifer receives throughflow from the adjacent Manuherikia Claybound aquifer and this boundary will be represented as a general head boundary in the model.

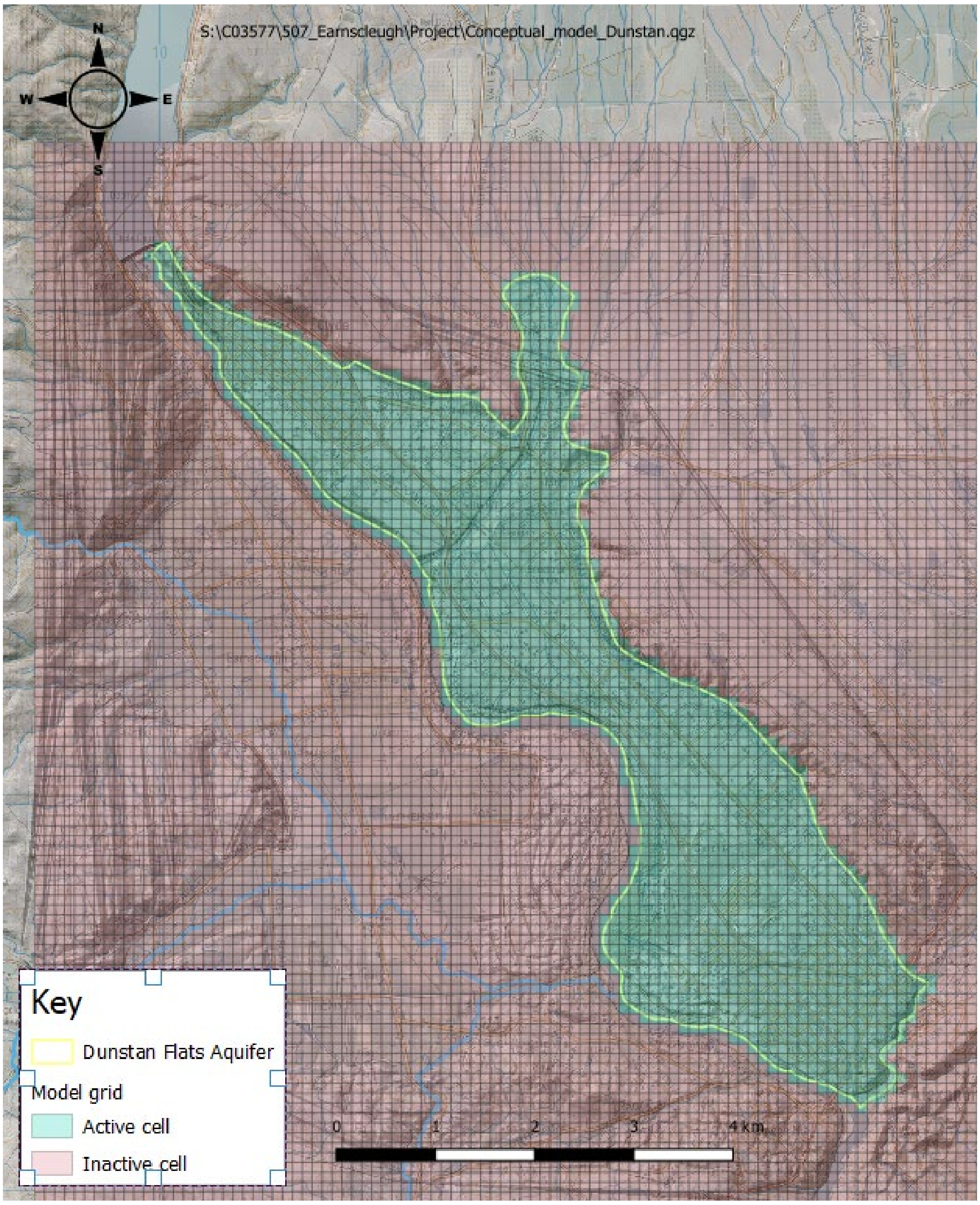

Figure 20: Dunstan Flats model extent.

Model grid

The model grid is also shown in Figure 20 and is based on the same 100 m cell size as used in the Earnscleugh model. This grid is expected to provide a reasonable balance between representing the model area with sufficient accuracy, whilst ensuring the model runs efficiently.

Model layering

Accurate information on the depth to the basement strata beneath the Dunstan Flats aquifer is not available, however evidence from the depth of bores in the area indicates that the permeable strata extend to a depth of around 40 m, although deeper bores are present in the area. Therefore, we have split the model into two layers with the upper model layer 10 m thick and the lower model layer 30 m thick.

This approach enables some vertical anisotropy to be modelled in the aquifer where it is required and also allows surface waterways to be modelled in an upper aquifer.

Time frame

The model will be steady state with a single stress period representing average conditions. In this context, average conditions will represent average annual recharge, average groundwater levels and average stream flows between 2010 and 2020.

4.3.2 Model boundary conditions

There are a number of boundary conditions that will be required as part of the model, including surface water boundaries, recharge boundaries, abstraction boundaries and drain boundaries. These are discussed in more detail below.

Surface water boundary conditions

Surface water boundaries in the Dunstan Flats Aquifer include the Waikerikeri Creek and the Clutha River. The Waikerikeri Creek will be modelled using the MODFLOW stream package (SFR) as this ensures that only the available flow in the river can be lost to the underlying aquifer. The stage in the creek will be set based on LiDAR data for the stream and the flow at the top end of the creek where it enters the model area will be based on gauged flows in the creek

The Clutha River will be modelled using the MODFLOW River package (RIV). Again the stage of the river will be based on LiDAR elevation data, but no specified flow is required for the river package. Likewise, the Manukerekia River will be simulated using the MODLOW River package.

The stream bed conductance parameter for both the Waikerikeri Creek and the Clutha River will be determined via calibration.

Abstractions

Groundwater abstractions in the model will be represented via the MODFLOW well package (WEL). Actual groundwater abstraction rates are not well defined for takes in the area and at this stage we will use an initial value of 30% of the annual volume as the abstraction rate. However, this may be altered during model calibration as required.

Recharge and Throughflow

Recharge to the groundwater system is based on a soil moisture model for the area, which will also incorporate irrigation losses. However, in addition to these losses we will allow for further losses from the irrigation race network. These losses are poorly defined, although it is likely that they represent a significant part of the Dunstan Flats aquifer water balance. The loss rates from the irrigation race network will be a key calibration factor.

In addition to recharge, throughflow from the Manuherikia Claybound Aquifer is also a potentially significant part of the water balance. We will represent throughflow via a general head boundary set along the north-eastern edge of the model area, approximately along the terrace edge that defines the Manuherikia Claybound aquifer. The head in this general head boundary will initially be based on observed groundwater levels from bores close to the terrace edge and the boundary conductance will be a calibration variable.

4.3.3 Model calibration

The model will be calibrated to observed groundwater levels and, where available, surface water flow rates. We note that overall, there is limited data available to calibrate the model to and we expect to also use the water balance estimates from the 2012 study of the aquifer as general calibration targets. In addition, we will use static groundwater level measurements from bores across the aquifer as calibration targets, although these will be given a relatively low weight.

In keeping with the Earnscleugh model above, there are a number of different calibration variables discussed above, including the conductances of various model boundaries. However, again, the key variable for calibration will be the distribution of hydraulic conductivity across the model area. We will also use a pilot-points based approach to determine how conductivity varies within the model area. This approach calculates the pattern of hydraulic conductivity based on interpolation between a number of discrete points that are specified across the model area.

5.0 Summary

The conceptual models developed in the report indicate that the groundwater systems for the Earnscleugh and Dunstan Flats aquifers are relatively simple, with reasonably clearly defined recharge and discharge locations.

The geology surrounding the Earnscleugh Aquifer is made up largely of low permeability schist strata which are likely to contribute only very small flows into the aquifer. The Earnscleugh aquifer is recharged predominantly from losses from the Fraser River, together with seepage losses from the irrigation races that flow across the aquifer. Flows in the Fraser River are regulated through the upstream dam, as well as discharges via a pipeline from the Clutha River and therefore losses are likely to be variable. The available water balance information indicates that rainfall recharge contributes only a small proportion of inflows to the aquifer.

Groundwater with the Earnscleugh Aquifer flows generally towards the Clutha River, with some flow focussed around the Fraser River where it loses and gains across the aquifer. That groundwater flow pattern indicates that the major discharge points for the aquifer are the Fraser River (towards its confluence with the Clutha River) and the Clutha River itself. There is limited groundwater abstraction across the aquifer with the majority of irrigation water sourced via irrigation races which are sourced from surface water (i.e. the Fraser River).

The Dunstan Flats aquifer is bounded by the Manuherekia Claybound Aquifer to the north-east and the Clutha River to the south-west. In contrast to the Earnscleugh Aquifer, seepage from adjacent strata makes up a key part of the inflows to the aquifer, together with seepage losses from irrigation races that flow across the aquifer. Also, in contrast to the Earnscleugh Aquifer, there are no significant losses from streams or rivers that flow across the aquifer; although the Waikerikeri Creek flows across the aquifer, it frequently has limited flows as a result of irrigation takes upstream.

Groundwater flow patterns across the Dunstan Flats aquifer are not well defined as no piezometric survey has been undertaken, however in general, groundwater flows are likely to be towards the Clutha River in the north or the area and towards both the Clutha River and the Manuherekia River in the south of the area. Some groundwater abstraction occurs across the Dunstan Flats aquifer, but this does not appear to be a substantial proportion of the overall water balance.

Although the overall patterns of groundwater movement across both aquifers are relatively simple, both areas suffer from some information gaps with limited information regarding groundwater levels across the aquifers (i.e. there are few long term monitoring bores with groundwater level measurements) and limited gauging data for the key surface waterways that flow across each of the aquifers.

The limited observed dataset means that the groundwater models will suffer from some uncertainty in terms of defining the patterns of aquifer parameters, which may feed through into some uncertainty in any scenarios and predictions based on those scenarios.

6.0 References

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