Understanding Eiffelton Irrigation’s Targeted Stream Augmentation

Thesis submitted in partial fulfilment of the requirements of

Master of Water Resource Management

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What I love most about rivers is
You can't step in the same river twice
The water's always changing, always flowing

But people, I guess, can't live like that
We all must pay a price
To be safe, we lose our chance of ever knowing

What's around the river bend

Pocahontas, 1995

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Thesis Summary

Eiffelton Community Group Irrigation Scheme (ECGIS) is a small owner-operated irrigation scheme located near the Ashburton Coast of Canterbury. ECGIS is bisected by a number of drainage channels which serve to lower the water table and keep the land suited for agriculture. ECGIS provides water to its members by targeted stream augmentation. This is where groundwater is pumped from bores into the drainage channels which transports the water to members to enable take for irrigation. Despite the length of operation of ECGIS, little is known about it beyond this conceptual understanding establish in consent documents. Thus, the aim of this investigation was to understand operation and operational effects of ECGIS. This was achieved by meeting four objectives.

The first objective was to document the operation of ECGIS and how operational decisions were made. This was achieved by undertaking semi-structured interviews with ECGIS members. ECGIS consists of 4,000 ha of land, 58 km of drains, and 20 production bores. ECGIS pumps water from the production bores into Deals, Windermere and Home Paddock drains to convey water for irrigation to its members. Bores are pumped into the closest drain, except HP1 which is pumped into Windermere Drain. Diversion gates allow transfer of water between these drains to enable the most cost-efficient use of water. Member access to water is proportional to their relative share of land within the ECGIS footprint. More water can be abstracted from the drains than can be supplied by ECGIS production bores, but each drain has a minimum flow rate which must be complied with whenever an ECGIS member is irrigating. The Race Manager and Assistant Race Manager are responsible for the day-to-day operation of ECGIS. Both are ECGIS members. ECGIS management make decisions on which production bores to use and how much flow to divert between the drains based on their understanding of ECGIS; capacity of the production bores, requirements of each irrigator, and the hydrology of the ECGIS area. Management operates to a 20 L/s surplus in provided water to prevent non-compliance. Management recognises that some bores have better yield than others, while some have higher operating costs. Because of these factors, there is no set order in which production bores are used.

The second objective was to understand the hydrological setting of ECGIS and how scheme operation impacts measured parameters. This was addressed by undertaking field investigation on the largest and centremost drain utilised by ECGIS; Windermere Drain. Gauging results showed Windermere Drain increased in flow towards the coast across 2018, while in 2019 flows increased to Surveyors Road and again fell. Highest nitrate-N concentrations were found at the top of ECGIS and in drain water. *E. Coli* detections were lowest at the top of ECGIS and increased in drain water down-gradient. Data from the top of ECGIS suggests that Windermere Drain gains in its upper to mid reaches, but loses flow from its mid reaches, with rate increasing towards the coast. When predicting the flow in Windermere Drain over the irrigation period in the absence of targeted stream augmentation and without irrigation abstraction there were significant periods of no flow. This suggests ECGIS ensures flow in Windermere Drain where it may otherwise be dry. Water quality parameters were considered relative to the 2018/19 irrigation season. Targeted stream augmentation by ECGIS is understood to have contributed to lower dissolved oxygen, lower electrical conductivity, and lower nitrate-N concentrations in Windermere Drain and shallow groundwater across the 2018/19 irrigation season.

The third objective was to identify values associated with the Hinds Drains, of which the drains used by ECGIS are a part. This was achieved by conducting semi-structured interviews with ECGIS members and individuals that have been involved in Ashburton water management. The most common value associated with the Hinds Drains by ECGIS members was their function as drains and keeping their land farmable. This likely reflected the fact that most interviewees lived within the Hinds Drains area and so benefitted directly from this primary function of the drains. Recreation (e.g. swimming, fishing) was the value most associated with the Hinds Drains by other interviewees. Presence of introduced and native fish was equally valued by ECGIS Members, but introduced fish were less valued by other interviewees. Interviewees were asked what they would like to see the Hinds Drains used for in a 'perfect world'. Most interviewees identified restoration to provide for native fish. Many interviewees commented that while it would be nice to see greater biodiversity in the area, developing the drainage network to support such things should not come at the expense of their drainage function.

The final objective was to determine how values could be met using an integrated framework. This was achieved by incorporating information obtained to address the previous three. Integrated water management was selected to identify opportunities to enhance drainage and native fish habitat. It was

considered that to address both or either of these that efforts should be made to better understand and optimise existing drainage, and to improve riparian management along Windermere Drain.

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Glossary of Terms

Term	Acronym	Definition
Adaptive management		A structured, iterative process of decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring
Adsorbed		Hold (molecules of a gas or liquid or solute) as a thin film on the outside surface or on internal surfaces within the material
Array		A grouping of three investigation sites consisting one piezometer in the bed of Windermere Drain, one piezometer approximately 5-10 m from the drain, and the drain itself
Ashburton		Refers to both the District and Water Management Zone
Assemblages		a collection or gathering of things or people
Attenuation		Attenuation takes an infectious agent and alters it so that it becomes harmless or less virulent
Bentonite		A clay used as a sealing agent
Bore development		Procedures to restore or improve bore characteristics so as to maximise performance by removing the fines and additives, and to allow the gravel pack to settle and consolidate
Bore log		A detailed record of the geology penetrated by a bore/well
Bypass flow		the potential for water bypass the soil matrix directly to groundwater
Canterbury Water Management Strategy	CWMS	Collaborative framework that seeks to help manage multiple demands on water
Carrying capacity		The number of people, animals, or crops that can be supported without environmental degradation
Colourimetry		A technique used to determine the concentration of coloured compounds in solution
Concretion		A solid mass formed by the local accumulation of matter
Controlled Drainage		is the practice of using a water control structure to raise the depth of the drainage outlet, holding water in fields during periods when drainage is not needed
Denitrification		The loss or removal of nitrogen or nitrogen compounds commonly by soil bacteria
Determinand		A constituent or property of water
Discretionary activity		One of six activity classifications in the RMA. The consent authority (Environment Canterbury) can exercise full discretion in granting consent for such an activity and what conditions to impose on the consent if granted
Dissolved inorganic nitrogen	DIN	The sum of nitrite-N, nitrate-N, and ammonia
Dissolved organic phosphorus	DOP	Exists in a variety of forms resultant from excretion, decomposition, death and autolysis
Dissolved reactive phosphorus	DRP	A measure of the dissolved (soluble) phosphorus compounds that are readily available for use by plants and algae. Dissolved reactive phosphorus concentrations are

Term	Acronym	Definition
		an indication of a waterbody's ability to support nuisance algal or plant growths
Dynamic drawdown		hydraulic gradients induced by pumping of wells
Ecohydrology		A subdiscipline of hydrology focusing on the interactions between water and ecological systems
Ecosystem Services		The benefits society derives from nature
Eiffelton Community Group Irrigation Scheme	ECGIS	Irrigation scheme of interest in this thesis. It is member operated. It discharges groundwater to surface water to convey water entitlements to members
Environment Canterbury	ECan	The Regional Council with statutory responsibility for managing land and water in the research area
Environmental flows		the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems
Groundwater mining		Take of groundwater that exceeds recharge
Groundwater mounding		Groundwater mounding is accumulation of water above the water table where infiltration rate exceeds hydraulic gradient
Hardpan		A hardened impervious layer that can impair drainage and plant growth
Hinds Drains		Drainage channels located along the coast of the Hinds Plains
Hinds Plains		The area spanning the Ashburton and Rangitata rivers and from the foothills to the coast
Hydrograph		A graph showing change in a hydrologic variable over time
Hyporheic zone		Also referred to as the hyporheos. the subsurface area spanning surface and groundwater
Integrated Catchment Management	ICM	A subset of environmental planning which approaches sustainable resource management from a catchment perspective
Integrated Water Resource Management	IWRM	A process which promotes the coordinated development and management of water, land and related resources, to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems
Interquartile range		The difference between the upper and lower quartile
Land and Water Regional Plan	LWRP	Statutory Plan that sets policies and rules for management of land and freshwater in Canterbury
Land surface runoff		Also known as overland flow. The movement of water over the land, downslope toward a surface water body
Leach		Drain away from soil by percolating water
Macrophyte		An aquatic plant
Managed Aquifer Recharge	MAR	Intentional recharge of water to groundwater for subsequent recovery or to achieve environmental outcomes
Memorandum of Encumbrance		A charge registered over a property's certificate of title which creates a security interest over that property in favour of a third party for the performance of an obligation

Term	Acronym	Definition
Millennium Ecosystem Assessment		Assessed the consequences of ecosystem change for human well-being
Morphology		a particular form, shape, or structure.
Neoliberalism		Liberalism that favours free-market capitalism
Nitrate-N		(NO3) the nitrogen present which is combined in the nitrate ion. It is the stable form of combined nitrogen for oxygenated systems. It is very soluble in water and reactive
Nitrate-N + nitrite-N		The sum of nitrite-N and nitrate-N. Total oxidised nitrogen
Nitrite-N		(NO2) the nitrogen present which is combined in the nitrite ion. It contains nitrogen in a relatively unstable oxidation state. Very soluble in water and unreactive
Non-complying activity		One of six activity classifications in the RMA. A resource consent can be granted for a non-complying activity, but first the applicant must establish that the adverse effects of the activity on the environment will be minor or that the activity will not be contrary to the objectives of the relevant plan or proposed plan (the 'threshold test'). If the threshold test is met. the consent authority (Environment Canterbury) can exercise full discretion in granting consent for such an activity and what conditions to impose on the consent if granted
Permeability		The ability of a substance to allow another substance to pass through i
Piezo[meter]		A small diameter, temporary well installed to measure height of the water table
Piezos		When used in text, this refers to the two piezometers in the specified array
Production bores		The 20 bores owned by ECGIS that are pumped to augment drain flow
Rangitata Diversion Race	RDR	A 67 km water race carrying water along the top of the Canterbury Plains, from the Rangitata River in the south to the Rakaia River in the north
Rating		In hydrology, a rating curve is a graph of discharge versus stage for a given point on a stream, usually at gauging stations, where the stream discharge is measured across the stream channel with a flow meter.
Real Time Kinematic surveying	RTK	A satellite navigation technique used to enhance the precision of position data derived from satellite-based positioning systems
Redox		A type of chemical reaction in which the oxidation states of atoms are changed. Reduction is the gain of electrons or a decrease in the oxidation state of an atom by a molecule, an ion, or another atom.
Resource Management Act	RMA	The primary piece of natural resource legislation in New Zealand whose purpose is to promote sustainable management of natural and physical resources.
Riparian		relating to or situated on the banks of a river.

Term	Acronym	Definition
Saturated zone		the area in an aquifer, below the water table, in which relatively all pores and fractures are saturated with water
Screen		A well screen permits water to enter the well from the aquifer, prevents sediment from entering, and structurally supports aquifer material
Targeted stream augmentation		Discharging groundwater to a surface water channel
Tile drain		A type of drainage system that removes excess water from soil below its surface
Total ammoniacal-N	TAN	(NH4-N) aka 'ammonium' covers two forms of nitrogen; ammonia (NH3) and ammonium (NH4). It can be transformed to other forms of nitrogen and is an important plant fertiliser but less mobile than nitrate-N. It enters waterways primarily through point source discharges and is toxic to aquatic life at high concentrations
Total dissolved phosphorus	TDP	All organic and inorganic phosphorus compounds
Total phosphorus	TP	The sum of DOP, particulate phosphorus, and phosphate
Unsaturated zone		the part of the subsurface between the land surface and the groundwater table.
Water Management Zone		Ten zones established under the CWMS to enable catchment management of land and water resources
Zone Committee		Each water management zone has a Zone Committee. They are made up of people with interests in water who have a strong connection to the zone. They meet monthly to develop actions and tactics to deliver on the ten targets of the CWMS in their zone. Each Zone Committee is responsible for developing ZIP and ZIPA
Zone Implementation Programme	ZIP	A programme of recommended actions to address Zone Committee priorities within a water management zone
Zone Implementation Programme Addendum	ZIPA	Addendum to a ZIP

1 Introduction

All facets of water are connected and interact through the water cycle. Many water management strategies do not acknowledge this interconnectedness, leading to fragmented management, which can in turn lead to mismanagement of the water resource. This has increasingly become reality with over-allocation and/or contamination of freshwater. As there is no single cause of the declining state of freshwater, there is no single solution. To remedy water mismanagement, natural resource management practitioners have turned to integrated frameworks. These attempted to integrate environmental, economic, cultural and social aspects of water, through systems and measures to improve the state of freshwater and restrict activities that negatively impact upon it. Ideally an integrated approach would deliver best outcomes for all, however trade-offs are necessary. Integrated management of water has been fraught with problems. Its success is only as effective as its uptake. Community buy-in and participation are crucial in achieving good water management outcomes. Lack of engagement, uncertain outcomes, lack of clarity around how to implement an integrated framework, and what integration can achieve, has proved controversial among researchers and practitioners.

The aim of this research is to understand the operation and operational effects of Eiffelton Community Group Irrigation Scheme (ECGIS), a small owner-operated irrigation scheme located within the Hinds Plains of Ashburton (Figure 1-1). This introductory chapter is structured to first present literary context of the investigation; secondly, the investigation setting, and; finally, the intentions of the investigation as informed by the thusly presented information.

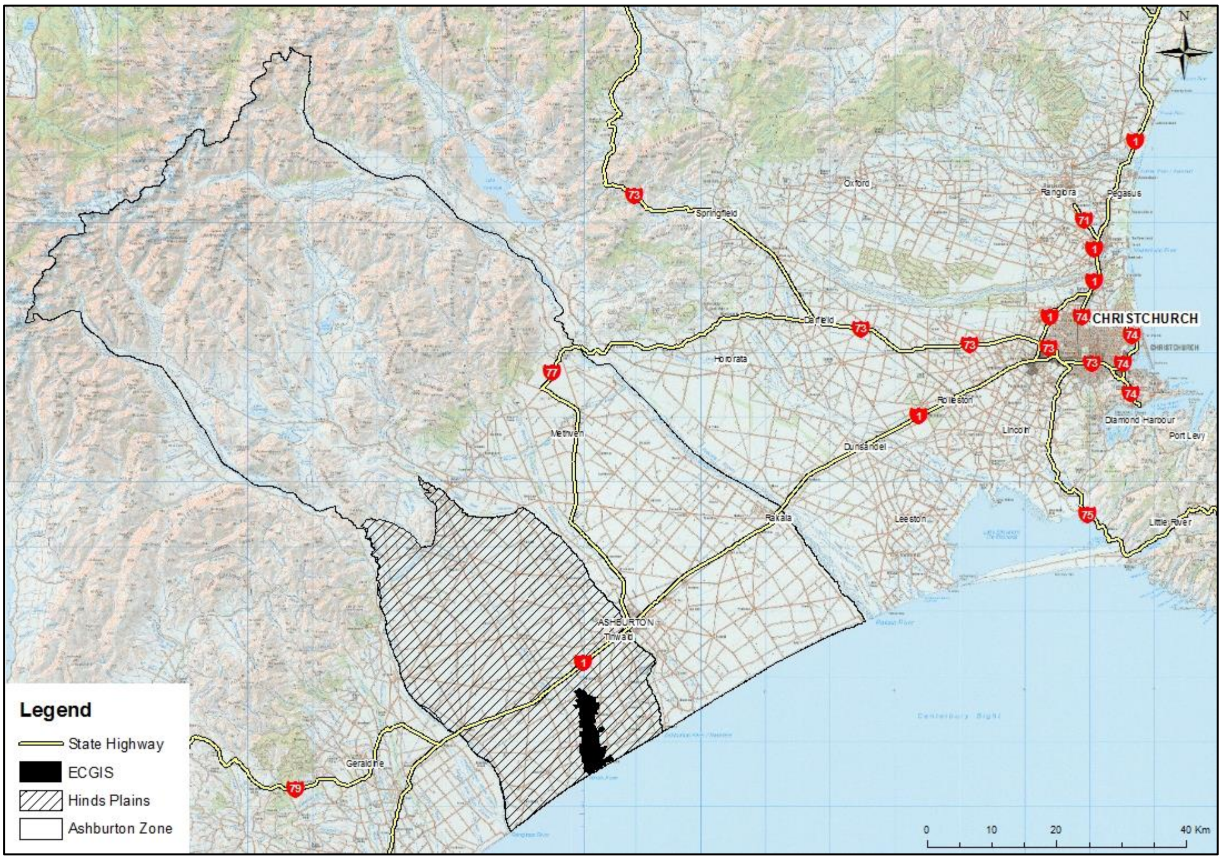

Figure 1-1 Location of Eiffelton Community Group Irrigation Scheme

1.1 Groundwater-Surface Water Interaction

Groundwater and surface water are fundamentally interconnected by multiple hydrological processes (Winter, 1998). Beyond precipitation (rainfall and snowmelt), surface water flow is controlled by river-aquifer exchange. The magnitude of this exchange is governed by hydraulic properties of both aquifer and aquitard materials within the hyporheic zone (Fleckenstein et al., 2006). There are four basic forms of groundwater-surface water interaction (Figure 1-2):

1. Gaining Stream: A stream that receives inflow from groundwater through the streambed or banks. Water table elevation is greater than stream stage

2. Losing Stream: A stream that loses flow to groundwater through the streambed. Groundwater elevation is lower than stream stage and there is a continuous saturated zone in-between

3. Disconnected Stream: A stream that loses flow through the streambed. Groundwater elevation is lower than stream stage. There is an unsaturated zone between the streambed and the water table which may mound below the stream if the recharge rate through the streambed and unsaturated zone is greater than groundwater flow. Pumping of this groundwater does not impact flow in the stream

4. Bank Storage: Where rapid rise in stream stage causes water to move from the stream into its banks. Providing the rise in stage does not overtop the banks, this volume returns to the stream (Winter, 1998).

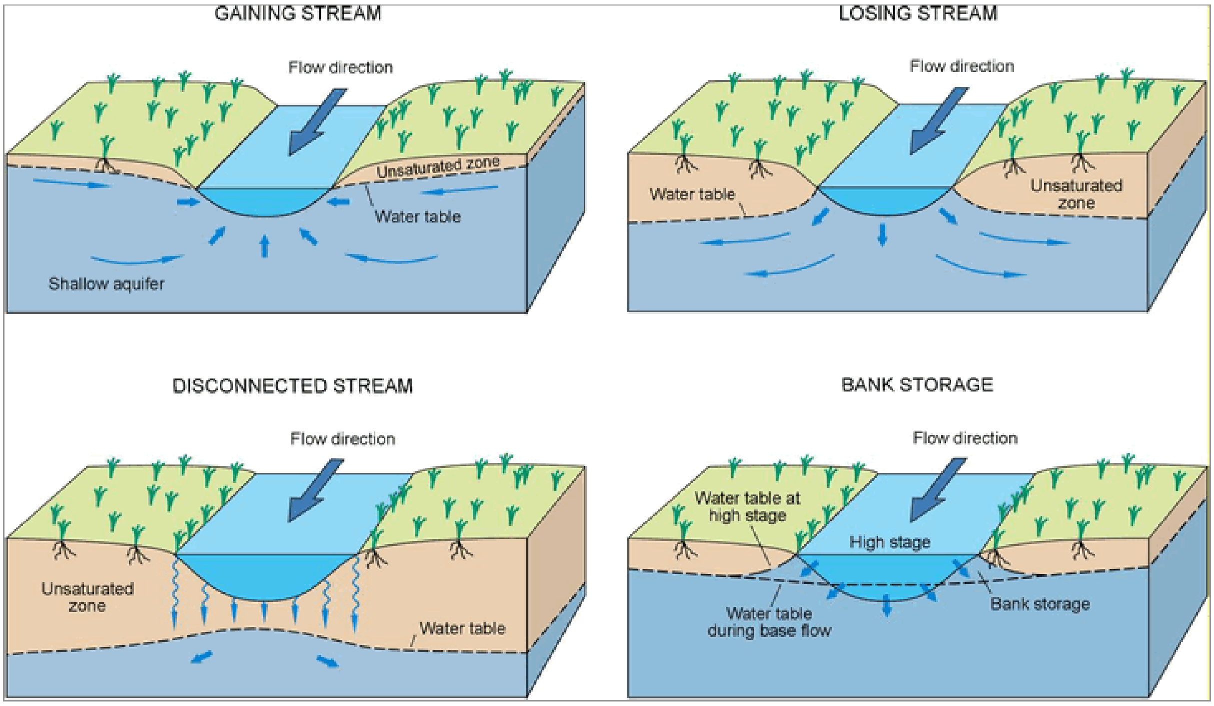

Figure 1-2 Examples of Interactions between Groundwater and Surface Water (Winter, 1998)

1.1.1 The Hyporheic Zone

The hyporheic zone is the saturated subsurface transecting the streambed and water table, providing exchanges between the two. Exchange of water plays a crucial role in hydrological, biogeochemical, and ecological processes and their interactions. It facilitates flows of biomass and energy, cycling of nutrients, pollution attenuation, and drives ecological function within the hyporheos (Boano et al., 2011, Boulton et al., 2010 , Fox et al., 2014, Peralta-Maraver et al., 2018). The dominant source of water within the hyporheic zone is not constant; it shifts between groundwater and surface water dependent on location and conditions (Malzone and Lowry, 2015). Flow paths and rates of water exchange through the hyporheic zone are strongly influenced by temporal and seasonal dynamics of surface and ground waters (Peralta-Maraver et al., 2018).

The predominant control over hyporheic exchange depends on the scale considered. At the sediment scale it is grain size distribution and permeability. This scale is where oxygen and nutrient exchanges occur. Grain size distribution and permeability is also the main control on exchanges in smooth riverbeds (Boano et al., 2011). At the reach scale the predominant control is hydrological exchange and discharge as impacted by channel morphology, or pressure gradients across the sediment-water interface (Cardenas, 2009). At the catchment scale, vertical and lateral components of stream and groundwater interactions and their variability drive the hyporheic zone (Boulton et al., 2010, Fox et al., 2014). Both gains and losses of net water can reduce the size of the hyporheic zone.

1.1.2 Research Relevance

All water in the ECGIS area is groundwater derived. Once groundwater is discharged to surface, it is then recognised as surface water. The interaction between groundwater and surface water must be understood to understand the hydrological setting of ECGIS and draw relevant and accurate conclusions. Regular channels (such as a drain) are more prone to hyporheic flux and area reduction than channels with greater variability where hyporheic zones are relatively constant (Cardenas, 2009). Complex bed forms can reduce sensitivity to water flux. In gravel-dominated beds, as in the case of the ECGIS drains, exchange is dominated by turbulent fluxes (Boano et al., 2011).

1.2 Freshwater Flow Augmentation

Augmentation of freshwater flow is a common practice worldwide as a tool to mitigate water shortages. Treated wastewater is often used for direct augmentation flowing waterways (Arnon et al., 2015, Bischel et al., 2013, Brewer et al., 2016, Lawrence et al., 2014, Nilsson and Renöfält, 2008, Parmar and Keshari, 2014, Plumlee et al., 2012), with the assumption that any nutrient load will be within the biological tolerance of impacted species. Legislation is often a factor in whether such discharges are acceptable (Bischel et al., 2013, Plumlee et al., 2012). In Canterbury, direct discharge of treated wastewater to freshwater is discouraged and would likely be a 'non-complying activity' due to the likely cultural unacceptability of such a discharge. Use of wetlands as an additional treatment step would increase the acceptability of such an activity. This technique is also used overseas (Bischel et al., 2013).

Augmentation can occur via alteration of baseflows, such as diversion (Hillman et al., 2016) and damming (Konrad et al., 2011, Muhlfeld et al., 2012). In the former, water is diverted from a higher flowing waterway to a lesser flowing waterway for provision of water for economic or ecological purposes. In the latter, flow is entirely regulated based on operational requirements. These can include requirements for environmental flows, though this is not common. In investigating the impacts of augmentation via diversion in rivers, Hillman et al. (2016) found timing and magnitude of augmentation could be managed to be of benefit to channel form, riparian ecosystems, and downstream river systems.

Freshwater flow augmentation can also occur as managed aquifer recharge (MAR) where water recharges shallow aquifers. Though such practices aim to replenish groundwater, where there is a strong surface water-groundwater connection, MAR can influence flows in stream channels. This was the case for Barber et al. (2009) when injection bores saw increased flow in the Spokane River (Washington, USA). MAR has been undertaken using both freshwater (Barber et al., 2009) and treated wastewater (Lawrence et al., 2014).

1.2.1 Research Relevance

Flow augmentation occurs in several forms on the Hinds Plains. The impacts of a MAR trial above State Highway 1 on the Hinds Plains are beginning to be seen below State Highway 1 towards Tinwald (Figure 1-1) in the form of a higher quality freshwater plume. As MAR expands across the upper Hinds Plains it is hoped that increased groundwater recharge will restore baseflow to the Hinds Drains. At the top of the Hinds River, a foothill-fed river in the centre of the Hinds Plains, out of catchment water is discharged to a riparian wetland to enhance River baseflow conditions down-gradient. Below State Highway 1 ECGIS uses groundwater to augment flow in three of the Hinds Drains to enable irrigation while meeting minimum flow conditions.

Literature review identified few cases of discharging abstracted groundwater to surface water for flow augmentation, as undertaken by ECGIS. Painter (2018) pumped water from an existing bore to a seldom flowing stream channel to provide habitat for endangered native fish in Selwyn District, Canterbury. Painter (2018) also installed a purpose-built system for delivering groundwater to surface water to provide habitat for endangered native fish in Selwyn, Canterbury. Wisniewski et al. (2016) described the benefits of groundwater augmentation of Spring Creek, Georgia (USA) on freshwater mussels. Rushton and Fawthrop (1991) developed a model to optimise use of existing bores to augment summer streamflow in Cambridgeshire, England. Kansas Water Office (2006) undertook a feasibility study for the use of groundwater to augment baseflow in Rattlesnake Creek, Kansas (USA) to address streamflow shortages.

1.3 Drainage

Landscape drainage has been used worldwide to transform waterlogged land for agricultural use. Drains can occur as channels on the land surface or conduits below. Tile drains are subsurface drainage features. They are installed in waterlogged areas to reduce land saturation and increase productivity. Tile drains can function in two ways. The first is to drain water from soils with high moisture retention, decreasing land saturation. The second is to locally lower the water table, preventing land saturation. Tile drains also create preferential flow paths, increase infiltration potential, lessen erosion, and can homogenise responses across a landscape (Boland-Brien et al., 2014, Kladivko et al., 2004, Wesström et al., 2001). Narrow drain spacing is more efficient at removing water than wide drain spacing. It also increases the rate of contaminant loss (Ale et al., 2010, Kladivko et al., 2004, Morrison et al., 2013). Drainage capacity needs to be maintained to ensure function. Drain maintenance generally involves managing riparian margins (e.g. mowing), macrophyte growth (removal of instream vegetation and detritus), and excess sediment using an excavator. Ward-Campbell et al. (2017) described drainage maintenance as a 'necessary' tool to mitigate bank destabilisation, sedimentation, and macrophyte growth, all of which can impede drainage capacity. Drainage channels can be important ecological refuges (Clarke, 2015). Greer et al. (2012) found accelerated macrophyte growth to be associated with high nutrient input, resulting in decreased drainage capacity. In trials they found complete macrophyte removal was detrimental to aquatic communities and concluded traditional drainage management to be to the detriment of ecological outcomes. Greer et al. (2012) stressed the threat traditional drainage management poses to New Zealand native aquatic species. Land drainage can over-drained soils, resulting in dramatic increases in irrigation development and water use.

1.3.1 Contaminant Transport

As tile drains impact hydrology, they also impact contaminant transport, producing greater discharges of water with generally higher contaminant concentrations. Ale et al. (2012) found drain flow volume to be of key influence on contaminant loss rather than vice versa. Rozemeijer et al. (2010) described tile drains as reducing groundwater residence time and hastening contaminant transport. Morrison et al. (2013) called tile drains "*a significant pollution pathway to surface water*" (p. 279), a sentiment echoed by Frey et al. (2016). Tile drains increase mobilisation of contaminants, leading to surface water degradation and related ecosystem impacts (Ale et al., 2010, Calsamiglia et al., 2018, De Schepper et al., 2015, Frey et al., 2016, Hernandez-Ramirez et al., 2011, Kladivko et al., 2004, Lalonde et al., 1996, Lavaire et al., 2017, Ma et al., 2018, Williams et al., 2015). Tile drains contribute significant flow to surface drains along with substantial nitrate-N loads (Ale et al., 2010, Kladivko et al., 2004). Nitrate-N is a key contaminant of concern in agricultural settings. Given its high solubility, is it very mobile in water and persists in well-oxygenated environments. Nitrate-N concentrations in surface drains are generally higher where drain spacing is smaller, and where subsurface drainage is significant (>5% land area (Capel et al., 2018)).

Phosphorus transport is less uncertain in tile drained environments. As it is generally sediment-bound and transported, phosphorus tends to be less of an issue in groundwater environments than surface water environments. Rozemeijer et al. (2010) and Lam et al. (2016) produced evidence both supporting and dismissing the significance of tile drains in subsurface phosphorus migration. Lam et al. (2016) and Vidon and Cuadra (2011) both commented that phosphorus concentrations increase significantly during storm and high flow events and decrease rapidly thereafter in tile drained environs.

1.3.2 Controlled Drainage

Controlled drainage seeks to maximise the benefit of naturally occurring excessive water. It has enabled better use of available water and reduced soluble nutrient losses (Ale et al., 2010, Ale et al., 2012, Bonaiti and Borin, 2010, Frey et al., 2016, Tolomio and Borin, 2018, Wesström et al., 2001). Williams et al. (2015) described controlled drainage as most effective on flat land with dendritic tile drain configuration, where one point can control drainage from a large area. Controlled drainage has achieved reductions in nitrogen losses of 18-79% (primarily due to reduced outflow), 35-60% reductions in phosphorus losses, and 20-95% reductions in outflow (Ale et al., 2012, Tolomio and Borin, 2018, Wesström et al., 2001, Williams et al., 2015). Frey et al. (2016) found that controlled drainage increased hydraulic gradients, increased nitrate-N and phosphorus mobilisation, and increased runoff. Lavaire et al. (2017) found retrofitting such a system on an existing tile system was of limited benefit to water quality.

1.3.3 Research Relevance

ECGIS occupies what was once a large swamp (Figure 1-3), fed by the Hinds River, rainwater runoff, and upwelling groundwater. This land was transformed to viable farmland in the mid-to-late-1800s by channelling the Hinds River to the ocean, constructing drainage channels across the swamp area, and installing huge numbers of tile drains to drain the land and lower the water table (Mitchell, 1980). The tile drains can carry large volumes of water. They primarily drain groundwater and are independent of surface soil characteristics and spatial scales. Tile drains captured discharges from strongly flowing springs and channel this flow to surface drainage channels, helping to prevent waterlogging of soils. Drainage of excessive soil water arising from surface wetting of soils is a secondary function of tile drains in this area. The ECGIS area now experiences periods of both droughts and flooding attributable to groundwater levels, soil-moisture content, and rainfall.

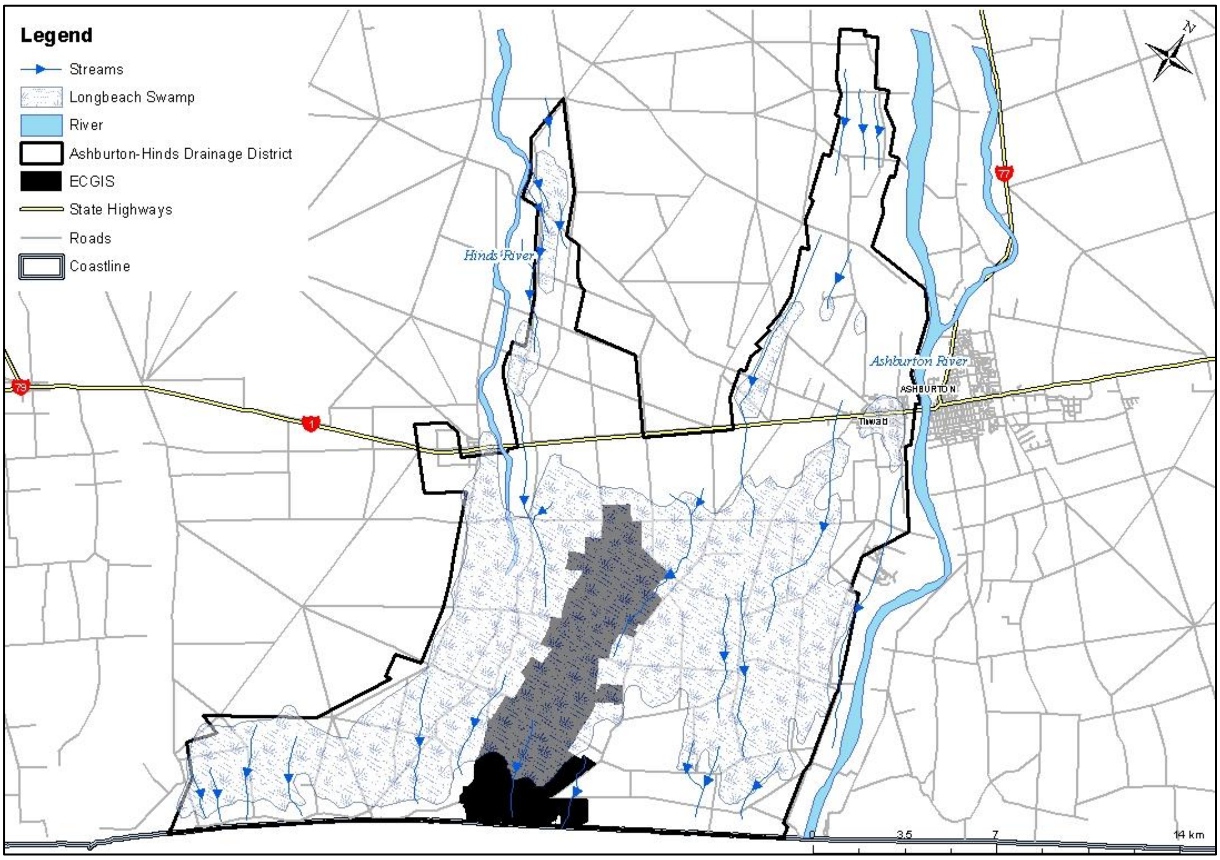

Figure 1-3 Longbeach Swamp (Adapted From Mitchell (1980))

Drain function in the Hinds Drains is maintained through active drain management by Environment Canterbury. As of 2015, the average yearly expenditure on the Ashburton Hinds Drainage District was $217,100 consisting of targeted rates (80%), works and services rates (15%), and general rates (5%) (Hinds Drains Working Party, 2016). 58% of this budget is spent on mechanical weed removal, 42% on chemical controls, and <1% on hand clearance. Drains are scraped on an as-needed basis (generally annually) to clear macrophytes. These grow within the drain, inhibit water flow, and reduce drainage capacity. Spraying of drain banks is undertaken on an as-needed basis.

1.4 Integration Frameworks for Water Management

Different frameworks and approaches to water resource management are implemented worldwide to balance water use and the health of water systems. This section reviews five examples of such frameworks to understand the defining aspects of these approaches. These do not consist a comprehensive list. Different uses and applications of the same frameworks in divergent situations mean that precise definition of each is elusive.

1.4.1 Adaptive Management

Adaptive management is learning and responding by doing. In this process goals are set (plans and policy), actions are undertaken achieve these goals (experiments and monitoring programmes), progress is assessed (collected information is reviewed and assessed against goals), and appropriate revisions are made as more information and better understanding either changes the trajectory or surpasses the initial goal (Allan and Curtis, 2005, Birnie-Gauvin et al., 2017, Curtis et al., 2014, Failing et al., 2004, Huitema et al., 2009, Marks et al., 2010, Pahl-Wostl, 2007, Ross and Martinez-Santos, 2010, Schreiber et al., 2004). Adaptive management seeks to develop optimum management within a range of acceptable outcomes while avoiding detriment (Allan and Curtis, 2002, Pahl-Wostl, 2007). Figure 1-4 gives an example of an adaptive management approach.

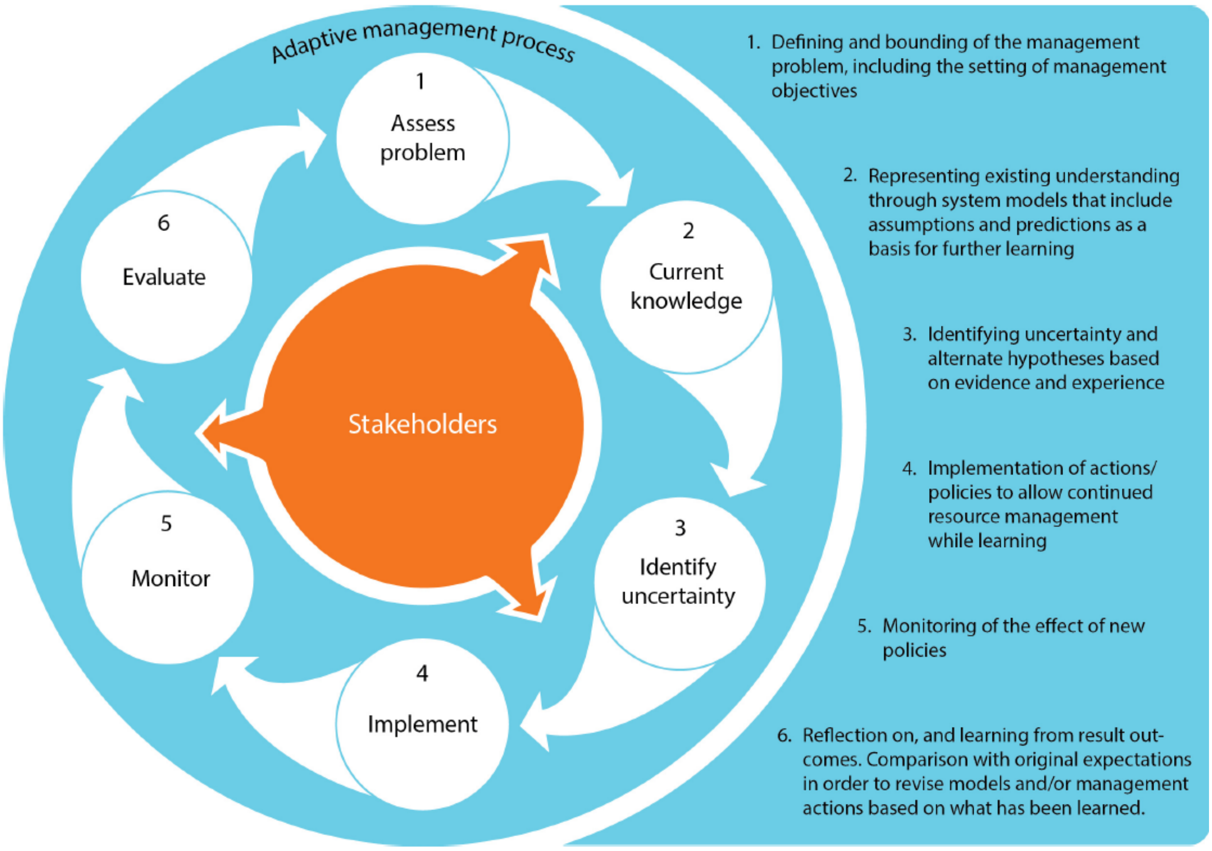

Figure 1-4 Example of an Adaptive Management Approach (Rist et al., 2013)

Many authors identify adaptive management as a solution to 'paralysis by analysis', or not knowing what to do given the available level of information, as it is inherently dynamic (Allan and Curtis, 2002, Allan and Curtis, 2005, Birnie-Gauvin et al., 2017, Failing et al., 2004, Rist et al., 2013, Rouillard and Spray, 2017), which is necessary when dealing with natural systems. Adaptive management is potentially most applicable in situations of high complexity and low certainty (Allan and Curtis, 2002, Allan and Curtis, 2005, Emerson et al., 2012, Rist et al., 2013). Peat et al. (2017) found adaptive management to be best implemented as part of a broader decision-making framework, not used in isolation. This is echoed by Failing et al. (2004) who found adaptive management most effective when focused on critical elements rather than an entire problem. Schreiber et al. (2004) found that use of adaptive management as a formalised and rigorous approach could result in more transparent and replicable management.

Adaptive management is a socio-environmental process. Community participation, buy-in, and support (both social and political) are essential for adaptive management to succeed. It requires a bottom-up desire but also top-down facilitation (Azhoni et al., 2018, Peat et al., 2017, Rist et al., 2013, Sultana and Thompson, 2017).

1.4.2 Ecohydrology

Ecohydrology is an approach that falls under the umbrella of hydrological sciences. Ecohydrology is the dual management of hydrology and ecology to achieve better outcomes for both. Ecohydrology is based on three pillars of social, hydrological, and ecological systems. It aims to "*achieve sustainability in both ecosystems and human populations*" (p. 1; (UNESCO, ND)) by reducing human impacts on ecosystems and strengthening ecosystem services (Section 1.4.3) in human-modified landscapes. Ecohydrology uses ecosystem processes as tools to meet freshwater resource management goals (UNESCO, 2006). It can inform management approaches to enhance, regulate, and/or remediate a systems resistance, resilience, diversity, and buffering capacity. Though not implicit, socioeconomic and cultural considerations can enhance the relationships recognised in the ecohydrological process (UNESCO, 2011).

Ecohydrology involves understanding ecosystem processes and communicating to water managers the benefit of retaining, restoring, or enhancing processes so they are protected (UNESCO, 2006). To enhance ecohydrology, past efforts must be understood, disciplines must be integrated, different facets of society must agree on shared goals, and there must be an actively pursued vision (UNESCO, 2011). Figure 1-5 shows a three step ecohydrological management process. In identifying a problem, it must be known why it is a problem and what came to cause it. Knowledge generation is understanding the interrelations associated with the problem and the interdependencies in the different interacting facets that must be considered. Improved knowledge is fundamental to using ecosystem properties as management tools (Zalewski and Wagner-Lotkowska, 2004). Problem solving is applying this information to the situation to achieve the desired outcome. Harmonising hydrologic provision with ecosystem requirements can increase carrying capacity and reduce ecosystem stress. The limitations of human knowledge, difficulty in accessing existing knowledge, and limited transferability between scenarios, means that understanding ecohydrological structure, state and relationships can be both a time-consuming exercise and a limiting factor.

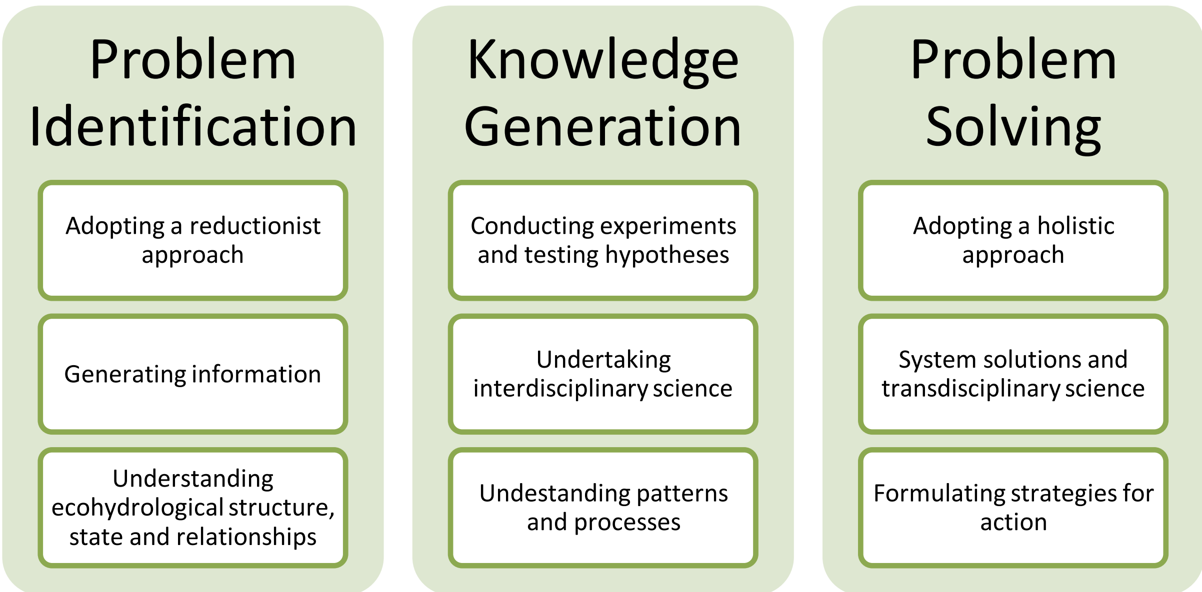

Figure 1-5 The Ecohydrological Approach (Adapted from (UNESCO, 2006))

1.4.3 Ecosystem Services

Ecosystem services are the benefits society obtains from nature. Ecosystem services can be both direct and indirect, and consist of material, energy, and information flows from natural capital (Pavan and

Ometto, 2018). Nature is both the provider and victim of the ecosystem services ethos in that not only is it inherently responsible for providing ecosystem services, but in doing so it is subject to pollution, exploitation, and potentially ecological collapse where minimum function is undermined (Cook and Spray, 2012). Provision of ecosystem services is dependent upon supply, demand and flow (Zhao et al., 2018); ecosystem services must be available for supply and able to flow to meet demand. If demand exceeds supply (and this is not managed) overexploitation and exhaustion can occur. The most widely used definition of ecosystem services is that presented in the Millennium Ecosystem Assessment:

> "*Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits*." (p. vii) (Millennium Assessment Board, 2005)

At a high level there are four ecosystem service types. Provisioning services are goods/products obtained from ecosystems. Regulating services maintain a world in which it is 'biophysically possible' for humans to live. Supporting services underlie the provision of all other services and have indirect impact on people. Supporting services are an intermediary and are essential to the delivery of the end products of the other three facets. Cultural services are non-material traits that are desirable by humans (Brauman et al., 2007, Ozdemiroglu et al., 2010). These are shown in Figure 1-6.

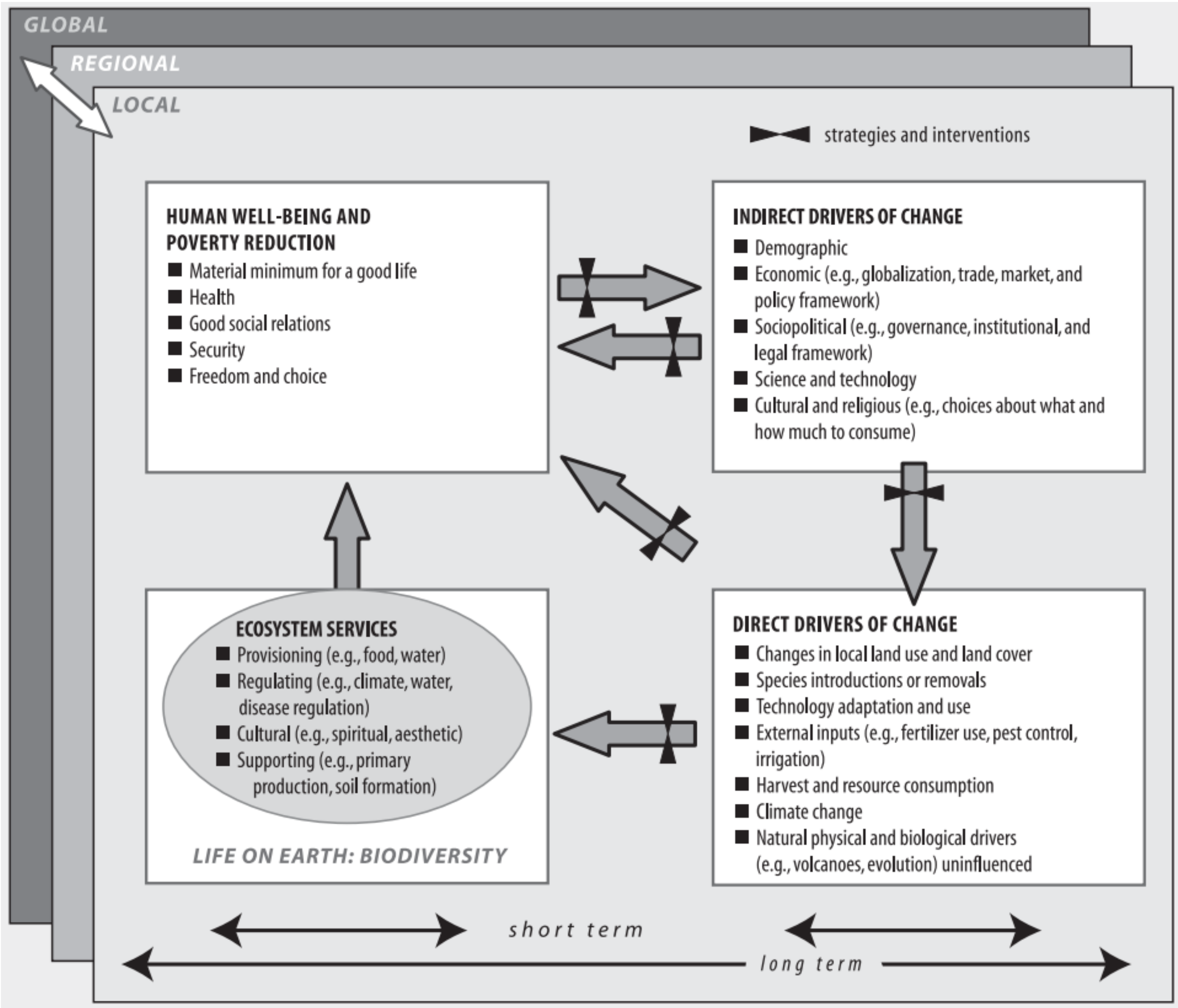

Figure 1-6 Millennium Ecosystem Assessment Framework for Ecosystem Services Assessment (Millennium Assessment Board, 2005)

Table 1-1 is a compilation of examples of ecosystem services from considered literature. A single ecosystem service can be provided by many different parts of the environment, just as a single part of the environment can provide many ecosystem services. The value provided by each ecosystem service depends on system characteristics (Dufour and Piégay, 2009). Different parts of society place different value on different ecosystem services. This is informed by motivation, knowledge, and interests (Smith and Sullivan, 2014). Ecosystems provide direct support to humans through natural resources, functions, and are a fundamental part of the social structure of many communities (Wallace et al., 2003). Nilsson and Renöfält (2008) found human interference in natural systems has reduced nature's ability to provide ecosystem services. Increased intervention by humans in natural systems reduces a systems capacity to adapt to change, meaning unanticipated externalities can see failure.

Table 1-1 Examples of Ecosystem Services from Considered Literature against Millennium Ecosystem Assessment Classifications

Service type	Examples	Sources
Provisioning services *e.g. food and water*	Food, water, fibre, timber, fuel, medicine, energy	(Brauman et al., 2007, Bunn et al., 2010, Jewitt, 2002, Loomis et al., 2000, Nilsson and Renöfält, 2008, Overton et al., 2014, Ozdemiroglu et al., 2010, UN Water, 2018)
Regulating services *e.g. regulation of floods, drought, land degradation, and disease*	Water filtration, air purification, soil stabilisation, erosion control, pollination, reduced impact from extreme events, nutrient removal and retention, habitat, water retention; groundwater recharge/water retention; flow regulation, waste treatment; biodiversity, structure	(Bischel et al., 2013, Brauman et al., 2007, Brewer et al., 2016, Halaburka et al., 2013, Jewitt, 2002, Kadykalo and Findlay, 2016, Loomis et al., 2000, Overton et al., 2014, Ozdemiroglu et al., 2010, Šatalová and Kenderessy, 2017, UN Water, 2018)
Support services *e.g. soil formation and nutrient cycling*	Nutrient cycling, soil generation, climate regulation, carbon cycling, genetic storage, habitat, primary production	(Bischel et al., 2013, Boulton, 1999, Brauman et al., 2007, Brewer et al., 2016, Loomis et al., 2000, Ozdemiroglu et al., 2010, UN Water, 2018)
Cultural services *e.g. recreational, spiritual, religious and other nonmaterial benefits*	Recreation, aesthetic, information, spiritual, conservation, biodiversity, tourism, education, amenity; transport	(Bischel et al., 2013, Brauman et al., 2007, Bunn et al., 2010, Jewitt, 2002, Loomis et al., 2000, Ozdemiroglu et al., 2010, UN Water, 2018)

1.4.4 Integrated Water Resource Management

Though 'water' is key in the term Integrated Water Resource Management (IWRM), IWRM does not focus solely on water. IWRM considers both human and natural dimensions of water. It seeks to recognise and integrate across biospheres, society, technology, space, and time, and in doing so acknowledge the entire water cycle and balance and provide for society (Al-Saidi, 2017, Chidammodzi and Muhandiki, 2017, Cook and Spray, 2012, Dillon et al., 2012, Ferreyra et al., 2008, Grigg, 2008, Jewitt, 2002, Liu et al., 2008, Mukhtarov and Gerlak, 2014, Nel et al., 2011, Norton and Lane, 2012, Pires et al., 2017, Pollard, 2002, Pórcel and Pérez, 2017, Savenije and Van der Zaag, 2008, Veale and Cooke, 2017). IWRM attempts to align water management to the 1992 Dublin Principles and the Rio Declaration (Dublin Principles, 1992). IWRM was adopted by the United Nations to achieve its Millennium Development Goals (United Nations, 2009) and retained in the Sustainable Development Goals (General Assembly, 2015), and by the European Union in the Water Framework Directive (2000). The Global Water Partnership definition of IWRM is the most widely used

> "…*a process that promotes the coordinated development of water, land and related resources to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.*" (p. 22)

Figure 1-7 shows a conceptual model of IWRM. IWRM recognises all water as part of the same system, its interactions within that system, and accounts for interdependencies in water availability and abstraction (Dillon et al., 2012, FAO, 2015, Jewitt, 2002, Ross and Martinez-Santos, 2010). IWRM allows decision makers to consider natural, social, and economic factors, and gives them greater ability to understand and manage the complexity and interconnections within and between natural and human environments (Liu et al., 2008). IWRM increasingly legitimises socio-environmental complexities and relationships and promotes shared values to improve todays water management to minimise tomorrows challenges (Cook and Spray, 2012, Grigg, 2008, Pórcel and Pérez, 2017). Pathways to IWRM must be developed based on political, social, environmental and economic circumstances (UN Water, 2018). Ferreyra et al. (2008) highlighted the importance of understanding an area's history in developing IWRM strategies as historic politics, ecology, and social factors influence reception to change.

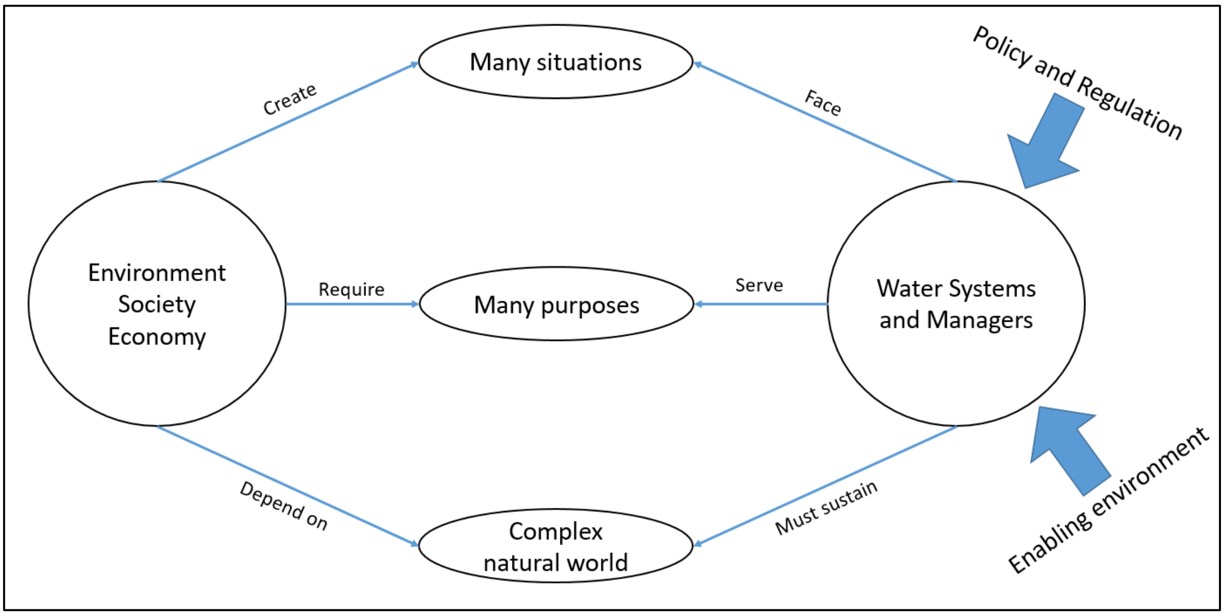

Figure 1-7 Conceptual Model of Integrated Water Resource Management (Grigg, 2014)

1.4.5 Integrated Catchment Management

IWRM (Section 1.4.4) is a subset of Integrated Catchment Management (ICM) (Figure 1-8). Where IWRM considers principally water, ICM gives greater equity in consideration of catchment resources (Collins and Ison, 2010). ICM recognises a catchment as a living ecosystem, consisting of an interlinked web of land, water, vegetation, biota, and people, and the many chemical and biological processes which link these (Pollard, 2002). ICM recognises that land and water are inexorably interlinked (Rowntree, 2006). Where water passes through a catchment, an activity that impacts its quantity and/or quality will be expressed in another part of the catchment. ICM is a framework that provides for coordinated planning and management of environmental and societal resources; seeks coordinated use, equitable, efficient, and sustainable resource use at a catchment-scale; considers a broad range of expertise and interests, and; can be effectively implemented without adverse outcomes (Barrios et al., 2009, Batchelor, 1999, Behmel et al., 2018, Booth et al., 2001, Pollard, 2002, RazaviToosi and Samani, 2016, Rowntree, 2006, Shaw et al., 2012).

Figure 1-9 gives example of an ICM process. For ICM to be successful, not only must the approach be integrated, it must be participatory from the outset, with involvement from individual stakeholders, communities of interest, industry, governance representatives, and inter-organisational collaboration and connection (Batchelor, 1999). Rowntree (2006) identifies that the greatest potential for and benefits from ICM can be achieved through grassroots approaches that promote public stewardship. Those responsible for catchment management must be able to adapt and respond according to best scientific knowledge and public demand; that ICM is a process, and not a means to and end (Collins and Ison, 2010). ICM acknowledges information gaps and presents new questions and approaches to addressing these (Orr et al., 2007). For ICM to be successful it must allow adequate and sustainable long-term water use; maintain water quality at levels that meet both legislated standards and social expectations; minimise damages from natural hazards, and; allow sustainable economic development across both the long- and short-term (Lee et al., 2008).

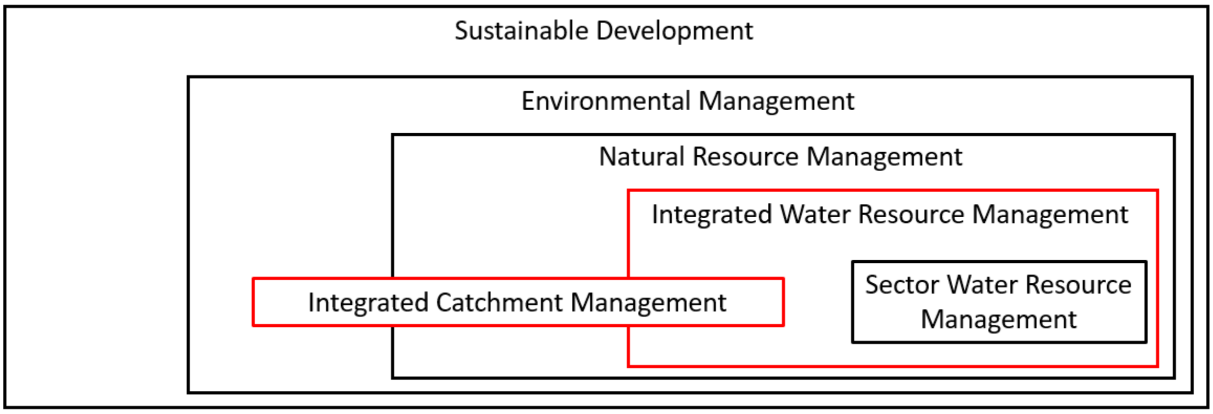

Figure 1-8 Integrated Water Resource Management versus Integrated Catchment Management within a Sustainable Development Framework (Adapted from (Davis, 2007))

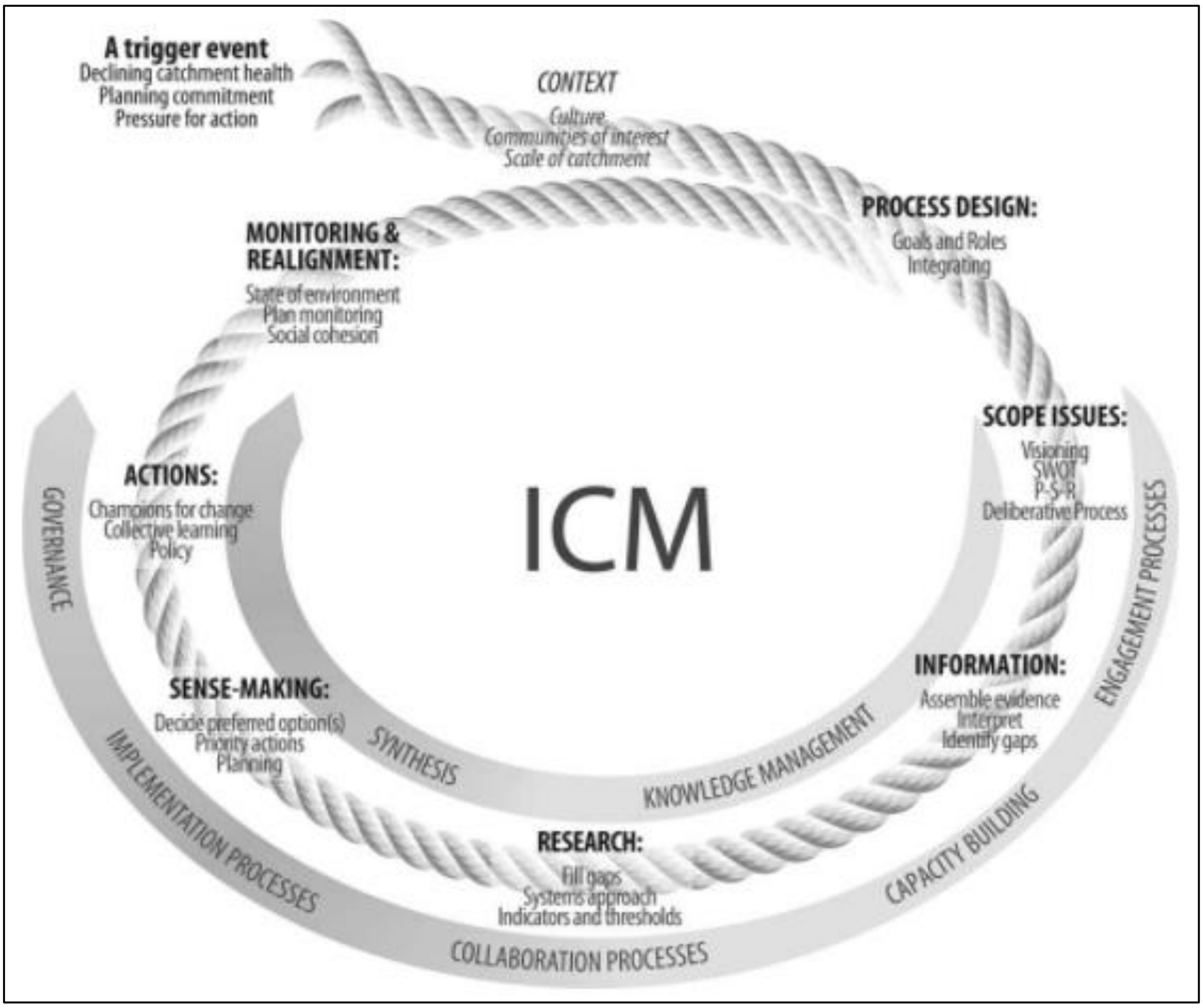

Figure 1-9 The Integrated Catchment Management Process (Fenemor et al., 2011)

1.4.6 Summary

Adaptive management is a learning by doing approach; ecohydrology, where hydrological and ecological outcomes are equally weighted, considered, and integrated. Ecosystem services is where the benefits society derives from nature are highlighted to better promote management for social and ecological outcomes. IWRM seeks integrated consideration of all aspects of the hydrosphere and its demands, while also recognising the impacts of land use and adequately providing for societal requirements and development. ICM seeks to give equal consideration to land, water, people, and their interactions and interdependencies. Each could be incorporated into all subsequent frameworks. An adaptive management approach could be applied to an ecohydrological process to monitor and modify to better address outcomes. Ecohydrology can be used to better quantify ecosystem services. Ecosystem services can be used to inform IWRM, and IWRM can inform ICM. Each has similarities. They require an enabling environment, decentralised management, adequate governance, multi-level decision making, resourcing, and stakeholder participation and buy-in to be successful. The choice to use one approach over another is dependent on the situation at hand.

1.5 Water Management in Canterbury

Figure 1-10 depicts the links between freshwater resource management planning and policy instruments for Canterbury. The Resource Management Act (RMA) is the primary piece of natural resource legislation in New Zealand. It seeks to promote sustainable management of natural and physical resources. Although the RMA recognised the general importance of managing resources on a catchment basis, it focused on managing 'downstream' impacts of activities (Bowden, 1999). Under the RMA, consent to take, use, dam, and/or divert water are granted on a first come, first served basis, and can be issued for up to 35 years. Thus, the legislative system is inherently inequitable in resource allocation. With the significant changes that have occurred to water quantity and quality within the last 15 years within Ashburton (Section 1.5), it is questionable whether permitting consents to be granted for such a considerable period of time is achieving the purpose of the RMA. Councils do have the power to 'call in' consents and review them, but this power is seldom used.

The Canterbury Water Management Strategy (CWMS) is a non-statutory document produced by the Canterbury Mayoral Forum to provide coordinated delivery of work to alleviate pressure on Canterbury's freshwater resources. The CWMS aims for parallel development of economy, culture, society, and the environment; to pursue agricultural production whilst protecting the environment (Duncan, 2013). Environment Canterbury address their commitments to the CWMS in the Land and Water Regional Plan (LWRP). In the LWRP, each Water Management Zone has a dedicated chapter of freshwater outcomes, policies and rules. These are informed by Zone Implementation Programmes (ZIP) and Zone Implementation Programme Addendums (ZIPA) that are developed by the Zone Committees of each Water Management Zone in consultation with communities, and in conjunction with councils. The Ashburton ZIP indicates a desire for improved environmental understanding and outcomes. In the Hinds Plains, the Ashburton ZIP has been succeeded by the Ashburton ZIPA: Hinds Plains Area. This builds on the outcomes and recommendations made in the Ashburton ZIP. The ZIPA states that:

> "*The Zone Committee believes it is time to take the first steps in what will be a long journey to reverse the current trends in water quality and quantity.*" (p. 10(2014))

There is also provision for 30,000 ha additional irrigated area in the ZIPA. These may appear to be inherently conflicted aims. Stricter nutrient rules, LWRP requirement for farm management plans, and dilution by way of MAR (Section 1.2.1), could make both goals achievable. ZIP and ZIPA are Zone Committee recommendations and are not legally binding. The ZIP informed the development of Plan Change 2 to the LWRP. The ZIPA and Plan Change 2 to the LWRP also led to the formation of the Hinds Drains Working Party, who were mandated to scope issues not directly addressed in Plan Change 2. The ZIPA and Hinds Drains Working Party informed later submissions to Plan Change 2, the direction of later plan changes (Plan Change 7), and established priorities for future actions and activities. Plan Change 7 to the LWRP was made available on 20 July 2019 for public submission. Environment Canterbury has indicated its intent to make this plan change operative before the expiration of the ECan Act (2010) in October 2019.

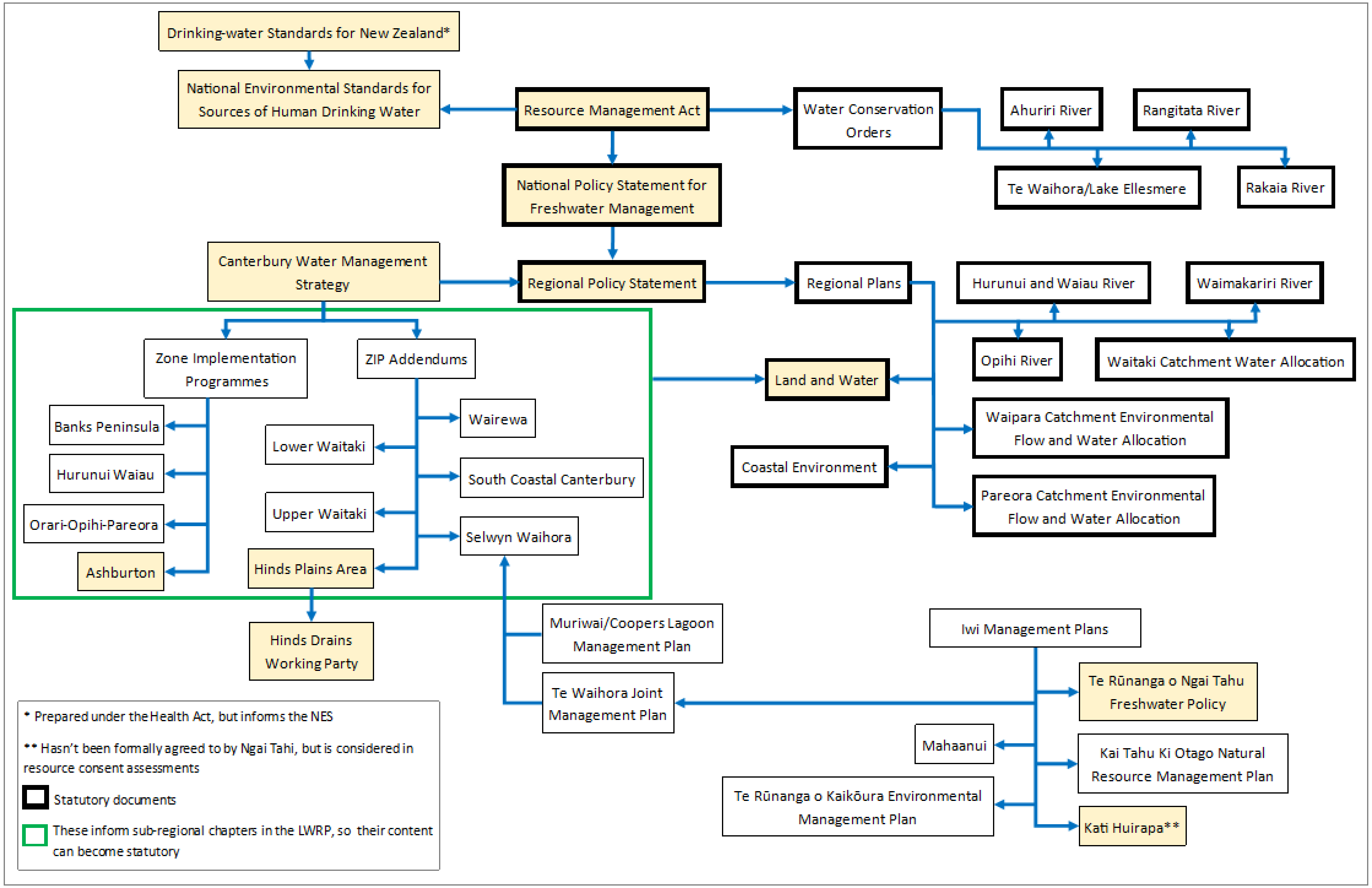

Figure 1-10 Canterbury Freshwater Resource Management Policy and Plans. Shaded Boxes (Yellow) are Those Relevant to the Hinds Plains. Iwi Management Plans, Though Listed Separately, Sit Alongside All Other Listed Documents

Plan Change 2 to the LWRP, made operative on 1 June 2018, gave effect to many ZIP and ZIPA recommendations. Plan Change 2 introduced rules relating to augmentation. The LWRP classified waterway augmentation as a 'discretionary activity' meaning a consent must be obtained for the activity to occur. In theory, this does not change the standing for the operation of ECGIS from before Plan Change 2 was implemented, but there are no matters of discretion around discharges of freshwater to 'contaminated' water. This is water that does not meet freshwater outcomes[1] (as specified in Table 13(a) of the LWRP). Windermere Drain is the only waterway used by ECGIS specifically identified as needing to meet outcomes. This does not necessarily preclude Deals and Home Paddock drains from needing to do so too. Poorly defined baseline conditions for freshwater outcomes means it is not possible to definitively determine whether the ECGIS drains could be considered 'contaminated' and what impact augmentation has on this status. Plan policies and rules could not readily make the ECGIS activities 'permitted' without this understanding.

A core concept across all documents presented in Figure 1-10 is integration; that nothing can be achieved in isolation, and that cross-disciplinary and community collaboration is necessary for the success of water management initiatives. This has been promoted and facilitated through the CWMS process and the LWRP, but uptake and application are marred by social politics. Integration cannot be considered purely of integrating water with water; it must also be considered contextually. Zone Committees are mandated to consider water management within the four wellbeings (social, cultural, economic, and environmental) but this consideration is not without bias. Biases are inherent in the CWMS in having first and second order priorities. Biases are also introduced by decision making parties, their background, relationships, and any agendas that may be operating. Making any sweeping, significant changes to the benefit of one wellbeing can easily be to the detriment of another. It is not possible to remove all sources of bias from resource management decision making as this process is inherently political and based on case law.

1.6 Research Setting

Land use in the Ashburton District has been characterised by its relationship with water, both water excess and deficit. Today's land users better understand their relationship with water than previous generations, including the impacts of their land management practices on water quality and quantity. This is perhaps attributable to the considerable engagement the people and communities have had in contributing to the setting of environmental limits through engaging in the planning processes established under the CWMS.

ECGIS has been operating continuously since the 1980s, making use of drainage channels to convey irrigation water to ECGIS members. These drainage channels were dug across the late-1800s as part of works to convert the area from a vast swamp to farmable land. Subsequent subdivision of this land saw the drainage system neglected and eventually fail, and the land start to revert back to swamp-like conditions. Meanwhile, flood-irrigation on the once water-sparse upper plains had commenced, using out-of-catchment water delivered via the Rangitata Diversion Race (RDR). This saw significant additional infiltration to groundwater amplifying the inundation issues experienced by lowland farmers due to the failure of the drainage system. Effective land drainage was not achieved again until 1970. The drains have been well maintained since.

The drains still serve this land drainage function, preserving the landscape as economically viable farmland. ECGIS also uses Deals Drain, Windermere Drain, and Home Paddock Drain to convey irrigation water to its members, serving a dual economic purpose. ECGIS pumps groundwater into these drains in what has become known as targeted stream augmentation. This is a low-cost method of water conveyance but has greater potential for water loss via infiltration and evaporation than piped conveyance. It also provides aquatic habitat through sustaining drain flows, exerting beneficial temperature controls, and diluting concentrations of land drainage contaminants (2014) – a trade-off ECGIS has championed as being a positive one that should be encouraged through planning mechanisms. Despite the significant operating period of ECGIS, the details of its operational regime and impacts on the local environment remain poorly known to Environment Canterbury, the organisation responsible for managing land and water in Canterbury. It is known that ECGIS discharges groundwater

[1] Outcomes are indicators of ecological health (e.g. dissolved oxygen saturation), macrophytes, periphyton, siltation, microbial content, and cultural factors.

to surface water on an as-needed basis to provide irrigation water to members and ensure that low flow conditions are met, but specifics beyond this conceptual understanding are unknown.

1.6.1 Soils

Soil properties and structure influence rates of water infiltration and retention, as well as contaminant losses through the root zone. The ECGIS area consists thick layers of heavy, poorly drained soils, with pockets of very poorly drained soil in its northern extent, and pockets of well drained soils coincident with shallow soils (Lilburne et al., 2012). This reflects the areas former swamp status. Hardpans of iron concretions are common within 50 cm of land surface. With land development these have frequently been fractured allowing groundwater upwelling. Where soil water and groundwater is present in excess, this can lead to waterlogging. This is not ideal for agricultural land use, hence the prevalence of drainage. The majority of the ECGIS area is covered with Wakanui soils. These are imperfectly to poorly drained; have compact subsoils that can locally perch the water table; experience both seasonal deficits and waterlogging, and; can facilitate reducing conditions when waterlogged, enabling potential for periods of redox reactions such as denitrification (Kear et al., 1967). Due to its waterlogging and high water table, the ECGIS area experiences high bypass flow meaning land use and drainage water quality are intimately linked. Soil drainage water leaches contaminants from soil. The main control on volume of contaminant lost to water (other than the inherent load associated with the land use practice) is the amount of water involved. If there is no water movement, there is no potential for mobilisation of contaminants. Water application rate above the soil infiltration capacity can result in overland flow and contaminants entering surface water. Similarly, water applied to soils above its moisture retention capacity results in subsurface bypass flow. Poor irrigation management, high rainfall events, or both, can cause either.

1.6.2 Hydrology

Early on, the hydrologic system of the Hinds Plains was recognised as being one large, interconnected system, wherein surface water could not be understood without also understanding groundwater. Land use expansion and intensification across the Hinds Plains was facilitated by the cutting of water races to supply stockwater and later irrigation, and to drain excess water to make more land farmable. Stockwater races lost huge volumes of water to groundwater. As surface water takes reached capacity in the late 20th Century, users switched to groundwater, with a proliferation in groundwater bores and water use consents from 2000. Davey (2006) found that prior to 2003 groundwater usage across the Hinds Plains was considerably less than the recharge groundwater received from out of catchment water, influenced by flood irrigation practices employed by RDR water users, meaning the groundwater system was often in net surplus. The economies of groundwater (less incidental water loss and greater potential water use efficiency) meant that many irrigators who did not have access to RDR water switched to groundwater completely, infilling their water races (reducing groundwater recharge) and increasing their abstraction (Davey, 2003). The increase in groundwater use also coincided with uptake of more efficient irrigation water use practices. More groundwater was being taken than was being replenished despite less water being used than consented limits (Aitchison-Earl et al., 2004).

Land use intensity and irrigation efficiency and expansion have altered water flows via greater water use and less recharge (Durney and Ritson, 2014, Everest et al., 2013, Hanson et al., 2006, Meredith et al., 2006, Meredith and Lessard, 2014, Moore, 2014, Sinton, 2008). Lower reliability in water supply has been experienced by Hinds Plains farmers below State Highway 1 who are increasingly being impacted by greater up-catchment water use and efficiency measures (Engelbrecht, 2005). Aitchison-Earl et al. (2004) found that resource management instruments were ineffective in ensuring water was effectively allocated across Ashburton, with the Hinds Plains over 100% allocated.[2] The Hinds River surface water catchment is also over-allocated. As not all water allocated on paper is being used (an average of 25-58% (Durney and Ritson, 2014)), and negative impacts associated with water exploitation and contamination are already being experienced, this raises concern as to the impacts full authorised use of water could have, economically, socially, and environmentally. The absence of irrigation recharge to groundwater due to efficiency requirements, in combination with over-allocation of groundwater and surface water, has caused water shortages, with the Hinds Drains, which previously flowed perennially, experiencing very low flows and drying during summer (Meredith and Lessard, 2014).

[2] Based on a safe-yield method where water is not allocated beyond natural recharge

1.6.3 Water Quality

The Hinds Plains water system is understood to be an interconnected unit. Groundwater discharging to surface in the ECGIS area is from shallow groundwater with a high contaminant load relative to deeper groundwater. Groundwater age increases with depth (Scott, 2013). Deep groundwater is generally less contaminated as it reflects historic dryland land use. This also means that the impacts of current land uses have yet to be fully realised.

Key water quality contaminants of concern across the Hinds Plains are nitrate-N and faecal indicators. Phosphorus has not proven to be of consistent concern. Nitrate-N persists in well-oxygenated water such as surface water and shallow groundwater. By 2010, Hinds Plains waterways had among the highest nitrate-N concentrations for surface water in New Zealand (Golder Associates, 2014, Scott, 2013). Scott (2013) described nitrate-N concentrations in groundwater in the Hinds Plains as high with an increasing trend. Nitrate-N concentrations in deep bores are lower than those found in shallow bores, but above average for deep bores in Canterbury (Hanson, 2002). Faecal indicators do not occur naturally in water; their detection suggests contamination. Faecal indicators such as *E. coli* die-off once outside a body, so they are predominantly detected in surface water and shallow groundwater. Detection indicates either a recent or a persistent source of contamination. While nitrate-N cannot be adsorbed by the ground, faecal contaminants can be adsorbed or filtered out by soils. The ZIPA (2014) reported that the constructed waterways of the Hinds Plains were highly enriched with nutrients and microbes, but also sustained healthy aquatic habitat. It is therefore important to take a holistic view of water quality determinands when assessing water quality.

1.6.4 Planning Processes

Through planning processes over the 21st Century there has been an increased focus on restoring water quality and flows in surface water. This has largely been to the detriment of groundwater, especially the deeper resource. Those with surface water takes and stream depleting groundwater takes have been encouraged to switch to deeper groundwater takes (Environment Canterbury, 2014). This has seen an increase in abstractions from deep groundwater and reduced over-allocation on surface water. Over-abstraction of shallow groundwater can cause a lowering of the water table and see groundwater levels dropping below pump levels. The same can occur with over-abstraction of deep groundwater, creating dynamic drawdown. The Hinds Plains groundwater system is one large interconnected system; taking groundwater from depth induces longer-term falling groundwater heads in shallower parts of the system as it equalises. Pumps that were thought to be sufficiently submerged become suspended above the water column. To prevent this, bore pump rate is reduced, or the bore is operated intermittently, otherwise the bore can fail completely. This has been the experience for many groundwater users coastward of State Highway 1. Although much water remains in the aquifer, it can no longer be exploited efficiently or sustainably. This is not without significant cost to the consent holder, but also with significant but unknown environmental cost. Switching to deep groundwater takes does abate immediate or short-term concerns and address planning goals. It could very well turn out to be more detrimental long-term, resulting in unsustainable groundwater mining, and colloquially be perceived as cutting off your leg to save your foot.

1.7 Research Objectives

To date, there has been no comprehensive assessment of the hydrologic effects from operation of ECGIS. The operation of ECGIS (other than a general understanding of use of targeted stream augmentation) remains poorly understood. The aim of this investigation is to understand the operation and operational effects of ECGIS. To do this, four objectives are to be addressed. Table 1-2 presents these and the rationale for each. This research focuses on the largest and centremost drain utilised by ECGIS; Windermere Drain. This decision was made to enable deployment of resources to tell a more comprehensive story along Windermere Drain, rather than making inferences from multiple sites along multiple drains, where conclusions may be less reliable.

Table 1-2 Research Objectives and Rationales

Objective		Rationale
1	Document the operation of ECGIS and how operational decisions are made.	To understand how the scheme is operated and the rationale behind this should inform and anticipate where and how operational effects of ECGIS could be felt and identify opportunity for greater efficiencies.
2	Understand the hydrological setting of ECGIS and how scheme operation impacts measured parameters	Field monitoring of ground and surface water quantity and quality will enable improved definition of their interrelationships both temporally and spatially and enable measurement of what effects targeted stream augmentation may have on hydrology.
3	Identify values associated with the Hinds Drains	Understanding what the community values about the Hinds Drains gives greater impetus for targeted restoration.
4	Determine how values could be met using an integrated framework	Present the above gained information within an appropriate integration framework to consider variables that impact viability of expansion of targeted stream augmentation.

2 Methods

The aim of this investigation is to understand the operation and operational effects of ECGIS. This requires knowing how ECGIS is operated, understanding its hydrological setting, and determining values that drive operation. Thus, both social and physical science methods were employed. This section details the methods employed to achieve the research objectives. It is presented to best demonstrate the methods used to address each objective.

2.1 Objective 1: Document the Operation of Eiffelton Community Group Irrigation Scheme and How Operational Decisions Are Made

The intent of this objective was to gain an understanding of how ECGIS is operated and the rationale behind operational decision making. This understanding should inform and anticipate where and how operational effects of ECGIS could be felt. To achieve Objective 1 semi-structured interviews were conducted with ECGIS members. 14 ECGIS members were approached for their input and 11 members were interviewed. All interviewees were provided the same information and consent forms (Appendix 1) and were asked the same questions (Figure 2-1). As the interviews were semi-structured, these questions provided a base commonality of responses; themes varied between interviewees. All interviews were recorded and transcribed to capture key themes and messages. Complementary secondary data such as resource consents and their conditions and requirements were also considered.

1. Describe your understanding of the area's hydrology, including any ties to climate, drivers, soil moisture, river flows, water use, and anything else as relevant
2. Are there any springs/seeps/tile drains/mole drains/etc. on your property/ies? (annotate)
    a. Do you have any wetland/swamp areas on your property/ies fed by any of these features? (annotate)
3. Confirm your land uses and irrigated areas on the provided maps (correct as needed)
4. Confirm the mapped reaches of the drainage network are correct (correct as needed)
    a. Are features related to the drainage network or scheme operation missing from the maps?
    b. Is your abstraction point correct? (location and abstraction rate)
5. Describe how ECGIS operates
6. Do you use scheme water/bores for anything else? e.g. stock/domestic water
    a. What proportion of your take is this?

Figure 2-1 Questions Asked of Eiffelton Community Group Irrigation Scheme Members Only

2.2 Objective 2: Understand the Hydrological Setting of ECGIS and How Scheme Operation Impacts Measured Parameters

This objective was addressed by undertaking field investigation on the largest and centremost drain utilised by ECGIS; Windermere Drain. This enabled deployment of resources that told a more comprehensive story along Windermere Drain using the same sites, rather than multiple sites along multiple drains, where the distribution of data may make conclusions less reliable. The aim of the field investigation was to collect sufficient data, both spatially and temporally, and from surface and groundwater, to draw conclusions regarding the hydrological setting of ECGIS and effects of its operation on measured parameters. Field monitoring of ground and surface water quantity and quality was to enable definition of their interrelationships both temporally and spatially, and to enable measurement of what effects targeted stream augmentation may have on hydrology. Spatial data was obtained by having sites aligned from near the top of Windermere Drain to near the bottom at semi-regular intervals (Figure 2-3). Temporal data capture was ensured through data collection occurring for just over a year (March 2018 to April 2019), capturing the tail end of the 2017-18 irrigation season, the full 2018-19 irrigation season, and the period between. To complement this data, ECGIS pumping and flow data, and rainfall data were also obtained.

2.2.1 Equipment Installation

Environment Canterbury field technicians Hamish Carrad and Tom Johns installed piezos at Lower Beach Road and Poplar Road on 23/11/2017, and at the remaining clusters on 14/12/2018. The saturation of the bed of Windermere Drain meant the instream (bed) piezos could be installed with manual percussion (Figure 2-2, left). However, mechanical percussion was required to install the out-of-drain (bank) piezos (Figure 2-2, right). Mechanical percussion was achieved through use of a piezo driver which drives connected lengths of 1 m sectional casing into the ground into which the piezo casing is installed and the sectional casing removed. Additional ground saturation (by way of drain water) was required to install the Surveyors Bank piezo due to a hardpan clay layer at approximately 1 m below ground level that the piezo driver was unable to puncture. A bentonite seal was installed around bank piezos to ensure land surface runoff did not affect data. As the piezos were driven rather than drilled, it cannot be ascertained whether screened intervals exactly intersect the water table. However, the extensive experience of Hamish and Tom in using the piezo driver across the Canterbury Region meant the intersection of the water table could be inferred by relative changes in resistance encountered. Less resistance reflects loosely packed deposits that are more likely to contain groundwater. The piezo screens are assumed to be intersecting groundwater that is hydraulically connected to Windermere Drain. Piezos were fitted with Solinst Levelogger® Edge water level loggers on 18/02/18.

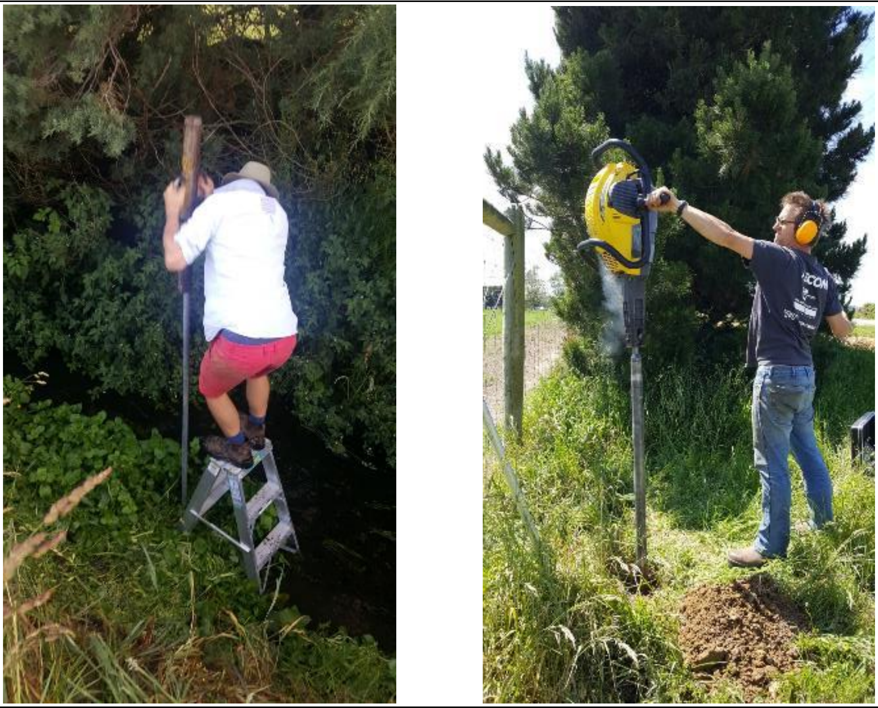

Figure 2-2 Environment Canterbury Science Technician Tom Johns Installing Piezo Boundary Bed (Left) and Poplar Bank (Right)

2.2.2 Monitoring Sites

Figure 2-3 shows monitoring sites and ECGIS drains and Table 2-1 shows site details. The core network consisted five arrays (large labels, Figure 2-3). Each array consisted a surface water site and two piezos; one in the drain bed, and one in the bank approximately 10 m adjacent to the drain. The sites were placed near road verges to ensure ease of access. Each array was named for the road it is placed on except 'Newtons' which was placed on Newtons Drain, an upstream tributary of Windermere Drain. Two piezos (Surveyors Bank and Lower Beach Bank) were placed on private land by necessity and with landowner permission for piezo installation and ongoing access. The intention of this core network was to provide information relating to the interaction of groundwater and surface water and give insights into its spatial interactions. Four ECGIS production bores were also included as part of the monitoring network (small labels, Figure 2-3). These were identified with input from the ECGIS Chair to ensure there was appropriate depth and spatial distribution of ECGIS bores sampled along the length of Windermere Drain, and that there would be no access issues. Data was collected from these bores to understand the relationship between ECGIS pumping and Windermere Drain flows and water quality.

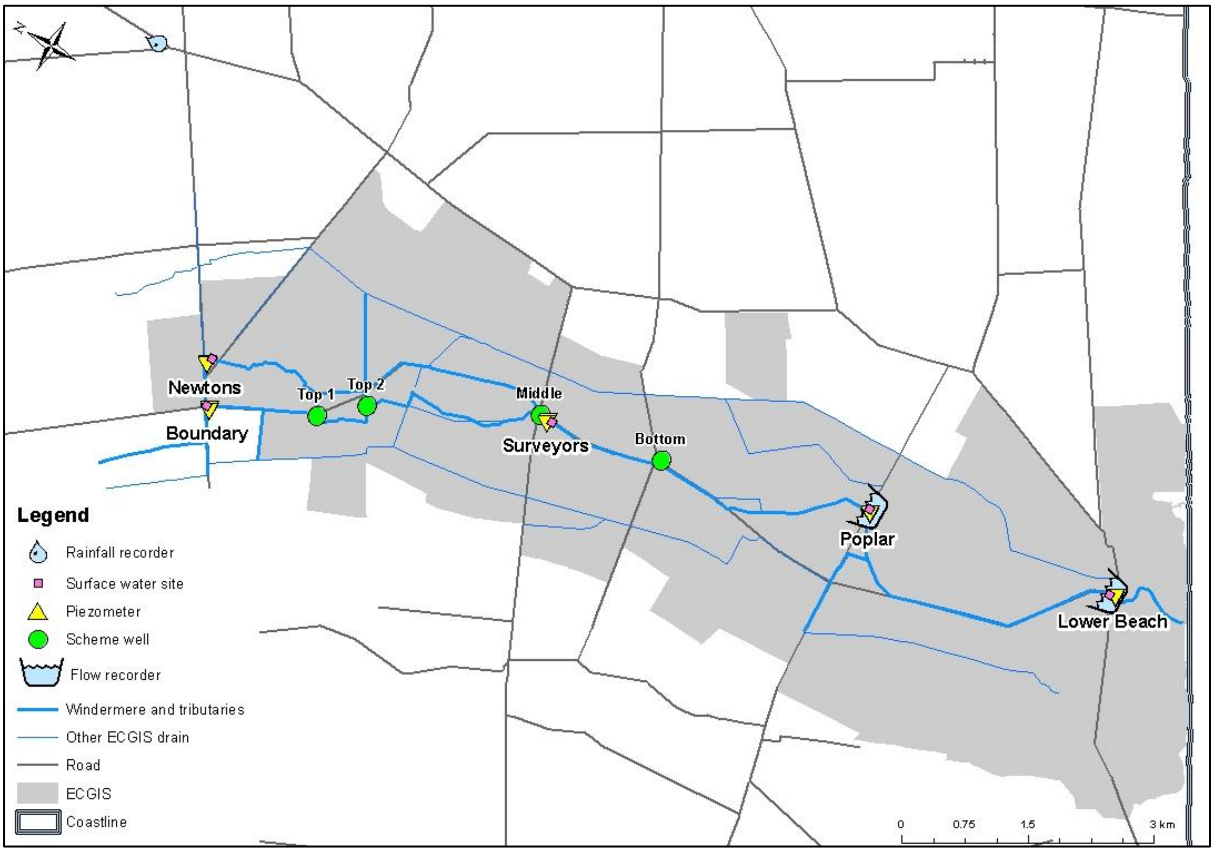

Figure 2-3 Monitoring Sites and Locations of Additional Data Sources. Large Labels Identify Each Array While Small Labels Identify Scheme Bores

Table 2-1 Monitoring Site Details

Array Name	Site Name	Water Type	Diameter (mm)	Depth (m)	Screen (m bgl[1])
Newtons	Bank Piezo	Ground	25	4.95	2.95-4.95
	Bed Piezo	Ground	25	2.5	2-2.5
	Drain	Surface			
Boundary	Bank Piezo	Ground	25	5.12	3.12-5.12
	Bed Piezo	Ground	25	3	2.5-3
	Drain	Surface			
Scheme	Top 1	Ground	300	100	72.5-100
	Top 2	Ground	300	72.5	32.25-45.25
	Middle	Ground	300	57.8	48.3-57.8
	Bottom	Ground	300	93.6	45-93.6
Surveyors	Bank Piezo	Ground	25	6.01	4.01-6.01
	Bed Piezo	Ground	25	2.835	2.335-2.835
	Drain	Surface			
Poplar	Bank Piezo	Ground	25	5.96	3.96-5.96
	Bed Piezo	Ground	25	2.35	1.85-2.35
	Drain	Surface			
Lower Beach	Bank Piezo	Ground	25	6.22	4.22-6.22
	Bed Piezo	Ground	25	2.5	2-2.5
	Drain	Surface			

[1]m bgl: metres below ground level

Additional Data

Additional data sources included 15-minute groundwater level data from all piezos, two flow sites, and rainfall information. The location of these are shown in Figure 2-3. The flow recorder on Poplar Road is operated by Boraman's consultancy on behalf of ECGIS for consent compliance. The flow recorder on Lower Beach Road is operated by Environment Canterbury. Both sites are gauged regularly to check their rating and ensure accuracy. They have been operational for some time. Rainfall information was taken from Environment Canterbury rainfall site 319602 on the Hinds Plains at Willowby.

2.2.3 Data Collection

Field runs were conducted near the start of each calendar month from February 2018 to April 2019 inclusive to collect groundwater levels, gauge Windermere Drain, and to collect water quality samples and field parameters at each array. Sample runs were ordered for collection of data from the coast moving sequentially inland. This ensured that actions at any site did not affect the data collected at a down-gradient site. Photographs of each drain site were taken on every visit to record any obvious changes in the state of the drain. These are in Appendix 2. Despite best efforts not all sites were visited on every field run and some data is missing. Table 2-2 details missing data. Where practical, synthetic data was created to replace missing values using correlation and interpolation.

Table 2-2 Missing Data Description

Date	Site	Parameter	Reason
18/02/2018-07/03/2018	Lower Beach Bed Piezo	Groundwater level	Piezo damaged and replaced
18/02/2018-5/6/2018	Boundary Bank Piezo	Groundwater level	Logger malfunction
4/03/2018	Newtons array Boundary piezos Lower Beach Bed Piezo	Dissolved reactive phosphorus Dissolved organic phosphorus	**Sites:** Lower Beach Bed: casing bent/damaged by flood waters, could not access to sample; Remainder: health and safety **Parameters:** Lab did not provide results for – possible miscommunication
03/04/2018	Newtons Bed Piezo Scheme Middle	Dissolved oxygen	**Sites:** Newtons Bed: piezo unexpectedly dried under pumping, wanted to find out why before sampling; Scheme Middle: health and safety **Parameters:** Meter malfunction
5/06/2018	Drain sites	Flow gauging	Microsoft Excel file corrupted
3/12/2018	Surveyors array Scheme Bottom	All	Health and safety
3/01/2019	Scheme Top 1 Scheme Middle	All	Health and safety
4/04/2019	All	Dissolved oxygen	Meter malfunction

Groundwater Level Data

Groundwater levels were measured from each piezo and ECGIS production bore using groundwater probes and recorded on paper field sheets. This was done in accordance with nationally consistent methods (NEMS, 2016). Each piezo was fitted with a logger recording groundwater level every 15-minutes. Groundwater levels were taken before and after the collection of each water quality sample to ensure logger data could be corrected to account for pumping interference. The same practice was adopted when downloading the data from the loggers. This is done in case the loggers rest at different depths pre- and post-removal from the piezos. Offset in logger depth within the piezo casing means the logged groundwater levels will be offset relative to the measuring position. During data processing, this can be corrected, providing before and after levels have been recorded. This highlights the importance of adhering to robust data collection methodologies. Data from the probes were downloaded as .csv files and processed in Hydstra[3]. Processing the data involved correcting the logger data against the manual readings and removing barometric influence in water levels.

Surface Water Gauging Data

Flow gaugings were undertaken at each array. All flow gaugings were undertaken using a flow probe (Global Water FP-111), and in accordance with NEMS (2013), including using sites on reaches that are relatively straight and are three to five times longer than the channel is wide; ensuring flow direction is at right angle to the gauging, and; selecting sites with relatively uniform cross section. The exception to this last factor is Newtons Drain as the accessible portion of the drain for gauging contained boulders,

[3] Hydstra is a time-series data management system used by Environment Canterbury for data processing, QA, and archiving

resulting in significant variation in depth across the gauging location. Cross section location was consistent at each site for the duration of the study period through leaving pegs in the banks at each site and marking their location using spray paint, as visible in Figure 2-4.

Figure 2-4 Flow Gauging Cross Section at Lower Beach Road. Pink Spray Paint on the Far Bank Indicates the Location of the Peg for Flow Gauging Use

Each cross section was divided into 10 intervals. Depth and flow were measured at each interval and at the banks and values recorded in Microsoft Excel. Recording these values enabled calculation of cross-sectional discharge using Equation 1. *Q* is the cross-sectional discharge, *A,* or area, is equal to the amount of water in each cross-section interval and was determined by multiplying the depth of water column by interval spacing. *V* is the velocity of flow for each cross-section interval. The Poplar array was on the same reach as a telemetered hydrometric flow gauge (Figure 2-3) operated by Boraman's consultancy on behalf of ECGIS to monitor compliance to low flow conditions during irrigation season. Lower Beach array was also on the same reach as a telemetered flow gauge, this one operated by Environment Canterbury. Comparison to this data will enable assessment of gauging accuracy.

$$Q = AV$$

Equation 1 Discharge Volume

Surveying

To enable absolute comparison between groundwater levels and surface water elevation, GPS surveying was undertaken in April 2019. This was done via RTK, or Real Time Kinematic, surveying. Three Trimble R8 GPS units were used to achieve this. The R8 unit has accuracy of up to 8 mm horizontal and 15 mm vertical. The first unit was set above a LINZ geodetic marker (Lynford). The LINZ geodetic marker has a known position and elevation; part of a nationally maintained dataset. Setting the first unit above this marker meant that data collected from the latter two units could be corrected to be relative to a known, accurate position. R8 unit two and three were mobile. Unit two was set on a tripod. This was set level in place for at least 30 minutes at each location to collect sufficient data to ensure its accuracy. While unit two was logging, unit three was used to collect spot measurements. Collected data was corrected to be accurate relative to the LINZ geodetic mark; as accurate as possible.

Water Quality

Water quality samples were collected in bottles supplied by Hill Laboratories for laboratory analysis. Bottles were stored in provided chilly bins lined with ice packs. It is assumed that as Hill Laboratories is an IANZ accredited lab, bottles were uncontaminated and fit for use, and that the number of ice packs maintained an appropriate sample temperature. Table 2-3 presents the water quality parameters measured and their analysis method.

Table 2-3 Water Quality Parameters. Total Suspended Solids Was Only Measured in Surface Water Samples. Lab Analysis Was Performed by Hill Laboratories and Field Analysis by the Author

Parameter		Analysis	Measurement
pH		Lab and Field	**Lab:** pH meter (Rice et al., 2012) **Field:** Orion Star™ A329
Conductivity		Lab and Field	**Lab:** Conductivity meter, 25°C (Rice et al., 2012) **Field:** Orion Star™ A329
Dissolved Oxygen		Field	Orion Star™ A329
Turbidity		Field	Orion™ AQUAfast™ AQ4500
Temperature		Field	Orion Star™ A329
Total Suspended Solids		Lab	Filtration of 2 L sample (pore size 1.2-1.5 µm), gravimetric determination (Rice et al., 2012)
Nitrogen	Dissolved Inorganic	Lab	Calculation: ammoniacal-N + nitrate-N + nitrite-N
	Total Ammoniacal		Filtered sample, phenol/hypochlorite colourimetry, flow injection analyser (Rice et al., 2012) Calculation: ammonium-N + ammonia-N
	Nitrite		Azo dye 1-13 colourimetry, flow injection analyser (Rice et al., 2012)
	Nitrate		Calculation: (Nitrate-N + Nitrite-N) – Nitrite-N
	Nitrite+Nitrate		Total oxidised nitrogen, 1-13 automated cadmium reduction, flow injection analyser (Rice et al., 2012)
Phosphorus	Dissolved Reactive	Lab	Total dissolved phosphorus digestion, ascorbic acid colourimetry, discrete analyser (Rice et al., 2012) Modified to include the use of a reductant to eliminate interference from arsenic present in the sample (Smith et al., 1982)
	Total Dissolved		Total dissolved phosphorus digestion, ascorbic acid colourimetry, discrete analyser (Rice et al., 2012) Modified to include the use of a reductant to eliminate interference from arsenic present in the sample (Smith et al., 1982)
	Dissolved Organic		Calculation: total dissolved phosphorus – dissolved reactive phosphorus
	Total		Total phosphorus digestion, ascorbic acid colourimetry, discrete analyser (Rice et al., 2012) Modified to include the use of a reductant to eliminate interference from arsenic present in the sample (Smith et al., 1982)
E. coli		Lab	MPN count using Colilert [18] (35°C for 18 hours) (Rice et al., 2012)

Surface water quality samples were collected from the middle of the water column across the gauged reach in accordance with NEMS (2019). Before taking a groundwater quality sample, the depth to groundwater was measured to enable calculation of the volume of water in each bore. Three times this volume was purged from each bore (Equation 2) before sample collection as per the nation protocol (NEMS, 2016, Daughney, 2006) to ensure that the groundwater sample collected represents water quality of the aquifer rather than the potentially stagnant water within the bore casing. Water from pumping the piezos was discharged to ground. ECGIS bores were purged using scheme pumps and the water was discharged into Windermere Drain as per normal operation. This highlights the importance in the order of sample collection. Had samples been collected starting inland and working towards the coast, any sample collected downstream of a purged bore could have been affected by this discharged water.

$$purge\ volume = \left(\pi \times \left(\frac{r^2}{1000}\right) \times [depth\ of\ water\ column]\right) \times 3$$

Equation 2 Purge Volume

Samples were also collected at each site in plastic test tubes for analysis of field parameters. Test tubes were rinsed using filtered water between sites. Field analysis of water chemistry parameters was undertaken using an Orion meter (Orion Star™ A329 Portable Multiparameter meter) to measure pH, conductivity, dissolved oxygen, and temperature, while a turbidity meter (Orion™ AQUAfast™ AQ4500 Turbidity meter) was also used. Values were recorded in Microsoft Excel.

Observations

Newtons Bed, Lower Beach Bed, and Boundary Bed piezos appeared to have issues with poor connectivity. It was common for these piezos to be purged dry before sampling could occur. The first recharge these piezos received after drying had a high sediment load. In trialling the best method to collect samples from these piezos post purge (continuous pumping of small volumes, or intermittent pumping of larger volumes) it was found that continuous pumping was the better alternative as intermittent pumping saw sedimentation exacerbated.

2.3 Objective 3: Identify Values Associated with the Hinds Drains

Key values associated with the Hinds Drains were identified by conducting semi-structured interviews with Hinds Drains stakeholders. These included ECGIS members; other Hinds Drains landowners; members of the Zone Committee; representatives from environmental interest groups, councils, rūnanga, and; representatives of economic interest groups. Of the 16 'other' stakeholders (not ECGIS members) approached for participation 10 were interviewed. This is additional to the ECGIS members identified in Section 2.1. All interviewees were provided the same information and consent forms (Appendix 1) and were asked the same set of questions (Figure 2-5). These questions provided a base commonality of responses, but points of emphasis varied between interviewees. Each interview was transcribed to capture key themes and messages.

1. Tell me about your association with the Hinds Drains
    a. length of association
    b. interests
    c. participation in planning processes
    d. any changes over time
2. Please describe your understanding of the area's hydrology, including any ties to climate, drivers, soil moisture, river flows, water use, and anything else relevant
3. What do you know about ECGIS and its operation? Can you describe any changes over time?

    (give brief explanation to all interviewees after answering this question to ensure same level of base knowledge)
4. What is your opinion on how it operates? What informs this?
5. In a perfect world, ignoring all other factors, what would you like to see the drains used for/to facilitate?

Figure 2-5 Questions Asked of All Interviewees to Establish Relationship with the Hinds Drains, Perceptions of Eiffelton Irrigation Scheme, Targeted Stream Augmentation, and Values Associated With/Desired Of the Hinds Drains

2.4 Objective 4: Determine How Values Could Be Met Using an Integrated Framework

Achieving this objective involved incorporating the information used to achieve the previous three. By understanding the hydrological setting, the effect of ECGIS on the environment can be better quantified. By understanding community perception of ECGIS and values associated with the Hinds Drains, it can be identified whether targeted stream augmentation is a tool that could be implemented to enhance values. It is assumed that other Hinds Drains have similar hydrological setting to Windermere Drain. By understanding the effects of targeted stream augmentation in the Windermere Drain setting, it can be assessed whether it is practical to address community values using this tool. Understanding community values can help inform what changes would be most welcomed by communities, and how such changes could be well-supported. Information obtained by addressing the preceding objectives is to be placed within an analytical integrated framework to identify where the most effective improvements can be made to aid the community in realising desired outcomes.

3 Results

This section presents the results for addressing objectives one to three. Objective 4 is excluded from this section as it is to be addressed using data generated in addressing objectives 1 to 3.

3.1 Objective 1: Document the Operation of Eiffelton Community Group Irrigation Scheme and How Operational Decisions Are Made

ECGIS consists of 4,000 ha of land, 58 km of drains, and 20 production bores (Figure 3-1). Most of ECGIS's production bores are concentrated inland meaning water reaches members under gravity, reducing electricity costs and increasing potential for incidental losses. Most production bores are concentrated along Windermere Drain reflecting the heavy reliance on this drain to provide the majority of ECGIS water, and its larger flow and transport capacity. Production bores have been installed further coastward than initially envisaged to provide more responsive supply as needed; there is less lag time in water reaching a member below Surveyors Road from W7 than from W8 (Figure 3-1). ECGIS drains have also been increasingly straightened and realigned since inception, notably in the case of Windermere Drain near Poplar Road to enable more effective centre pivot irrigation operation (Figure 3-1). Secondary drains running perpendicular to the main drains allow movement of water between Deals, Windermere, and Home Paddock drains for the efficient conveyance of water.

Member access to water is determined by their relative share of land within the ECGIS command area. ECGIS is approximately 4,000 ha. Ownership of 250 ha within ECGIS would give a member access to a proportional allocation (i.e. 6.25% (250/4000) of the total ECGIS allocation). This share enables irrigation to 3.5 mm/ha. Few members rely solely on ECGIS for irrigation water. Most also have groundwater takes and/or takes from other drains (providing there is sufficient flow to enable take).

3.1.1 Establishment

The impetus for ECGIS was to resolve inequitable access to water in Eiffelton. Before the 1980s all irrigation in Eiffelton and surrounding areas was via water from the drains. Different landowners had different priority access to drain water based on when the right was obtained, causing friction in the community. Community members also realised that the existing pressures on access to water would be prohibitive to future development. Scheme Member 2 summarises pre-ECGIS sentiments:

> "*For a farming district to have somebody to have different access to make a living; that was a major driver, from the first people, to put everyone at the same level and have the same opportunity. … People were willing to play ball; everyone was willing because everyone was going to win because there was more water available and it was a cost sharing scheme.*"

In 1980 the Ministry of Works sunk two exploratory bores; HP3 (91.5 m deep) and D1 (37 m deep) (Figure 3-1). These bores proved the area contained significant groundwater. With time, ECGIS has added more production bores, giving greater access to water for members. This was generally done to facilitate more intensive land use, whether it be cropping or dairy. Water use efficiency was less of an issue as ECGIS has always been under spray irrigation. The most recent production bores (W9 and W10) were installed in response to recent drought conditions to provide greater water security to members. To date, no land has been removed from the ECGIS command area. ECGIS has increased to include additional land parcels. The intent of this approach is to "*protect riparian access*" (Scheme Member 8).

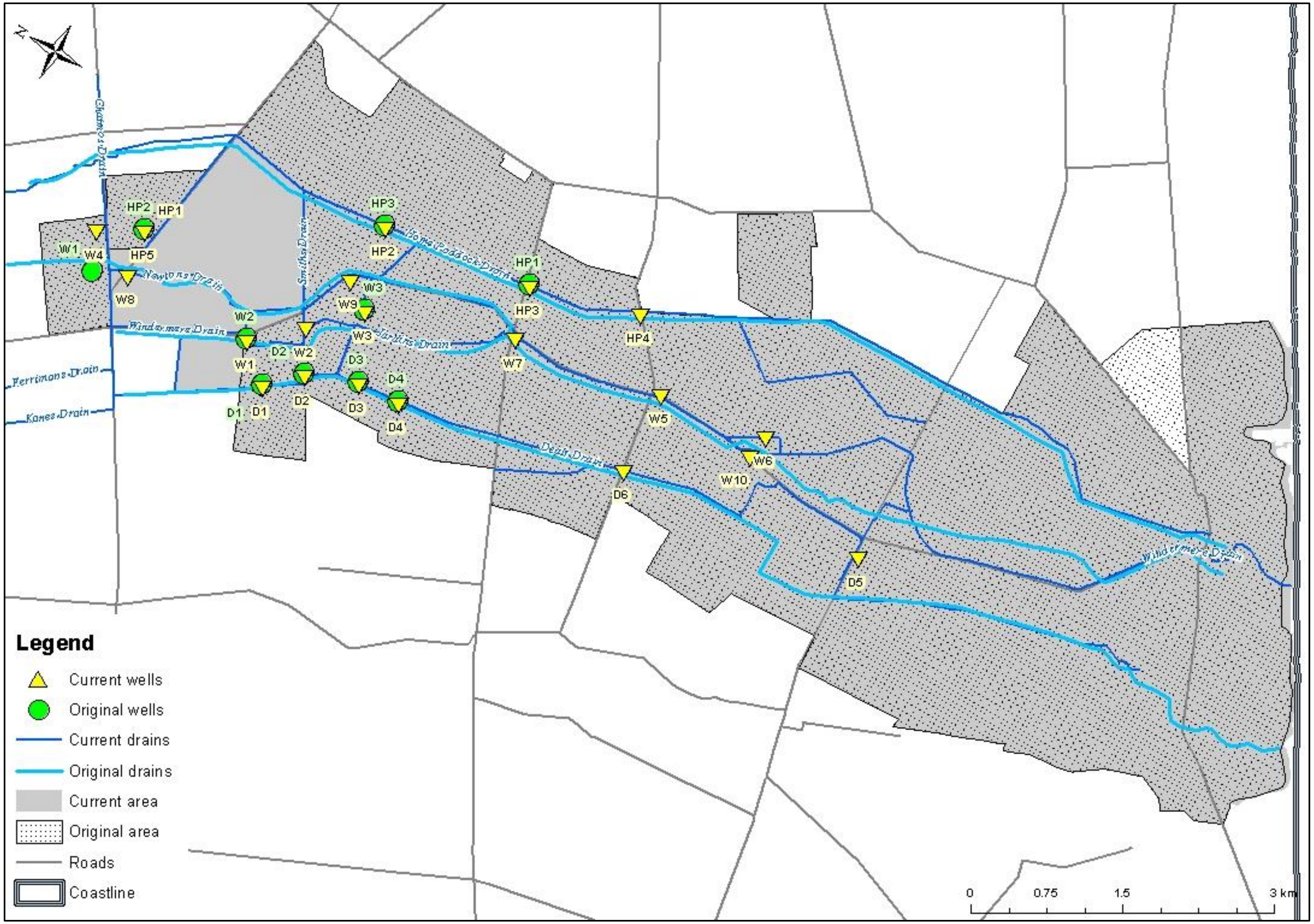

Figure 3-1 Drain Layout and Intended Eiffelton Community Group Irrigation Scheme Production Bore Locations in 1983 (Green Shading) Vs. Current (Yellow Shading)

3.1.2 Membership

ECGIS membership is recognised by a Memorandum of Encumbrance on land titles. This legal encumbrance requires members to pay nominal fees for ECGIS maintenance (monthly on a per hectare basis) and for water use (based on relative pumping cost). It also permits access to private land by ECGIS personnel on ECGIS business, e.g. accessing a production bore. The encumbrance cannot be removed from the title; on sale it passes to any new owner. It also means any outstanding fees on sale must be paid before the transaction can be completed. This has been invoked twice. The number of members has changed as land has been sold, merged, and divided; originally there were 22 members, now there are 17.

ECGIS members were found to pride themselves on the democracy of their decision making, their cohesion, and their ability to get on with things (Scheme members 3, 4, 7). Proposed changes to ECGIS are put to members to vote on. This is generally done at the Annual General Meeting (AGM), held early each year. Outside of the AGM, leadership is responsible for making decisions on behalf of members, and for keeping members informed of these decisions. There were varying opinions on the adequacy of this communication. There were also comments suggesting current operation is geared towards supporting larger landowners, potentially to the detriment of members with smaller holdings.

Scheme Member 2 highlights the importance of established rules and practices in helping new members understand ECGIS, see the value in operating in the manner they do, and integrate:

> "*The scheme has run very well over the time, right through. Everyone's been enthusiastic and committed to it and had good chairmen, committee – they just work very well together. It's got to for a small scheme.*"

Because ECGIS operates based on goodwill, "*when someone bucks, the system it breaks*" (scheme Member 5). This is especially apt when considering the efforts of ECGIS management:

> "*It's always when things come under pressure, that's when you start having issues*."
>
> (Scheme Member 5)

> "*Some people abuse that in that they expect people to always do a superb job but won't contribute to helping in the first place*"
>
> (Scheme Member 8)

Despite any short-term friction, ECGIS members recognise the need for cooperation, and the value for community ECGIS brings; knowing your neighbours and supporting biodiversity. Some have been members of ECGIS since inception. These and more are intergenerational farmers in this area. They grew up alongside the drains, and place value on the aesthetic, recreational, biodiversity, and incidental values they provide, as well as their function of keeping their land farmable:

> "*That was always an important component - when we started the scheme, I think we were the only scheme in New Zealand where we had the support of Fish and Game to start an irrigation scheme, because they could see the net effect of our scheme operation would benefit fish life in the drains, and they'd be right. We've always taken that connection with Fish and Game seriously.*"
>
> (Scheme Member 8)

Members are committed to working towards a common goal of making sure there is enough and equitable access to water:

> "*It operates because everybody cooperates. The scheme keeps everybody talking to everybody – some more than others – and I think everybody respects everybody else. And they fall in line and do what is needed.*
>
> (Scheme Member 4)

There is unity in facing externalities. A continued frustration of members is their relationship with Environment Canterbury. Vast changes to planning rules implemented by Environment Canterbury have been largely perceived by members as threatening to the longevity of ECGIS. This is still to be resolved. As per Scheme Member 2:

> "*We try our best, and we've always tried our best, but we've always had to fight people who don't understand. We kept having to keep come and argue the same point because the turnover of staff at ECan. You have somebody that you've put lots of time into to bring them up to speed, then you have to redo it again*."

Members recognise that times are changing and "*there's not so many who have come through from the next generation*" (Scheme Member 4). This is coupled with a change in the farming landscape, from a traditionally cropping area to one that has seen increased dairy in line with the regional trend. Scheme Member 2 describes this as "*the progress of things*", while Scheme Member 3 comments "*things change, farms get bigger. The people in our district have changed considerably in the time I've been here*."

3.1.3 Leadership

ECGIS is overseen by a Board (Figure 3-2) responsible for ECGIS operation and consisting ECGIS members. This includes acquiring resource consents (Chairperson), ensuring compliance to consent conditions (Chairperson, Race Manager, Assistant Race Manager), operating ECGIS (Race Manager, Assistant Race Manager), and managing finances (Treasurer). The Secretary is responsible for general coordination of information and record-keeping. The chairperson oversees governance of ECGIS and is responsible for "*doing the nasty stuff*"; ensuring compliance with operational and financial rules and advocating on behalf of ECGIS as necessary. This has been a huge task over the last decade.

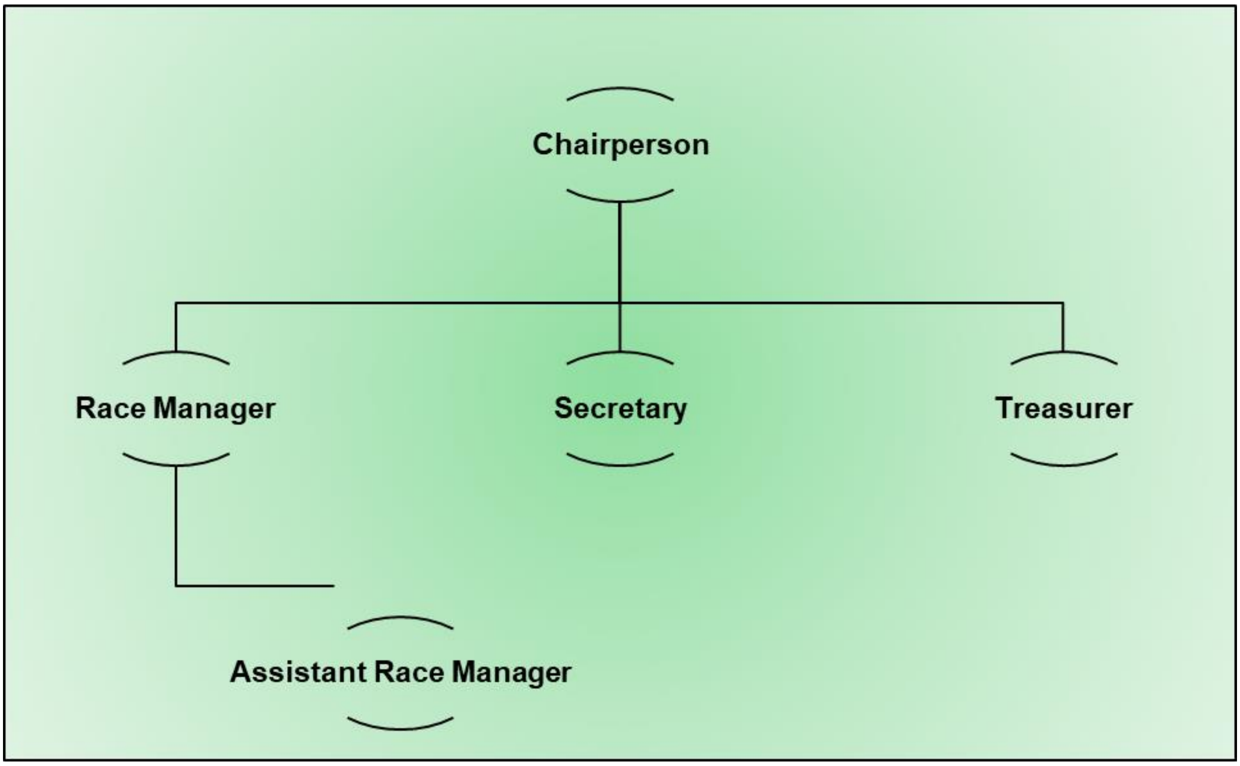

Figure 3-2 Eiffelton Community Group Irrigation Scheme Board Structure

Race managers are responsible for day-to-day operations. Unlike most modern irrigation schemes in New Zealand, ECGIS does not employ staff. Both race managers are ECGIS members; running farms fulltime while also performing the duties associated with ECGIS management. The different farming types of the race mangers means each can have time away from managing ECGIS during their respective busy period and ECGIS will continue to function in their absence. Accordingly, the Race Manager receives the highest stipend, while the Secretary is the only board member not to receive a stipend.

3.1.4 Resource Consents

ECGIS has been issued almost 100 resource consents to authorise its operation and ensure changes to infrastructure are captured within consent documents, dating back to 1991. Table 3-1 shows ECGIS production bores details and current consent information. Though Table 3-1 lists maximum pumping rates, these are not always achievable due to factors affecting bores, the groundwater resource, and combined maximum rates between production bores specified in consent conditions. The combined rate of groundwater take from all production bores is not to exceed 913 L/s (CRC164334). Production bores on CRC164334 are subject to a combined maximum rate of 277 L/s. Production bores on CRC173935 can each take 60 L/s but if both are pumping, they are not to exceed this rate. Under CRC173935 W10 cannot be used beyond August 2019 and take from W4 must cease when water level in K37/0553 (non-ECGIS bore) is lower than 2.88 m below ground level as estimated by Environment Canterbury. There is no record of K37/0553 being measured.

Table 3-1 Eiffelton Community Group Irrigation Scheme Production Bore Details and Consent Information

<table>
<tr><th>ID</th><th>Depth (m)</th><th>Drain</th><th>First Consented</th><th>Current Consent</th><th>Max Rate (L/s)</th><th>Max Volume</th></tr>
<tr><td>D5</td><td>93</td><td>Deals</td><td>29/10/2002</td><td>CRC030387</td><td>45</td><td></td></tr>
<tr><td>HP4</td><td>48.5</td><td>Home Paddock</td><td>22/12/2004</td><td>CRC041251</td><td>45</td><td>3,888 m^3/1 day</td></tr>
<tr><td>D4</td><td>99.3</td><td>Deals</td><td rowspan="2">22/12/2015</td><td>CRC164333</td><td>50</td><td></td></tr>
<tr><td>W9</td><td>95</td><td rowspan="2">Windermere</td><td rowspan="7">CRC164334</td><td>50</td><td rowspan="7">23,933 m^3/1 day</td></tr>
<tr><td>W6</td><td>52.6</td><td rowspan="5">9/09/2005</td><td>47</td></tr>
<tr><td>D6</td><td>48</td><td>Deals</td><td>40</td></tr>
<tr><td>W7</td><td>57.8</td><td rowspan="5">Windermere</td><td>52</td></tr>
<tr><td>W8</td><td>84</td><td>60</td></tr>
<tr><td>HP1</td><td>87.6</td><td>60</td></tr>
<tr><td>W10</td><td>95.18</td><td>15/05/2017</td><td rowspan="2">CRC173935</td><td rowspan="2">60</td><td></td></tr>
<tr><td>W4</td><td>9.8</td><td>20/10/1999</td><td></td></tr>
<tr><td>D1</td><td>37</td><td rowspan="3">Deals</td><td rowspan="9">12/06/1991</td><td>CRC962609</td><td>55</td><td>33,264 m^3/7 days</td></tr>
<tr><td>D2</td><td>50.8</td><td>CRC962610</td><td>54.2</td><td>32,780 m^3/7 days</td></tr>
<tr><td>D3</td><td>56.5</td><td>CRC962611</td><td>44.2</td><td>26,732 m^3/7 days</td></tr>
<tr><td>W1</td><td>100</td><td rowspan="3">Windermere</td><td>CRC962613</td><td>58.2</td><td>35,199 m^3/7 days</td></tr>
<tr><td>W2</td><td>72.5</td><td>CRC962614</td><td>47.2</td><td>28,547 m^3/7 days</td></tr>
<tr><td>W3</td><td>80</td><td>CRC962615</td><td>38.9</td><td>23,527 m^3/7 days</td></tr>
<tr><td>HP2</td><td>100</td><td rowspan="2">Home Paddock</td><td>CRC962616</td><td>51.9</td><td>31,389 m^3/7 days</td></tr>
<tr><td>HP3</td><td>91.5</td><td>CRC962617</td><td>36.7</td><td>22,196 m^3/7 days</td></tr>
<tr><td>HP5</td><td>10</td><td>Newtons</td><td>CRC962618.1</td><td>32</td><td>12,500 m^3/7 days</td></tr>
<tr><td>W5</td><td>93.6</td><td>Windermere</td><td>29/10/1999</td><td>CRC992800</td><td>68</td><td></td></tr>
</table>

Table 3-2 summarises maximum potential augmentation ('Max in' and 'Cumulative max in') and abstraction for each drain based on consents. The total volume abstracted by members from Deals Drain is not to exceed 176,800 m^3/7 days (CRC962600.1); Windermere Drain 250,975 m^3/7 days (CRC962601.1), and; Home Paddock Drain 174,250 m^3/7 days (CRC962602.1). Maximum abstractions from Deals and Home Paddock drains exceed cumulative inputs. However, each drain has minimum flow conditions. This means that abstractions can only occur so long as a minimum drain flow is maintained. Before 2004, minimum flows (40 L/s Deals Drain; 57 L/s Windermere and Home Paddock drains) were set at Lower Beach Road. From 2004 the minimum flow sites moved up-gradient to Poplar Road and increased (70 L/s Deals Drain; 80 L/s Windermere and Home Paddock drains).

Table 3-2 Augmentation Balance for Each Eiffelton Community Group Irrigation Scheme Drain in L/s. 'Max in' is Maximum Augmentation from Maximum Pump Rates per Bore; 'Cumulative Max In' Reflects Consent Restrictions

Drain	Max In	Cumulative Max In	Max Abstractions	Difference
Deals	288.4	273.3	289	-15.7
Windermere	633.3	513.0	415	+98.0
Home Paddock	133.6	126.6	243	-116.4

3.1.5 Operation

ECGIS has 20 production bores from which groundwater is pumped and delivered via surface drainage channel to 17 scheme members. All bores pump into the closest drain except HP1 which pumps into Windermere Drain. As none of the Home Paddock Drain abstractors take water until below Smiths Drain (Figure 3-1), it was seen a 'waste of water' to pump HP1 into Home Paddock Drain to essentially 'keep the channel wet' as the efficiency of water-on-water conveyance is lost when the drains have no flow; up to 15% of discharge can be used just to sustain flow (Scheme Member 5). Piping HP1 to Windermere Drain was seen as a more efficient use of water. Figure 3-3 shows the location of ECGIS infrastructure.

There is no predetermined order in which production bores are turned on. Production bores are operated in accordance with irrigation demand and to ensure minimum flow conditions are met. Scheme member 5 noted 2-3 irrigators per drain could often operate from non-augmented flow[4] alone and minimum flow conditions would still be met, but any more required additional water. Once a production bore is turned on, it generally stays on. There are exceptions to this:

> "*If, all of a sudden, we get short down the bottom and they need water in a hurry, well I'll turn on one further down for a start until they catch up, and then maybe turn on another one further up and then turn it* [the lower one] *off.*"
>
> (Scheme management)

Table 3-3 identifies production bores considered better and poorer, as indicated by ECGIS management through their interviews. Not all production bores were commented on, thus some are missing from Table 3-3. Unlisted production bores can be assumed to perform fine; they do their job and there is nothing outstandingly good or poor about them. W4 is the shallowest production bore in ECGIS at 10 m. It is also the least reliable for this reason; if the water table drops away, it cannot be operated. Though W7 is seen as a good production bore, it serves dual purpose in also providing drinking water to a scheme member. Management indicated that they try to delay use of this production bore to limit impact on the member. ECGIS is required to get water to property boundaries of all members. Pump placement can therefore impact on the amount of water members receive.

Table 3-3 Production Bore Performance by Drain. Included Comment Reflects Management's Reasoning for this Definition Where Available

	Well Performing		**Poorly Performing**	
Deals Drain			D3	Cost
			D5	Efficiency
Windermere Drain	W5	Yield	W3	Yield
	W1	Yield	W2	Access
	W6			
	W7	Access		
	W8	Yield		
	W4	Cost	W4	Reliability
	HP1			
Home Paddock Drain	HP2		HP3	Cost
	HP4			

[4] Providing baseflow is occurring, this was not the case in recent drought years

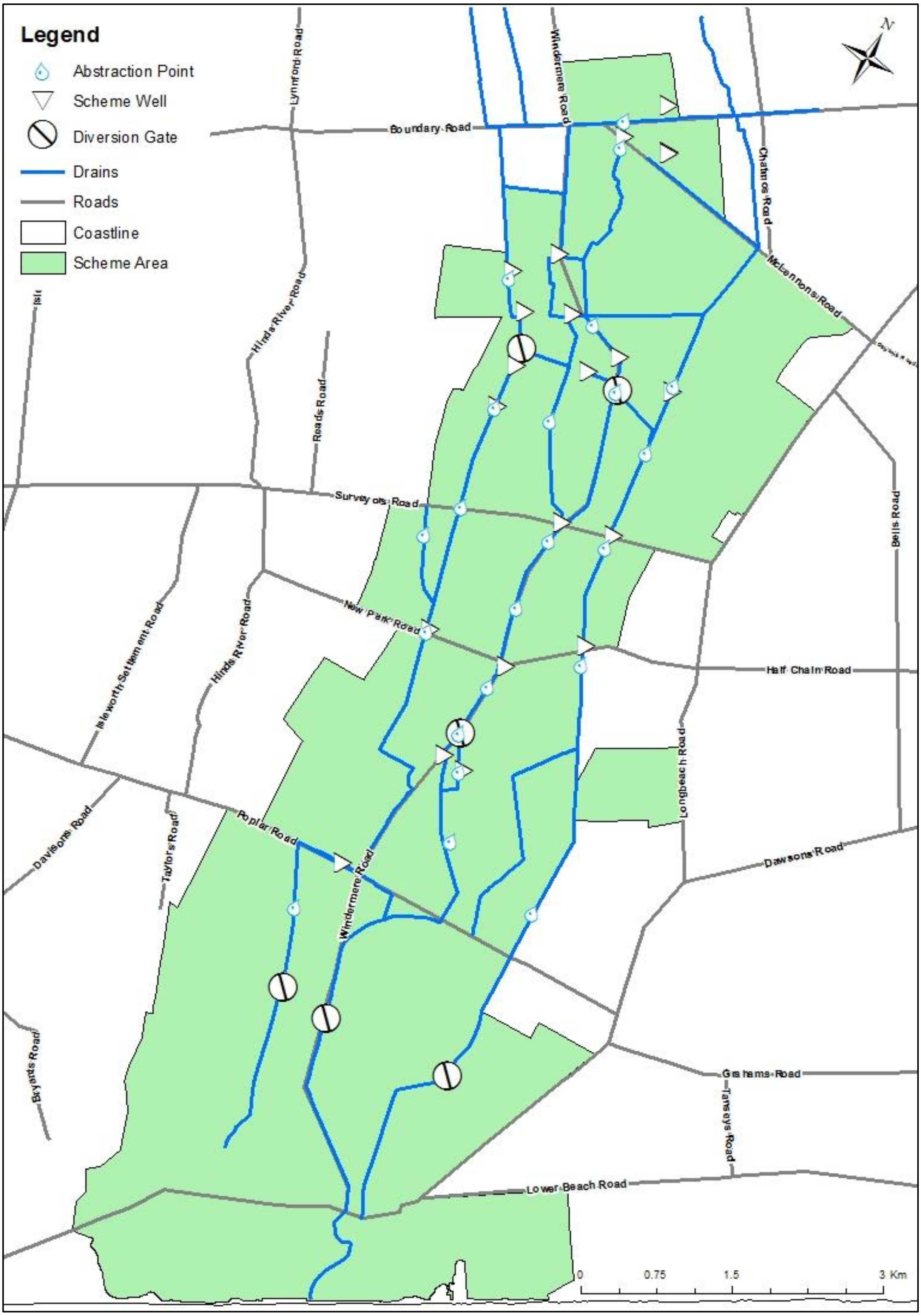

Figure 3-3 Locations of Scheme Bores, Abstraction Points, and Diversion Gates. The Two Diversion Gates Above Surveyors Road Are to Divert Flow Between Drains. The Three Gates below Poplar Road Are to Divert Flow to Fill Private Storage Ponds

Drought years can see members face water use restrictions if ECGIS bores are unable to pump enough water to meet irrigation requirements and minimum flow conditions. When facing water restrictions, the Board has a meeting and decide the restriction required, be it 10% or 25%. New allocations are determined and physically delivered to everyone. If further restriction is required, the process is repeated. This process is generally not without confrontation from ECGIS members.

Diversion gates on perpendicular drains between Deals and Windermere drains, and Windermere and Home Paddock drains allow flow to be transferred between the drains and make best use of the more efficient and cheaper to operate production bores. ECGIS management notes "*We always bring a couple of wells across the top of the diversion*" from Deals to Windermere drain. The diversion gates are manually operated, thus the quantity of water diverted is based on judgement, not a quantifiable volume. Diversion gates are the only facet of ECGIS operation that does not have associated telemetry.

Technological Improvements
Members (4, 5, 7) praised the transparency and reliability of the ECGIS's telemetry and online monitoring system. This system has been operational for 2-3 years. Each pump within ECGIS is fit with a telemetered flow meter (as now required by law). Each low flow site is also telemetered (as required by consent conditions). These were all verified in the 2016/17 irrigation season so accurate reporting can be ensured. Telemetry data is shown on a webpage that all members have access to. Management and members can view all information in one place; can see who may have turned on without proper notification; and can see where pumps may not be performing as expected. Similarly, all members can see how much each other are taking. The visibility of this encourages social responsibility; members taking only their allocation and not tempted to be greedy. This system has removed perceptions of some members taking more than their fair share of the shared resource, as was the case when the use of each member was unknown (Scheme Member 5). As per Scheme Member 8:

> "…*everyone can see what's going on, which is I think the best decision they* [leadership] *made*."

With technology comes glitches. Flow meters can fail; telemetry can fail; batteries die; power can be cut; equipment can be affected by the weather and other interferences. Depending on availability it can take time for management to notice when flow meters fail. If this happens during the irrigation season, this leads to unregistered pumping charges, inequality, and difficulty in determining lost costs. The production bores used for augmentation are generally turned on and off remotely. Each bore has an associated modem that can either be called or text by management to turn on or off. When properly functioning, each bore's modem alerts the race manager to power cuts or any failures:

> "*When the phone system's working well it's quite good. But I do get frustrated every time we get a power cut. If we have a power cut it trips the overload, so you've got to physically go to the pump shed. Some of them come on, some of them don't.*"
>
> (Scheme management)

Based on interviews with management, failures with ECGIS electronics seem to be commonplace. Working out what failed; why; if it can be fixed immediately, or if a technician needs to be called in, and; attending a technician visit, all take time. These time commitments for scheme management were considerable during the recent drought years, and amplified by other issues:

> "…*it was ringing my phone every 30 seconds because it would cut out, ring me, start back up; cut out, ring me, start back up. Couldn't work it out, it was driving me nuts! Then I worked out it was sucking air*[5], *so I just cut it back on the gate valve*[6]*. Had to do that with a few of them when it was dry. So that's not ideal when you're struggling for water when you've got to shut it down or turn it back a bit.*"
>
> (Scheme management)

There have also been instances of bores 'over-sucking' groundwater, with sand entering the pump and collapsing the bore. This has happened to several ECGIS bores and requires them to be redeveloped

[5] Water in the bore had drawn down below the pump, meaning it was pumping air through, not water
[6] Reduced the pump rate

to be usable again. This costs money to have a company come and provide the service, but also in lost revenue for the members by having a supply of water unavailable.

Minimum Flows
When any member is pumping from a drain, the corresponding minimum flow at Poplar Road (Section 3.1.4) must be maintained. ECGIS management require each member give notice before they commence pumping to ensure sufficient augmentation has occurred to enable both minimum flow conditions and irrigation demand to be met. This does not always occur. This is a major frustration of management as it results in 'reactive responses' and temporary non-compliance with consent conditions. Members who have done the right thing can run out of water, and management must rush to provide additional augmentation to both meet irrigation demand and minimum flow requirements. For example, if Windermere Drain is flowing at 60 L/s and someone starts taking 40 L/s, at least 60 L/s needs to be augmented to meet minimum flow and irrigation demand as management generally try to maintain 20 L/s above the minimum flow. With two race managers, the burden is lesser on the individual, but it is still a time commitment for the managers away from their normal operations, and a failure by members to adhere to rules. If an ECGIS production bore fails, for example due to a power cut, and irrigation abstraction is still occurring, minimum flow concerns can arise. Management notes that so long as such non-compliance is adequately explained in submitting data, Environment Canterbury does not presently see reason for non-compliance enforcement action.

Scheme Operation below Minimum Flow Sites
Members below the Poplar Road minimum flow sites all have large storage ponds. This enables them to divert and capture flow for their own irrigation purposes. Diversions for filling ponds are operated 'as needed' to top up the ponds when the storage has been depleted by irrigation. The periods of these diversions do not necessarily reflect take for irrigation rotation, as per other scheme users. They can be periods of continuous diversion to replenish storage after a series of irrigation rotations have been completed. These members can struggle to get enough water, meaning extra work for ECGIS management to maintain equitable access to water:

> "…*sometimes when things get tight and* [member]*'s not getting his allocation, he's still sucking out of his pond, so his pond level's dropping. It got to the stage his pond level dropped too much, so we got everybody to turn off for a day to fill the pond up. And* [different member] *didn't reckon he should have the same privilege, and I said, 'well no, you weren't short of your allocation and* [member] *was'.*"
>
> (Scheme management)

Like ECGIS's own perpendicular diversion gates, private storage diversions are largely operated manually by the members. As they are located below the minimum flow sites, members could theoretically divert all drain flow to recharge their pond. This seldom occurs as members value the ecology of the drains and do not want to be responsible for fish kills. However, this does appear to have happened coincident with the field visit of 18 February 2018 as there was no water in Windermere Drain at Lower Beach Road (Figure 3-4) and reasonable flows at Poplar Road (Appendix 2).

3.1.6 Costs

Members are required to pay monthly fees based on the number of hectares they have within ECGIS. This monthly maintenance fee covers the cost of contractors (e.g. Boraman's who oversee the telemetry network), board member stipends, costs associated with resource consents, ECGIS upkeep (e.g. updating equipment, servicing), etc. ECGIS limits spending to only what is deemed necessary to keep costs as low as possible for members. Costs can fluctuate based on the servicing of loans. For example, loans were taken to meet the initial cost of installing new production bores. These are being paid down by ECGIS "*as quickly as possible*" (Scheme Member 2) to try "*limit the cost of the scheme"* (Scheme Member 8). Interviewee 4 described ECGIS's finances as "*money in, money out."* Scheme member 2 described ECGIS as financially "*efficient*"; it does not carry money in reserves and relies on everyone paying their bills on time, every time. Despite being financially efficient, operational costs do continue to rise. Scheme Member 7 highlights this in their interview. Scheme Member 4 identifies electricity as being a major factor, with off-season bills raising by 20-30% in recent years. Pumping costs used to be charged on a per hectare basis. Members came to see this as unfair, given the different water requirements of different farm types. Pumping costs per member are now determined on a kilowatt basis per litre pumped. All pumps and flow meters are telemetered. This enables accurate determination of water use:

"*Boraman's set up a programme that records how many litres everyone's using. When we get a bill,* [treasurer] *puts the total cost of the power in and it divvies up evenly on how much everybody's used.*"

(Scheme Member 5)

Figure 3-4 Windermere Drain at Lower Beach Road on 18 February 2018

3.1.7 Summary

ECGIS pumps groundwater from 20 production bores into Deals, Windermere, and Home Paddock drains to supply irrigation water to members. Scheme members are required to advise management of their intent to start irrigating prior to doing so to ensure there is enough water to meet irrigation demand and minimum flow conditions. Management has no predetermined order for production bore operation but do have bores they favour. Technically, more water can be abstracted from the drains by members than can be supplied by ECGIS production bores but each drain has a minimum flow rate which must be complied with whenever a member is irrigating. Below the minimum flow sites there is no requirement for ECGIS to maintain drain flow. However, scheme members value the ecological values provided by the drains, so maintenance of drain flow is actively practiced, including outside of irrigation.

Drain flow is further managed by inter-drain diversion gates. These allow water to be transferred between the drains to enable the most cost-efficient provision of water. Diversion gates are the only ECGIS infrastructure that is not telemetered. This means the transfer of water between drains cannot be quantified. All other ECGIS infrastructure is telemetered. All members have online access to view the status of each production bore, each surface water abstraction, and each low flow site. This is one way in which ECGIS management ensures enough flow in the drains and encourages social responsibility between members. Managing electronics can be quite time consuming for ECGIS management and is a point of frustration.

Cooperation, cohesion, and community values were identified as important aspects of ECGIS, with ECGIS working best when everyone gets along and does their part. This includes members paying their bills on time. Members are identifiable through a Memorandum of Encumbrance on land titles within ECGIS, requiring members to pay monthly maintenance fees for ECGIS upkeep and additional for water used based on pumping cost. Members' access to water is proportional to their land area within ECGIS. Maintenance fees partly cover stipends for ECGIS leadership. This ensures incentive for management to continue their role in keeping ECGIS operational, and; for the chairperson to continue in resolving internal frictions and to be an advocate on behalf of ECGIS; maintain its good standing with some parties, and; to manage relationships with other parties that may threaten ECGIS's continued existence.

3.2 Objective 2: Understand the Hydrological Setting of ECGIS and How Scheme Operation Impacts Measured Parameters

This section first presents hydrological investigation results, followed by water quality results. Surface water and groundwater data are presented separately and/or together dependent on variable being considered to enable greater data clarity and enhance description. Appendix 3 shows raw field data.

3.2.1 Hydrology: Surface Water

Figure 3-5 shows cross-sectional discharge at each gauging site across the monitoring period. In 2018 cross-sectional discharge progressively increased with proximity to the coast. This includes when ECGIS was not pumping. Boundary and Newtons consistently had the lowest discharge. Both sites are above most of the operation of ECGIS. Surveyors and Poplar had consistently similar discharges, with discharge at Surveyors being slightly higher than down-gradient Poplar. Across 2018 Lower Beach, below ECGIS's low flow site, generally had the greatest discharge. In 2019 discharge at this site decreased drastically to where it generally had the least discharge across all five gauging sites.

Using collected data, annual average discharge from Windermere Drain can be determined. Table 3-4 presents annual average discharge in Windermere Drain at each gauging site. This value is extrapolated from 1 March 2018 to 28 February 2019 gauging data. For the same period, annual average discharge is also presented based on instantaneous data from the ECGIS recorder at Poplar Road and Environment Canterbury Recorder at Lower Beach Road. Gauging data indicates discharge increases significantly between the top ECGIS to Surveyors, is then relatively stable to Poplar, and decreases to Lower Beach. Hydrometric agrees with a decrease in discharge between Poplar and Lower Beach but suggests a greater magnitude of decrease. When comparing extrapolated gauging data to hydrometric data, discharge at Poplar is 10% greater using hydrometric data, and 2% greater at Lower Beach.

Table 3-4 Annual Average Discharge (1 March 2018 to 28 February 2019) of Windermere Drain at Gauging Sites. 'Gauged Data' is Average Annual Discharge Extrapolated from Gaugings. 'Hydrometric Data' is Annual Average Discharge Extrapolated from Boraman's and Environment Canterbury Logger Data. Discharge is Million Cubic Metres per Year

		Newtons	Boundary	Surveyors	Poplar	Lower Beach
Gauged Data	M m^3/year	2.413	5.730	10.307	10.435	9.668
	Flow Change from Upstream Site			*27%*	*1%*	*-7%*
Hydrometric Data	M m^3/year				11.493	9.881
	Flow Change from Upstream Site					*-14%*

3.2.2 Hydrology: Groundwater

Figure 3-6 to Figure 3-10 show groundwater elevation data for piezos at each array plotted with rainfall, ordered inland to the coast. Data are presented in six-hour averages for groundwater elevation and six-hour totals for rainfall to increase the readability of the plots without losing significant variation compared to the raw 15-minute data.

Figure 3-6 and Figure 3-7 show groundwater elevation and rainfall for Newtons and Boundary piezos. High rainfall generally translated to elevated groundwater levels for all piezos. Rainfall had greater impact on the Boundary piezo hydrographs than the Newtons. Piezo data from the Boundary array were also much more alike than the Newtons. Newtons Bank Piezo had values generally half a metre greater than Newtons Bed Piezo. For both arrays, values were relatively stable across February to October 2018. In mid-October there was a decline, though less pronounced in Newtons Bed Piezo. The relatively wet early summer period saw levels recover, with subsequent decline through to end of summer, where rainfall saw temporary increase of groundwater elevations in the Newtons piezos and a levelling off of elevation in Boundary piezos.

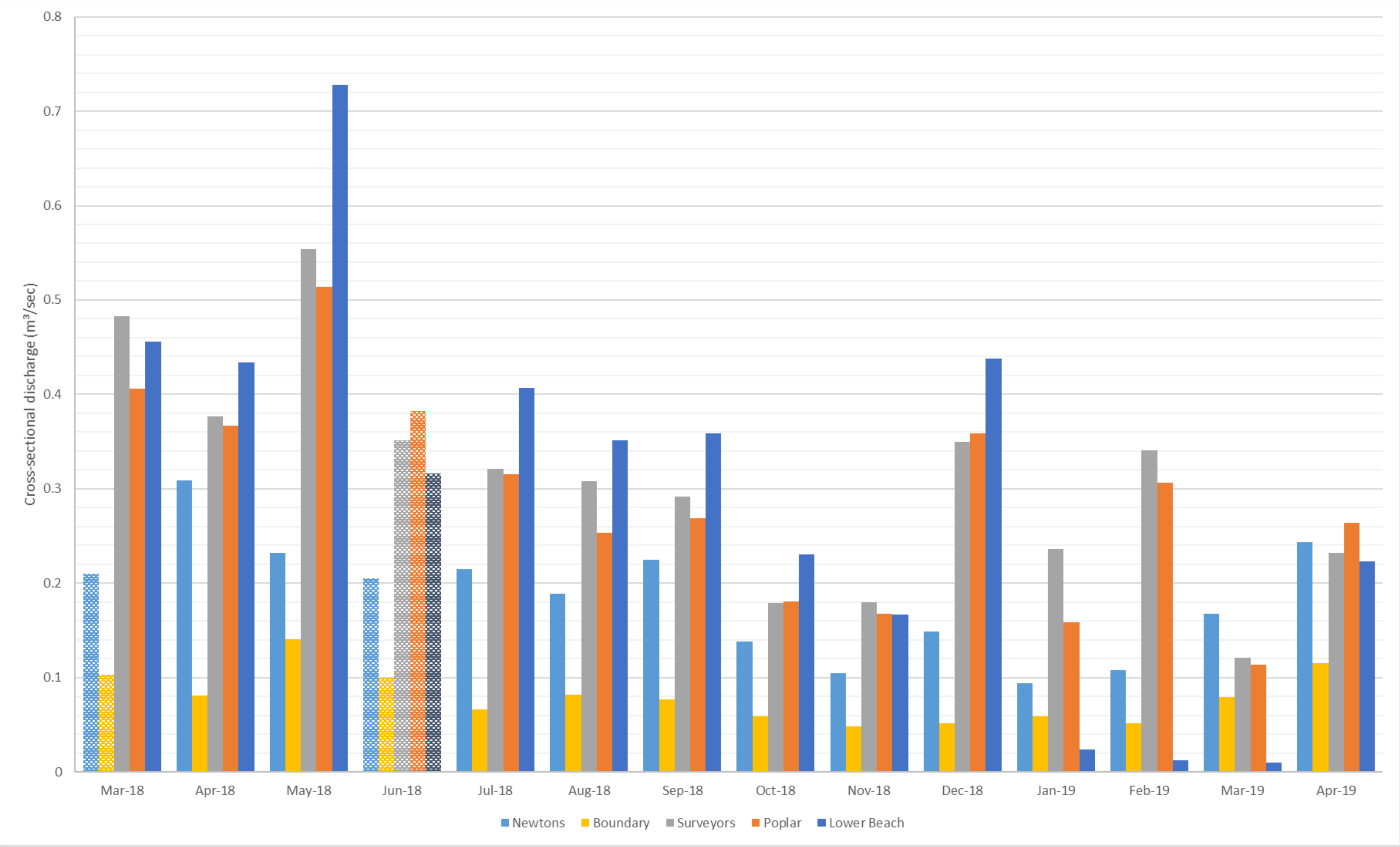

Figure 3-5 Cross-Sectional Discharge by Gauging Site Across Monitoring Period. Legend Order Reflects Site Distribution Inland to the Coast. Patterned Bars are Synthetic Data Created via Correlation

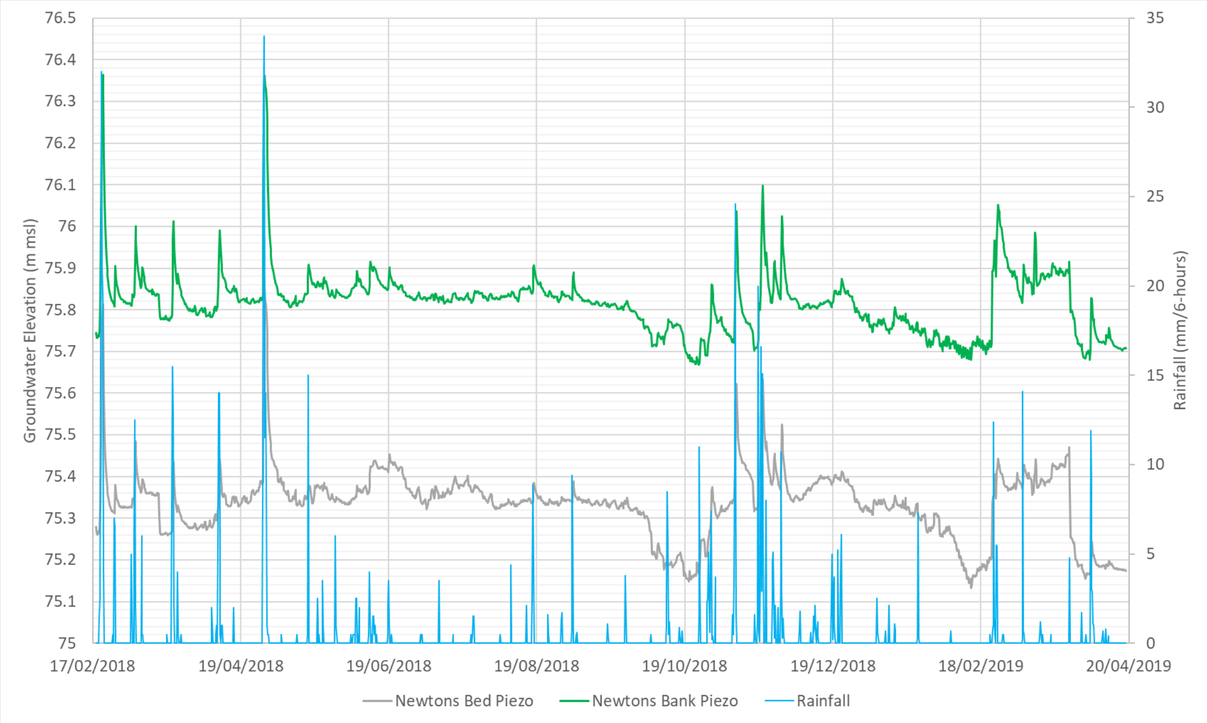

Figure 3-6 **Newtons Piezo Groundwater Elevation (in Metres Relative to Mean Sea Level (m msl)) and Rainfall Rate. Groundwater Elevation Values are Six Hour Averages While Rainfall is Cumulative Six Hour Value**

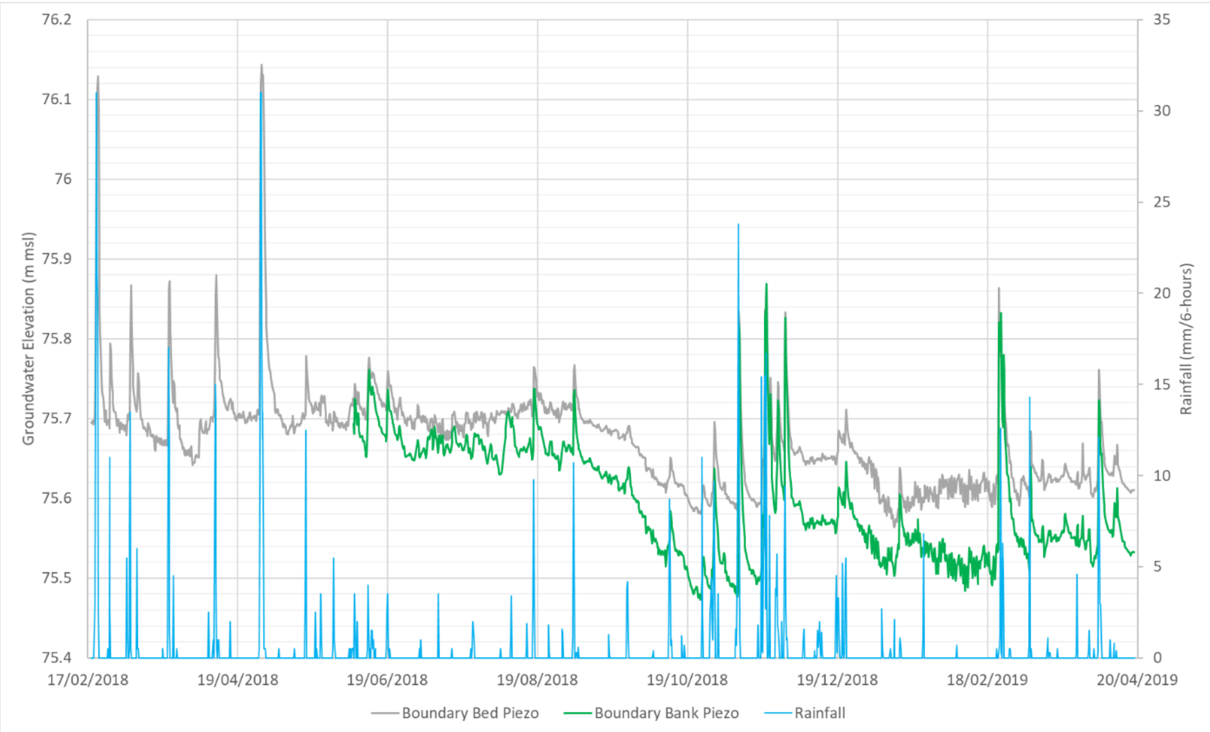

Figure 3-7 **Boundary Piezo Groundwater Elevation (in Metres Relative to Mean Sea Level (m msl)) and Rainfall Rate. Groundwater Elevation Values are Six Hour Averages While Rainfall is Cumulative Six Hour Value**

Figure 3-8 shows groundwater elevation data for the Surveyors piezos and rainfall rate. Here there was no evident influence from rainfall outside of significant events. Piezo values were very similar across summer and autumn months, with Poplar Bed Piezo occasionally having greater elevation groundwater than Poplar Bank Piezo. Across winter and spring, the piezo hydrographs were distinct from each other but similarly trending with high variation but an overall gradual decline between May and October. As with the Newtons and Boundary piezos, there was a significant drop in levels in late October, with subsequent recovery to pre-decline levels. In 2019 groundwater elevation again drastically decreased to a minimum towards the end of February. Subsequent recovery saw groundwater elevations return to levels seen in the October drop, but not to what could be considered 'steady' in terms of this piezo hydrograph.

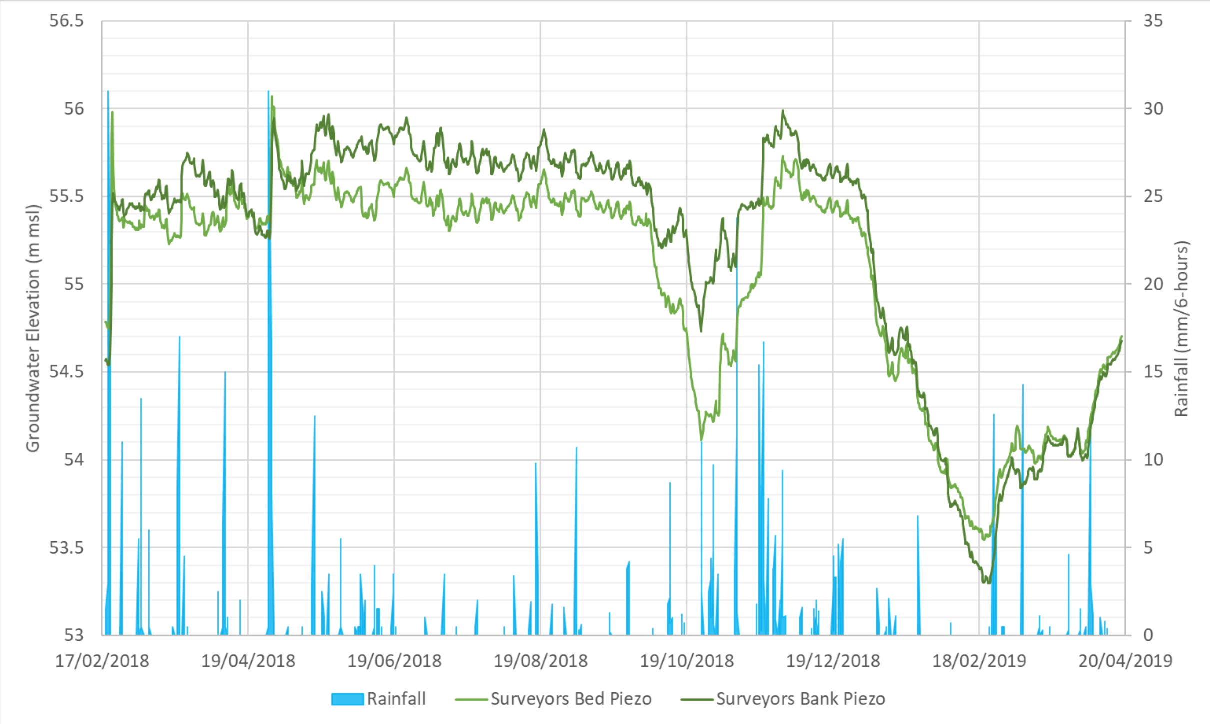

Figure 3-8 Surveyors Piezo Groundwater Elevation (in Metres Relative to Mean Sea Level (m msl)) and Rainfall Rate. Groundwater Elevation Values are Six Hour Averages While Rainfall is Cumulative Six Hour Value

Figure 3-9 shows groundwater hydrographs for the Poplar piezos and rainfall data. Hydrographs showed some response to rainfall. Poplar piezos had a consistent relationship across February to October 2018, with groundwater consistently higher at Poplar Bank Piezo. In October 2018 the relationship changed drastically. Groundwater elevation in Poplar Bank Piezo took on a similar hydrograph profile to that seen in the Surveyors piezos with substantial variation in groundwater elevation and an overall decrease in the October 2019 to April 2019 period. Conversely, the groundwater hydrograph of Poplar Bed Piezo from October on better resembled the piezo hydrographs of the Newtons, Boundary, and Lower Beach piezos. There was no October fall in groundwater elevation, as at the Newtons and Boundary piezos, but there was ongoing correlation to rainfall, with an overall gain in groundwater elevation in early summer, followed by a steady decline in elevation, which stabilised in autumn.

Figure 3-10 shows groundwater hydrographs for the Lower Beach piezos and rainfall data. Groundwater hydrographs show response to rainfall similar to that seen at the Poplar piezos. Lower Beach Bed Piezo had consistently higher groundwater elevation than Lower Beach Bank Piezo. The large rain event across late April saw the only evidence of convergence in the groundwater hydrographs. Groundwater elevation had an overall decline across 2018. The October drop in groundwater elevation evident at the other piezos was not present here. There was some recovery in groundwater elevation across late-spring, early-summer, followed by much more rapid decline in late summer, stabilising in autumn.

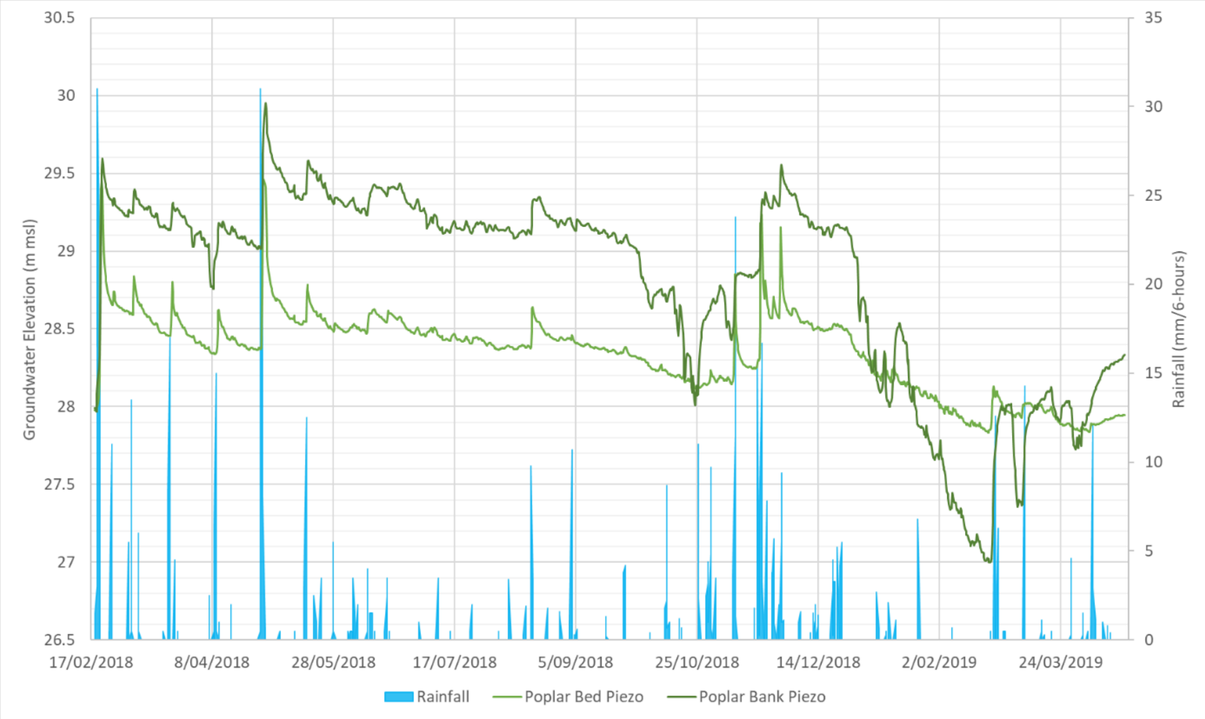

Figure 3-9 Poplar Piezo Groundwater Elevation (in Metres Relative to Mean Sea Level (m msl)) and Rainfall Rate. Groundwater Elevation Values are Six Hour Averages While Rainfall is Cumulative Six Hour Value

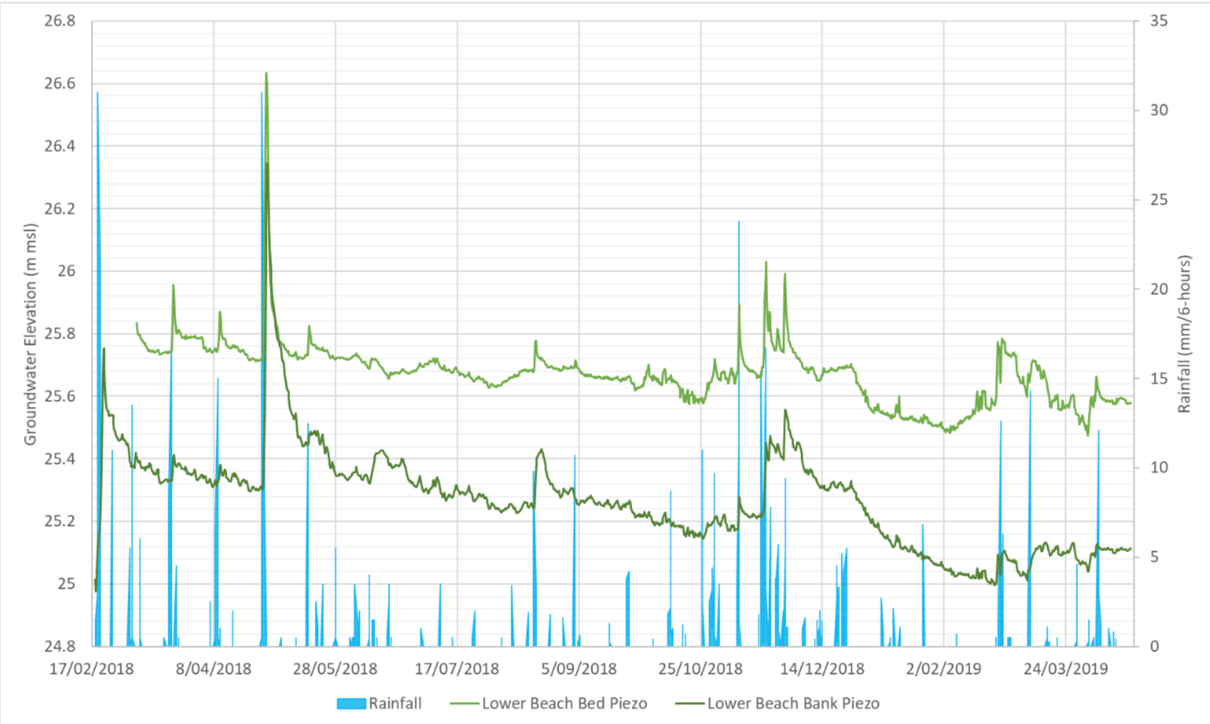

Figure 3-10 Lower Beach Piezo Groundwater Elevation (in Metres Relative to Mean Sea Level (m msl)) and Rainfall Rate. Groundwater Elevation Values are Six Hour Averages While Rainfall is Cumulative Six Hour Value

3.2.3 Hydrology: Comparison of Surface Water and Groundwater Data

Also considered was the elevation of water in Windermere Drain relative to spot measurements of groundwater elevation. Figure 3-11 through Figure 3-15 show the hydrographs for each array ordered inland to the coast. Water elevation decreased with proximity to the coast. Drain sites had the least variation in elevation at all arrays, with the largest variation in drain stage (Poplar Drain) being less than the smallest variation in groundwater elevation (Boundary Bank Piezo). Data from the similarly located (compared to the spread of the remaining sites) Newtons and Boundary arrays were alike, with data from the Boundary array measuring between the Newtons array. These arrays had the least variation in their measured elevation. The Surveyors array had the greatest variance in its groundwater data, while the Poplar array has the greatest overall variance in measured water elevation. All sites had higher average water elevation outside of the irrigation season than within, except Poplar Bank Piezo. The least variation in groundwater elevation when comparing in and out of irrigation season groundwater elevation data was in the Newtons array, and Boundary and Lower Beach bed piezos, all of which had <0.1 m difference in values.

At Newtons array (Figure 3-11) elevation of water in the Bank Piezo was greater than elevation of water in the Drain, which was greater again than the elevation of water in the Bed Piezo. There were similarities between all three hydrographs at this array. At Boundary array (Figure 3-11) the Bed Piezo had the greatest elevation, followed by Bank Piezo, then Drain elevation. Hydrographs for Boundary piezos were generally similar. Some resemblance was also seen in the Drain hydrograph, but this was less evident. At Surveyors array (Figure 3-13) the elevation of water in the Drain was generally lower than that seen in the piezos. The inverse occurred when there were sharp falls in measured groundwater elevation. Drain water elevation was relatively stable, while piezos had similar profiles, with less variance in the Bank Piezo hydrograph. At Poplar array (Figure 3-14) Drain elevation was greatest, with a similarly stable profile to Surveyors Drain. Poplar piezos had similar hydrograph profiles, with greater variability in the Bank Piezo hydrograph. Elevation of water was generally greater in the Bank Piezo than the Bed Piezo. At Lower Beach array (Figure 3-15) Drain water elevation was again greater than what was seen in piezos, however here the Bed Piezo tended to have greater elevation than the Bank Piezo. All sites had similar profiles, but Lower Beach Bank Piezo had the most exaggerated profile.

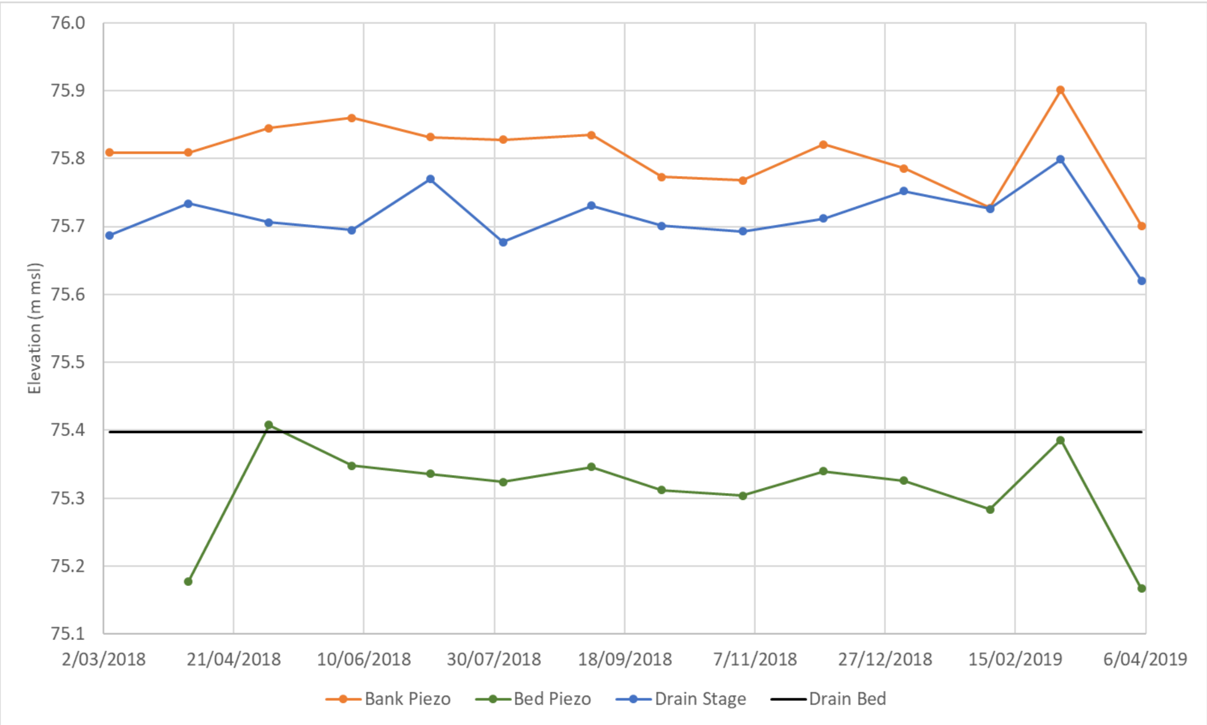

Figure 3-11 Newtons Array Water Elevation Hydrograph

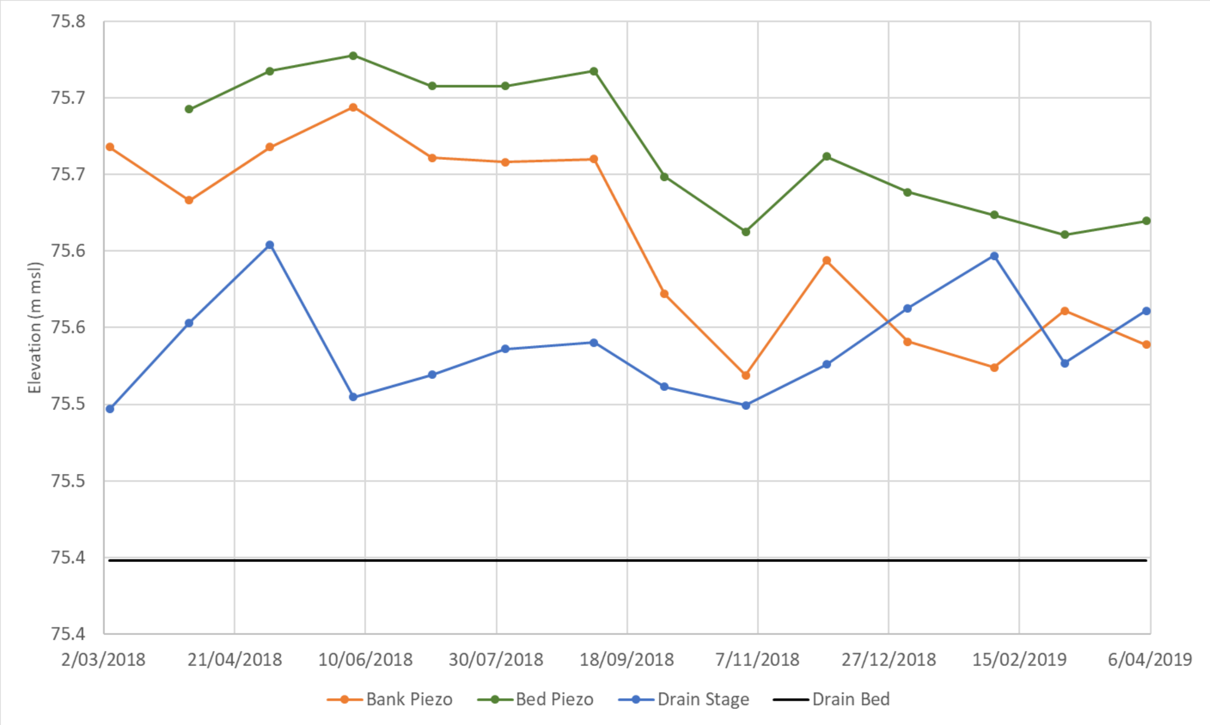

Figure 3-12 Boundary Array Water Elevation Hydrograph

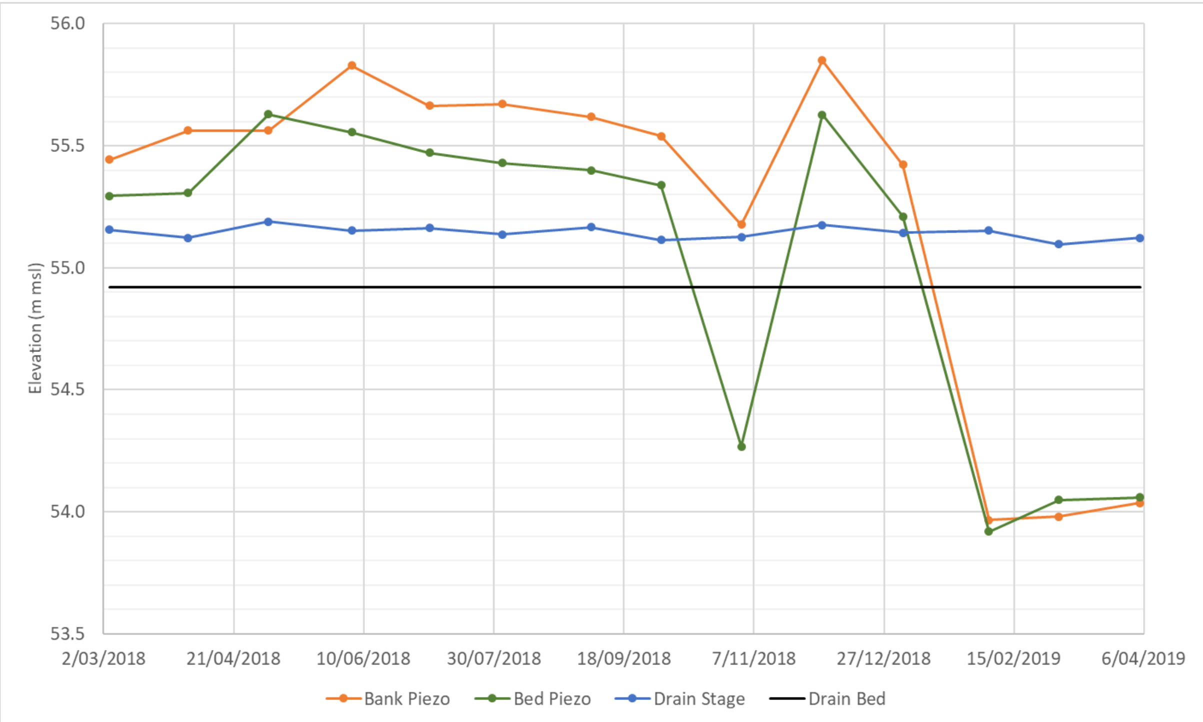

Figure 3-13 Surveyors Array Water Elevation Hydrograph

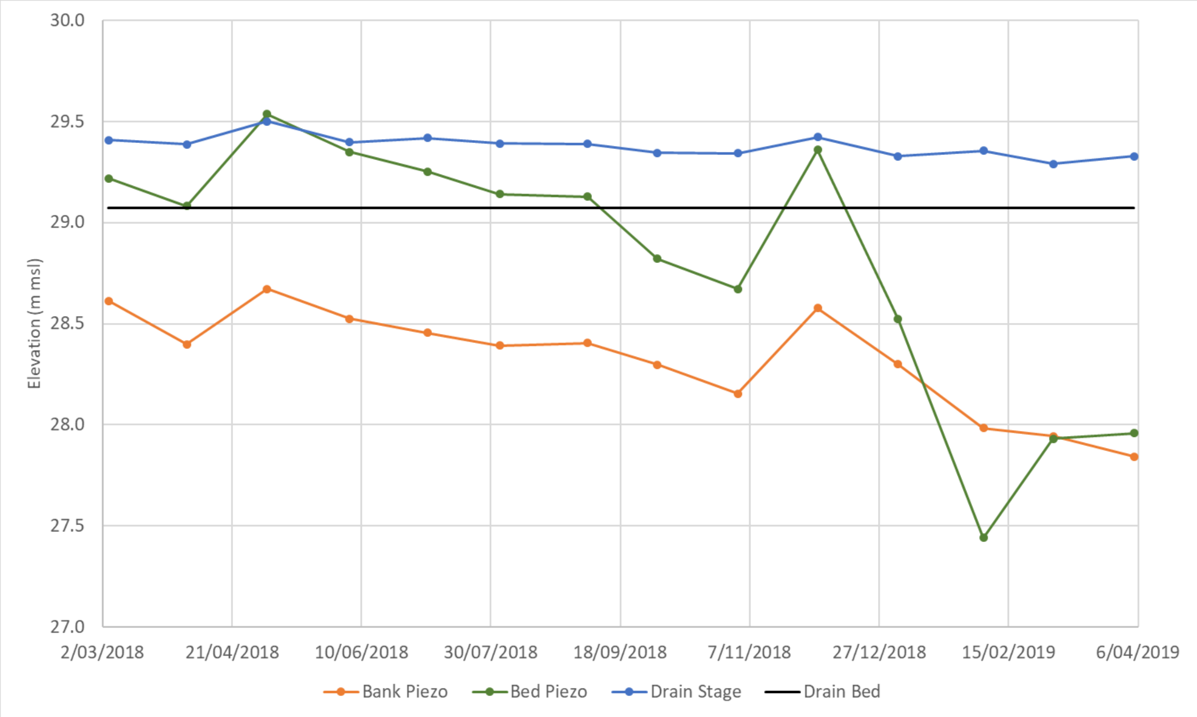

Figure 3-14 Poplar Array Water Elevation Hydrograph

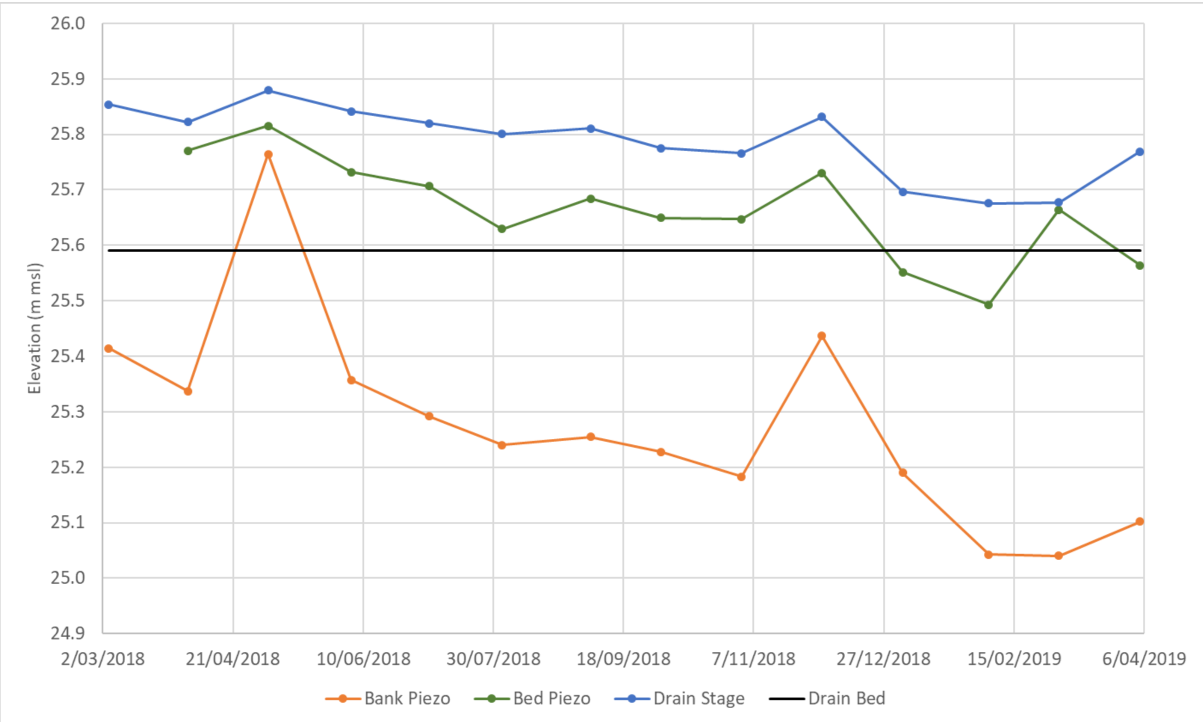

Figure 3-15 Lower Beach Array Water Elevation Hydrograph

3.2.4 Water Quality: Nitrogen Species

57.5% of samples had no detectable concentration of total ammoniacal-N (TAN; <0.01 mg/L). The remaining samples ranged between 0.1 mg/L and 0.28 mg/L TAN; very low concentrations. Newtons Bed Piezo and Surveyors piezos were the only sites that had detectable TAN in every sample. 42.9% of samples had no detectable concentration of nitrite-N (<0.002 mg/L). Eight of the 19 sites had detectable concentrations in every sample. This included every drain sample. Detectable concentrations ranged 0.002-0.183 mg/L Nitrite-N; very low concentrations.

Nitrate-N, dissolved inorganic nitrogen (DIN), and nitrate-N + nitrite-N all occurred at much higher concentration than TAN and nitrite-N. Boundary and Newtons arrays had the highest concentrations of the three species. In the remaining arrays higher concentrations were generally seen in the drain samples than the groundwater samples. Differences in concentrations in these nitrogen species between Drain and piezos in the Poplar array was up to 5 mg/L, while at the Lower Beach array it was up to 3 mg/L. At the Surveyors array, this difference was much higher; up to 13 mg/L due to the number of samples below detection limit. Surveyors Bed Piezo had four nitrate-N and one nitrate-N + nitrite-N sample below detection limit, while Surveyors Bank Piezo had two nitrate-N samples below detection limit. Scheme bores had consistently low concentrations of these nitrogen species, ranging 2-5 mg/L. The least variability in nitrate-N and DIN was seen in Newtons and Surveyors drains and Poplar Bed Piezo. Similar stability was seen in nitrate-N + nitrite-N in Scheme Top 1, Middle, and Bottom. All arrays had at least one site with a nitrogen specie with 3-9 mg/L variability. No Scheme bores had this much variation.

Nitrate-N

Figure 3-16 through Figure 3-21 show distribution of nitrate-N data for each array. Presented order reflects array distribution inland to the coast. Each graph compares pre-irrigation data (March-September 2018) to irrigation season data (October 2018-April 2019). Highest nitrate-N concentration occurred in the Newtons and Boundary arrays and drain sites. Lowest concentrations occurred in Surveyors piezos and Scheme bores.

Across both data periods nitrate-N concentrations at Newtons array decreased from Bank Piezo to Bed Piezo to Drain (Figure 3-16). Most data from each site had <1 mg/L difference. Nitrate-N values from this array are very high. Medians and ranges drop for the piezos between data periods. Newtons Drain increases in median and range between periods. Nitrate-N values were also high at the Boundary array (Figure 3-17). During irrigation season medians decreased for the Bed Piezo and Drain but were consistent for the Bank Piezo where range instead decreased. This array had much greater overlap in values between sites and between data periods than Newtons. Most nitrate-N values from Scheme bores were 3-5 mg/L (Figure 3-18). Scheme Top 1 had <0.5 mg/L variation pre-irrigation season, which decreased during irrigation season. Scheme Bottom was similarly trending, with no significant change in values. Nitrate-N concentrations in Scheme Top 2 increased during irrigation season as did data variability. Scheme Middle also saw an increase in variability during irrigation season, but concentrations decreased.

Surveyors piezos had noticeably lower nitrate-N concentrations than all other sites (Figure 3-19). Most samples from these sites had <1 mg/L nitrate-N. Data range increased at both piezos during irrigation season compared to before. Variation also increased in Surveyors Drain, alongside a decrease in nitrate-N concentration. Nitrate-N concentrations at the Poplar array were elevated, but only the pre-irrigation Drain samples were in the same range as values seen at Newtons and Boundary arrays (Figure 3-20). All sites increased in range but decreased in concentration during the irrigation season. Concentrations from Poplar Drain were generally >8 mg/L whereas piezo nitrate-N concentrations were generally <8 mg/L, with less variation in the Bank Piezo than the Bed Piezo. At the Lower Beach array concentrations at all sites and ranges at the piezos decreased during irrigation season (Figure 3-21). Medians decreased by approximately 3.5 mg/L between data periods. Pre-irrigation nitrate-N concentrations in the piezos were higher than that seen at Poplar, but Drain concentrations were consistent.

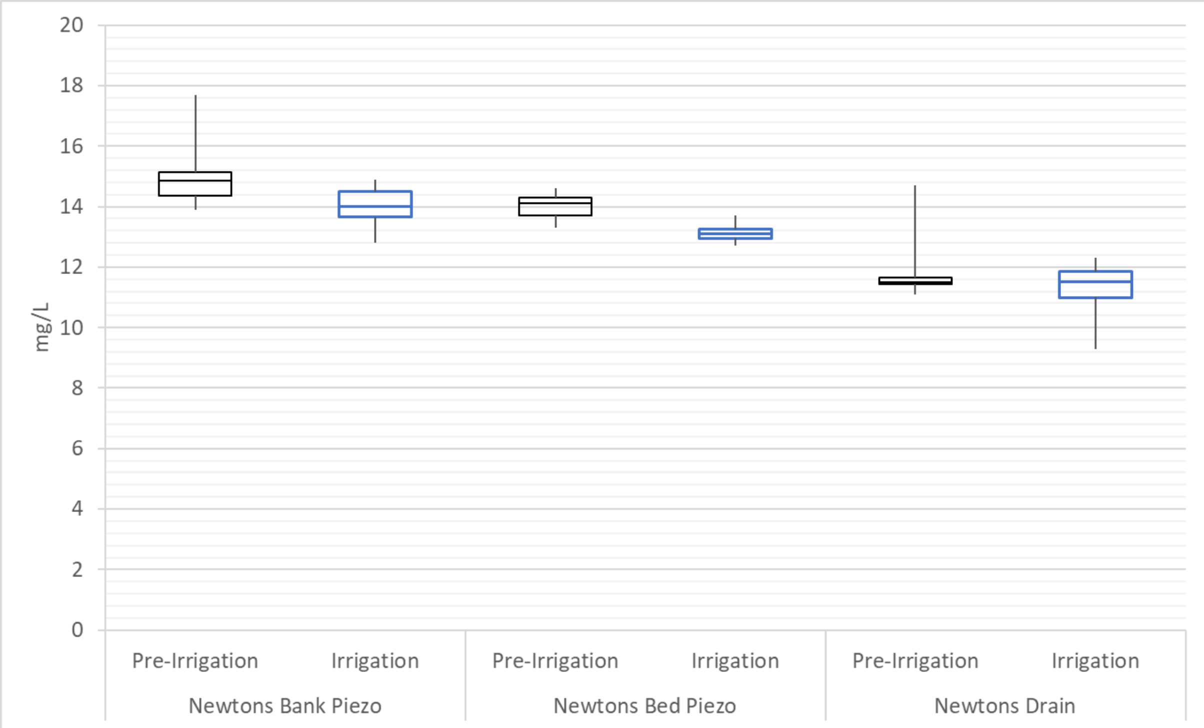

Figure 3-16 Newtons Array Nitrate-N Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018- April 2019)

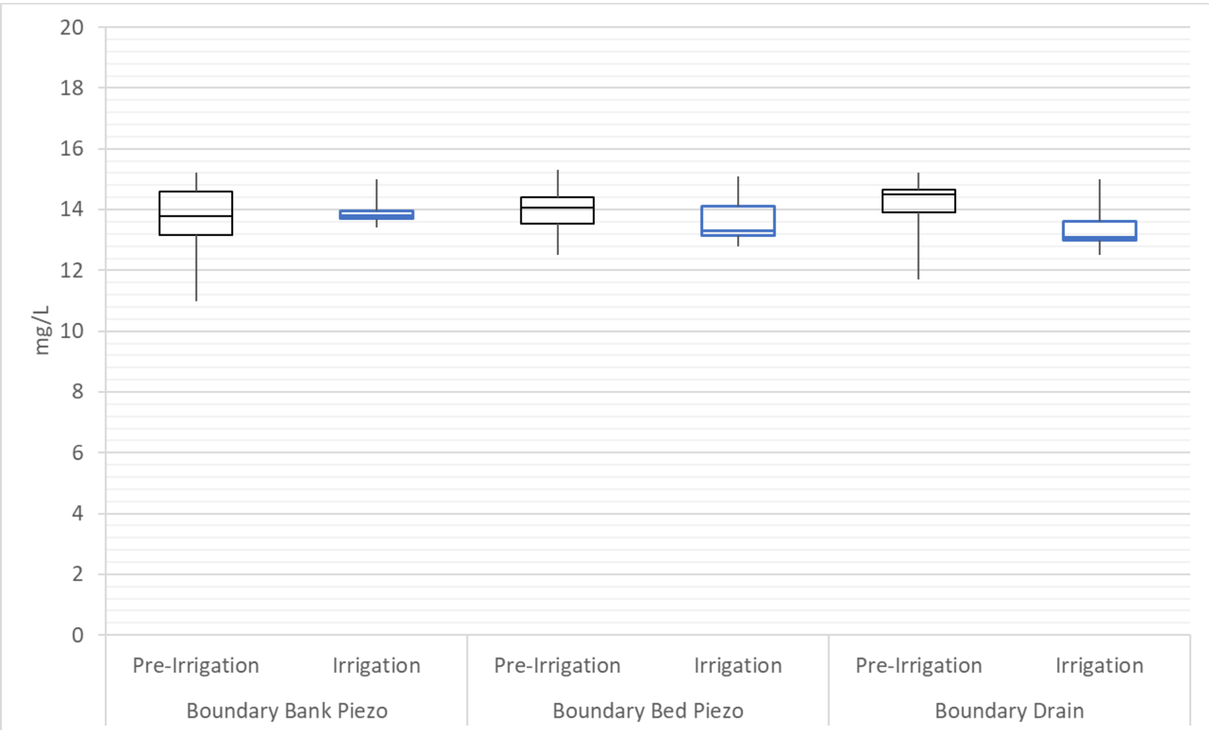

Figure 3-17 Boundary Array Nitrate-N Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

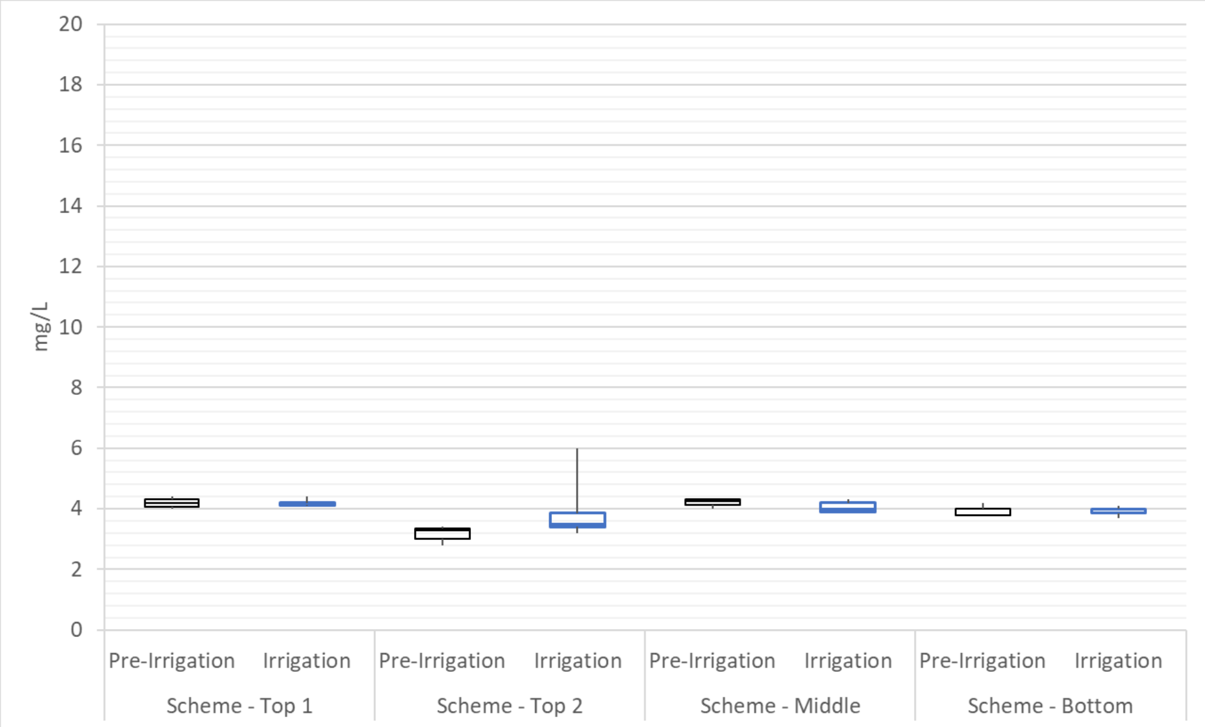

Figure 3-18 Scheme Bore Nitrate-N Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

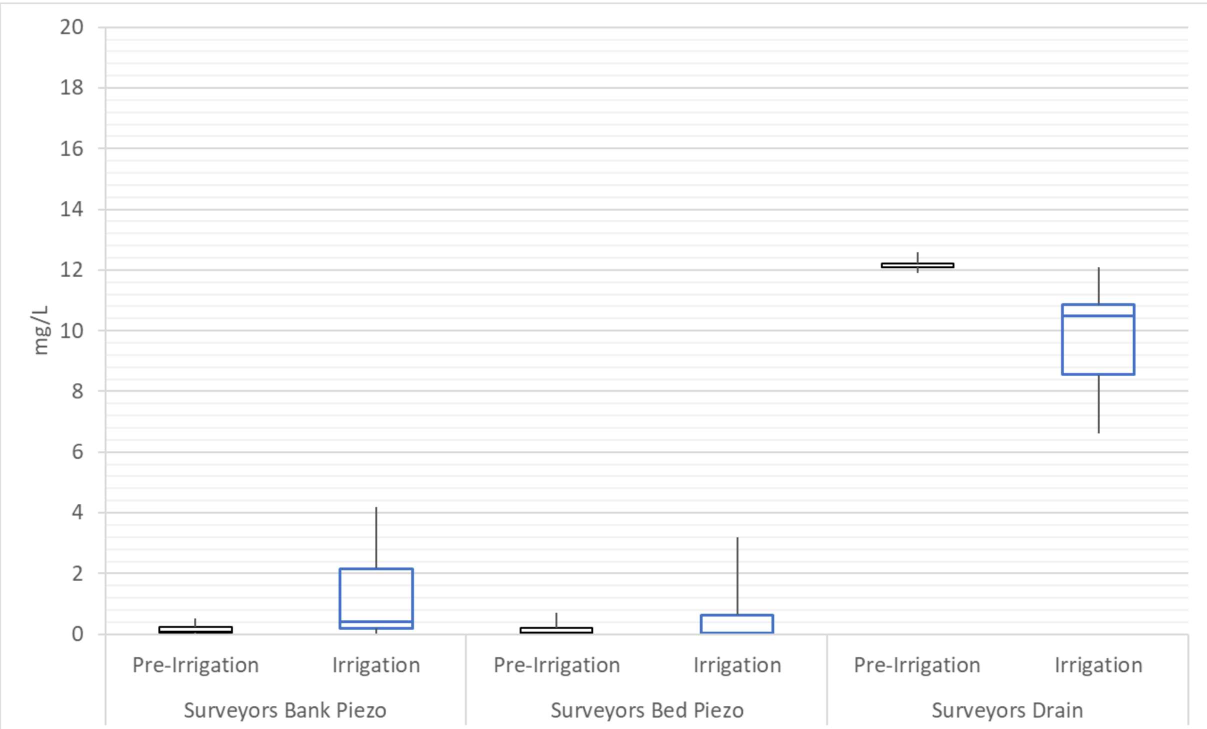

Figure 3-19 Surveyors Array Nitrate-N Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

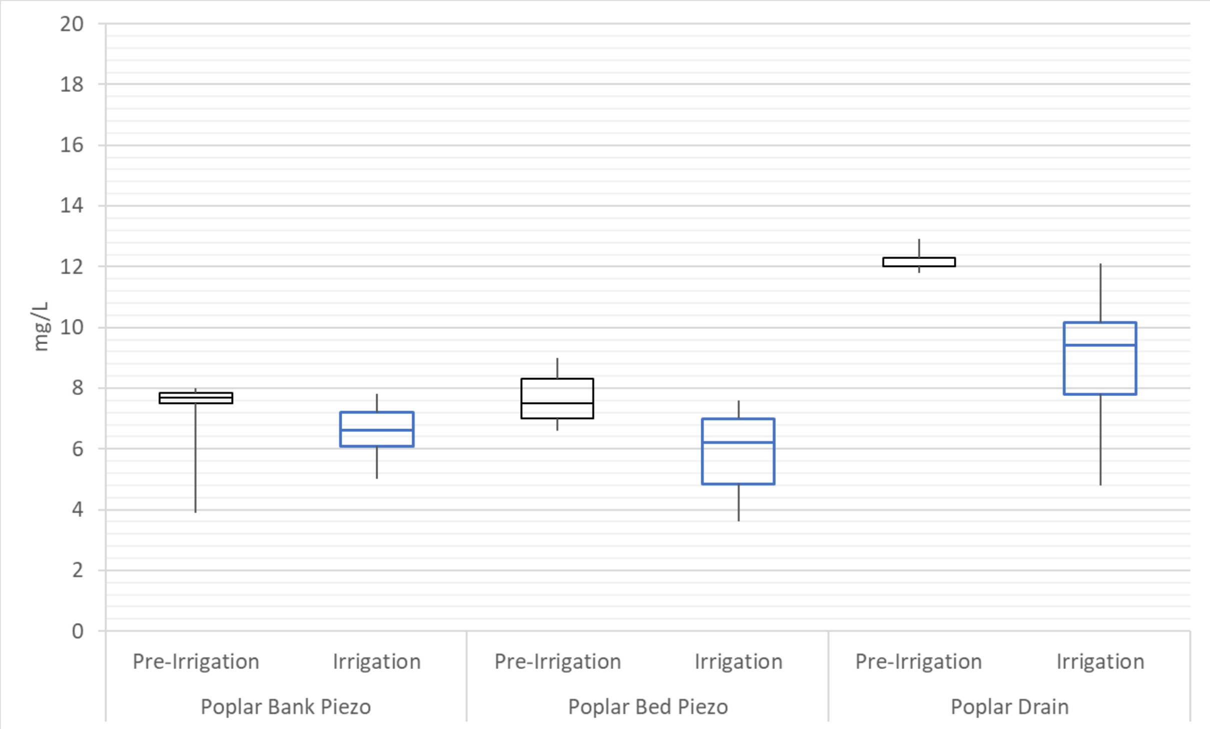

Figure 3-20 Poplar Array Nitrate-N Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

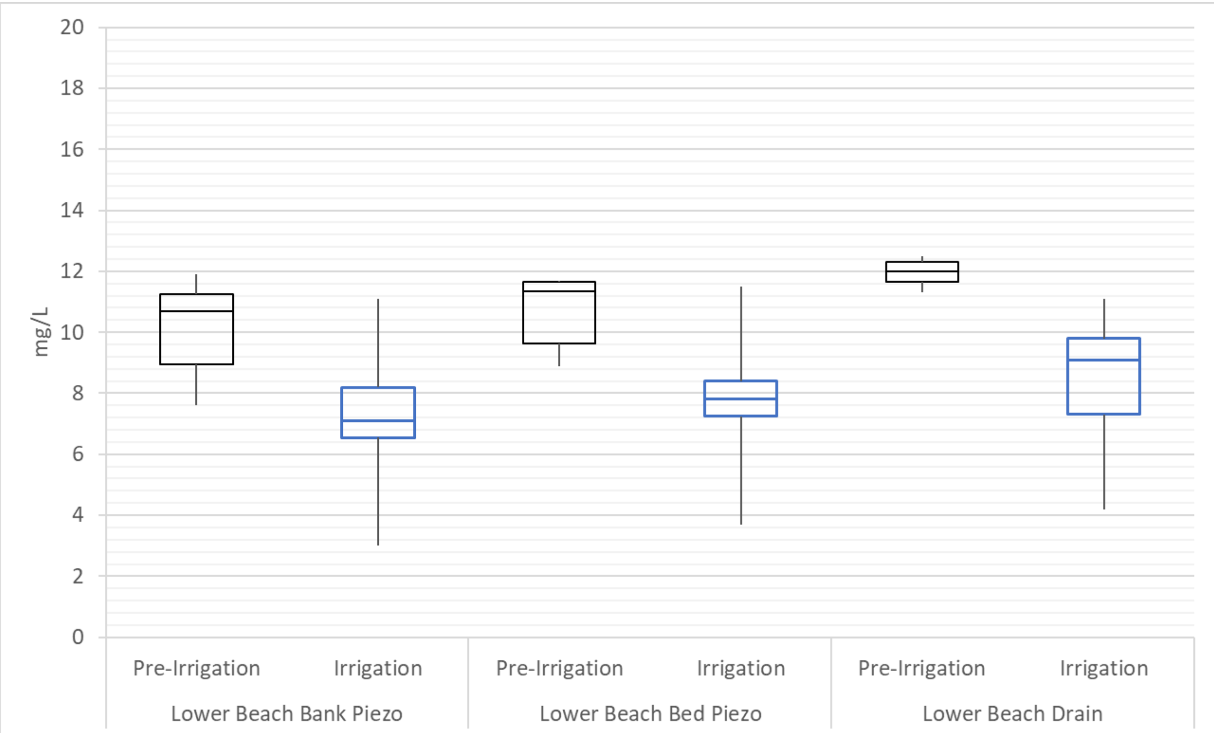

Figure 3-21 Lower Beach Array Nitrate-N Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

3.2.5 Water Quality: Phosphorus Species

79.7% of samples had no detectable concentration of dissolved organic phosphorus (DOP; <0.005 mg/L). Boundary and Newtons piezos, and Scheme Top 2 and Middle had no detectable concentrations of DOP in any samples. Every site had at least three DOP samples below detection limit. 16% of total dissolved phosphorus (TDP) samples, and 7% of both dissolved reactive phosphorus (DRP) and total phosphorus (TP) were below detection limit (0.004 mg/L and 0.001 mg/L respectively). Generally, DRP and TP had the same concentrations, while TDP occurred at the highest concentrations across all sites. Scheme Top 2, Scheme Middle, Newtons Bank Piezo, and Boundary Bed Piezo had the least variability in their phosphorus species concentrations. Poplar Bed Piezo had the greatest data variability across all parameters, followed by Surveyors Drain and Poplar Bed Piezo. As with nitrogen species, phosphorus species at the Lower Beach array were among the most variable, but not as variable as the Poplar array.

Dissolved Reactive Phosphorus

Figure 3-22 through Figure 3-27 show distribution of DRP data for each array. Presented order reflects array distribution inland to the coast. Each graph compares pre-irrigation data (March-September 2018) to irrigation season data (October 2018-April 2019). Lowest DRP concentrations were in Newtons and Boundary piezos, Scheme bores, and Surveyors Bank Piezo. Highest concentrations were in the Poplar and Lower Beach arrays, Surveyors Bed Piezo, and all drain sites. At Surveyors, Poplar, and Lower Beach arrays DRP concentrations were higher in bed piezos than in the bank piezos. This is opposite to what was seen at Newtons and Boundary arrays.

Most samples from Newtons Drain were <0.01 mg/L, while Newtons piezo samples were predominantly <0.005 mg/L (Figure 3-22). During irrigation concentrations increased in Newtons piezos but decreased in Newtons Drain alongside range. Newtons Bed Piezo had little variation in data before irrigation, quadrupling during irrigation season. Range was relatively consistent between periods for Newtons Bank Piezo. Figure 3-23 shows DRP data distribution for the Boundary array. Before irrigation, all sites had relatively similar data distributions, with medians decreasing from the Bank Piezo, to the Bed Piezo, to the Drain. During irrigation, piezos decreased in range while Drain increased. Boundary Drain also had a higher median during irrigation season alongside Boundary Bank Piezo, while Boundary Bed Piezo had a lower median. All Scheme bores had higher DRP concentrations during irrigation season (Figure 3-24). Despite this there was little change in the median for Scheme Middle. Scheme Bottom maintained a similar profile between seasons, while the similarities between Scheme Top 1 and Top 2 pre-irrigation were lost during irrigation season. Top 1, Top 2, and Middle appear to have a stepwise increase in concentrations between them that is maintained across seasons.

Pre-irrigation Surveyors piezos had similar interquartile ranges, with greater range seen in the Bed Piezo extremes (Figure 3-25). Surveyors Drain DRP concentrations pre-irrigation were almost double that in the piezos. During irrigation, the relation between the sites changed with staggering of values; lowest for Surveyors Bank Piezo and highest for Surveyors Drain. During irrigation, values for Surveyors Bed Piezo coincided with the lower quartile range of Surveyors Drain. Poplar Bank Piezo had similar concentrations pre and during irrigation, with a general increase in values during irrigation season (Figure 3-26). Pre-irrigation, Poplar Bed Piezo and Drain had narrow interquartile ranges, with Bed Piezo having treble the concentrations seen in Poplar Drain. Under irrigation the interquartile range of DRP increased for Bed Piezo and Drain. For Bed Piezo this sees a lowering of the lower quartile and raising of median and upper quartile, and for Poplar Drain an increase in both median and upper quartile. At the Lower Beach array, the Bank Piezo had a very low range pre-irrigation which significantly increased during irrigation season, in both range and value (Figure 3-27). Lower Beach Bed Piezo also had a significant increase in DRP values during irrigation. Lower Beach Drain had the lowest DRP concentrations of the array. These change little from pre- to during irrigation.

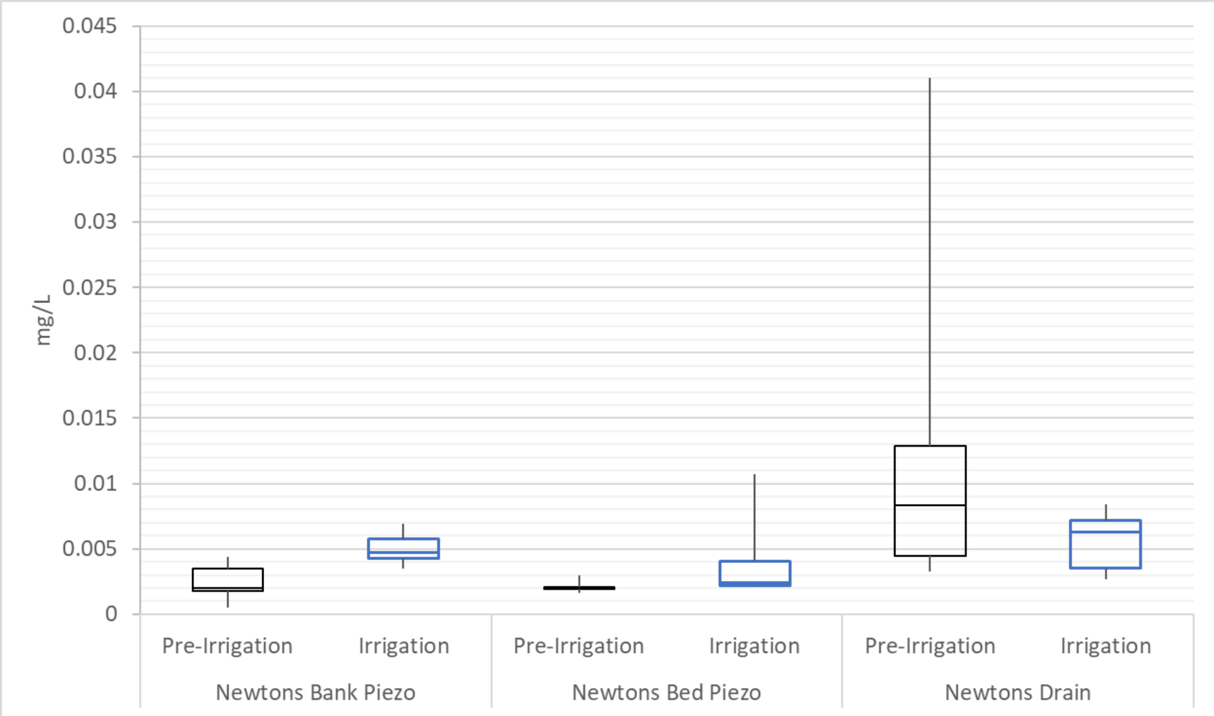

Figure 3-22 Newtons Array Dissolved Reactive Phosphorus Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

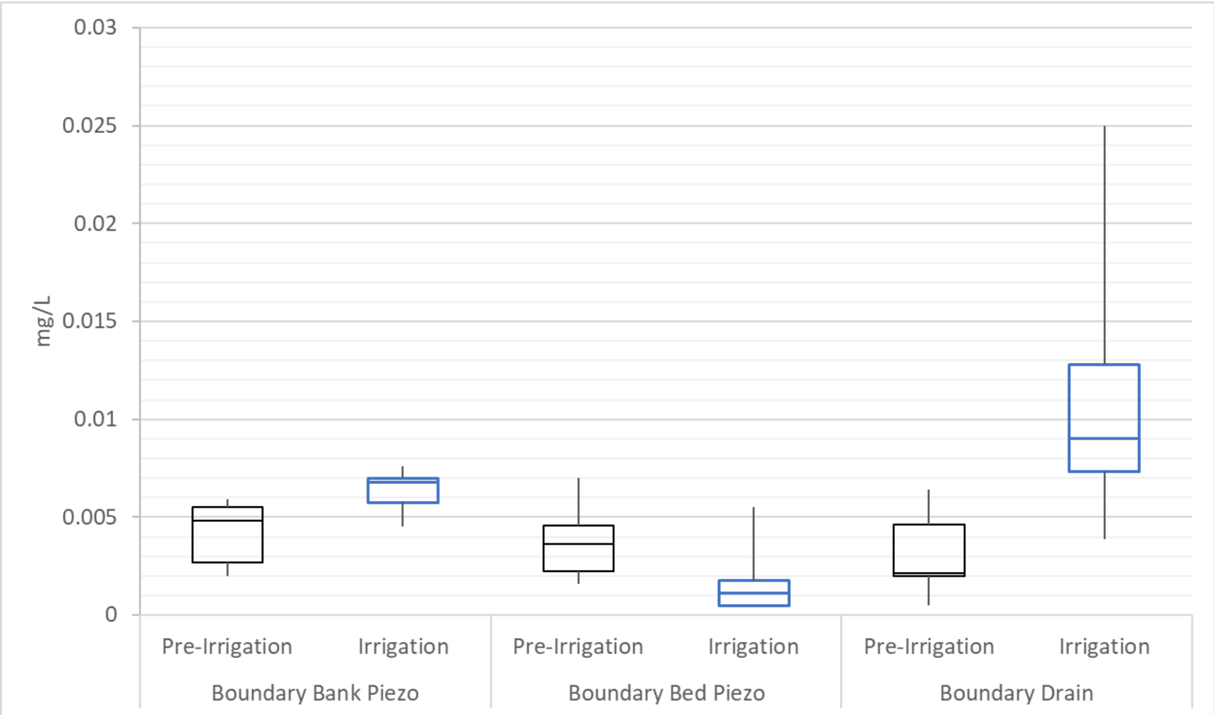

Figure 3-23 Boundary Array Dissolved Reactive Phosphorus Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

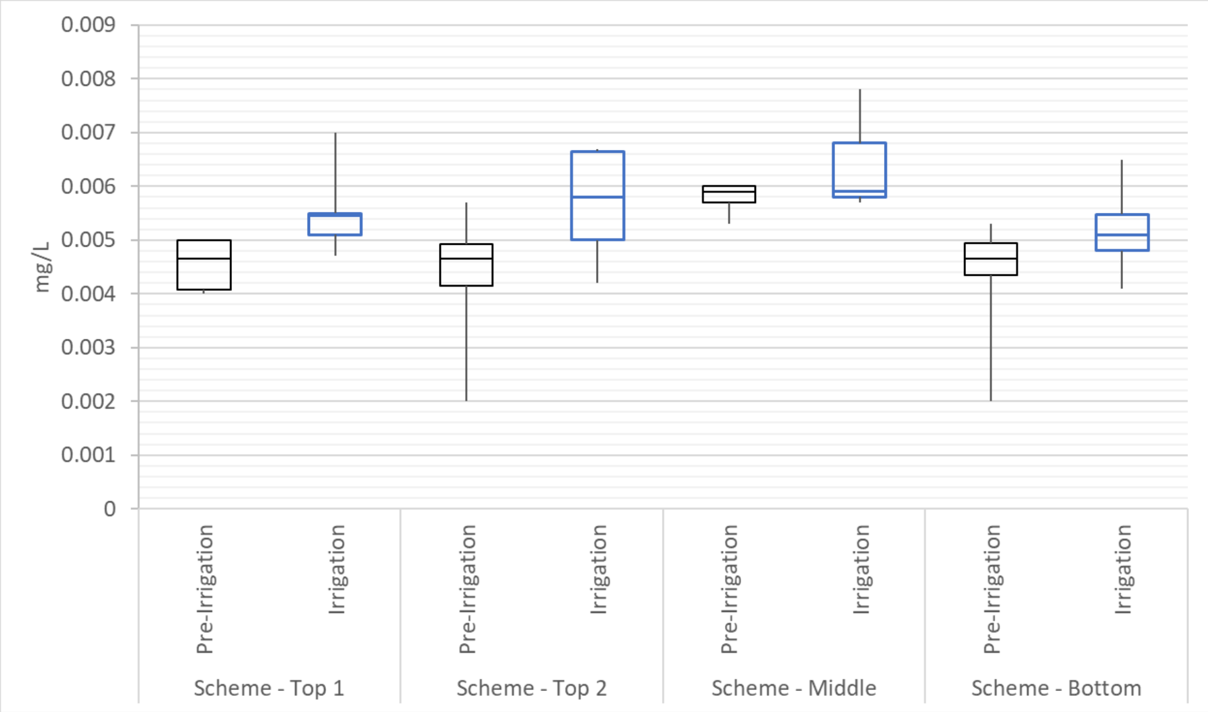

Figure 3-24 Scheme Bore Dissolved Reactive Phosphorus Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

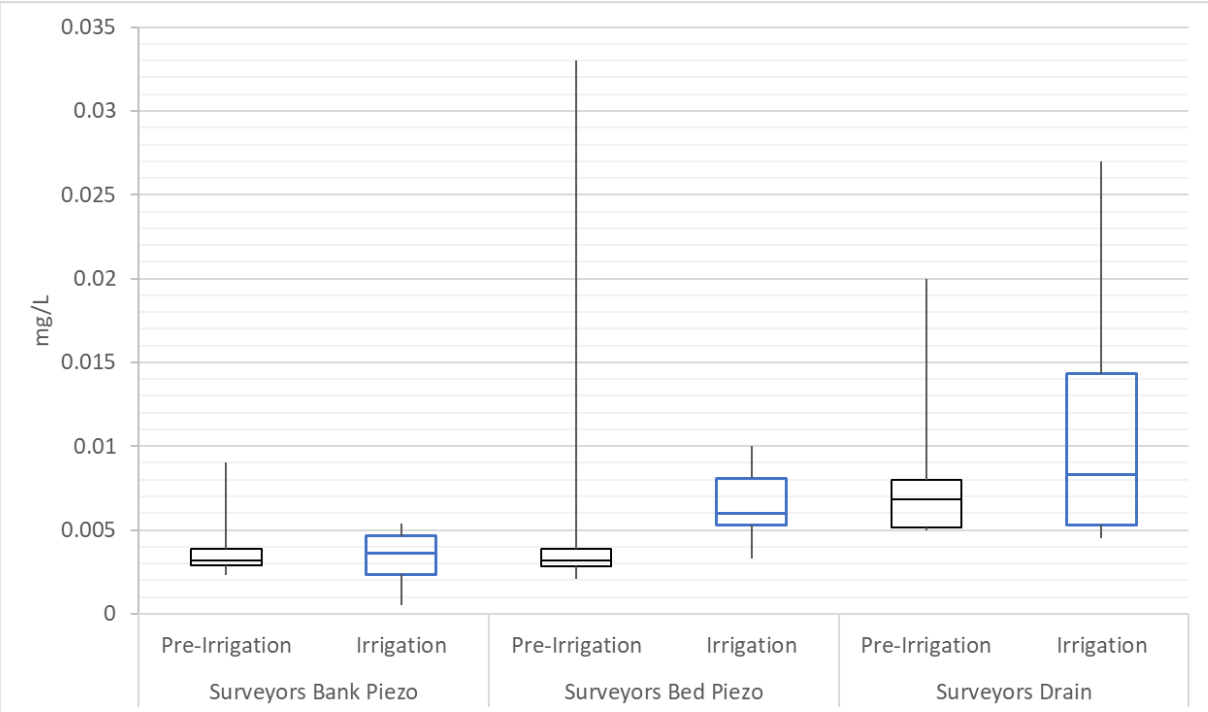

Figure 3-25 Surveyors Array Dissolved Reactive Phosphorus Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

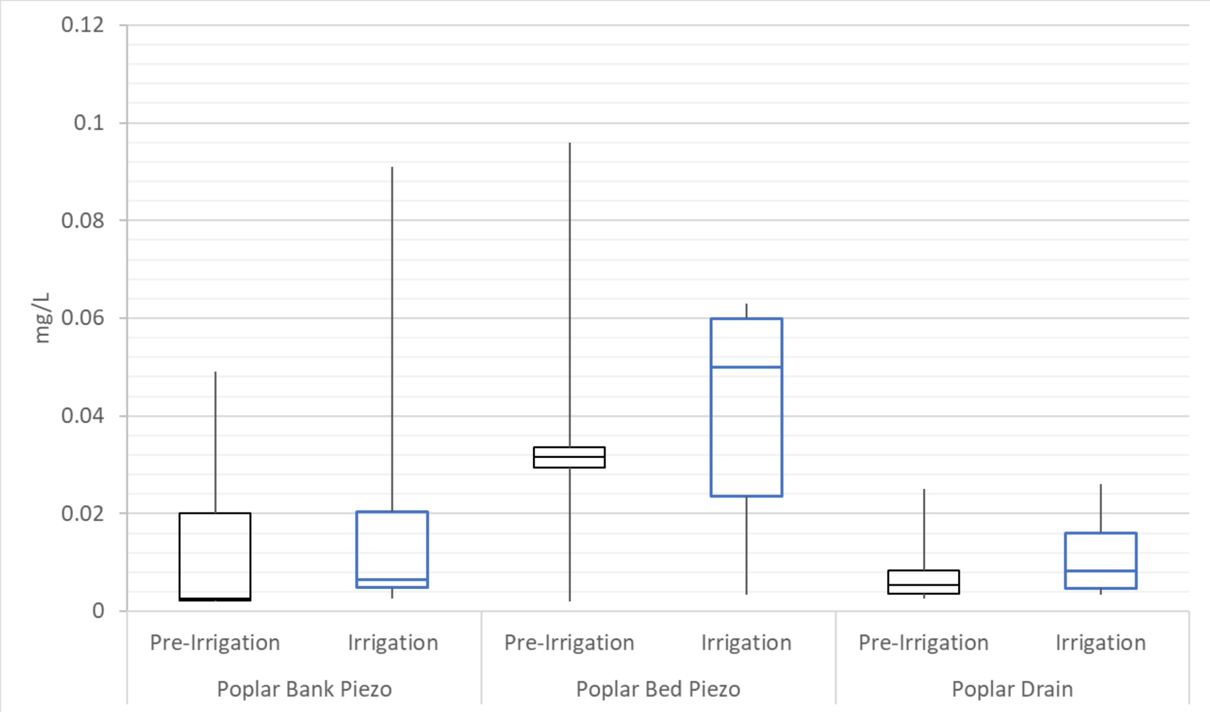

Figure 3-26 Poplar Array Dissolved Reactive Phosphorus Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

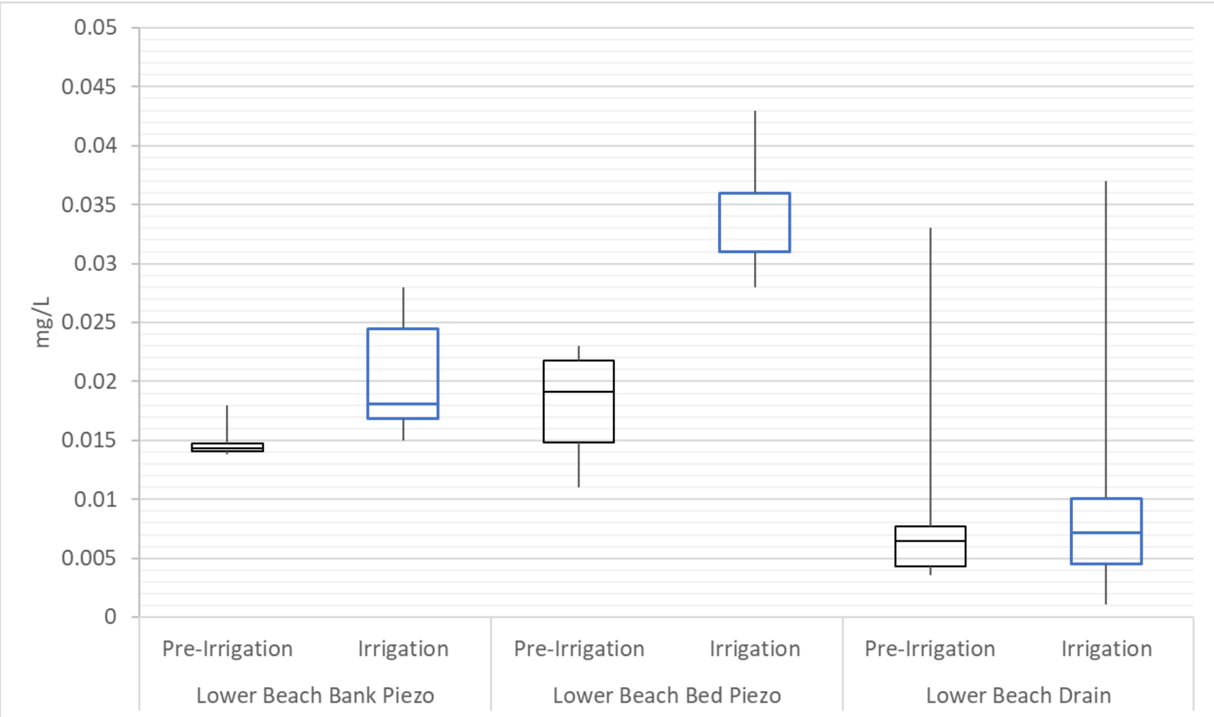

Figure 3-27 Lower Beach Array Dissolved Reactive Phosphorus Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

3.2.6 Water Quality: Other Parameters

Temperature

Water temperature had a relatively expected trend of cooler across winter and warmer in summer. Scheme bores had among the higher temperatures across winter and the highest temperatures across spring. This is likely due to thermal insulation provided by the ground. Water temperature at all sites was generally within the daily air temperature range[7]. Water temperature occasionally exceeded air temperature across winter and spring 2018. This can be attributed to sampling occurring on a colder than average day, whereby water temperature is higher than air temperature by way of its thermal capacity and that it can retain heat better in cooler conditions, and insulation from the earth. Nine sites had >10 °C in temperature variation across the monitoring period; all drain sites, Lower Beach array, and Surveyors and Newtons bed piezos. Lower Beach Bed Piezo had the greatest range, followed by Newtons Bed Piezo, Lower Beach Bank Piezo, and Surveyors Bed Piezo. Scheme Top 1, Top 2, and Middle bores had the least variation in temperature data, with Boundary piezos having similarly low variation.

Dissolved Oxygen

Figure 3-28 through Figure 3-33 show distribution of dissolved oxygen (DO) data for each array. Presented order reflects array distribution inland to the coast. Each graph compares pre-irrigation data (March-September 2018) to irrigation season data (October 2018-April 2019). Across all data, DO fluctuated 2-14 mg/L. Drain sites, excluding Boundary, are among those with the highest DO concentrations; generally 8-12 mg/L. Piezo values were generally below 6 mg/L, excluding those at Lower Beach. Scheme and Lower Beach DO concentrations spanned these groupings.

At Newtons array DO decreased during the irrigation season (Figure 3-28). There was a general increase in range of concentrations and decrease of median concentrations at this array. Pre-irrigation Newtons Bed Piezo had the greatest range in data, during irrigation Newtons Bed Piezo did. Newtons Bank Piezo had the lowest range across both periods and the lowest concentrations, generally below 6 mg/L while the rest of the array is generally above 6 mg/L. Value ranges were much lower at the Boundary array compared to the Newtons array values (Figure 3-29). At the Boundary array there was little difference between DO in the piezos before and during irrigation season, but concentration ranges decreased markedly for Boundary Drain. Concentrations were generally below 6 mg/L for both piezos, but above this for the Drain. DO concentrations were generally below 8 mg/L in Scheme bores, except Scheme Bottom which exceeded this both pre and during irrigation (Figure 3-30). Between datasets Scheme Top 1 decreased in range with slight decrease in median. Scheme Top 2 increased in range with little change in median. Scheme Middle has the greatest change in median between seasons, increasing by approximately 2 mg/L. It decreased in range, along with Scheme Bottom, whose median decreases slightly during irrigation season. Surveyors array all increased in range but decreased in median concentration of DO during irrigation season (Figure 3-31). This was not seen to such an extent at the other arrays.

DO concentration in Surveyors Drain was noticeably higher than that in the piezos. Surveyors Bank Piezo had the greatest range in data. Piezo DO concentrations were generally below 6 mg/L. At the Poplar array, Drain DO concentrations were again noticeably higher than those from the piezos, which were generally below 6 mg/L (Figure 3-32). Under irrigation the range of values increased for both Poplar Bank Piezo and Drain but was relatively consistent for Poplar Bed Piezo which already had a high range. Median DO concentrations decreased during irrigation season across the Poplar array. Lower Beach Bed Piezo had the most significant change in concentrations between periods, with median concentrations decreasing over 7 mg/L, and range increasing from <0.5 mg/L to >6.5 mg/L during irrigation season (Figure 3-33). Lower Beach Bank Piezo and Drain also saw decreases in median. Lower Beach Drain saw range increase to a lesser extent, and Bank Piezo saw a decrease in range. Pre-irrigation DO concentrations were similar for Lower Beach Bed Piezo and Drain, while during irrigation season concentrations were more similar between piezos, with limited overlap with Drain concentrations.

[7] Based on data from Ashburton Aero AWS (Automatic Weather Station), approximately 15 km northeast of ECGIS. Data was downloaded from NIWA's CliFlo website.

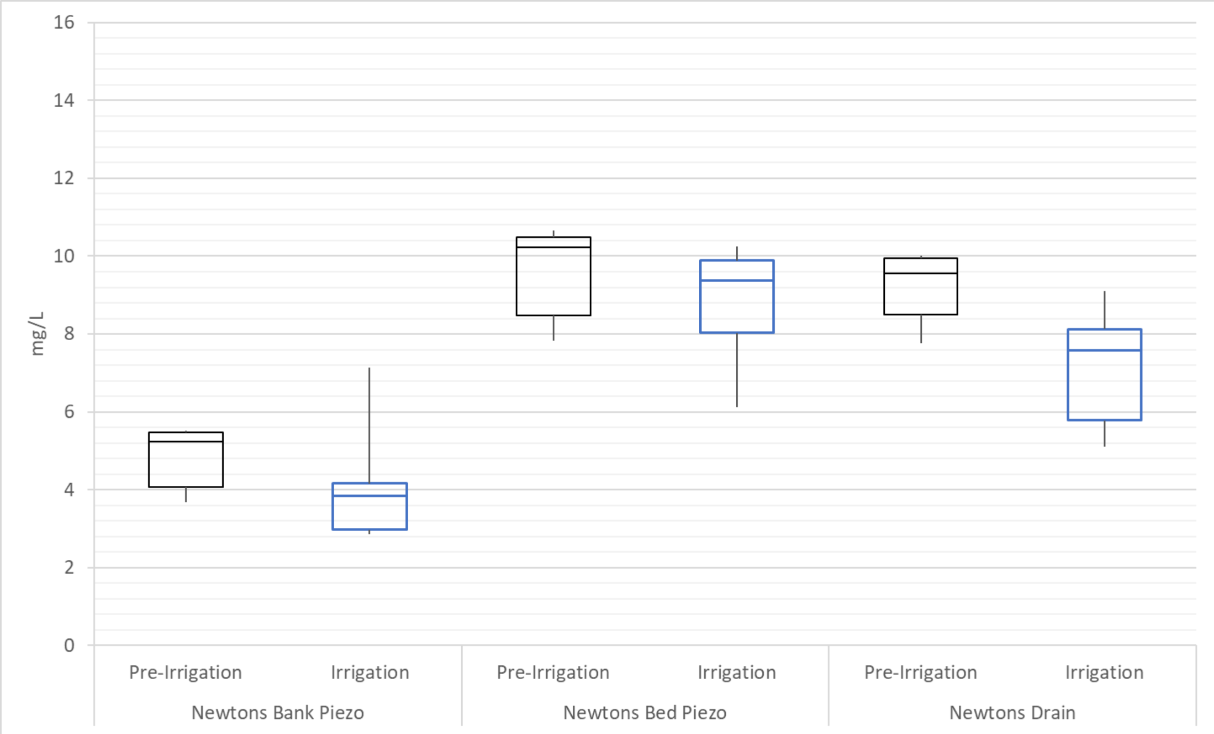

Figure 3-28 Newtons Array Dissolved Oxygen Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

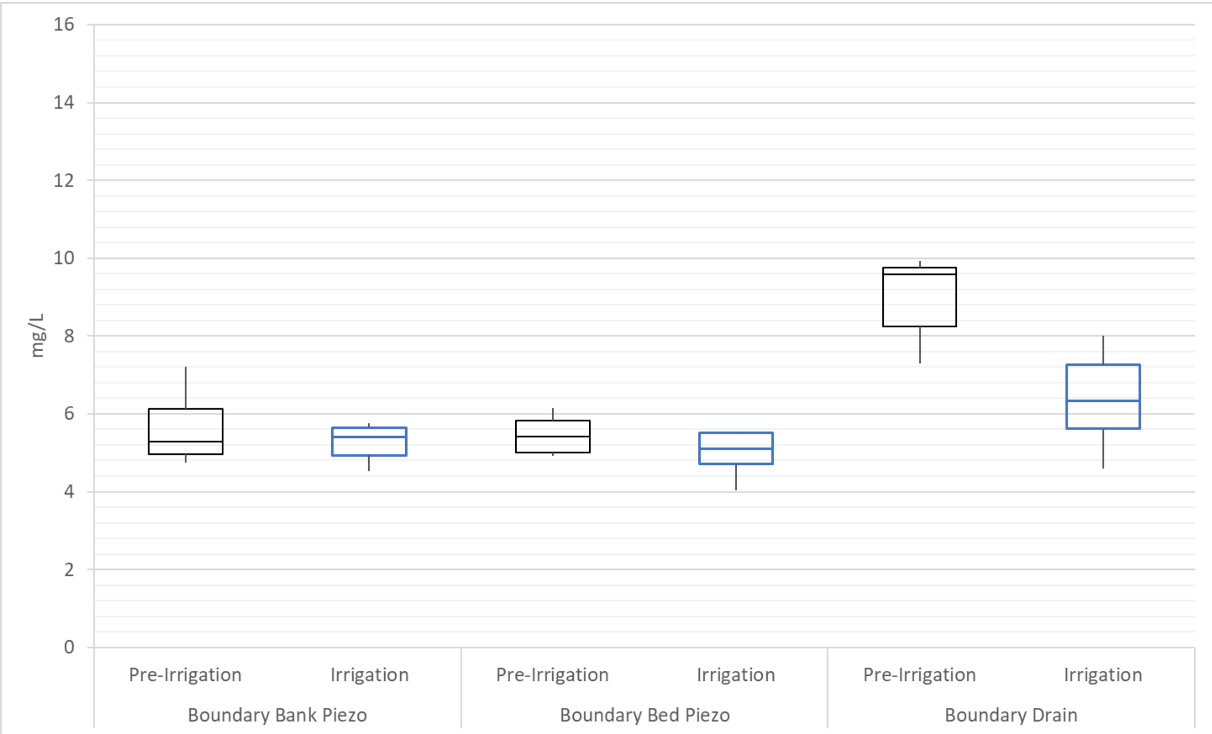

Figure 3-29 Boundary Array Dissolved Oxygen Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

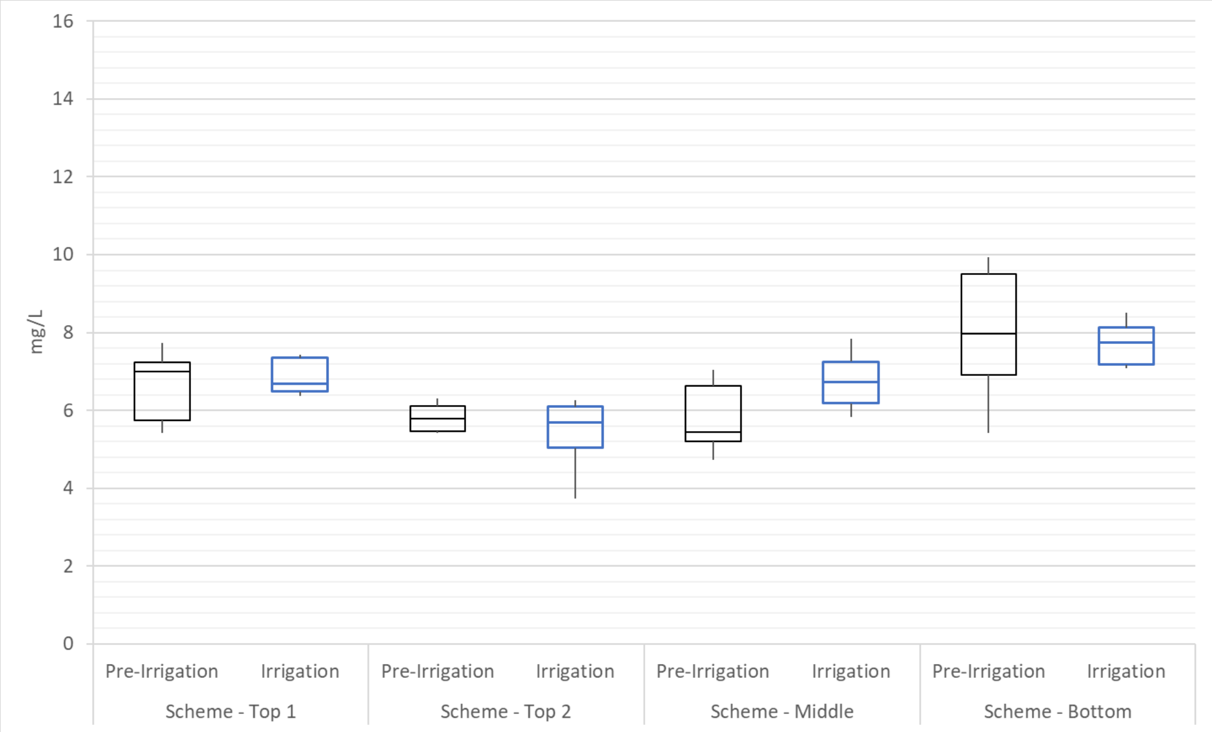

Figure 3-30 Scheme Bore Dissolved Oxygen Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

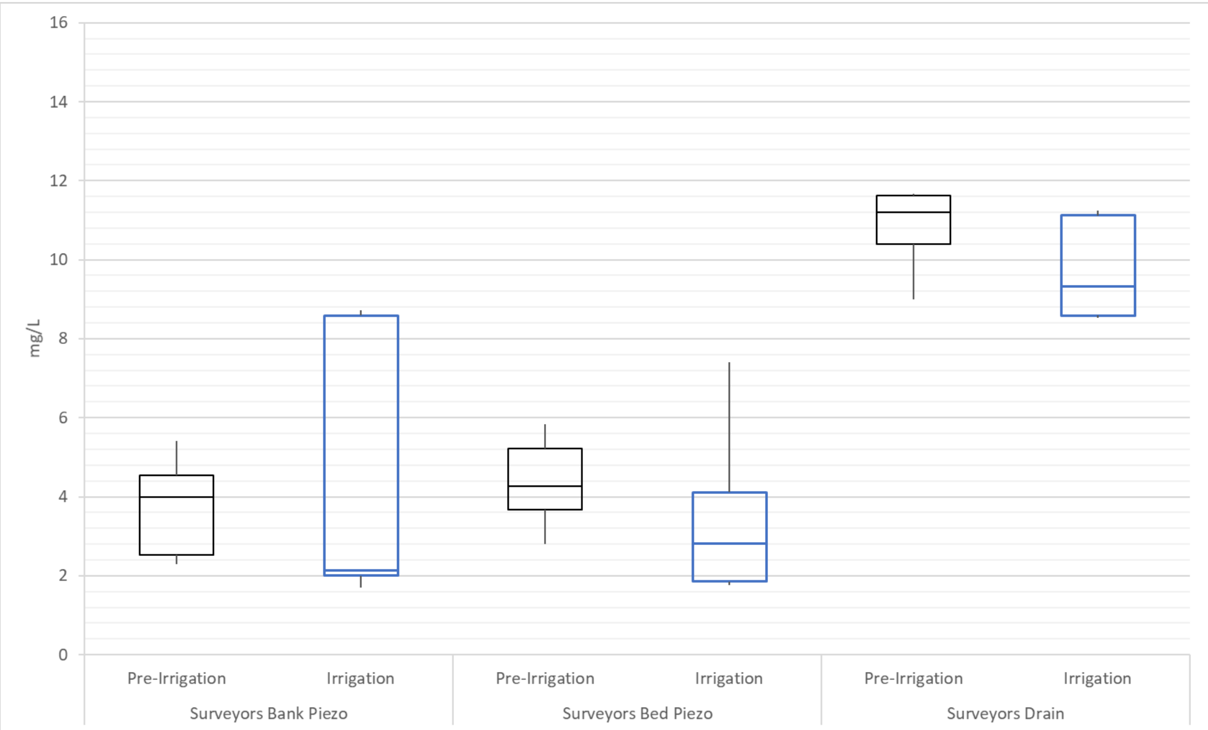

Figure 3-31 Surveyors Array Dissolved Oxygen Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

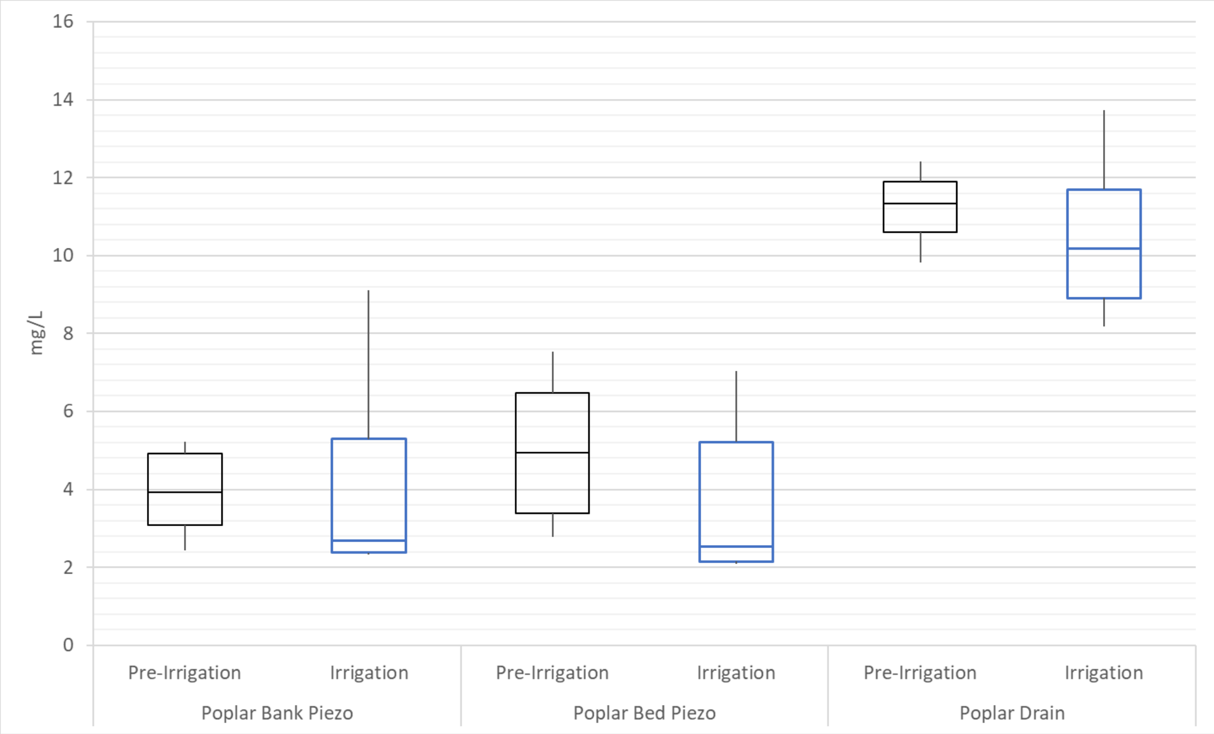

Figure 3-32 Poplar Array Dissolved Oxygen Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

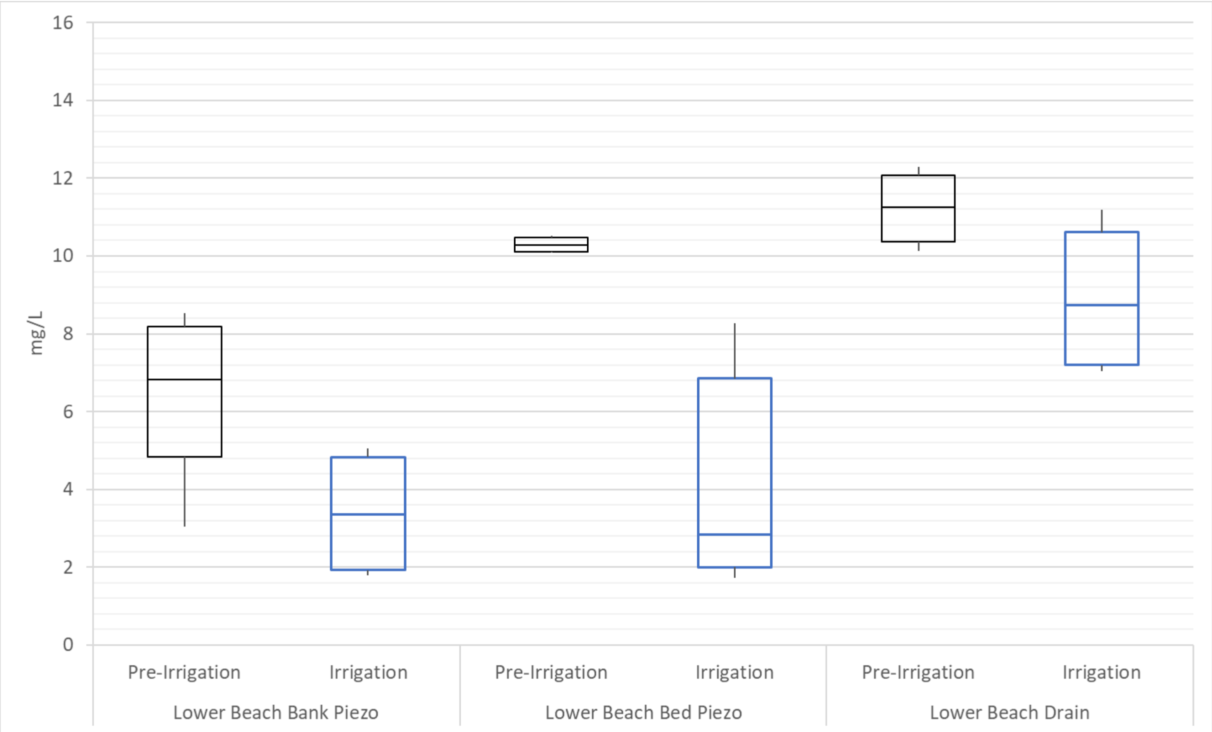

Figure 3-33 Lower Beach Array Dissolved Oxygen Concentrations. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

Electrical Conductivity

Figure 3-34 through Figure 3-39 show distribution of Electrical conductivity (EC) data for each array. Presented order reflects array distribution inland to the coast. Each graph compares pre-irrigation data (March-September 2018) to irrigation season data (October 2018- April 2019). Scheme bores had the lowest EC values of all sites. Irrigation season generally translates to increased EC variability from the Surveyors array to the coast, and decreased variability above.

At the Newtons array (Figure 3-34) piezo EC decreased in range and value during irrigation season. EC values were higher in these piezos than in the Drain where values varied little between seasons. At the Boundary array all sites decreased in range and values during irrigation season. Before irrigation season, Boundary Drain had the greatest range in values (Figure 3-35). Due to the lack of low EC measurements, the Boundary array had the highest EC values across all groupings. Scheme bores had the lowest EC values across all sites (Figure 3-36). All samples from Scheme Top 1 and Middle were approximately 15 mS/m; very little variation in data. Values in Scheme Top 2 increased during irrigation season and were much more variable than beforehand. Scheme Bottom had the greatest range of data and highest EC values compared to the other Scheme bores. Values remained low relative to data from investigation arrays.

At the Surveyors array (Figure 3-37), the range of EC values increased during irrigation season, with an overall decrease in measured values. Before irrigation Bank Piezo EC values were above 35 mS/m. During irrigation season over half of measured values were below this value. Irrigation season EC values were similar for piezos, with Bank Piezo EC being slightly lower. EC values were lowest for Surveyors Drain but overlapped with data from the piezos. The EC range from this array aligns with that seen at the Newtons (Figure 3-34) and Poplar (Figure 3-38) arrays. At the Poplar array the Bank Piezo had lower EC than the Bed Piezo and Drain pre-irrigation, with little overlap to the other two sites, which largely coincided. All pre-irrigation season EC values were above 30 mS/m. During irrigation, most values were below 30 mS/m. There was also much more overlap in values across sites. The Poplar array during irrigation season had higher ranges and lower medians. The Bed Piezo switched from the highest to the lowest values. Like the Poplar array, the Lower Beach array also had little variation in EC values before the irrigation season, with all values above 30 mS/m (Figure 3-39). Similarly, irrigation season saw increased ranges and lower medians. Values were generally consistent across all sites.

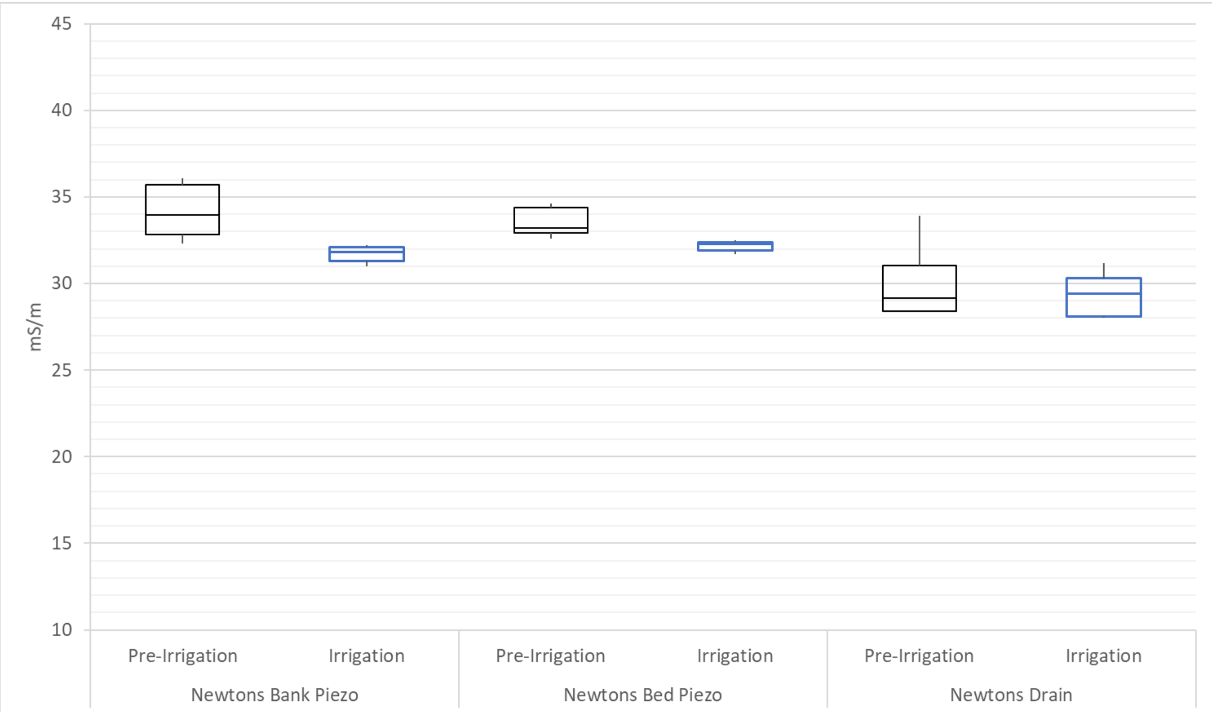

Figure 3-34 Newtons Array Electrical Conductivity Values. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

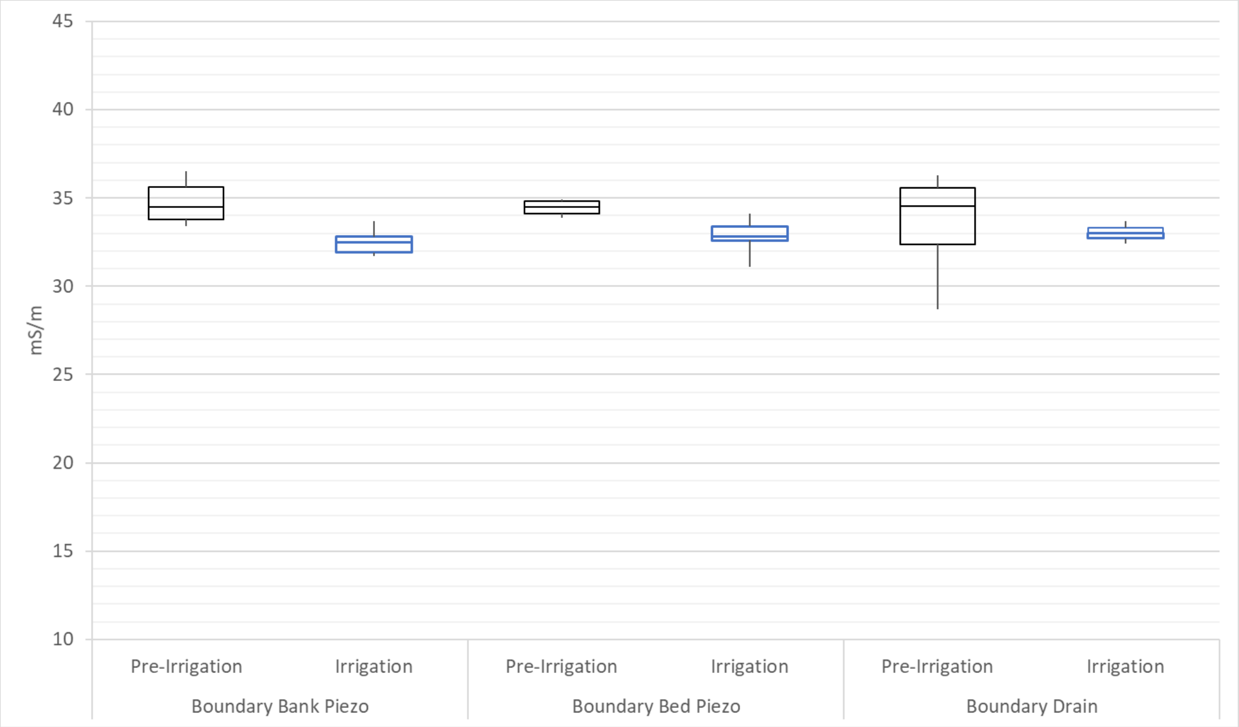

Figure 3-35 Boundary Array Electrical Conductivity Values Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

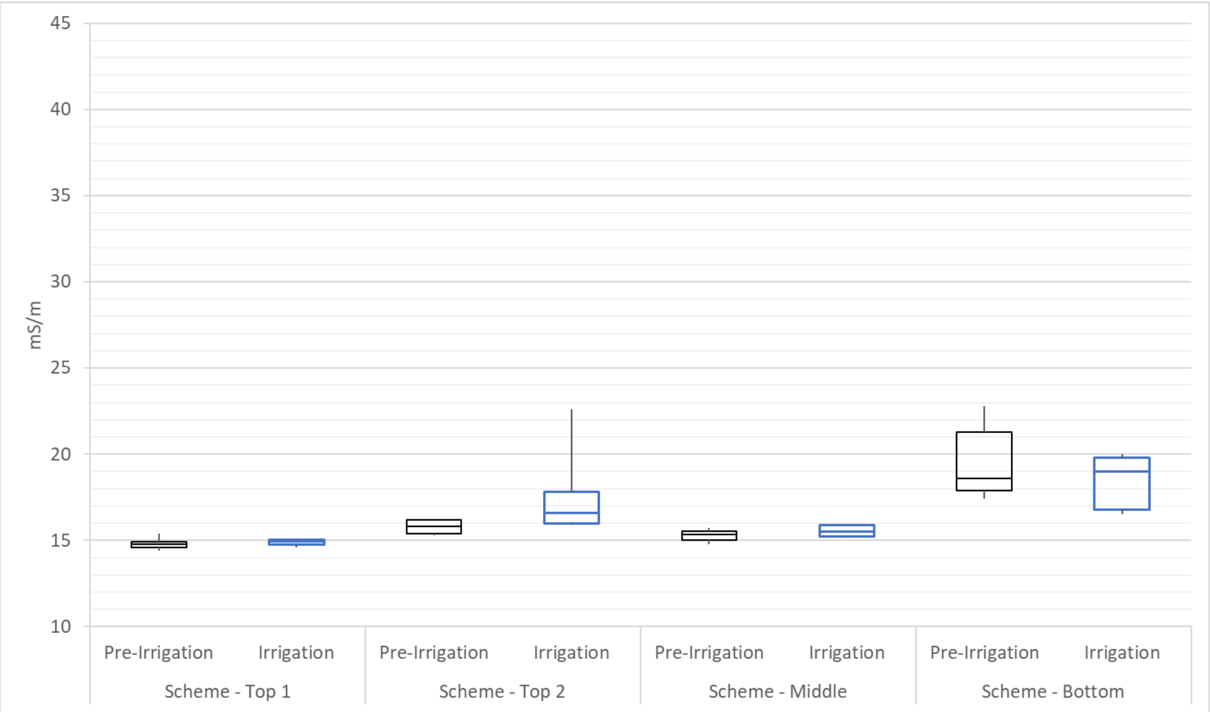

Figure 3-36 Scheme Bore Electrical Conductivity Values. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

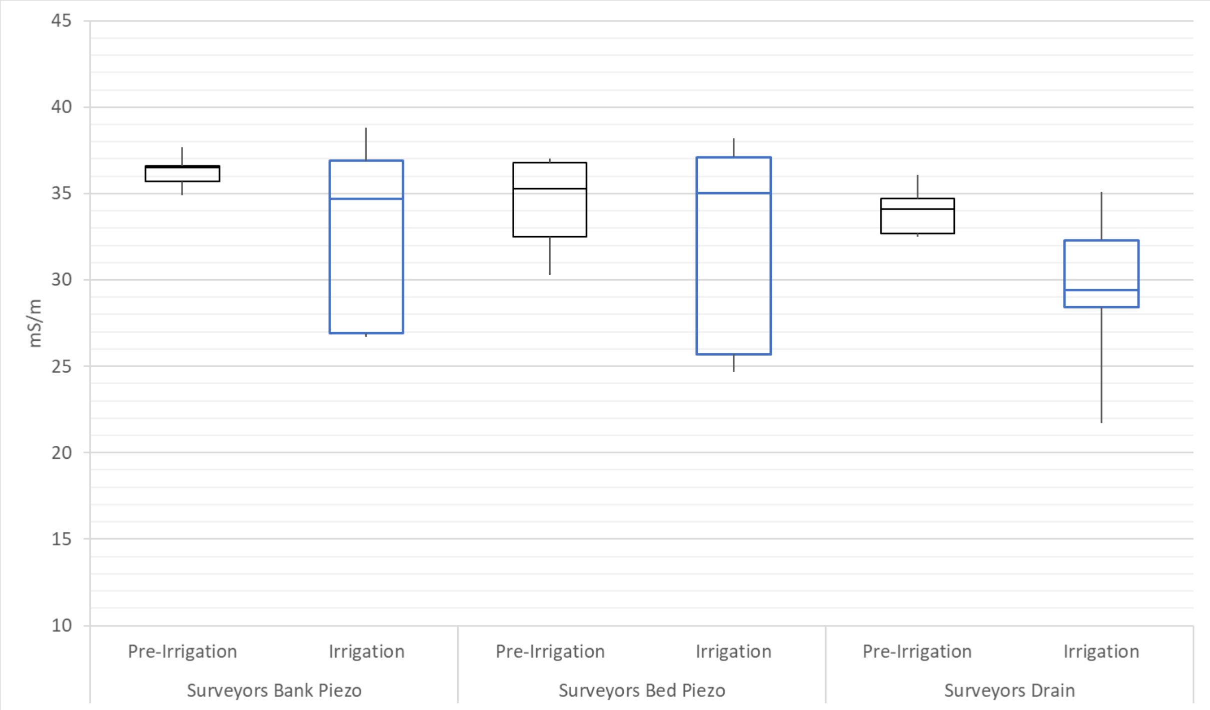

Figure 3-37 Surveyors Array Electrical Conductivity Values. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

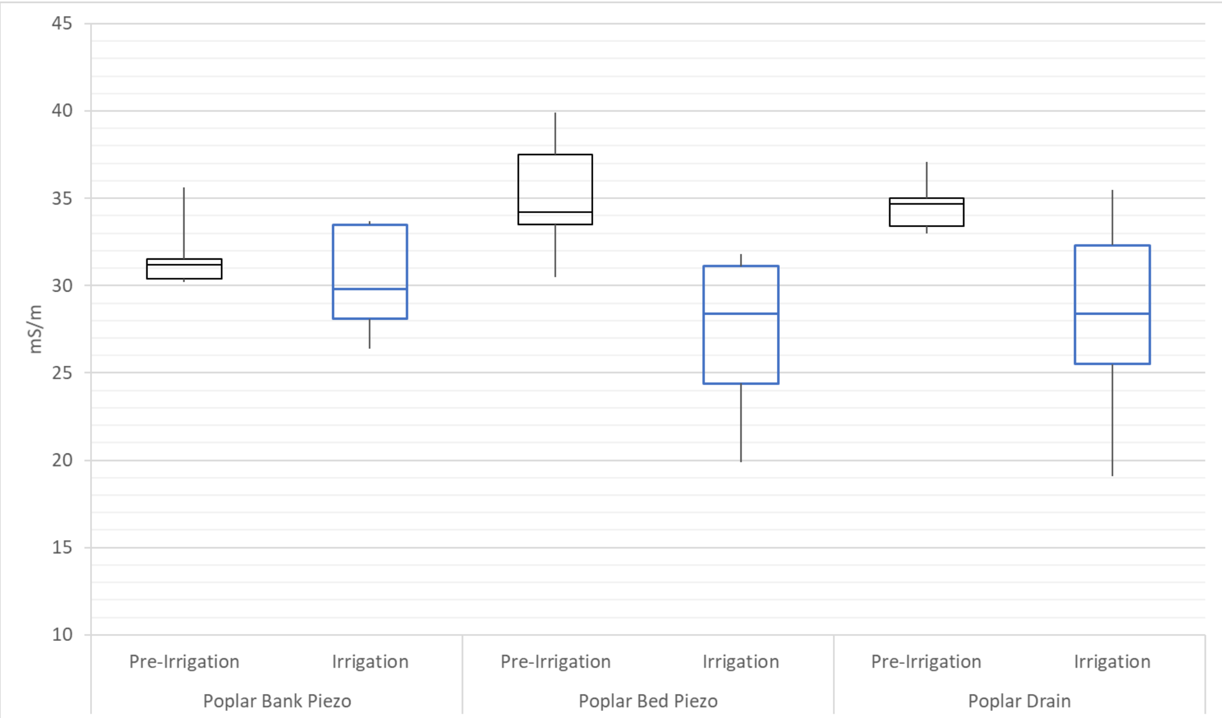

Figure 3-38 Poplar Array Electrical Conductivity Values. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

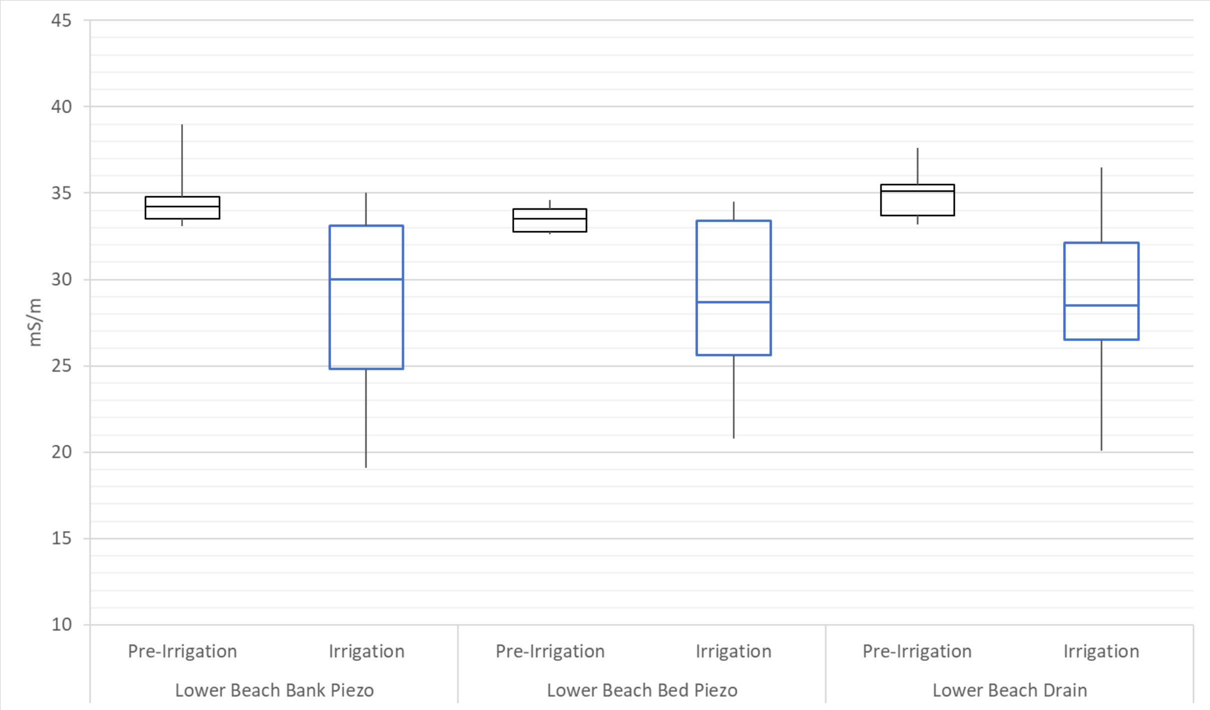

Figure 3-39 Lower Beach Array Electrical Conductivity Values. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

E. Coli

Figure 3-40 through Figure 3-45 show distribution of *E. coli* data for each array. Presented order reflects array distribution inland to the coast. Each graph compares pre-irrigation data (March-September 2018) to irrigation season data (October 2018-April 2019). Drain sites generally had the highest detections of *E. coli*. Newtons and Boundary drain sites had much lower *E. coli* detections than the drain sites at Surveyors and Poplar. All drain sites medians increased during irrigation season, significantly at Surveyors.

At the Newtons (Figure 3-40) and Boundary (Figure 3-41) arrays significant *E. coli* was only detected in the drain sites. During irrigation season, minimum detections at Newtons Drain increased along with the median, while the upper range decreased. At Boundary Drain all representative values increased during irrigation. *E. coli* detections were generally low from Scheme bores (Figure 3-42). Top 1 had no detections of *E. coli* pre-irrigation, with detections of 1 MPN/100 mL during. Top 2 had some detection of 10-90 MPN/100 mL outside of the irrigation season. Remaining samples from Scheme bores were all less than 10 MPN/100 mL.

Surveyors Bed Piezo had the greatest change in values of all sites between seasons, decreasing from above detection limit (2,420 MPN/100 mL) to 10 MPN/100 mL (Figure 3-43). During irrigation season this decreased significantly. Surveyors Bank Piezo consistently had low detections between seasons. Drain detections increased from predominantly 200-500 MPN/100 mL before irrigation, to 500-700 MPN/100 mL during. Where Surveyors Bed Piezo decreased from above detection limit during irrigation, Poplar Bank Piezo increased to have detections above detection limit during irrigation season (Figure 3-44). This increase was from an already elevated detection range. Poplar Bed Piezo also had an elevated *E. coli* detection range before irrigation. This decreased during irrigation season. Poplar Drain saw an increase in all values during the irrigation season. *E. coli* detections were elevated for all sites at the Lower Beach array prior to irrigation (Figure 3-45). During irrigation the majority of detections from the piezos were <100 MPN/100 mL. For Lower Beach Drain, a per-irrigation interquartile range decreased from 400-1400 MPN/100 mL to 200-800 MPN/100 mL, however median increased from <500 MPN/100 mL to >600 MPN/100 mL.

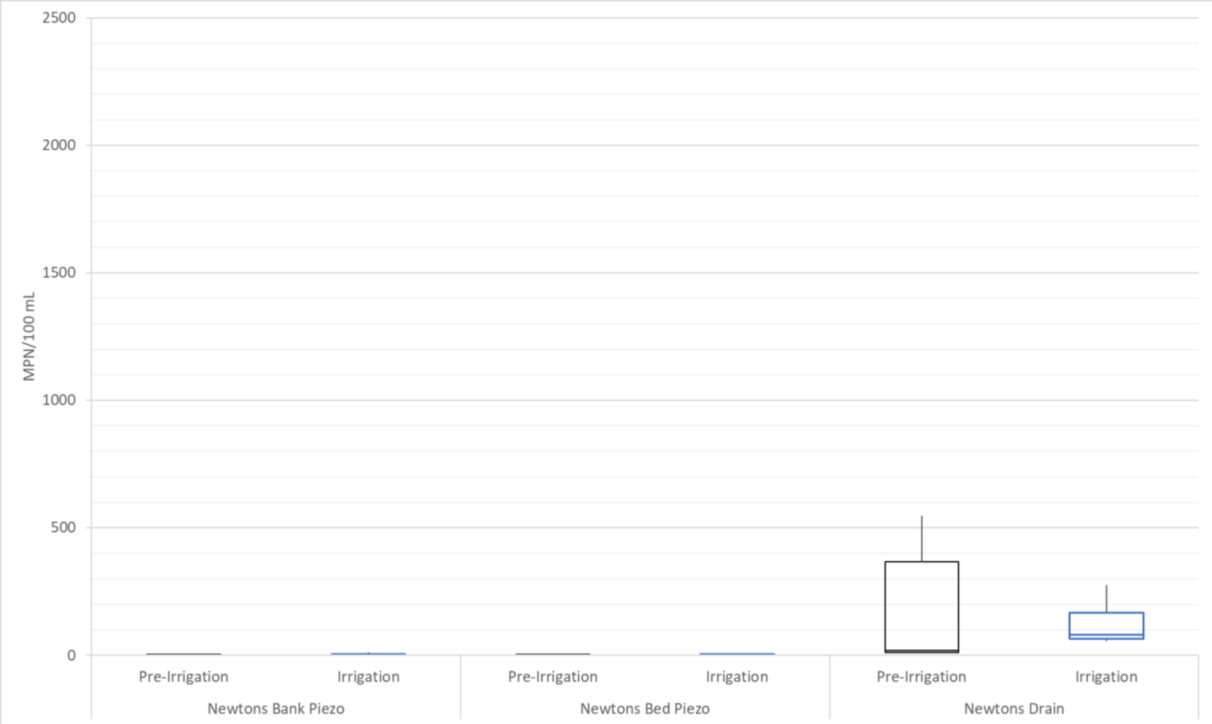

Figure 3-40 Newtons Array *E. Coli* Detections. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

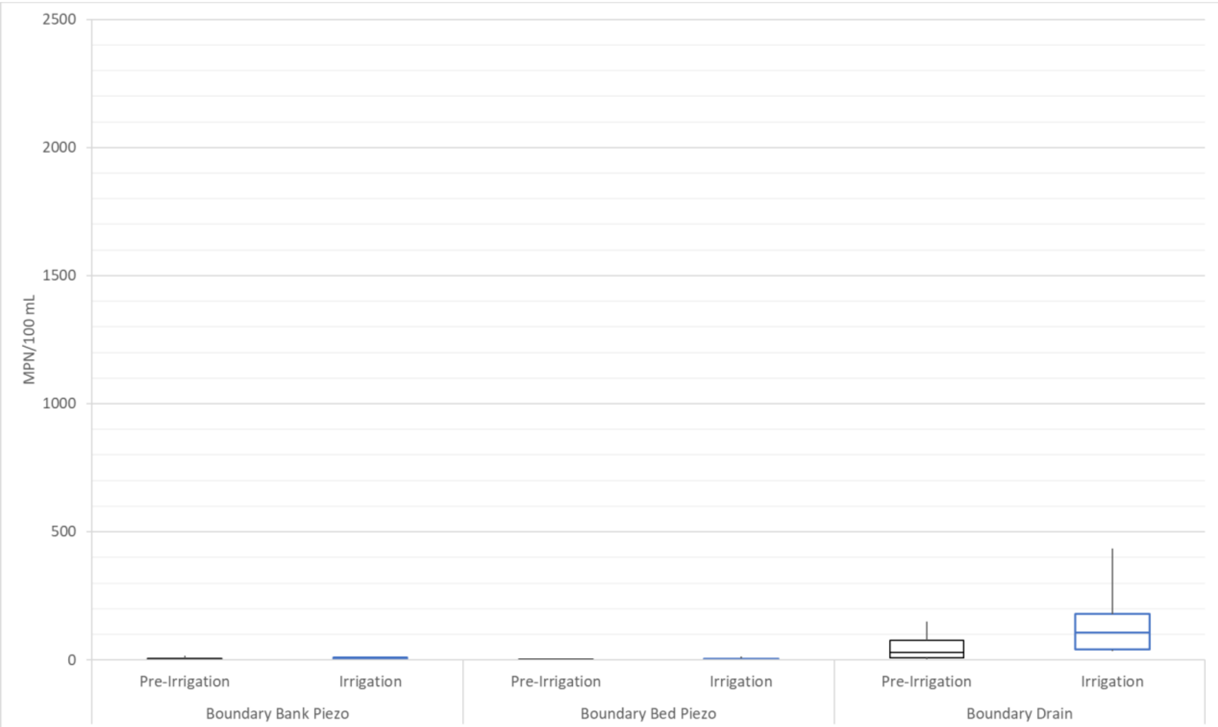

Figure 3-41 Boundary Array *E. Coli* Detections. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

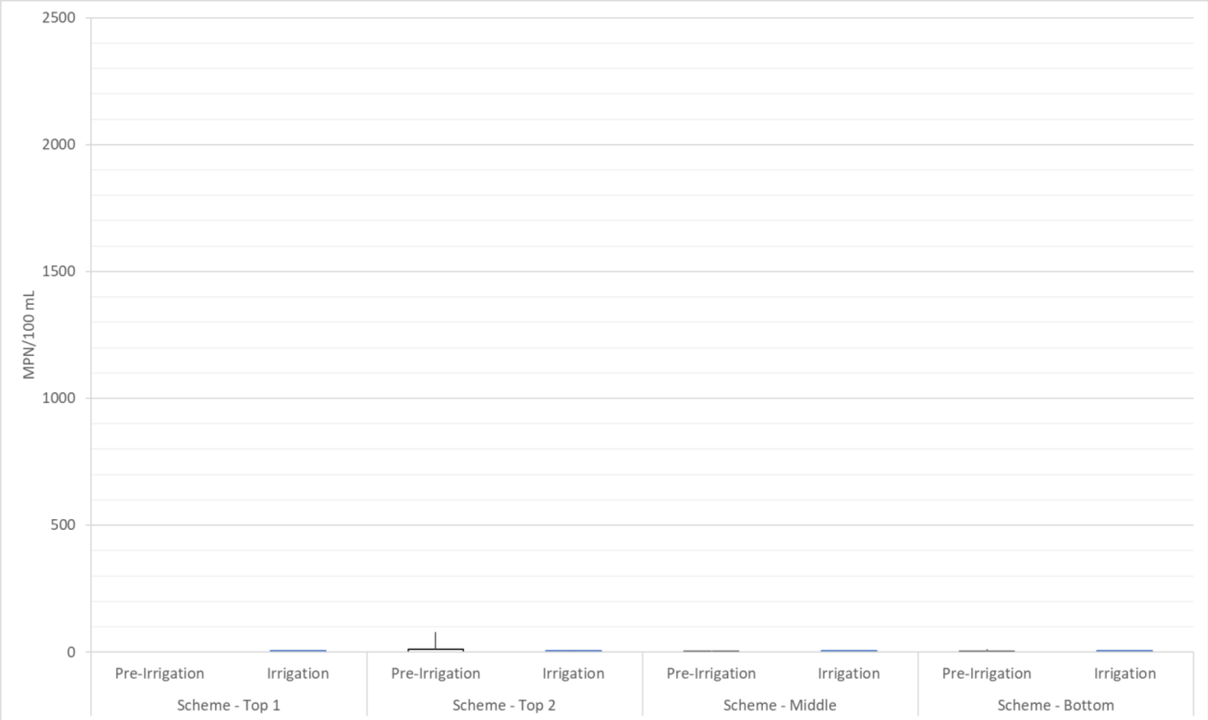

Figure 3-42 Scheme Bore *E. Coli* Detections. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

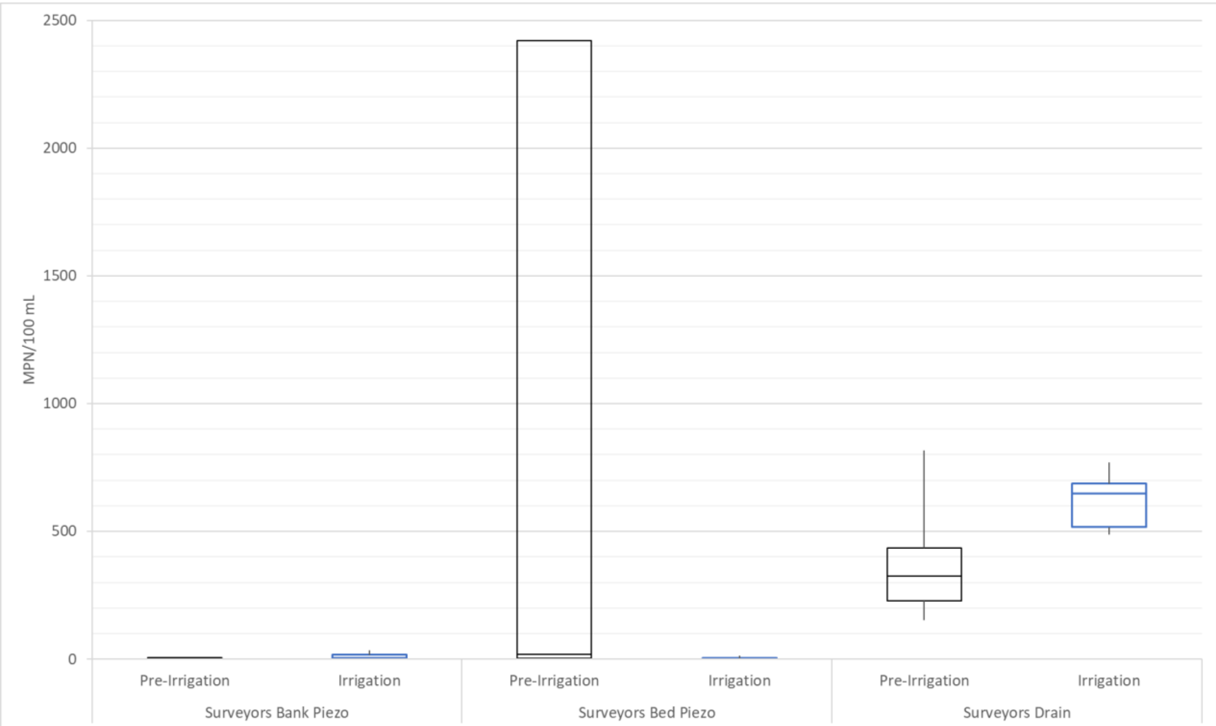

Figure 3-43 Surveyors Array *E. Coli* Detections. Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

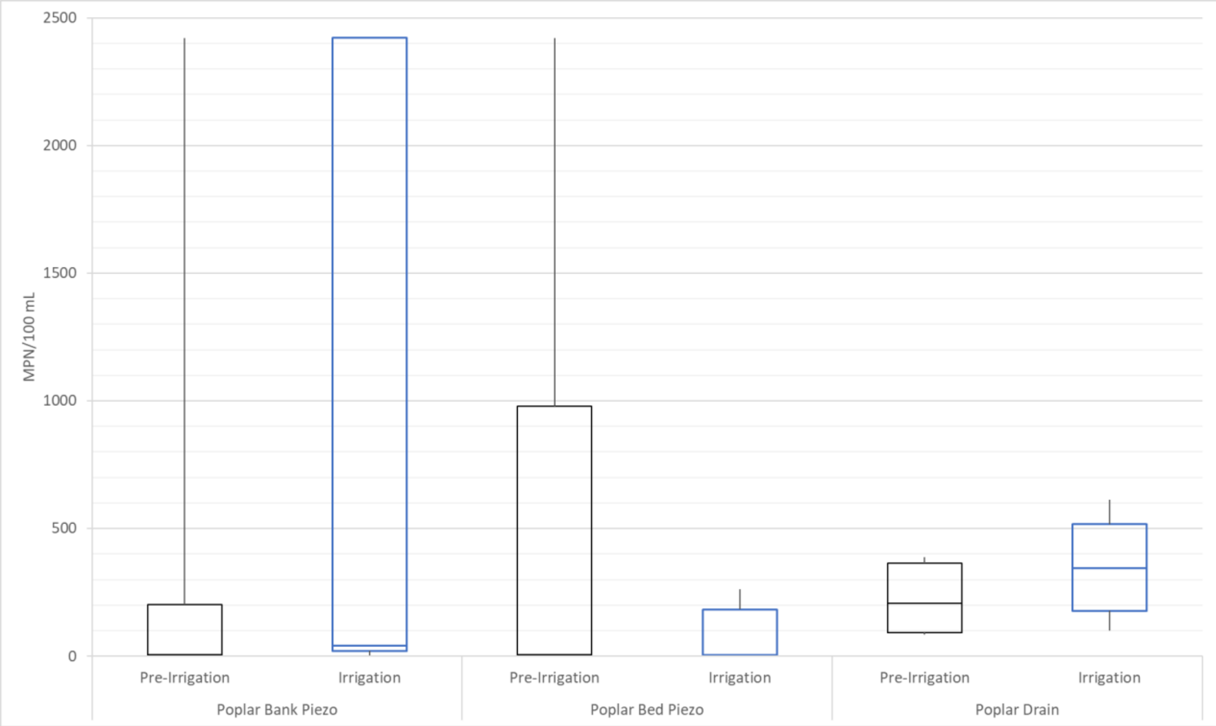

Figure 3-44 Poplar Array *E. Coli* Detections. Black Boxes Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

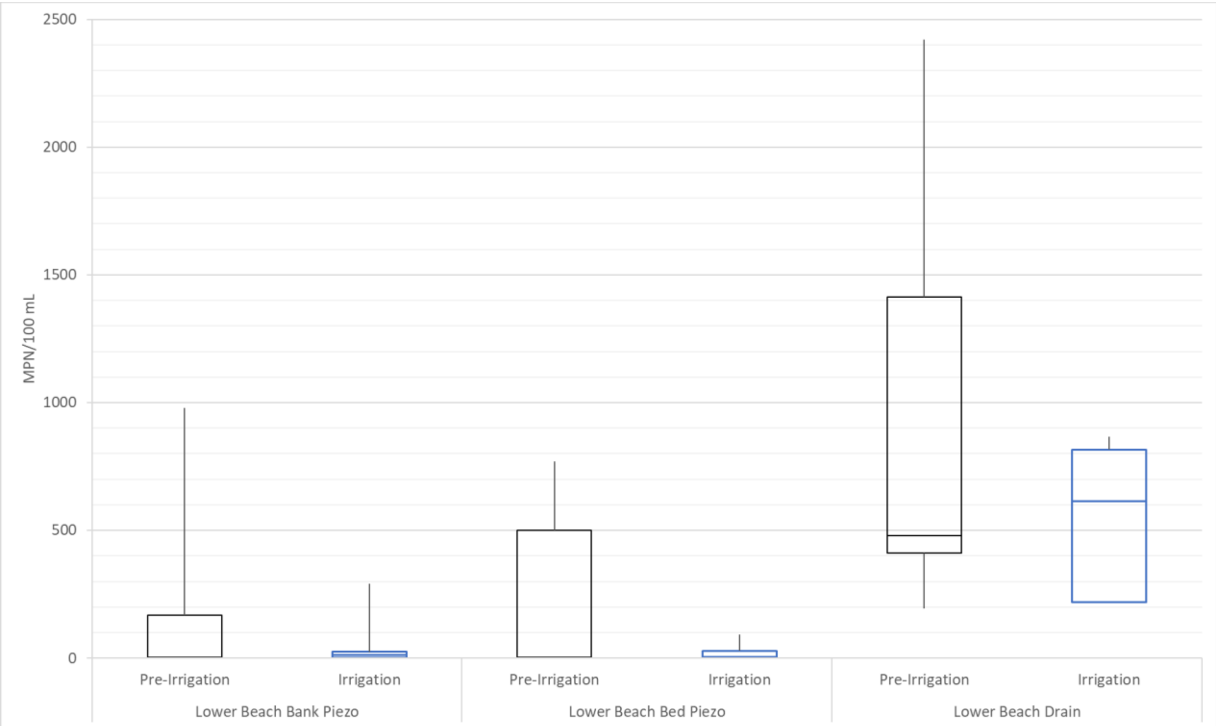

Figure 3-45 Lower Beach Array *E. Coli* Detections Black Boxes Indicate Pre-Irrigation Season (March-September 2018), While Blue Boxes Indicate During Irrigation Season (October 2018-April 2019)

3.2.7 Summary

First, gauging results from Windermere Drain were presented. These showed increases in flow towards the coast across 2018, while in 2019 flows increased to Surveyors and again fell. Next, in considering level logger data collected from piezos at each array it was found that levels showed influence from rainfall at all arrays, though limited at Surveyors. Another influence was evident in the hydrographs for Surveyors piezos, and Poplar Bank Piezo. Ground and surface water elevation were then considered together. No array had the same relation between sites as another, as per Table 3-5. At the top and bottom of ECGIS arrays have similar hydrograph profiles, while in the middle similarities only exist between the piezos. There is an overall decrease in water elevation with proximity to the coast. Drain sites had the least variation in their data, while the Surveyors array had the greatest data range. Excluding Poplar Bank Piezo, all sites had higher average water elevation outside irrigation season.

Table 3-5 Relationship between Water Elevation at Each Array

Array	Highest Elevation		Lowest Elevation	Similar Hydrograph Profiles
Newtons	Bank	Drain	Bed	All sites
Boundary	Bed	Bank	Drain	All sites
Surveyors	Bank	Bed	Drain	Piezos
Poplar	Drain	Bank	Bed	Piezos
Lower Beach	Drain	Bed	Bank	All sites

TAN and nitrite-N had limited detection; 42.5% and 57.1% respectively at concentrations <0.3 mg/L. nitrate-N, DIN, and nitrate-N + nitrite-N all occurred at much higher concentrations. Newtons and Boundary arrays had the highest concentrations of nitrogen species, including nitrate-N, while within arrays the drain site generally had the highest concentrations. Scheme bores and Surveyors piezos had nitrate-N concentrations much lower than the other sites.

Four phosphorus species were sampled for. 79.7% of samples had no detectable DOP, 16% had no detectable TDP, and 7% had no detectable DRP and/or TP. DRP and TP tended to have the same trend at each site. TP had the highest median value of all phosphorus species. Scheme bores had the lowest phosphorus concentrations and the lowest concentration ranges. In considering DRP, lowest concentrations were found in Scheme bores, Newtons and Boundary piezos, and Surveyors Bank Piezo. Highest concentrations were found in Poplar and Lower Beach piezos.

The expected water temperature trend is found, with variation reflecting seasonal differences, and groundwater being better insulated from temperature changes than surface water. Drain sites generally had the highest DO concentrations, with most samples ranging 6-12 mg/L. Surveyors, Poplar and Lower Beach piezos had the lowest DO concentrations, ranging 2-7 mg/L. Most sites saw decreases in DO during irrigation season. There were no significant differences in EC concentrations across arrays, most samples ranging 25-35 mS/m. Scheme bores had noticeably lower concentrations at around 15 mS/m. Almost a third of samples had no detectable *E. coli* but a handful of samples exceeded detection limit. *E. coli* detections were lowest at the top of the ECGIS. Lower Beach and Poplar arrays, Surveyors Bed Piezo, and all drain sites had the highest concentrations.

3.3 Objective 3: Identify Values Associated with the Hinds Drains

This section presents values associated with the Hinds Drains as reported by interviewees. Most interviewees (57%) had association with the Hinds Drains area of >20 years. In places differences in interviewee group responses are discussed. The first group is referred to as 'ECGIS Members'. They are those who participated in discussion detailed in Section 2.1. The second group is referred to as 'Other Interviewees'; additional parties identified in Section 2.3.

3.3.1 Participation in Planning Processes

Half of ECGIS Members had no direct participation in planning processes related to creation of the Hinds Plains Zone Implementation Programme Addendum, nor Plan Change 2 to the LWRP. This is because they were being represented by their Chairman and trusted his ability to represent ECGIS. This delegation structure appears reflective of that seen the wider community:

> "…*certain people there that knew there was a problem, and knew things had to change. They were the quiet movers and shakers and had the respect of the community.*"
>
> (Interviewee 13)

> *"…we've got a couple of people that are really, really involved representing well our drains area, so I haven't had a lot to do with it.*"
>
> (Interviewee 18)

ECGIS Members who did participate in planning processes mainly did so in the form of attending community meetings. All Other Interviewees were involved in these processes. This was mainly through being on the Zone Committee, being a member of the Hinds Drains Working Party (formed on recommendation of the Zone Committee), being a member of the MAR Governance Group (formed from the Plan Change 2 process), or in providing technical support to these processes. Eight interviewees (four ECGIS Members and four Other Interviewees) were critical of the Environment Canterbury approach to these processes. Common among these responses was the view that Environment Canterbury had already decided outcomes and their attempts at community engagement was tokenistic. Contrarily, two Other Interviewees saw these processes as successful. Regarding the politics of these processes:

> "*Always trust the logic of the argument. Eventually rationale and logic will win against the people playing politics. … Politics is unfortunately a necessary part of life. The world would be a much nicer place if we didn't have politics at all; if we could trust science and rational behaviour, rational thought and logic*."
>
> (Interviewee 11)

This is perhaps an idealised view. Interpersonal, organisational, and interest group politics all influence how planning processes evolve, be it intentional or not. Politics can oftentimes be a greater driver than logic as it is easier to accept than dealing with the often harsh, difficult, and complex reality of things:

> "*The Hinds Drains Working Party was pretty good, but again they came to the same conclusion that 'we don't want to change anything because it would be too hard on us.' So, some special interests, because of some concerns of what might happen to their own patch, let a great opportunity for the whole catchment, for everybody, slip past*."
>
> (Interviewee 20)

The most prevalent theme across interviews as relating to the planning processes was the importance of community collaboration, communication, and negotiation, as mentioned by 70% of Other Interviewees:

> "*I think we get much better results making the decisions ourselves, the people who live here and know how things work, rather than having some commissioners who look at it as black and white on a piece of paper and make a decision*."
>
> (Interviewee 7)

> "*The farming community are much more involved now than they used to be. That's a good thing. That Hinds Drains Working Party got a whole group of local people involved and tried to sort out a set of recommendations and suggested rules and various things that would actually work. That's got to be a good thing to do that – successfully come up with rules that mattered.*
>
> *"Having a local group working where they could see that and say 'Parakanoi used to be the biggest drain in the district' well now it's bone dry for most of the time so it's a huge change*."
>
> (Interviewee 16)

> "*Making a difference; people taking action, not pointing fingers at each other and yelling opinions from the corner of the room*."
>
> (Interviewee 21)

3.3.2 Understanding of Hinds Plains Hydrology

Interviewees were asked to describe their understanding of the hydrology/water system and interactions of the Hinds Drains and/or the wider Ashburton area. Similar numbers of ECGIS Members and Other Interviewees (82% and 70% respectively) did so by describing their understanding of the hydrologic system, including interactions between aspects such as rainfall, river flow, and groundwater. One Other Interviewees included risk of seawater intrusion. 80% of Other Interviewees discussed the effects of increased water use in response to this question, compared to 18% of ECGIS Members. Other themes included the need for increased on-farm storage of water for greater security:

> "*I think without storage, we're going to be faced with some big issues, whether it's reliability or environmental issues; they're all inextricably linked*"
>
> (Interviewee 9)

And concerns regarding safe drinking water; whether private bore owners knew their responsibilities, and whether freshwater would continue to be safe to drink with little to no treatment in the Hinds Plains area. Another major theme was MAR and its potential to shape the future of the area.

Interviewees were asked to discuss the changes they had seen in the Hinds Drains area. Figure 3-46 summarises these by respondent type. The largest change identified by ECGIS Members, and the second largest change identified by Other Interviewees, is a reduction in the flowing length of waterways. Interviewees identified that many of the Hinds Drains had dried completely in recent years, and that many did not flow as consistently as they did historically. There were conflicting views on whether this was down to poor management of water, or a symptom of water availability. Interviewees discussed changing irrigation practices and effects this has had on groundwater quantity and freshwater quality. Reduction in fish abundance was attributed to this reduction of flow in waterways and to reduced water quality limiting available habitat.

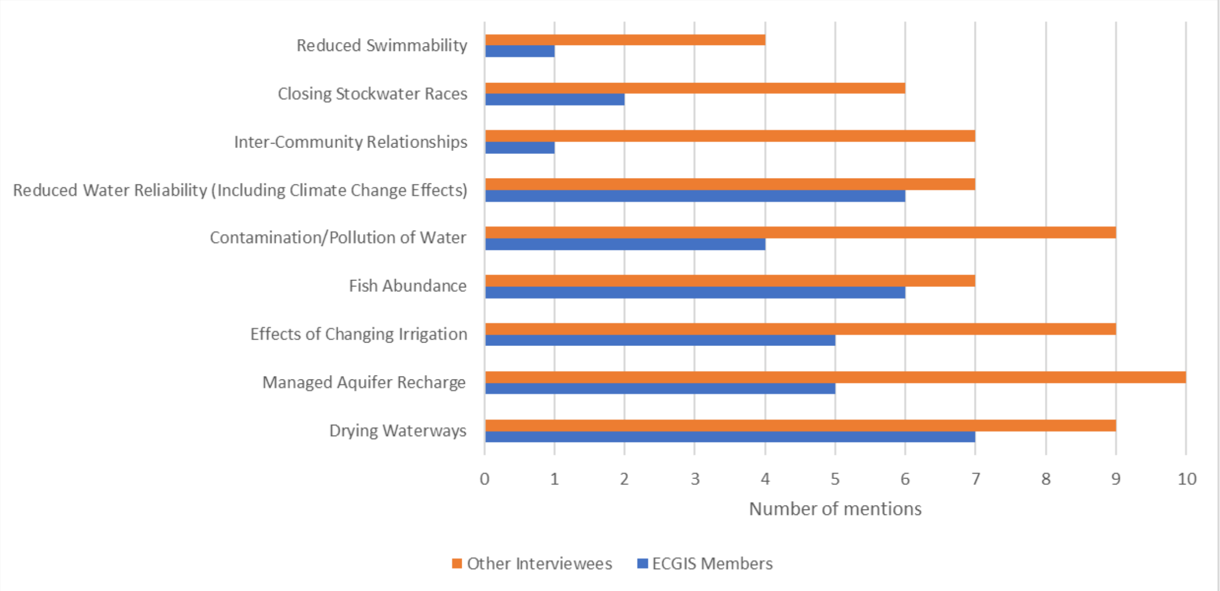

Figure 3-46 Bar Chart Showing Interviewee Identification of Changes in the Hinds Drains Area Over Time

The change mentioned most by Other Interviewees was MAR (Figure 3-46) and the perceived benefits this practice would eventually have on both water quality and quantity. Several interviewees mentioned the adage 'dilution is the solution' regarding both MAR and water quality. Changes in intercommunity relationships (between communities from different areas, with different interests, between interest groups, and with councils) were a common response among Other Interviewees but not ECGIS Members (Figure 3-46). The largest perceived intercommunity change was that between the farming community and Environment Canterbury. Besides intercommunity changes, changes within the farming community itself was also a common theme:

> "*The big attitude change that I saw was complete denial gone and the realisation that there is actually a problem. But on a really positive note, a desire to do something about it. These are practical people and they want a practical solution that still lets them farm their land, which many of them have been doing generationally, and what's nice to see is that they do actually care about the catchment*."
>
> (Interviewee 20)

3.3.3 Perceptions of Eiffelton Community Group Irrigation Scheme

Interviewees were asked to describe to the best of their ability how ECGIS operates. Most interviewees described targeted stream augmentation (64% ECGIS Members; 100% Other Interviewees); 55% of ECGIS Members and 30% of Other Interviewees discussed ECGIS establishment and history, and; 45% of ECGIS Members and 30% of Other Interviewees discussed the importance of minimum flows to ECGIS operation. Many interviewees commented on the strong leadership of ECGIS and perception of this; both positive and negative. All who commented on ECGIS leadership acknowledged the benefit of this leadership to ECGIS:

> "*…he's a great advocate; he's an asset to the scheme. He's not a good person to come head to head with*"
>
> (Interviewee 3)

> "*All the battles he's had to fight on behalf"*
>
> (Interviewee 5)

> *"…he has been pretty vocal, pretty aggressive really in a lot of the meetings, and he talks about there being no alternative to the scheme. That's not strictly true.*
>
> *"… where I have a slight difference of opinion is where they slavishly say 'nothing can change' because farming changes, irrigation changes, the environment changes, and they have to be ready to adapt to that as well.*"
>
> (Interviewee 9)

> "*…he is a man of fixed opinions. He's right in a way. He's a real advocate for this. …he is quite a strong advocate, but you need a strong advocate."*
>
> (Interviewee 15)

> "*Mainly because of his vocal attitude and I would say certain people inside* [organisation] *would like to see it shut down from comments I've heard off the cuff. I think that would be a very bad outcome for the ecology of the catchment, but those people don't really care about the ecology of the catchment. They're box tickers.*"
>
> (Interviewee 20)

When asked whether they viewed ECGIS positively or negatively, 100% of interviewees indicated they viewed it positively. In exploring interviewee rationale for their perception of ECGIS, there were some very impassioned responses. Figure 3-47 summarises the reasons given for this perception. The largest factor was that ECGIS was seen as having a positive effect on maintaining aquatic ecosystems and thus promoting greater biodiversity because it maintains flow in the drains it uses. This was stressed by Other Interviewees in their responses:

> "*I would argue that* [ECGIS] *is probably one of the most environmentally friendly irrigation schemes in New Zealand. There's not many others that do as good a job as they do. It's got a lot going for it. They've done a good job over the years*."
>
> (Interviewee 16)

> "[ECGIS] *has probably the only decent ecological outcome of anything in the catchment, whether it was intended for the purpose or not. I have argued in the past, and I will continue to argue, that if Environment Canterbury does actually care about keeping some of the ecosystem alive, and not just ticking boxes, they should continue to fund some water into those drains*."
>
> (Interviewee 20)

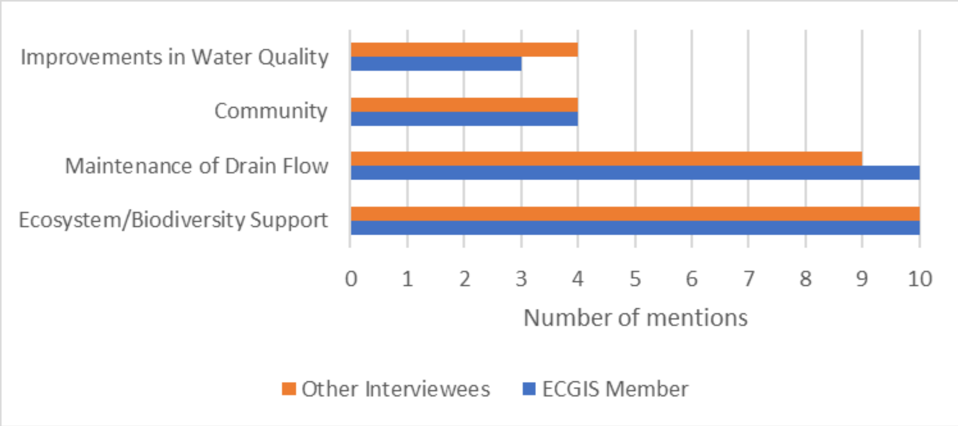

Figure 3-47 Bar Chart Showing Interviewee Identification of Factors Influencing Perception of Eiffelton Community Group Irrigation Scheme

Perhaps the most unexpectedly common rationale for viewing ECGIS positively was community (Figure 3-47). Many identified the importance of ECGIS in terms of knowing the people around you, having a strong social and support structure, and in terms of being better informed and aware of things that have the potential to impact individual situations. Interviewees emphasised the importance of strong social and societal relationships both within the district and further afield:

> "[ECGIS] *is a scheme that's a really good example of that 'David and Goliath' analogy where several of our farmers have invested tremendous time and energy and resources into that on behalf of the whole community. I just would like to think there's a huge acknowledgement from Environment Canterbury that their time and effort is welcomed and warranted because the day that farmers stop doing that, we've got huge issues in our rural towns*."
>
> (Interviewee 17)

As part of exploring factors that influenced interviewees' perception of ECGIS, some concerns were raised with operation, despite interviewees maintaining their positive stance. 82% of ECGIS Members and 50% of Other Interviewees commented on the costs associated with ECGIS, while an equal number of each group raised concerns regarding the reliability of power supply and the effects that has on ECGIS operation. 40% of Other Interviewees made the point that ECGIS does not guarantee flow to the coast and questioned the ecological value provided by ECGIS in failing to do so.

3.3.4 Values

Figure 3-48 summarises interviewee values associated with the Hinds Drains. Interviewee response was not limited to one category. ECGIS Member interest in the Hinds Drains predominantly relates to their function as drains. As per Interviewee 9: "*that's what they were there for; to drain the land*." Presence of introduced and native species was equally valued by ECGIS Members. As per Interviewee 11: "*There's a whole – life; the natural life revolves around the drains, and our farming operations revolve around the drainage network*." Recreation (e.g. swimming, fishing) was the value most associated with the Hinds Drains by Other Interviewees. Introduced species (e.g. trout) were mentioned least.

Interviewees were asked what they would like to see the Hinds Drains used for in a 'perfect world'. Most interviewees (55% ECGIS Members; 50% Other Interviewees) identified restoration of native species numbers, habitat, and increased biodiversity as their most desired use. 27% of ECGIS Members and 20% of Other Interviewees wanted to maintain drain function (to enabled continued agricultural land use). 27% of ECGIS members and 10% of Other Interviewees wanted to see the trout population restored. Many commented that while it would be nice to see greater biodiversity in the area, developing the drainage network to support such things should not come at the expense of their drainage function:

> *"You've got to have a balance. The pendulum may have gone a bit too far one way in terms of land development, but I really don't think so because if it can be managed to*

go that way, it can be managed to go the other way as well. It's just a matter of putting things in place, and for farmers to understand it."

(Interviewee 12)

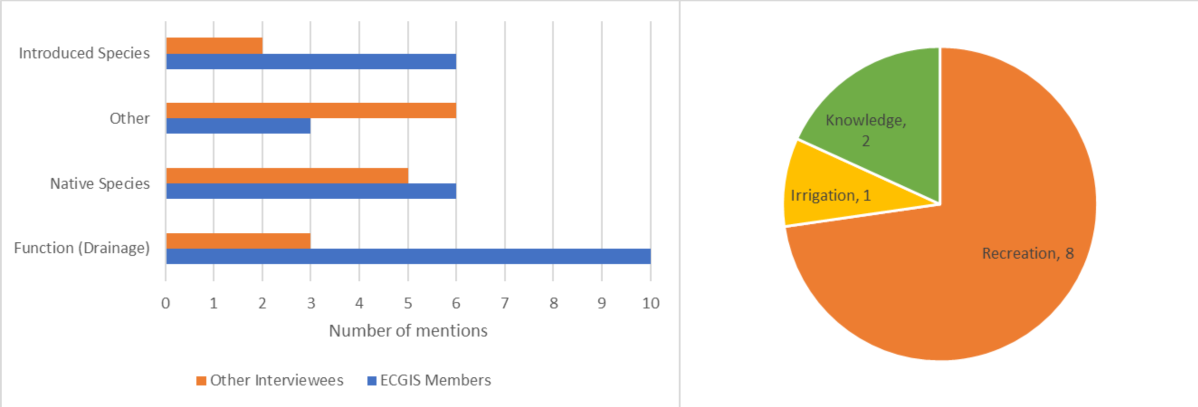

Figure 3-48 Bar Chart Showing Interviewee Identification of Interest in the Hinds Drains by Interviewee Type. Pie Chart Shows Breakdown of 'Other' Interests across All Interviewees ('Knowledge' Refers to Increasing One's Own Understanding of the System or Part Thereof)

3.3.5 Summary

21 interviews were conducted with ECGIS members, Zone Committee members, and other parties with interests in the Hinds Drains. Members of this community were aware of their social responsibility to each other and the environment. They indicated a desire to improve on the status quo but a reluctance to do so on the basis of good faith; they wanted to see evidence of benefit before making a significant financial commitment. It is not financially prudent to jeopardise their livelihoods for a chance of payoff. Interviewees indicated that they were willing to take measured risks:

"*I said to* [person] *'you can see what's happening in Europe as far as things are going, and at some stage you're going to get rules and regulations, so we may as well learn to farm – rather than going flat out and making a mess – may as well learn to farm for the future now, that way when the change does come it's not so dramatic.'*"

(Interviewee 6)

And this is perhaps the nature of things "*We're never satisfied, there's always a bit more that can be done*" (Interviewee 7).

3.4 Summary

This chapter has presented the results of qualitative and quantitative investigation undertaken to address objectives 1 to 3 and enable assessment for achieving Objective 4.

In addressing Objective 1 (document the operation of ECGIS and how operational decisions are made) it is found that there is no set procedure for operation of ECGIS. ECGIS management (consisting ECGIS members) operate ECGIS based on their understanding of infrastructure and systematic demands. Social responsibility to one another and the environment appears to be a key tenet of ECGIS. Such tenets are maintained and enhanced through common access to metering data, equitable division of costs, and intergenerational understanding. ECGIS tries to keep costs as low for members as possible, while still providing incentive for members to act in Board roles and keep ECGIS operating as effectively and efficiently as possible.

Considerable data was collected to address Objective 2 (determine the hydrological setting of ECGIS and its hydrological effects). Hydrology data shows dynamic fluxes of water along Windermere Drain, with generally consistent relationships between sites within arrays. Water quality data were considered in the context of pre- and during ECGIS operation. DO generally decreased during operation by an average of 1 mg/L, with drain sites having the highest values. EC values were generally consistent (25-35 mS/m) across arrays and between pre and during operation, with Scheme bores having noticeably lower values. Of the five nitrogen species sampled for, presentation of data focused on nitrate-N. Highest concentrations were found in Newtons and Boundary arrays (>13 mg/L), with Scheme bores and Surveyors piezos having significantly lower nitrate-N concentrations (<6 mg/L) than the other sites. Of the four phosphorus species sampled for, presentation of data focused on DRP. Highest concentrations (>0.01 mg/L DRP) were found in Poplar and Lower Beach piezos, with Scheme bores and Newtons and Boundary piezos having the lowest DRP concentrations (≤0.006 mg/L DRP).

21 interviews were conducted to meet Objective 3 (identify values associated with the Hinds Drains). ECGIS Member interest in the Hinds Drains predominantly relates to their function as drainage channels; to convey excessive water away from farmland and maintain its economic agricultural viability. Presence of introduced and native species was equally valued by ECGIS Members. Recreation (e.g. swimming and fishing) was the value most associated with the Hinds Drains by Other Interviewees.

4 Discussion

4.1 Objective 1: Document the Operation of Eiffelton Community Group Irrigation Scheme and How Operational Decisions Are Made

Section 3.1 documented the establishment, membership, leadership, operation, and costs of ECGIS. It also outlined operational decision-making within the context of ECGIS operation and membership. It is the opinion of the author that Section 3.1 adequately captured operation of ECGIS and rationale behind operational decision making. The intent of this Section is to further expand on key facets of ECGIS operation to better enable the remaining objectives to be addressed.

4.1.1 Communication

Good communication was identified as a fundamental to the success of ECGIS. Effective communication across levels of governance and understanding helps identify where different priorities lie and can potentially overlap (Rouillard and Spray, 2017). This is seen in ECGIS where conveyance of water for irrigation has also provided benefits for water quality and aquatic ecology. Effective communication can foster participatory approaches to resource management and serve as a catalyst for environmentally beneficial social change (Wijnen et al., 2012). Successful operation of ECGIS is inherently dependent upon timely and effective communication among its members. ECGIS Members must communicate to ECGIS management their intent to begin irrigation prior to doing so to ensure sufficient drain flow to meet both irrigation demands and minimum flows. ECGIS Leadership must communicate their decisions to members. They must also communicate with external parties to ensure ECGIS's continued operation. Effective communication is not guaranteed. Barriers to communication have (or have the potential to) become pressure points in the operation of ECGIS.

Member Communication of Intent to Irrigate

All bulk irrigation schemes in Canterbury rely upon members ordering water before irrigating, generally 24 hours prior. This gives time for water to travel between source and destination. ECGIS is a small and spatially discrete scheme which can allow more rapid response between irrigation requirement and water delivery. Water provision is still not instantaneous. Members failing to advise ECGIS management of intent to irrigate was identified as a frustration of ECGIS management. Generally, members were reliable at advising management of their intent to begin irrigating, but not always. This can affect provision of water to those who have followed the rules and result in noncompliance with minimum flow conditions. Action by the individual can affect the whole. So why are ECGIS members relied upon for this action when it can have such wide-reaching consequences? As each ECGIS production bore can be operated remotely, so too could each drain abstraction. For example, if an ECGIS member wanted to begin irrigating, they could physically turn their pump on, but no water is abstracted until one of the following conditions is met: 1) minimum flow being exceeded by the sought abstraction rate plus 20% (the buffer volume set by ECGIS management to ensure consent compliance), or 2) if 1) is not occurring, an alert is sent to the ECGIS manager advising of the desire to take. The ECGIS manager provides augmentation sufficient to enable abstraction. Once 1) is occurring abstraction can commence. Such a system would resolve management frustration and ensure fair and equitable access to water.

External Communication

ECGIS leadership, on behalf of ECGIS members, has been extensively involved in the processes associated with the LWRP for the better part of a decade. There is a general perception by ECGIS members that changes introduced through the LWRP threaten ECGIS's continued existence. Resultantly, there has been some fierce confrontations to 'protect' ECGIS. This does not help ECGIS, other communities, nor decision makers achieve resolution. Russell and Lennox (2011) and Green et al. (2015) identified that conflicting perceptions and understandings of resource management issues and processes can be overcome by effective, open communication between parties; allaying fears, building understanding and trust, and clarifying uncertainties. There has been extensive dialogue between parties, but conflict remains. It could be a case of an immovable object meeting an unstoppable force, or it could be the lack of a 'common language'; different interpretation of terminologies creating unnecessary conflict (Phillips et al., 2004). If a common language does not exist or is not explicit, parties could assume that all other parties interpret language and terms the same way they do. If this is the case, no matter how robust explanations may be, if people listen with different filters resolution will likely not be reached (Grigg, 2014). Friction with external agencies could be resolved by stepping back to this starting position and ensuring everyone is working from the same rulebook.

4.1.2 Community

ECGIS members set rules to manage individual abstraction based on a cumulative total to ensure equitable access to water, fair distribution of benefits, and better conservation and protection of freshwater in the ECGIS area. A defining characteristic of a community is the existence of social relationships and communication networks that bond the members (Curtis et al., 2014). The continued operation of ECGIS is inherently based on members understanding why ECGIS operates in the manner it does, working together as part of a whole, and communicating. Members who have joined ECGIS since inception described how they were initially sceptical of the touted benefits of ECGIS operating in the manner it does. After seeing ECGIS in action, they were convinced and now buy-in to targeted stream augmentation and associated benefits. Many passionately touted these benefits during their interview, with enthusiasm that paralleled those who had been members since inception. This reflects ECGIS as the catalyst of a community. It also highlights the importance of building and maintaining a community fabric based on long-term relationships, mutual respect, trust, communication and cooperation (Allen et al., 2011). Cooperation, cohesion, and community values were identified as important aspects of ECGIS, with ECGIS working best when everyone gets along and does their part. Communities that successfully link economic vitality, ecologic integrity, civic democracy, and social wellbeing have stronger foundations for fostering high quality of life and sense of reciprocal obligation (Memon and Weber, 2010). ECGIS foster these links with varying degrees of success. ECGIS demonstrated their reciprocal obligation by acting to resolve when members are receiving an inequitable supply of water and rectifying this by temporarily reducing access by other users until an equilibrium can be reached.

Social Responsibility

How ECGIS operates encourages social responsibility. All ECGIS members have access to the same data online and can view pumping across the whole scheme – by production bores and irrigation take by members. This encourages members to use only their share of total allocation as they can easily be held accountable by their neighbours. All interviewees local to the Eiffelton area discussed the community and social values that ECGIS provides. This included stronger connections and more active sharing of information. Part of this included recognition that activity on one property could affect others, ensuring that drains were not accessed or used in ways that are not permitted, and 'calling out' actions contrary to community values in a manner that encouraged compliance with societal norms rather than rebellion.

ECGIS Members saw value in the drains that cross their property beyond that provided in irrigation conveyance. They expressed desire to retain and enhance (where feasible) the drains aesthetic and ecological values. A key aspect of feasibility is proof of concept. This was demonstrated in recent years where ECGIS worked alongside Central South Island Fish and Game to install weirs in Windermere Drain to create conditions more suited to trout. This trial has proven successful, with the number of trout redds[8] increasing significantly since weir installation. Involved members have seen for themselves the increasing presence of trout in Windermere Drain. Tangible payoff of action strengthens the case for undertaking such action elsewhere, as could be said for use of targeted stream augmentation. ECGIS Members described a general desire to undertake actions that preserved and enhanced their environment but expressed a reluctance to do so in cases where their actions could be undermined.

Given the number of intergenerational farmers represented, it is perhaps to be expected that the ECGIS community has strong themes of preservation, for both their environment and themselves. They are willing to invest in systems that are proven to have benefit, be it economic or environmental. They are also willing to take measured risks on investments for the environment, as in the trout weir scenario, and in paying for augmentation beyond the irrigation season when drains would otherwise run dry, as seen in other Hinds Drains in recent years.

4.1.3 Hydrotechnical Solutions

Electronics must be online and communicating correctly (via telemetry) to enable them to operate and be operated remotely. Failures in the electrics and electronics of ECGIS is a problem faced by ECGIS

[8] A trout redd is a nest created within river gravels in which a trout lays its eggs

management. Power supply can be unreliable during peak irrigation season due to high regional demand. This leads to temporary power failures, and so cessation of pumping. Power failures do not affect ECGIS uniformly due to the distribution of the network. Information on electricity network distribution and system backups could not be readily located for further consideration herein. After a power failure production bores are meant to resume immediately. This is not always the case. Thus, there are two facets to the issue: how to ensure reliable power supply to production bores, and how to keep pumps operating. Having a backup power supply to each of the production bores could provide temporary power in the event of a power cut. It may not be cost effective to provide a secondary power source to all 20 ECGIS bores, but targeted deployment to those which are most heavily used and/or experience the most unreliability could offset the effects of a power cut. Alternatively, ECGIS could petition Electricity Ashburton to increase network capacity, or provide more fail-safes so that power failures are less of an issue. In terms of maintaining pumping, the existing system alerts ECGIS management when a pump fails so they can rectify the situation. Pump failures are not just due to power losses; there are a host of factors that can cause pumps to fail. It is the responsibility of ECGIS management to investigate each failure and resolve it. Investing in appropriate diagnostic software alongside alert management would reduce the time spent resolving pump failures and could reduce down-time, creating a more efficient system.

The remote operation of each production bore occurs in isolation. Each bore has a phone number which ECGIS management can phone or text (depending on configuration) for activation or deactivation. ECGIS management advised that remote operation of production bores for augmentation has been standard for over ten years. Production bore data can be viewed alongside drain abstraction data and drain flow data at the minimum flow sites on a Boraman's web portal. It could be considered that the individual operation of each bore, and the use of a separate system to monitor operative status is unnecessary. In this space, it is suggested that ECGIS could in a single system from which all members can view operations, as per the current Boraman's set up, but also from which ECGIS management can operate bores from a single space. This would streamline operational management of ECGIS. Incorporating the aforementioned alert system into such a space could further increase ease of managing ECGIS. Having a 'one-stop-shop' for management to operate pumps, see diagnostics and status, and for all members to access usage and flow data would improve on the status quo and create a more transparent and user-friendly setup.

In describing the status of the drains prior to the commissioning of the ECGIS, Middleditch (1983) describes the secondary drains[9] that run between the main drains of Deals, Windermere, and Home Paddock, as being used only "*during high flood flows"* (p. 5). This was also the case at the later writing of McFall (1991) report, stating "*there is provision to divert flows … This seldom occurs*" (p. 16). This is quite to the contrary of today's situation where ECGIS management divert water between drains as a matter of habit. This is to maximise efficient use of water by moving water most efficient bores to the highest demand areas. Flow is diverted via manually operated diversion gates such as that in Figure 4-1. These diversion gates are not fitted with any form of flow meters. The volume of water transferred between ECGIS drains is unknown, other than as reported in Section 3.1.5, with ECGIS management diverting "*a couple"* of bores worth of water across from Deals Drain to Windermere Drain. This is a potentially significant knowledge gap in understanding ECGIS operation and the effects thereof. If it is not known how much water is being transferred between drains, the cumulative effect of ECGIS operation on a given drain cannot be definitively determined, nor the influence of augmentation on parameter flux.

4.1.4 Perceived Threats

Changes to Water Use

As ECGIS is at the bottom of the Hinds Plains, activities that occur up-gradient affect the quantity and quality of water ECGIS receives and can access. When stockwater races and flood irrigation using out-of-catchment water were common in the upper Hinds Plains groundwater received significant recharge. This translated to strong spring flow and dilute contaminant concentrations down-gradient. These activities no longer occur. Council encouraged closure of stockwater races and requirements for irrigation efficiency saw conversion to spray irrigation. Farm intensity increased to increase productivity to service associated loans. This saw less recharge to groundwater by water of increasingly poorer quality that would eventually discharge as drain flow.

[9] Barkers, Whalebone Extension, Windermere Extension, Smiths, and Scotts drains

Figure 4-1 Example of a Flow Diversion Gate (Accessed 5/07/2019 from https://medium.com/@ShawnH2O/can-i-lose-my-california-water-right-7ea825226831)

The last decade this has seen the Hinds Drains run dry on many occasions, and for significant periods, killing large number of native and introduced aquatic species. The only Hinds Drains that had continuous flow during these periods were those augmented by ECGIS. ECGIS's ability to maintain flows sufficient to meet irrigation demand and minimum flow conditions during drought periods was challenged. Low groundwater levels meant less groundwater discharge to the drains and lower yield from production bores. Water could often not be supplied in sufficient resulting in restrictions. When there is no baseflow in the drains, it can take up to 20% of volume pumped from ECGIS production bores just to keep the drains wet. This is not a cost-effective nor an economically efficient use of water. As indicated by members, costs associated with ECGIS operation keep rising. If lack of baseflow is a condition that perseveres, it is not clear how long members can reasonably afford to continue to operate ECGIS.

ECGIS has also raised concerns relating to MAR. Thus far MAR has been largely confined to areas near Tinwald. The success of the trial to date has seen expansion of recharge sites. ECGIS is worried that MAR could result in groundwater flooding and loss of farm viability in the lower Hinds Plains. MAR could also be a replacement for the groundwater recharge that was previously provided by inefficient irrigation in up-catchment areas. MAR on the Hinds Plains is used to dilute concentrations of contaminants, predominantly nitrate. Water managers have increasingly considered using MAR for its traditional function; underground water storage. The conditions associated with the resource consents for MAR means it can only occur in conditions where groundwater recharge would not be otherwise happening, and with a limited volume of water. So long as the regulation and effects of MAR continue to be carefully monitored, modelled, and accurately predicted, concerns of the ECGIS community could be considered adequately mitigated and managed for.

Changes to Legislation

Plan Change 2 to the LWRP introduced rules relating to stream augmentation in the Hinds Plains area. Table 4-1 replicates these rules and indicates whether ECGIS meets them. ECGIS does not meet Rule 3.5.35 nor Rule 3.5.36 but could be granted a discretionary activity consent under Rule 3.5.36. ECGIS meets Rule 3.5.37. ECGIS saw these rules as a change to the status quo that would threaten their continued operation. ECGIS submitted on Rule 13.5.36 directly through the Plan Change 2 hearings process:

> "…*the conditions for this rule suggest a significant bias against some current activities that are known to have no adverse environmental or human health effects and specifically exclude the supply of irrigation water as a purpose for such discharges. The ECGIS relies on such discharges. We oppose 4 [delete 4] and propose the inclusion of irrigation in 5.*"
>
> (Eiffelton Community Group Irrigation Scheme, 2014)

> "*ECGIS considers that the conditions are unnecessarily restrictive and not reflective of reality (especially in the case of condition 4 – noting that in the case of the Scheme and elsewhere this will often be occurring already). ECGIS also considers that condition 5 of the rule should be amended to refer to irrigation.*"
>
> (Eiffelton Community Group Irrigation Scheme Incorporated, 2014)

These alterations were not adopted, as per Table 4-1. ECGIS were concerned that policies introduced in Plan Change 2 to the LWRP would see the scheme close by 2025. This concern first arose when the Zone Committee proposed a default position for allocating water from the Hinds Drains in the ZIPA. The Hinds Drains Working Party process attempted to address these concerns by undertaking transparent and collaborative community processes to understand drain flows to inform appropriate allocations from each of the main Hinds Drains. The final recommendations from the Hinds Drains Working Party had community support. However, these recommendations weren't seen as appropriately captured in Plan Change 2 to the LWRP It is understood that Plan Change 7 to the LWRP, publicly notified on 20 July 2019, was to give better effect to the Hinds Drains Working Party recommendations. It is not within the scope of this works to consider this plan change. On Plan Change 2, ECGIS submitted that

> "…*the proposed rules, allocation regime and minimum flows combine to make the ECGIS unworkable from 2020. No-one from the ZC* [Zone Committee] *discussed these proposals with us and the effect that these proposals will have on our irrigation supply and our farms and families.*"
>
> (Eiffelton Community Group Irrigation Scheme, 2014)

The adopted Plan Change 2 saw the provisions that ECGIS described as 'unworkable' delayed from 2020 to 2025, as per the below LWRP Policies:

13.4.22 *In the Lower Hinds/Hekeao Plains Area, with the exception of the Lower Hinds River/Hekeao, and until 30 June 2025, any water permit granted to replace an existing water permit will be subject to the minimum flow and allocation limits in Table 13(e).*

13.4.23 *After 1 July 2025 a minimum flow of 50% 7DMALF*[10] [seven-day mean annual low flow] *and an allocation limit of 20% 7DMALF will be applied to all water permits granted to abstract surface water from the waterbodies listed in Table 13(e), or to abstract groundwater with a direct, high or moderate stream depletion effect on those waterbodies, unless there is a collaboratively developed flow and allocation regime that has been included in this Plan through a Schedule 1 RMA process*

[10] LWRP 7dMALF definition: Determined by adding the lowest seven-day low flow for every year of record and dividing by the number of years of record (In any year the seven-day low flow is the lowest average flow sustained over seven consecutive days)

Table 4-1 Land and Water Regional Plan Plan Change 2 Rules Relating To Stream Augmentation in the Hinds Area

Rule		Does ECGIS meet the requirements of this rule?
13.5.35	The taking and use of surface water or groundwater in the Lower Hinds/Hekeao Plains Area for the sole purpose of augmenting surface water or groundwater to reduce concentrations of nitrate nitrogen in surface water or groundwater and/or increase flows in lowland streams is a discretionary activity.	**NO**. Stream augmentation does not occur for the sole purpose of reducing nitrate-N concentrations or increasing lowland stream flow – though these are by-products of ECGIS operation.
13.5.36	The discharge of water into water, or onto land in circumstances where it may enter water (where that water contains contaminants), that is for the purpose of augmenting groundwater or surface water within the Hinds/Hekeao Plains Area, is a restricted discretionary activity, provided the following conditions are met: 1. *The discharge is part of a trial for investigative purposes and the duration of the trial will not exceed 5 years; and* 2. *The activity does not take place on a site listed as an archaeological site; and* 3. *The discharge is not within a Community Drinking Water Protection Zone as set out in Schedule 1; and* 4. *The discharge is not within 100 m of any well used to supply potable water; and* 5. *The discharge is for the purpose of reducing the concentration of nitrate nitrogen in surface water or groundwater or increasing flows in lowland streams for ecological or cultural benefits.* The exercise of discretion is restricted to the following matters: 1. *The location, method and timing of the discharge to groundwater or surface water; and* 2. *The adequacy of the scheme design, construction, operation, monitoring, reporting; and* 3. *The appropriateness of integration with existing or planned infrastructure and water conveyance systems; and* 4. *Any adverse effects on people and property from raised groundwater levels and reduced drainage capacity in the drainage system; and* 5. *Any adverse effects on water quality in the receiving aquifer or river or significant habitats of indigenous flora and fauna; and* 6. *Any adverse effects on sites or values of importance to Ngāi Tahu from moving water from one catchment or water body to another; and* 7. *Any adverse effects on sites or areas of wāhi tapu, wāhi taonga or mahinga kai; and* 8. *The potential benefits of the activity to the community and the environment*.	**AT ENVIRONMENT CANTERBURY'S DISCRETION**. Of the five conditions needing to be met, ECGIS meets three: 1. *This condition <u>is not met</u> because the discharge is not part of an investigative trial and will exceed five years* 2. *This condition <u>is met</u> as the activity does not take place on a site listed as an archaeological site* 3. *This condition <u>is met</u> as the discharge is not within a Community Drinking Water Protection Zone* 4. *This condition <u>is met</u> as there are no potable use wells within 100 m of discharge locations* 5. *This condition <u>is not met</u> as the discharge is not for the purpose of reducing nitrate-N concentrations or increasing lowland stream flow for ecological or cultural benefits.* As all five conditions are not met, ECGIS does not immediately meet the conditions for this rule. In the matters of discretion: 1. *Location, method, and timing of discharges are well established* 2. *ECGIS design, construction, operation, and monitoring is compliant with existing consent requirements, so can be assumed adequate* 3. *ECGIS is integrated with existing water conveyance systems* 4. *ECGIS does not raise groundwater levels or reduce drainage as it only operates in time of high water demand* 5. *ECGIS ensures provision of habitat for aquatic fauna an moderates water quality* 6. *ECGIS operation does not affect sites of Ngai Tahu importance nor is it contrary to Ngāi Tahu values* 7. *ECGIS operation does not affect wāhi tapu, wāhi taonga or mahinga kai* 8. *Environmental benefits of ECGIS have previously been identified via the Hinds Drains Working Party Process, and community and environmental effects are explored in this thesis.* It is possible for ECGIS to be granted consent under this rule at the discretion of Environment Canterbury.
13.5.37	The discharge of water into water, or onto land in circumstances where that may enter water (where that water contains contaminants), that is for the purpose of augmenting groundwater or surface water in the Hinds/Hekeao Plains Area, that does not meet one or more of the conditions of Rule 13.5.36 is a discretionary activity.	**YES**. ECGIS meets this rule as it is a catch-all designed to capture all augmentation activities that do not meet 13.5.36.

These are 'defaults' to be applied in situations lacking detailed understanding. Table 13(e) of the LWRP sets flow and allocation from Deals, Windermere, and Home Paddock drains to what is currently specified on issued resource consents. This means that until 30 June 2025 ECGIS can operate unchanged. Beyond this date, Policy 13.4.23 applies. Under this policy, allocation limits are based on 7DMALF values unless a collaboratively developed flow and allocation regime has been included in the LWRP via a Schedule 1 RMA process. A Schedule 1 LWRP process is a full plan change process including public submissions and hearings. It is understood that such a flow and allocation regime has been included in Plan Change 7 to the LWRP for Deals, Windermere, and Home Paddock drains. Should this not be the case, or it is later excluded from the Plan Change, ECGIS would be subject to 7DMALF values beyond 2025 unless another plan change process can be ratified before this date. This is considered unlikely. In the ZIPA, anticipated abstraction volumes from the ECGIS drains under 7DMALF values would see reductions to:

- Deals Drain: 49 L/s (14% of current 347 L/s)
- Windermere Drain: 88 L/s (13% of current 690 L/s)
- Home Paddock Drain: 40 L/s (12% of current 333 L/s; (2014)).

These are drastic reductions on currently consented abstractive volumes. For abstractors on other Hinds Drains with similar reductions, this gives greater emphasis to switch their takes to deep groundwater, as permitted in the LWRP. In the case of ECGIS, operating under this regime is not possible. ECGIS already has deep bores, but without use of the drains, lacks conveyance infrastructure. Under Rule 13.5.36 (/37) of the LWRP, ECGIS could continue to operate via targeted stream augmentation in spite of these policies. These rules give Environment Canterbury discretion to grant consents for targeted stream augmentation that do not meet the plan rules. Environment Canterbury granting consent under these rules could depend on the relative weighting given to the evidence of beneficial effects from ECGIS operation versus black and white interpretation of LWRP policies.

4.1.5 Summary

Good communication is critical to the successful operation of ECGIS. Internally this is generally adequate but there can be friction in relation to provision of water. Externally, there is friction with legislative bodies. These strained relationships are the result of failed communication. Dedication, sincerity, and relationship building on both sides is required to re-establish relationships. This will not be straightforward if each continues to be suspicious of the other's agenda.

Community is a big part of ECGIS. ECGIS has provided for stronger relationships between neighbours and direct conflict resolution. ECGIS has brought members closer together so that members better understand one another and what is happening beyond their farm gate. ECGIS has fostered a sense of social responsibility to one another and to the environment within which ECGIS is situated. ECGIS members value the drains for the inherent values (ecological, aesthetic, drainage) they provide, as well as for a means of water conveyance. This is potentially enhanced by the presence of many intergenerational families.

Electronics are used across ECGIS, but technological failures are a time-consuming reality for ECGIS management. Suggested are integrated interfaces and alert systems to reduce time associated with active ECGIS management. Transfer of water between drains is the only unmetered aspect of ECGIS, thus a potentially significant knowledge gap in understanding.

ECGIS does face several challenges. Changing water use practices have impacted the cost effectiveness of ECGIS operation, through reducing baseflow in the drains and increasing pumping costs. Changes in water use practice have been driven by legislation. New legislation is further changing practices and posing alternate threats to the longevity of ECGIS. Despite operating under a system of targeted stream augmentation for over 30 years, ECGIS does not meet the conditions to operate as a restricted discretionary activity under Plan Change 2 to the LWRP. Policies introduced in this plan change would mean that targeted stream augmentation in support of irrigation would no longer be viable. Rules introduced in Plan Change 2 do give scope for ECGIS to apply for a discretionary consent to overcome this. ECGIS is of the understanding that Plan Change 7 to the LWRP includes a regime to meet Policy 13.4.23 and enable ECGIS to continue to operate in the same manner. ECGIS leadership is anxious to see whether this is indeed the case.

4.2 Objective 2: Understand the Hydrological Setting of ECGIS and How Scheme Operation Impacts Measured Parameters

Section 3.2 presented the data collected for this investigation, separated into water quantity and quality themes, and again by whether it coincided with anticipated irrigation season as appropriate. This section discusses both hydrological and hydrochemical data to describe the hydrological setting of ECGIS and the effects of ECGIS operation. Information relating to determining the hydrological setting and that relating to the effects of ECGIS operation are presented separately herein to demonstrate achievement of both parts of this objective.

4.2.1 Setting: Hydrology

Correlations and derivation of R^2 are used to understand relationships between hydrological interactions within and between arrays. R^2 is a statistical value that indicates how well values fit to a 1:1 relationship; 100% is a 1:1 fit. The lower the percentage, the poorer the fit. Where there is a strong relationship between data, this suggests influence of the dependent factor on the independent factor. The lower the R^2, the greater the difference in influence between sites. Examples of external influences include preferential flow paths, local confinement, rainfall, pressure gradients, water use, etc.

Drain discharge, groundwater level and rainfall rate were considering alongside one another to identify relationships and drivers of change. Correlations were performed to calculate R^2 values to understand relationship strength. Sites with strong correlations suggest response to the same influences. Table 4-2 summarises relative influences on each piezo. The correlation between piezo data within the arrays of Newtons, Boundary, and Surveyors suggests at these arrays, the dominant driver of groundwater level was groundwater pressure gradients. At Poplar and Lower Beach drivers appear to be a balance between groundwater and surface water pressure gradients.

Table 4-2 R^2 for Correlations between Considered Hydrological Data. Site Order Reflects Distribution Inland to the Coast. Green Cells Are the Best Correlation to Each Piezo. Blue Cells are Additional Correlations >75%

		Array Piezo	Other Piezo	Rainfall[A]	Gauging Discharge	Poplar Discharge	Lower Beach Discharge
Newtons	Bank Piezo	77%	67%[1]	26%	68%	48%	36%
	Bed Piezo	77%	43%[1]	40%	59%	39%	25%
Boundary	Bank Piezo	94%	46%[2]	41%	27%	37%	59%
	Bed Piezo	94%	58%[3]	11%	26%	58%	44%
Surveyors	Bank Piezo	93%	69%[2]	22%	56%	11%	8%
	Bed Piezo	93%	92%[4]	18%	43%	16%	7%
Poplar	Bank Piezo	79%	92%[5]	34%	70%	17%	12%
	Bed Piezo	79%	77%[5]	24%	96%	45%	27%
Lower Beach	Bank Piezo	64%	78%[2]	36%	65%	37%	34%
	Bed Piezo	64%	58%[2]	42%	73%	58%	58%

[1] Boundary Bed Piezo
[2] Poplar Bed Piezo
[3] Lower Beach Bed Piezo
[4] Poplar Bank Piezo
[5] Surveyors Bed Piezo
[A] Based on green cells in Table 4-3

In considering piezo logger data, the best correlations were seen between Boundary piezos (94%), between Surveyors piezos (93%), between Surveyors Bed Piezo and Poplar Bank Piezo (92%), and between Surveyors Bank Piezo and Poplar Bank Piezo (91%). These strong relationships suggest similar influences. When a change is seen in one site in one of these groupings, it should also be evident in the other(s). Other grouping of piezos with some relationship included Boundary and Newtons bank piezos, and Lower Beach Bank Piezo with Surveyors Bed Piezo and Poplar piezos. These had some relationship, but not as strong as seen between the Boundary piezos, and the relationship between Poplar Bank Piezo and the Surveyors piezos meaning they had some degree of similar drivers.

Logger data was correlated against rainfall to understand the influence of rainfall on collected data. Table 4-3 presents results. None of the correlations were particularly strong, indicating that though rainfall may be an influence, it is not a significant driver in most cases. Where groundwater level or drain flow and cumulative rainfall rate best align suggests how long it takes for rainfall recharge to be seen. The Newtons and Boundary piezo data best correlated to cumulative rainfall rate between one and two days. This same delay was seen in the drain flow loggers. Drain flow logger data had the strongest correlation with rainfall; both site at over 50%. Boundary Bank, Surveyors, and Poplar piezos had poor correlations with rainfall. The rate of recharge seen at the Newtons piezos, Boundary Bed Piezo, and flow loggers was much faster than what was calculated for the remaining sites. Rainfall appears to drain to shallow groundwater very rapidly at Newtons, disperse more widely and slowly in the middle three sites, but appears to accumulate at the lowest site. Data suggested rainfall influence on levels in the Lower Beach Bed Piezo after three days, and the Bank Piezo after 30. A significant difference for such closely positioned sites. These patterns illustrate that shallow groundwater behaviour varies significantly down the Windermere Drain catchment and have very different rainfall influence behaviours.

Table 4-3 R^2 Derived from Correlations between Logger Data and Cumulative Rainfall Rate across Specified Intervals. Green Cells Are the Best Correlation for Each Site, Blank Cells are <1%. Site Order Reflects Distribution from Inland to the Coast

	Newtons		Boundary		Surveyors		Poplar			Lower Beach		
Interval	**Bank Piezo**	**Bed Piezo**	**Bank Piezo**	**Bed Piezo**	**Bank Piezo**	**Bed Piezo**	**Bank Piezo**	**Bed Piezo**	**Drain Flow**	**Bank Piezo**	**Bed Piezo**	**Drain Flow**
1 Day	38%	25%	10%	**41%**		1%	1%	13%	55%	5%	25%	41%
2 Days	**39%**	**25%**	**10%**	37%	1%	1%	2%	17%	**56%**	12%	36%	**54%**
3 Days	30%	19%	8%	27%	1%	2%	4%	16%	45%	18%	**36%**	41%
14 Days	10%	13%	1%	8%	6%	7%	12%	20%	23%	**33%**	31%	12%
30 Days	11%	17%		7%	14%	16%	21%	31%	24%	42%	32%	9%
40 Days	10%	16%		7%	17%	20%	24%	33%	24%	40%	30%	8%
45 Days	9%	16%		7%	18%	22%	**24%**	33%	22%	40%	26%	7%
50 Days	9%	17%		7%	17%	**22%**	23%	**34%**	20%	39%	22%	6%
55 Days	7%	17%		6%	**18%**	22%	22%	34%	20%	37%	18%	6%
60 Days	6%	19%		5%	18%	22%	22%	34%	24%	36%	16%	7%

When considering the correlations at each array between the monthly manual measurements (of groundwater level and drain discharge), a strong correlation was evident between Poplar Bank Piezo and gauging. Reasonable correlations were also evident at Newtons and Poplar Bed piezos, and the Lower Beach piezos. Boundary piezos had the weakest correlation with gauging data, suggesting drain flow does not influence groundwater level. This is consistent with conceptual understanding; that groundwater discharges to surface water in the upper reaches of Windermere Drain. At Newtons, Boundary, and Surveyors arrays gauging data related better to bed piezos than bank. For the Poplar and Lower Beach arrays the inverse was true. This suggested that in the case of the former, drain flow benefitted from groundwater discharge through the drain bed, while for the latter groundwater benefitted from drain discharge through the drain. Surveyors array data suggested a weak influence of drain flow on groundwater level, with a marginal relationship evident at the Newtons array. Correlation values for the Boundary piezos were almost identical, suggesting a stable relationship between local groundwater and that drain flow was not a significant factor in this. Boundary piezos had the strongest correlations to instantaneous flow logger data at Poplar and Lower Beach (Table 4-2). This is despite significant separation distance and other sites in between that did not have the same strength of relationship. In considering rainfall data, it became apparent that these correlations were because of a similar time lag associated with rainfall and flow at the logger sites and rainfall and groundwater level response in the Boundary piezos.

Summary

This section explored relationship between hydrological features. Strong correlation between considered sites indicates similarity of influences. External influences are largely unaccounted for. It is understood that groundwater discharges to the drain at the Boundary array. The presence of macrophytes across the gauging site (Appendix 2) may have compromised the relationship between piezo data and Drain data. Though the piezos correlated well to each other, correlation with drain discharge was poor. Relative strength of correlation suggests that Surveyors piezos and Poplar Bank Piezo respond mainly to regional groundwater flow, while Poplar Bed Piezo responds predominantly to drain discharge. Lower Beach piezos mimic Poplar piezos. Data from flow loggers suggest drain flow has a much stronger response to rainfall than shallow groundwater. Response to rainfall is seen in data within one to two days, and again between 45 and 55 days.

4.2.2 Setting: Water Quality

As per Section 3.2, Newtons and Boundary arrays had the highest concentrations of nitrogen species, including nitrate-N. At each array the drain site generally had the highest concentrations of nitrate-N. Scheme bores and Surveyors piezos had nitrate-N concentrations much lower than the other sites. Scheme bores had the lowest phosphorus concentrations. Highest DRP concentrations were found in Poplar and Lower Beach piezos. Drain sites generally had the highest DO concentrations. Most sites had decreases in DO during irrigation season. There were no significant differences in EC concentrations across arrays, most samples ranging 25-35 mS/m. Scheme bores had noticeably lower concentrations at around 15 mS/m. *E. coli* detections were lowest at the top of ECGIS. Lower Beach and Poplar arrays, Surveyors Bed Piezo, and all drain sites had the highest concentrations.

One potential cause of both elevated *E. coli* counts, and nitrate-N concentrations seen in drain water, and to a lesser extent in groundwater, is effluent. Figure 4-2 shows consented effluent discharges relative to ECGIS features based on publicly available consent data. Based on this, it appears consented dairy effluent discharge along Windermere Drain appears to only occur coastward of New Park Road. However, interviews with ECGIS Members indicated that dairy does happy above New Park Road. This information is likely incomplete.

ECGIS irrigation water is used on crops and grass. The suitability of water for these purposes needs to be considered. To do this, water quality data was considered against ANZECC (2000) water quality guidelines for suitability for irrigation water quality and ecosystem health. The Hinds Plains area also has water quality targets set under Plan Change 2 to the LWRP; water quality data must also be considered in this context. The following Sections consider investigation data against these standards.

Comparison to ANZECC Water Quality Standards for Irrigation

ANZECC (2000) sets limits for water quality for irrigation use for salinity, major and radioactive ions, metals, pesticides, nitrogen, phosphorus, and biological parameters. All samples had electrical conductivities within the tolerance for sensitive crops. Ions, metals, and pesticides were not sampled for. Nitrogen is an essential plant nutrient. Excess quantities of soil and soil surface nitrogen can see it leach into the ground and/or be carried by overland flow to surface waters. Excess nitrogen can also alter plant morphology and stimulate algal growth. Nitrogen in irrigation water can increase maintenance costs to clear excessive vegetation growth in irrigation channels and biological growths from operational and fish exclusion screens. Total nitrogen is the sum of soluble nitrate-N, nitrite-N, organic-N and ammonia, and particulate nitrogen content. Total nitrogen is used by ANZECC (2000) in its guidelines for water quality. Soluble organic nitrogen was not measured, only the components of soluble inorganic nitrogen. Total nitrogen cannot be estimated, but the fraction of soluble inorganic nitrogen contributing to this can be assessed against long- and short-term total nitrogen trigger values. Total phosphorus consists the sum of its reactive and unreactive parts, each of which consists dissolved and particulate forms. Phosphorus is usually found in the form of phosphates in minerals, which are more soluble than the pure form (ANZECC, 2000). Biological parameters were measured in the form of *E. coli. E. coli* are a gut bacterium found in warm blooded animals (birds and mammals), so their presence in the environment can be indicative of raw or treated effluent. Outside of the body *E. coli* generally die-off within days. Sampling for *E. coli* can capture both instances of isolated discharges and indicate persistent sources.

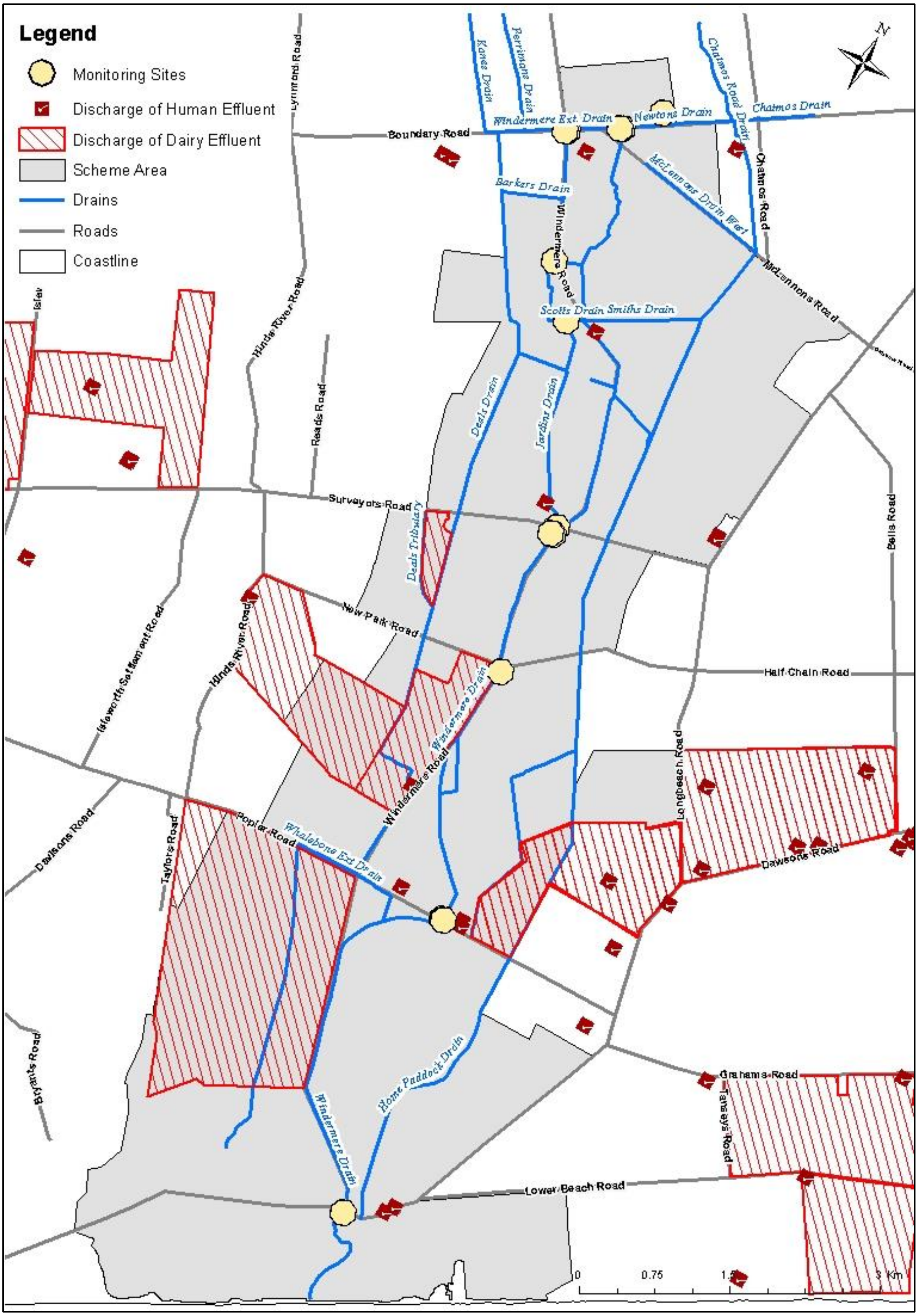

Figure 4-2 Effluent Discharges Relative to Eiffelton Community Group Irrigation Scheme and the Drains it Uses

Medians of inorganic nitrogen, TP, and *E. coli* were compared against ANZECC (2000) trigger values for irrigation water (Table 4-4). For each parameter three medians were derived; one from all data (overall), one from March-September 2018 data (pre-irrigation), and one from October 2018-April 2019 data (irrigation). Table 4-4 suggests the suitability of drain water for irrigation use decreases with distance down-gradient, especially regarding *E. Coli*. Given ECGIS takes from surface water this is a potential area for concern. It raises questions regarding the source of *E. coli*, the adequacy of the riparian area of Windermere Drain for capturing/treating overland flow, and whether the subsurface drainage is providing a quick flow path (as in Section 1.3), preventing biological processes from providing an ecosystem service by reducing the *E. Coli* count.

Table 4-4 Comparison of Median Inorganic Nitrogen, Total Phosphorus, and *E. Coli* Values to AZECC Trigger Values for Irrigation Water. Medians Are Included for All Collected Data ('Overall'), Pre-Irrigation ('Pre-Irr', March-September 2018), and Irrigation ('Irrig', October 2018-April 2019). 'All' Indicates Where Each Median Falls Within the Same Category

	Median Inorganic Nitrogen (mg/L)		Median TP (mg/L)		Median *E. Coli* (CFU/100 mL)		
	<5	>5	<0.05	>0.05	<10	<100	<1000
Newtons Bank Piezo		All	All		All		
Newtons Bed Piezo		All	All		All		
Newtons Drain		All	All			All	
Boundary Bank Piezo		All	All		All		
Boundary Bed Piezo		All	All		All		
Boundary Drain		All	All			Overall Pre-Irr	Irrig
Scheme Top 1	All		All		All		
Scheme Top 2	All		All		All		
Scheme Middle	All		All		All		
Scheme Bottom	All		All		All		
Surveyors Bank Piezo	All		All		All		
Surveyors Bed Piezo	All		All			Overall Irrig	Pre-Irr
Surveyors Drain		All	All				All
Poplar Bank Piezo		All	All			Pre-Irr	Overall Irrig
Poplar Bed Piezo		All	Overall Pre-Irr	Irrig	All		
Poplar Drain		All	All				All
Lower Beach Bank Piezo		All	All		All		
Lower Beach Bed Piezo		All	All		All		
Lower Beach Drain		All	All				All

Inorganic nitrogen was assessed against the ANZECC (2000) long-term (>20 years) trigger value for total nitrogen (5 mg/L). This value was set to ensure no decrease in crop yields or quality (ANZECC, 2000). Most inorganic nitrogen medians exceeded this value (Table 4-4). Scheme bores and Surveyors piezos were the only sites below this limit. No inorganic nitrogen medians exceeded the short-term trigger value (<20 years; 25 mg/L) but some sites had inorganic nitrogen concentrations above 50% of this value. The relative contribution of organic nitrogen could see the total nitrogen short-term value exceeded. Almost all sites had median TP concentrations below the long-term trigger value of 0.05 mg/L. This value was set by ANZECC (2000) to restrict algal growth. Poplar Bed Piezo irrigation median was the only value to exceed this. This suggests there may be an additional TP source during this period. Medians did not exceed the TP short-term value (0.8 mg/L) but there were individual values that did. *E. Coli* has three ANZECC (2000) trigger values. <10 CFU/100 mL is the limit for raw food crops in direct contact with irrigation water. Newtons, Boundary, and Lower Beach piezos; Scheme bores; Surveyors Bank Piezo, and Poplar Bed; Piezo all fell within this classification. This suggests a lack of persistent *E. Coli* sources. Newtons Drain falls into the next category of <100 CFU/100 mL; the limit for pasture for dairy animals without holding period. The final trigger is <1,000 CFU/100 mL for raw food crops not in direct contact with irrigation water, pasture for dairy animals with 5-day holding period, and pasture for grazing animals. All medians for Surveyors, Poplar, and Lower Beach drains were in this category. This suggests a persistent source of *E. Coli* relative to Windermere Drain in these locations.

Comparison to ANZECC Water Quality Standards for Aquatic Ecosystems
The ANZECC (2000) guidelines define trigger values that offer 95% species protection for freshwater ecosystems. Appendix 4 identifies exceedances while Figure 4-3 presents a summary of exceedances by site. Scheme bores and Surveyors array had least exceedances. Drain sites in the lowermost arrays had the least exceedances of ecological triggers, while inland they had the most. Down-catchment piezos had the most exceedances overall. Appendix 4 suggests a general increase in exceedances during irrigation season compared to the preceding months across all sites.

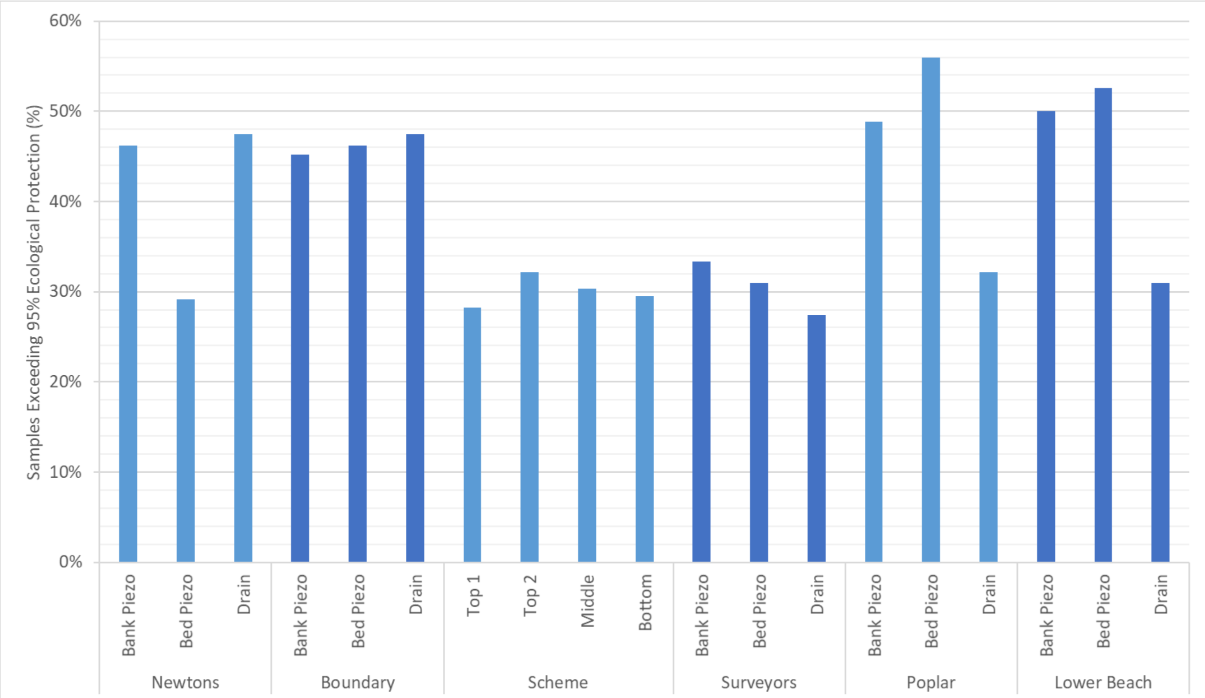

Figure 4-3 Percent of Samples That Exceed The 95% Protection Level for Freshwater Ecosystems (As Defined In ANZECC (2000)) By Site. Considered are Total Nitrogen[11], Total Phosphorus, Total Ammoniacal-N, pH, Dissolved Reactive Phosphorus, and Dissolved Oxygen Data. Legend Order Reflects Site Order: Inland to the Coast.

All samples exceeded limits for at least one parameter. One sample had five parameter exceedances (of six sampled for). 43% of samples had at least three parameters that exceeded ANZECC (2000) values for ecosystem protection. 92% of samples were above the trigger level for nitrogen oxides (nitrate-N + nitrite-N). Surveyors piezos were the only sites to not regularly exceed this value. 67% of samples were outside the DO range and 44% of samples outside the pH range. DO was generally within the ANZECC (2000) range across winter at all sites indicating a temporal influence, potentially from ECGIS discharging lower DO groundwater from deeper production bores to the drains. Scheme bores and drain sites from Surveyors coastwards were generally within the ANZECC (2000) range for pH. 23% of samples exceeded the trigger value for DRP. The vast majority of these exceedances were in the arrays from Surveyors coastward. 7% of samples exceeded TP values, mainly from Poplar piezos and Lower Beach Bed Piezo and Drain. No exceedances occurred over winter. Only 2% of samples

[11] Total inorganic nitrogen competent of total nitrogen as organic nitrogen was not measured

exceeded the trigger value for ammoniacal nitrogen. Three of the four samples were collected in May 2018 suggesting an anomaly at this time.

Comparison to LWRP Limits

Nitrate-N is a key contaminant of concern in Canterbury, as it worldwide in agricultural areas. High concentrations occur where poor farming practices have seen excessive leaching from land. The Ashburton area has long been recognised as one with elevated nitrate-N concentrations (Hanson, 2002, Hanson et al., 2006, Meredith and Lessard, 2014, Moore, 2014, Scott, 2013, Walsh and Scarf, 1980). Plan Change 2 to the LWRP saw introduction of a nitrate-N target for the Hinds Plains area. By 2035 nitrate-N concentrations from groundwater and spring-fed streams are not to exceed an annual median of 6.9 mg/L and an annual 95th percentile of 9.8 mg/L. Table 4-5 presents annual median nitrate-N concentrations from investigation data relative to LWRP nitrate-N targets. As with the comparison to ANZECC (2000) irrigation water quality standards, three averages are presented; one from all data (overall), one from March-September 2018 data (pre-irrigation), and one from October 2018-April 2019 data (irrigation). Scheme bores and Surveyors and Poplar piezos had medians that met the 2035 median target for nitrate-N. These and Poplar piezos also met the 2035 95th percentile target for nitrate-N. Groundwater at the top of ECGIS had higher nitrate-N concentrations than those further down-catchment. This suggests that elevated nitrate-N concentrations along the length of Windermere Drain could be a relic of groundwater inflow from the upper reaches, or an alternate source. Recommendation 6.1.d. of the ZIPA (2014) sets interim nitrate-N targets for 2020 (9.4-10 mg/L), 2025 (8.8-9.4 mg/L), and 2030 (7 mg/L). Blue cells of Table 4-5 indicate values that meet 2020 target values. Newtons and Boundary arrays were well in excess of targets. Drain sites at the remaining arrays were similarly poorly tracking towards these targets whereas piezos were generally on-track. Considering pre-irrigation versus irrigation values suggests contribution of ECGIS's targeted stream augmentation to lower nitrate-N concentrations across investigation sites.

Table 4-5 Annual Median and 95th Percentile Nitrate-N Concentrations for All Data ('Overall'), Pre-Irrigation (March-September 2018), and Irrigation (October 2018-April 2019). Green Cells Meet 2035 Land and Water Regional Plan Targets (Median 6.9 mg/L, 95th Percentile 9.8 mg/L), Blue Cells Meet the Hinds Plains Zone Implementation Programme Addendum 2020 Interim Target (Median 9.4-10 mg/L)

	Annual Median (mg/L)			Annual 95th Percentile (mg/L)		
	Overall	**Pre-Irrigation**	**Irrigation**	**Overall**	**Pre-Irrigation**	**Irrigation**
Newtons Bank	14.3	14.9	14.0	16.2	17.1	14.8
Newtons Bed	13.3	14.1	13.1	14.4	14.5	13.6
Newtons Drain	11.5	11.5	11.5	13.3	14.0	12.2
Boundary Bank	13.8	13.8	13.8	15.1	15.1	14.7
Boundary Bed	13.7	14.1	13.3	15.2	15.1	14.8
Boundary Drain	13.7	14.5	13.1	15.1	15.1	14.6
Scheme Top 1	4.2	4.2	4.2	4.4	4.4	4.4
Scheme Top 2	3.4	3.3	3.5	4.8	3.4	5.4
Scheme Middle	4.2	4.3	4.0	4.3	4.3	4.3
Scheme Bottom	4.0	4.0	4.0	4.1	4.1	4.1
Surveyors Bank	0.2	0.1	0.4	3.7	0.5	4.0
Surveyors Bed	0.0	0.1	0.0	1.9	0.6	2.6
Surveyors Drain	12.0	12.1	10.5	12.4	12.5	11.8
Poplar Bank	7.3	7.7	6.6	7.9	8.0	7.6
Poplar Bed	7.0	7.5	6.2	8.9	9.0	7.5
Poplar Drain	11.9	12.3	9.4	12.5	12.7	11.5
Lower Beach Bank	8.8	10.7	7.1	11.6	11.8	10.5
Lower Beach Bed	8.9	11.4	7.8	11.7	11.7	10.6
Lower Beach Drain	11.2	12.0	9.1	12.4	12.4	10.7

Summary
To contextually understand water quality data, it was assessed against ANZECC (2000) use suitability guidelines and LWRP targets. When considering ANZECC (2000) guidelines for irrigation water all sites except Scheme bores and the Surveyors array exceeded the long-term total nitrogen value based on inorganic nitrogen data only. This suggests potential to exceed the short-term trigger value depending on relative volume of organic nitrogen. Only the Poplar Bed Piezo had a median that exceeded the long-term trigger value for TP in irrigation water. With distance coastwards there was a general increase in the quantity of *E. Coli* in drain water, reducing its suitability for irrigation use. Where sites did not have all *E. Coli* medians fall within the same category, it was generally the irrigation median that was the highest of the three presented. All samples from every site had at least one exceedance of an ANZECC (2000) ecosystem protection trigger value. Least exceedances were in Scheme bores and the Surveyors array, and down-gradient drain sites. There was an increase in exceedances of ecological protection thresholds during irrigation season. When considering nitrate-N concentrations, six sites already meet the 2035 target of 6.9 mg/L set in the LWRP. Four of these are the deeper scheme bores. Four additional piezos are also below the 2020 target of 9.4-10 mg/L. None of the sites at the top ECGIS are on track to meet this, neither is Windermere Drain at any of the locations sampled. Nitrate-N concentrations decreased at all sites across irrigation season.

4.2.3 Setting: Surface Water-Groundwater Interaction

All water within the ECGIS area is groundwater dependent as the drains are spring-fed. This Section presents characterisation of each array based on collected data.

Figure 4-4 presents a summary of conclusions derived from data collected from the Newtons array. Groundwater elevation in Newtons Bank Piezo was higher than the drain stage. Groundwater elevation in Newtons Bed Piezo was below the drain bed (Section 3.2.3). This may suggest a locally depressed water table, or that the piezo inadequately penetrated the hyporheic zone. It may also suggest local perching of the drain above groundwater, with lateral groundwater inflow. Newtons array had high nitrate-N and DIN, and low DOP and TP. Newtons piezos had high EC and low *E. coli*, DRP, and TDP (Figure 4-4). This suggests low phosphorus concentrations in groundwater and low faecal contamination. Elevated *E. coli* in Newtons Drain is likely from an alternate (surface) source. As all sites had high nitrate-N but Newtons Drain had lower EC, there may be hyporheic processes (Section 1.1.1) sequestering ions that could otherwise contribute to elevated EC. Elevated phosphorus species in Newtons Drain samples suggest additional inflows of contaminant-laden water. Based the conceptual examples of Winter (1998) (Section 1.1), it is considered that the Newtons array represents a gaining stream with some localised disconnection. It also likely receives additional inflows of water and contaminants, as suggested by elevated *E. coli* and phosphorus concentrations relative to groundwater.

Figure 4-5 presents a summary of conclusions derived from data collected from the Boundary array. Groundwater elevation was greater than the drain stage, with the Bed Piezo having greater head than the Bank Piezo. Boundary Bed Piezo head being greater than stage elevation indicates groundwater discharging to surface water. Boundary array had high EC, nitrate-N and DIN. As the array had high EC and nitrate-N it is possible that elevated EC is dominated by concentrations of the nitrate ion. Piezos had low DO, *E. coli* and nitrite-N, while Boundary Drain had elevated concentrations of these. Elevated nitrite-N concentrations in Boundary Drain alongside elevated DO seems contradictory as nitrite-N is a reduced form of nitrate-N so generally present in anoxic conditions. At the Boundary array, as at Newtons, drain water again has elevated phosphorus and *E. coli* concentrations. The close proximity of the two arrays may suggest similar sources of up-gradient contamination. Lack of evidence in groundwater suggests similar surface contaminant pathways from discrete locations. Based the conceptual examples of Winter (1998) (Section 1.1), it is considered that the Boundary array consists of a well-connected gaining reach, with some contribution of additional overland inflow accounting for elevated *E. coli* and phosphorus.

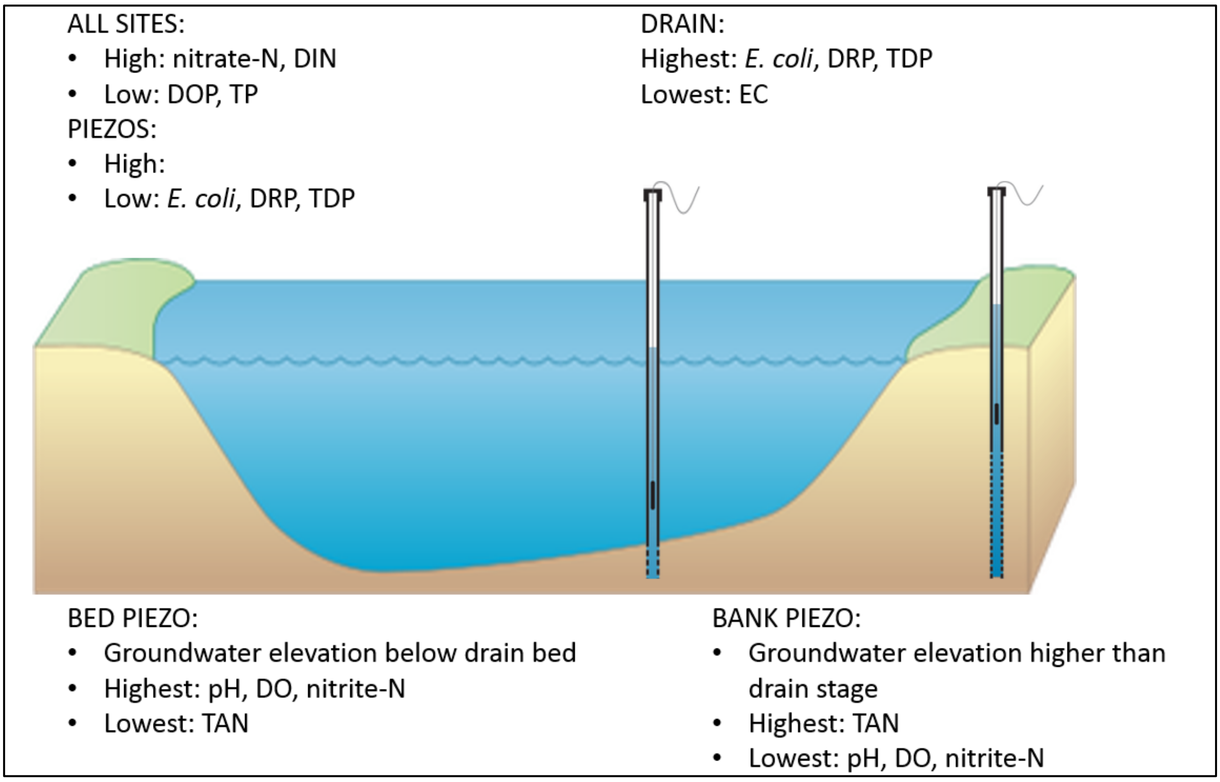

Figure 4-4 Summary of Data from Newtons Array

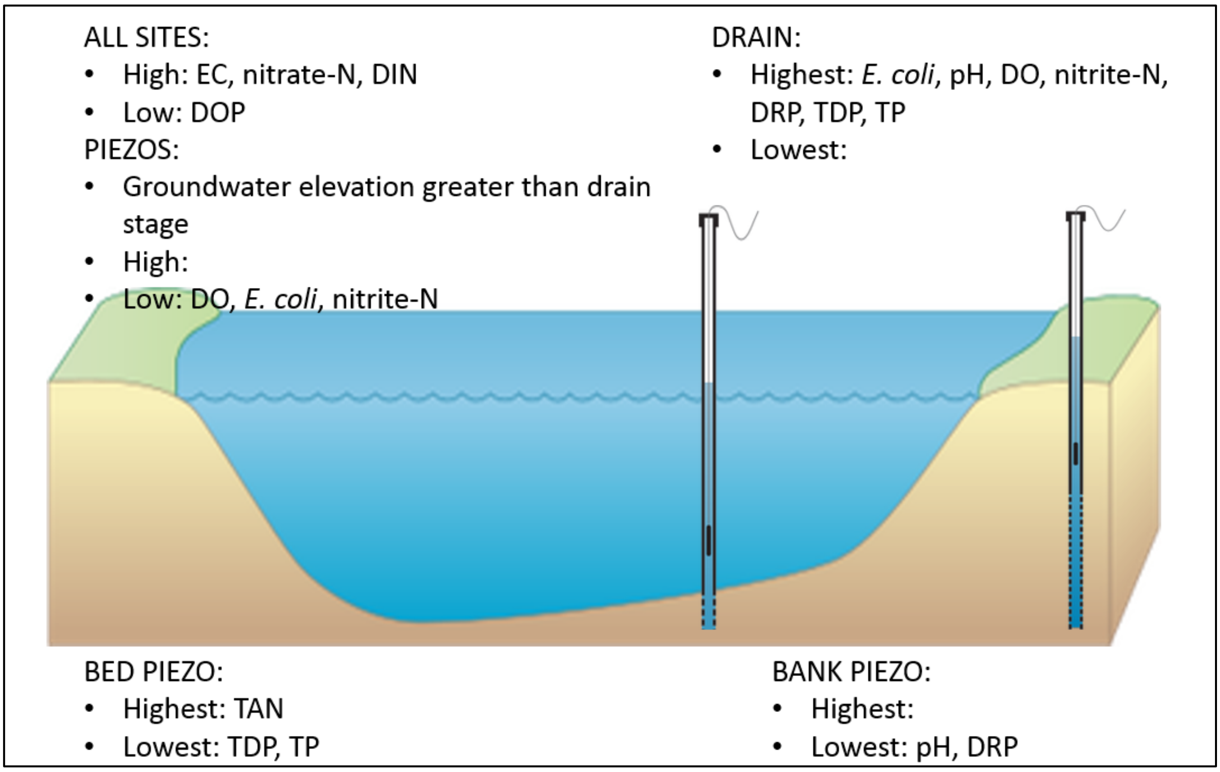

Figure 4-5 Summary of Data from Boundary Array

Figure 4-6 presents a summary of conclusions derived from data collected from the Surveyors array. Unlike at Newtons and Boundary, concentrations of nitrate-N in Surveyors piezos are significantly lower than in Surveyors Drain. Nitrate-N concentrations from Surveyors piezos were similarly significantly lower than all other drain and piezos water quality samples collected for this investigation. Nitrate-N concentrations of drain water reflect those seen up-gradient, as does concentration of phosphorus species and *E. Coli*. Samples from groundwater also indicate presence of *E. coli*. This suggests there may be a more persistent source of contamination than at the up-gradient sites. Based on values presented in Section 3.2.3, Windermere Drain gains in flow from groundwater between Boundary and Surveyors roads. At Surveyors, groundwater elevation varied greatly, with elevations in both piezos dropping below bed elevation in 2019. This array is located closely down-gradient of W7 (Scheme Middle). Drops in piezo groundwater level align with pumping of this ECGIS production bore. Based the conceptual examples of Winter (1998) (Section 1.1), it is considered that the Surveyors array is a gaining reach. However, the local setting is more hydrogeologically complex than that at the up-gradient sites, with dynamic concentrations of nitrogen species.

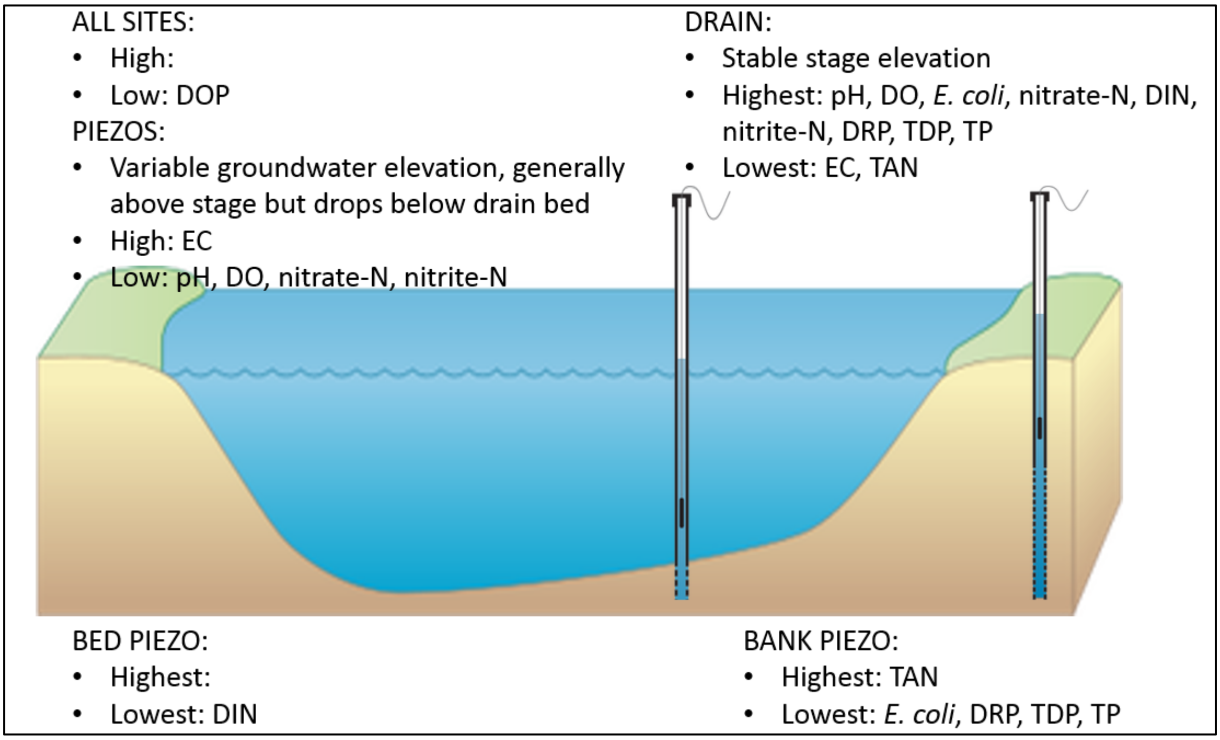

Figure 4-6 Summary of Data from Surveyors Array

Figure 4-7 presents a summary of conclusions derived from data collected from the Poplar array. Poplar Drain stage had the highest water elevation and Poplar Bank Piezo the lowest; consistently below the drain bed. Head in Poplar Bed Piezo fell below the drain bed in the second half of the monitoring period. Where Poplar Drain water elevation increased there was increase in groundwater elevation. All Poplar array sites had high EC, but piezos had lower nitrate-N than the Drain. As with the Surveyors array, this suggests greater concentrations of available ions. Poplar Bed Piezo had the highest concentrations of some phosphorus species. Up-gradient of this array, high phosphorus had only occurred in drain water. This suggests there may be a local phosphorus source, or that phosphorus has accumulated out of the drain into the drain bed. Poplar Bed Piezo also had the highest *E. coli* counts, while Poplar Drain had the lowest. Another inconsistency with up-gradient arrays. This may suggest a local and/or persistent source. Figure 4-2 suggests there are no effluent discharges immediately up-gradient of this site. Based the conceptual examples of Winter (1998) (Section 1.1), it is considered that the Poplar array consists a losing reach, with groundwater elevation decreasing with distance from the drain, and a settling of sediments with attached contaminants. This may contribute to elevated contaminant concentrations in groundwater through hyporheic exchange of sediment.

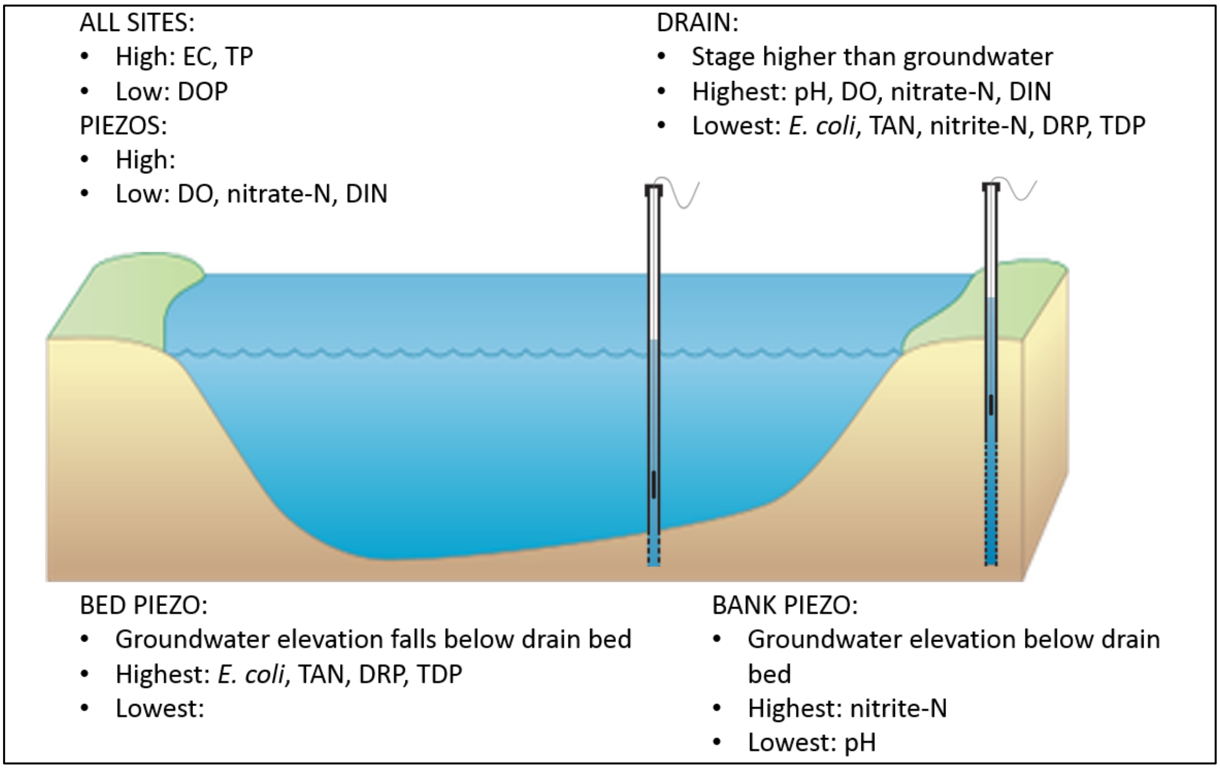

Figure 4-7 Summary of Data from Poplar Array

Figure 4-8 presents a summary of conclusions derived from data collected from the Lower Beach array. Lower Beach water elevation data was similar to that from the Poplar array, but head in Lower Beach Bed Piezo remained above the drain bed more often. Lower Beach piezo groundwater elevation was consistently lower than Lower Beach Drain water elevation, but trends were similar at each site. At each site visit, bank saturation above stage height was evident on the true right bank (Appendix 2). This may suggest strong inflow from the west, a gradient likely originating from as far away as the Hinds River. This would not be captured in array data as Lower Beach Bank Piezo is on the true left bank, and Lower Beach Bed Piezo, whilst against the true right bank, may be screened too deep to capture this flux. Lower Beach array had elevated nitrate-N, DIN, and EC concentrations, and low TAN concentrations. TAN can be considered an indicator of organic (effluent) pollution. Low TAN concentrations alongside elevated nitrate-N and EC suggests persistent sources of nitrogen species rather than local contamination. Low *E. coli* concentrations in Lower Beach piezos and high concentrations in Lower Beach Drain was similar to trends at Surveyors array, suggesting a persistent source of contamination. At Lower Beach array there was higher concentrations of some phosphorus species in piezos than drain water, as was seen at Poplar. Section 3.2.1 indicates flow losses along Windermere Drain between Poplar and Lower Beach. It is likely that sediment has settled from the water column and become subterranean via hyporheic sediment exchange. Based the conceptual examples of Winter (1998) (Section 1.1), it is considered that the Lower Beach array consists a generally losing reach but may gain from lateral groundwater flow.

Summary

Newtons, Boundary, and Surveyors arrays were identified as gaining reaches where groundwater discharged to surface water. Poplar and Lower Beach arrays were identified as possibly losing reaches where surface water discharged to groundwater. This was based on water quality and quantity data collected in this investigation. There was some ambiguity from chemical parameters in reaching these conclusions, but this was not considered to make material difference to derived conclusions. Both *E. coli* and nitrate-N are parameters of particular concern, as identified in planning processes and reinforced in findings here. Their presence in samples along the length of Windermere Drain suggested that inflowing groundwater at the top of the catchment is not the only source of nitrate-N, nor do consented effluent discharges alone adequately explain *E. coli* counts. Riparian planting and minimising the cumulative effects of tile drain discharge into the drains could mitigate these factors and improve drain water quality.

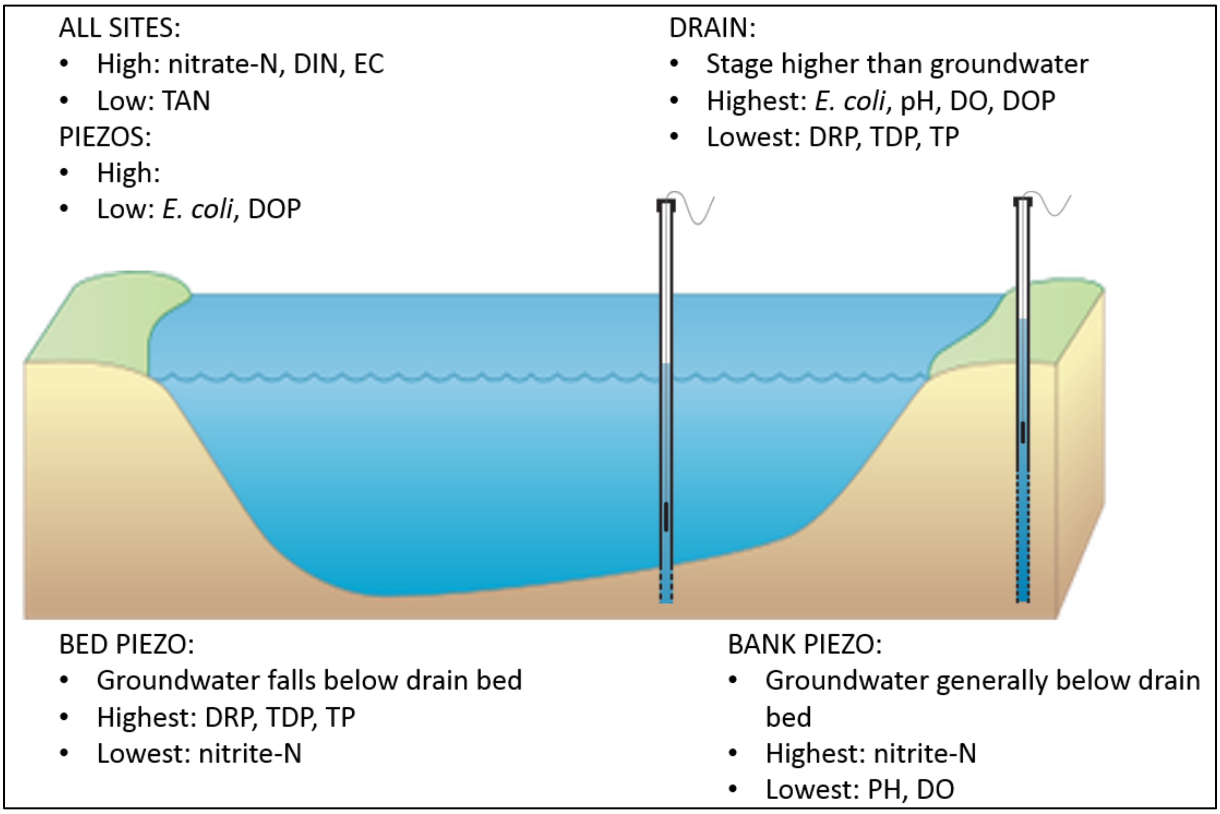

Figure 4-8 Summary of Data from Lower Beach Array

4.2.4 Operational Effects

Hydrology

To understand the balance of water in Windermere Drain, augmentations and abstractions must be understood. Figure 3-3 shows the locations of these and diversion gates in ECGIS, while Table 4-6 presents a summary. The abstraction rate per site has not been defined. ECGIS member access to water is determined by their relative area within ECGIS but where and how they choose to use their water is at member discretion. Some ECGIS members have multiple abstraction points. They can choose to take water from one or all of these depending on where water is needed. The abstraction points below Poplar in Table 4-6 reflect diversion gates in Figure 3-3 as these are used to fill ponds for irrigation. The upper diversion gates are excluded from count as they are not for abstractive purposes.

Table 4-6 Relative Locations and Number of Abstraction and Augmentation Points along Each Drain of Eiffelton Community Group Irrigation Scheme

		Deals	Windermere	Home Paddock
Above Surveyors	Abstraction	3	5	2
	Augmentation	4	7	1
Surveyors to Poplar	Abstraction	2	6	3
	Augmentation	2	4	2
Below Poplar	Abstraction	1	1	1
	Augmentation	1		

Table 4-7 shows the days each irrigation take and ECGIS production bore was used on each of the ECGIS drains across March 2018 to February 2019 inclusive. Irrigation take D4 had the greatest use, being operated on over half (56% of) the target period. The next most utilised irrigation takes, HP1 and D2a, were used over a third of the days (39%) across the target period. Most irrigation takes (60%) operated between 50 and 100 days across the target period. When considering ECGIS production bores, W2 and W3 were used the most; almost every day. This is contrary to the information presented in Section 3.1.5 where ECGIS management reported a reluctance to use W2 due to access difficulties and W3 due to poor yield. HP2, W5, and W1 were also commonly used ECGIS production bores, operating on 25-29% of days across the target period. All three were identified by ECGIS management as being preferred bores, with W1 and W5 identified as preferential due to their high yield. 40% of ECGIS production bores operated between 46 and 76 days. In Section 3.1.5 ECGIS management identified they tended not to use HP3 and D3 due to cost. The values presented in Table 4-7 agree with this sentiment. HP1, W4, and W8 were identified as a 'good' ECGIS production bores by ECGIS management, contrary to their frequency of use across the target period.

Table 4-7 Pumping Days per Drain Abstraction and Per Augmentation Bore, March 2018 to February 2019 Inclusive. Drain Order Reflects Distribution North to South

Deals Drain		**Windermere Drain**		**Home Paddock Drain**	
Irrigation Take	*Days Pumping*	*Irrigation Take*	*Days Pumping*	*Irrigation Take*	*Days Pumping*
D1	29	W1a	74	HP1	144
D2a	143	W1b	59	HP2	77
D2b	56	W2	78	HP3	60
D3	57	W3	53	HP4	10
D4	203	W4	37	HP5	93
		W5	94		
		W6	30		
		W7a	98		
		W7b	4		
		W8	93		
Production Bore	*Days Pumping*	*Production Bore*	*Days Pumping*	*Production Bore*	*Days Pumping*
D1	74	W1	90	HP2	107
D2	68	W2	337	HP3	1
D3	2	W3	337	HP4	51
D4	8	W4	26		
D5	55	W5	102		
D6	46	W6	64		
		W7	76		
		W8	53		
		W9	26		
		W10	28		
		HP1	20		

Figure 4-9 to Figure 4-11 consider discharge data across March 2018 to April 2019 coincident with this investigation. They compare continuous discharge data based on Boraman/ECGIS flow logger data at Poplar Road to that which could be anticipated without augmentation or abstraction. This was calculated by removing production bore and irrigation abstraction from the discharge data. Other groundwater takes and stream depletion effects are not accounted for. As other Hinds Drains ran dry across the period shown, it would be reasonable to anticipate the same for ECGIS drains, thus the dry periods are not unexpected. It is possible that interference effects from groundwater takes exacerbated the deficits seen.

Figure 4-9 to Figure 4-11 compare recorded discharge of Deals, Windermere, and Home Paddock drains at Poplar Road to alternate discharge scenarios. The first scenario removes all irrigation takes and production bore discharges on the target drain from the flow record. This is to simulate flow without ECGIS operation in the case of each drain operating in isolation. This is shown as the yellow area. ECGIS does not operate the drains in isolation. The second scenario simulates D1 and D2 discharging to Windermere Drain rather than Deals Drain. This is indicated by an orange line. The final scenario simulates W8 and W9 discharging to Home Paddock Drain rather than Windermere Drain. This is indicated by a blue line. In their interviews, ECGIS management indicated that they used perpendicular drains to move a 'couple' of production bores worth of water between Deals and Windermere drains, and Windermere and Home Paddock drains. This has been simulated using D1 and D2 for the former, and W8 and W9 for the latter.

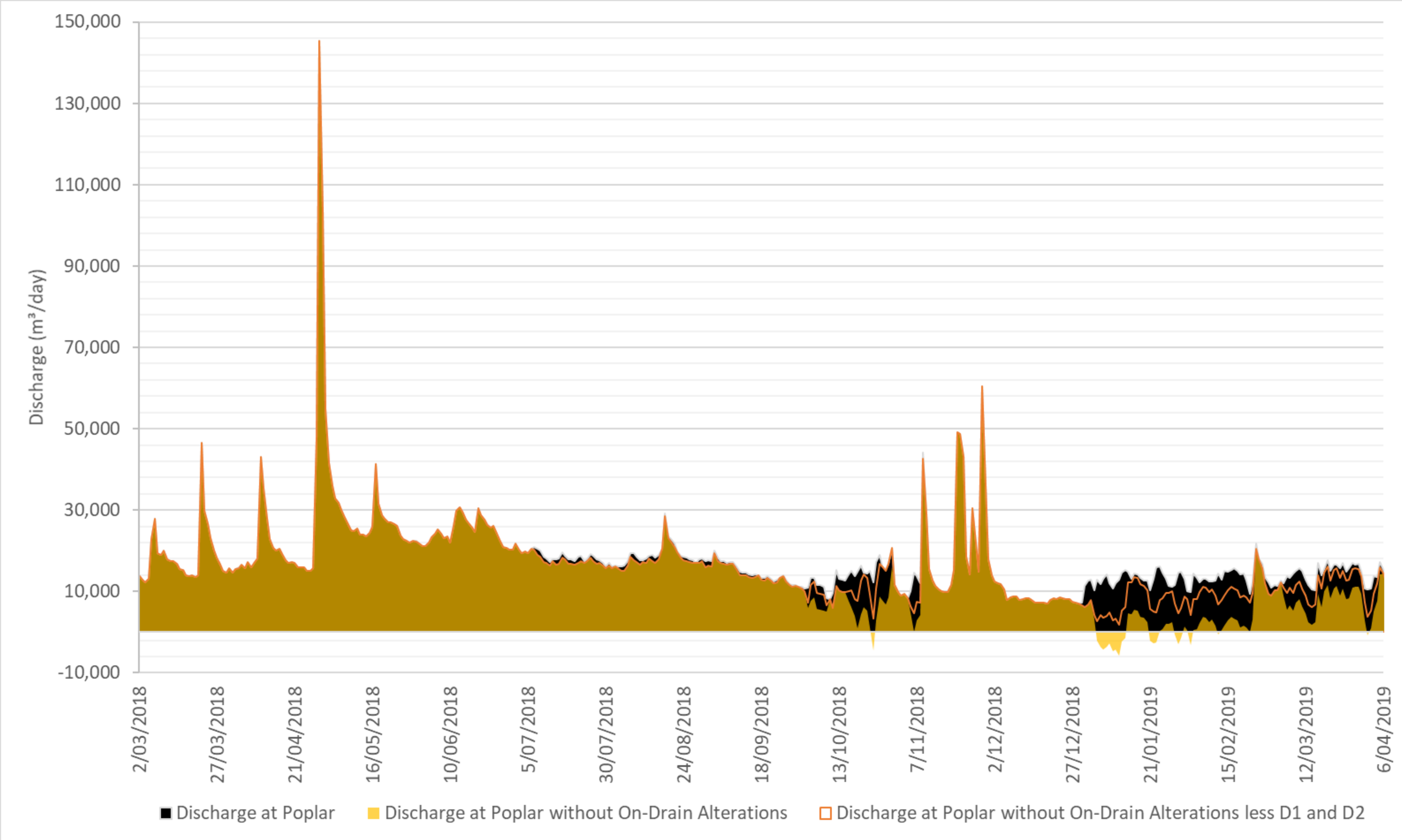

Figure 4-9 Deals Drain Daily Discharge at Poplar Compared to Daily Discharge Less Irrigation Takes and Scheme Production Bore Augmentation

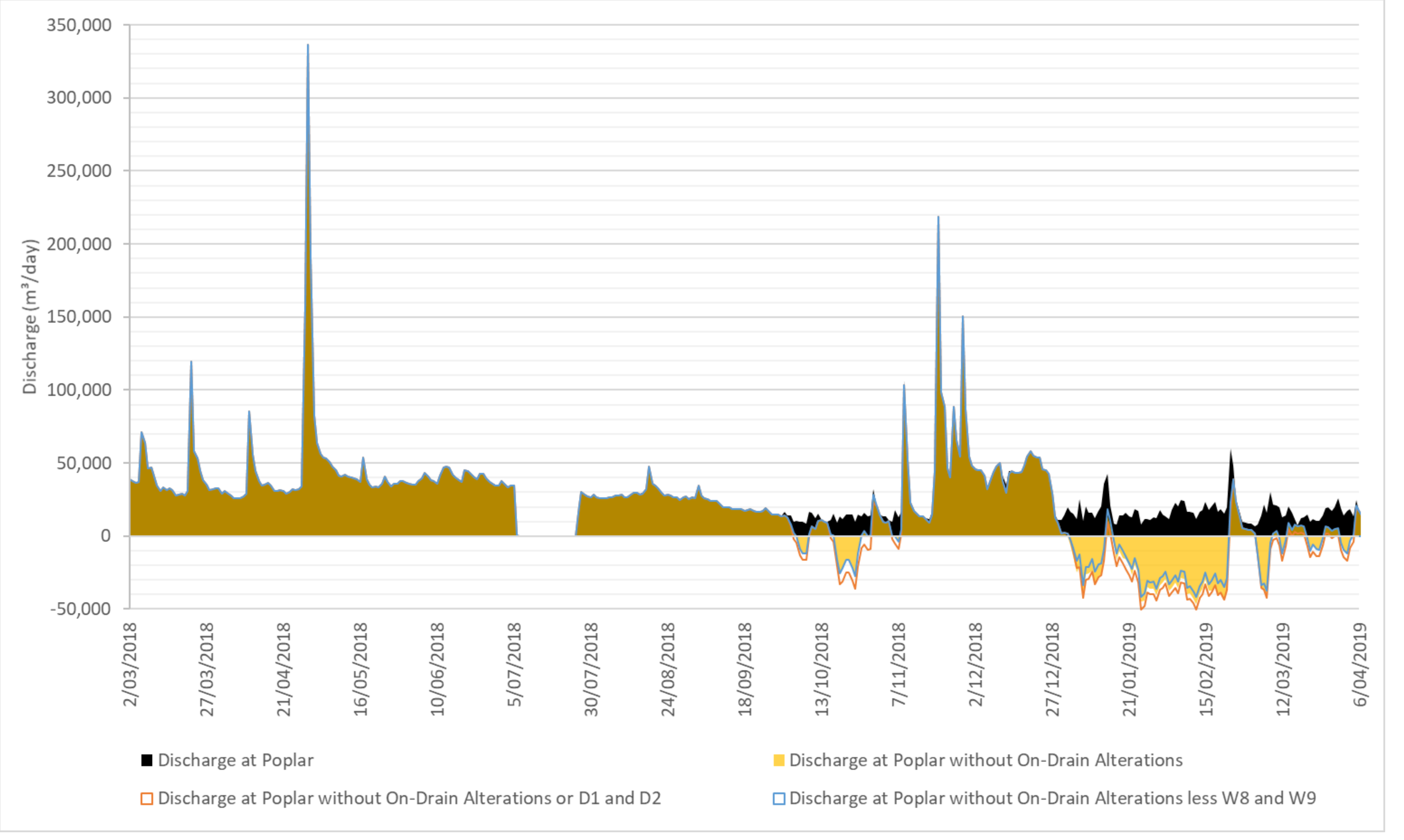

Figure 4-10 Windermere Drain Daily Discharge at Poplar Compared to Daily Discharge Less Irrigation Takes and Scheme Production Bore Augmentation

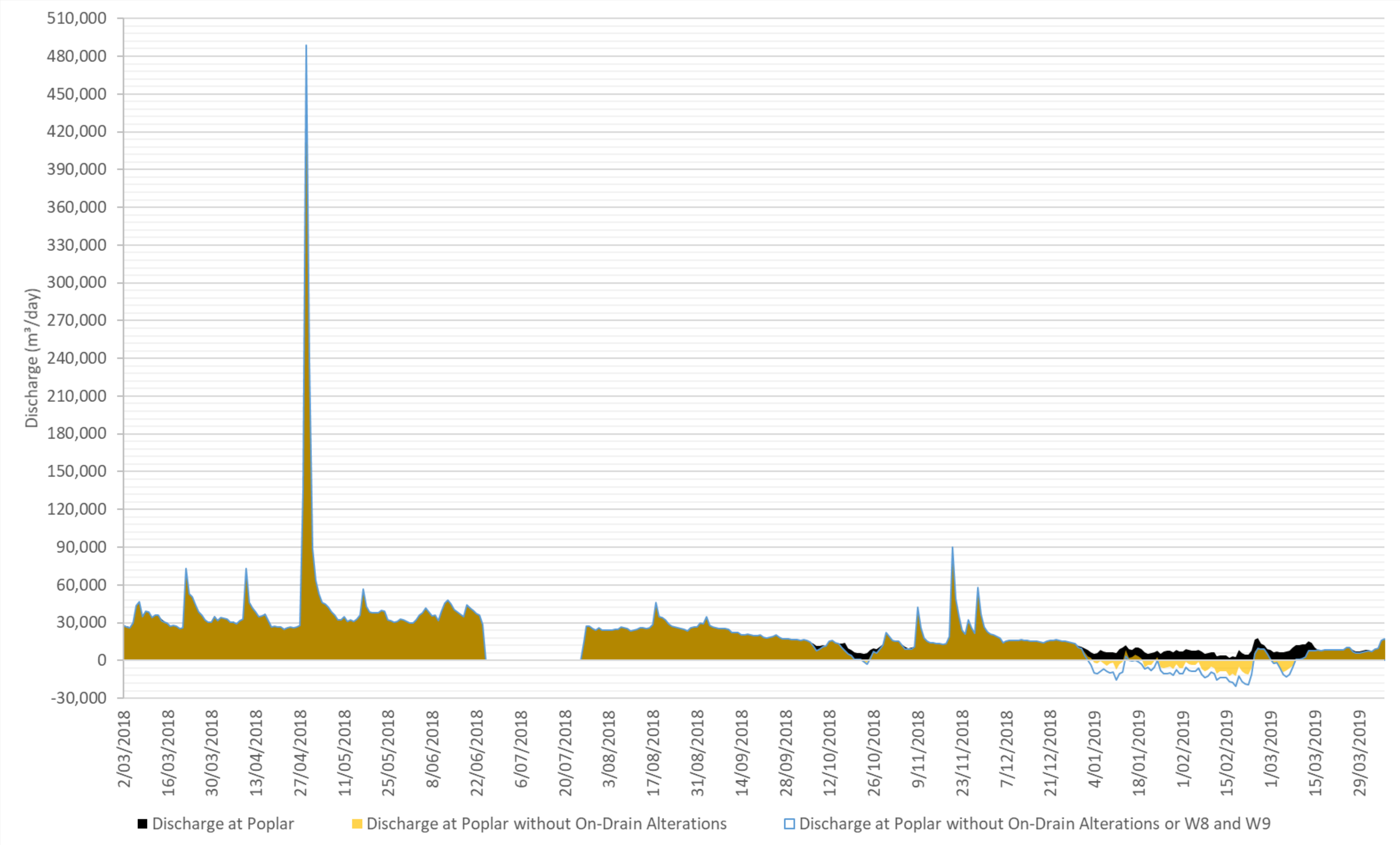

Figure 4-11 Home Paddock Drain Daily Discharge at Poplar Compared to Daily Discharge Less Irrigation Takes and Scheme Production Bore Augmentation

In considering Deals Drain (Figure 4-9), scenario two (diverting D1 and D2 to Windermere Drain) has greater flow than scenario one. This is because it assumes less augmentation thus a greater proportion of flow at Poplar Road represents drain flow. With no ECGIS influence it is possible that Deals Drain would have dried for periods in October 2018 and across January and February 2019. Figure 4-10 suggests Windermere Drain would have flowed dry for much of October 2018 and most of the 2019 period shown. Considering D1 and D2 in the context of Windermere Drain would have enhanced the October dry but had little comparative impact on the 2019 deficits. Removal of W8 and W9 flow from Windermere Drain would not have impact on the October deficit but would equate to additional flow during the 2019 deficits. Analysis indicates that the absence of ECGIS would have resulted in Home Paddock Drain flowing dry for a period in October and across January to March 2019 (Figure 4-11). Including W8 and W9 in analysis noticeably amplifies the deficit in 2019. In the absence of ECGIS daily deficits across the target period could have been up to 50,000 m^3/day in Windermere Drain, up to 30,000 m^3/day in Home Paddock Drain, and less than 10,000 m^3/day in Deals Drain.

Prior to ECGIS being commissioned, Middleditch (1983) estimated annual average discharge at intervals along each ECGIS drain. Table 4-8 compares these to annual average discharge estimated from investigation data. Middleditch (1983) estimated that Windermere Drain increased in discharge continuously along its length. All data (March 2018-April 2019) suggested Windermere Drain increased in discharge to Poplar and subsequently decreased in discharge. Pre-irrigation data was extrapolated largely from autumn and winter values. Table 4-8 values for this scenario reflect likely conditions of high baseflow and low augmentation. This scenario suggested Windermere Drain would increase in discharge to Surveyors, decrease in discharge to Poplar, and increase again to Lower Beach. Irrigation data was extrapolated from spring and summer values. Table 4-8 values for this scenario reflect likely conditions of low baseflow and high rates of augmentation and abstraction. This scenario agrees that Windermere Drain increase in discharge to Surveyors and decrease in discharge to Poplar as in the pre-irrigation scenario. Unlike the pre-irrigation scenario, it suggests a continued decrease in discharge to Lower Beach. This was the same trend seen when using all data.

Table 4-8 Annual Average Discharge from Windermere Drain at Gauging Sites. Middleditch (1983) Represents Flows Estimated Before Commencement of Eiffelton Community Group Irrigation Scheme. Three Scenarios Are Presented For Annual Average Discharge Based On Investigation Data: 'All Data' Uses All Gauging Data, 'Pre-Irrigation' Uses March to September 2018 Gauging Data, and 'Irrigation' Uses October 2018-April 2019 Gauging Data

		Newtons	Boundary	Surveyors	Poplar	Lower Beach
Middleditch	M m^3/year	3.536	1.248	6.812	7.488	9.308
All data	M m^3/year	2.413	5.730	10.307	10.435	9.668
Pre-Irrigation	M m^3/year	7.143	2.923	12.097	11.293	13.745
Irrigation	M m^3/year	4.530	2.089	7.383	6.983	4.972
% Difference to Middleditch Values	All Data	-38%	128%	41%	33%	4%
	Pre-Irrigation	68%	80%	56%	41%	39%
	Irrigation	25%	50%	8%	-7%	-61%

At the top of ECGIS there is drastic differences in discharges compared to Middleditch (1983) estimates; Newtons discharge was 38% less than Middleditch (1983) estimated and Boundary 128% more in the all data scenario (Table 4-8). Pre-irrigation and irrigation discharges at these sites were all greater than estimated by Middleditch (1983). At Surveyors all scenarios have greater discharge than estimated by Middleditch (1983), with the greatest pre-irrigation. This may suggest higher discharge in winter months than occurred historically. In the irrigation scenario there was lower flow at Poplar and Lower Beach than was estimated by Middleditch (1983), significantly so in the case of Lower Beach. Regarding Poplar, this may suggest that the minimum flows do not reflect historical conditions. Regarding Lower Beach this decrease reflects that ECGIS is not required to ensure flow to this site during irrigation, so perhaps this decrease is expected. These decreases on Middleditch (1983) estimates are not seen in the pre-irrigation scenario, nor when using all data. In both these scenarios annual average discharge is higher than estimated by Middleditch.

All scenarios and Middleditch (1983) values suggest increase in discharge to Surveyors. Between Surveyors and Poplar there are small changes in discharge, Middleditch (1983) and all data suggests increase, while pre-irrigation and irrigation data suggest decrease. Between Poplar and Lower Beach Middleditch (1983) and pre-irrigation data suggest increase in discharge while all data and irrigation suggest decrease. Estimates from investigation data do not closely align to Middleditch (1983) estimates in any one scenario across every site. This may reflect difference management practices or a different 'an overall change in the hydrology of the area since the review by Middleditch (1983).

Water Quality

Section 3.2 presented water quality results for select parameters, comparing values from outside and within the 2018-19 irrigation season. presents a summary of these. Median temperature increased at all investigation sites during irrigation season compared to preceding data. This reflects the seasonality of sampling. Conversely, DO medians generally decreased, with a handful of sites having no meaningful difference and Scheme Middle increasing. This decrease in DO concentrations may reflect the introduction of deeper, lower DO water from ECGIS production bores to the drains and shallow groundwater. EC similarly had lower median values during irrigation season compared to prior across most sites. The exception was Scheme bores which all had higher EC during irrigation season. Only Scheme Top 2 also saw a higher median nitrate-N during irrigation season, meaning the increase in median EC across Scheme bores was likely due to an increase in other ions. Changes in median EC during the 2018-19 irrigation season generally reflected changes in median nitrate-N across other investigation sites. The most notable features of the water quality patterns were the reduction in nitrate-N concentrations due to the dilution with augmentation water from lower nitrate irrigation bores. It is only disappointing that the irrigation season is shorter than the non-irrigation season, so this reduction is seldom displayed in reductions in median nitrate-N concentrations. Median DRP concentrations generally either increased or had no significant difference on pre-irrigation season values. As Scheme bore DRP concentrations were no higher than that seen in other investigation sites (Section 3.2.5) this suggests an external contribution across this period. As data gave no indication of a source of DRP, it is likely that these elevated concentrations are resultant of land use. Median *E. Coli* counts also increased during the 2018-19 irrigation season compared to prior. As Scheme bores had among the lowest *E. Coli* counts from investigation sites (Section 3.2.6) this again suggest an external source for these elevated values, most likely land use.

Table 4-9 Relative Change in Median of Select Parameters During Operation of Eiffelton Community Group Irrigation Scheme Relative to Pre-Irrigation Values

		Temp.	DO	EC	Nitrate-N	DRP	*E. coli*
Newtons	Bank Piezo	▲	▼	▼	▼	=	▲
	Bed Piezo	▲	▼	▼	▼	=	=
	Drain	▲	▼	=	=	▲	▼
Boundary	Bank Piezo	▲	=	▼	=	=	▲
	Bed Piezo	▲	=	▼	▼	=	▼
	Drain	▲	▼	▼	▼	▲	▲
Scheme	Top 1	▲	▼	▲	=	▲	▲
	Top 2	▲	=	▲	▲	=	▲
	Middle	▲	▲	▲	▼	=	=
	Bottom	▲	=	▲	=	=	▲
Surveyors	Bank Piezo	▲	▼	▼	▲	=	=
	Bed Piezo	▲	▼	=	=	▼	▲
	Drain	▲	▼	▼	▼	▲	▲
Poplar	Bank Piezo	▲	▼	▼	▼	▲	▲
	Bed Piezo	▲	▼	▼	▼	=	▲
	Drain	▲	▼	▼	▼	▲	▲
Lower Beach	Bank Piezo	▲	▼	▼	▼	▲	▲
	Bed Piezo	▲	▼	▼	▼	=	▲
	Drain	▲	▼	▼	▼	▲	▲

▲ Higher
▼ Lower
= No significant difference

Summary

This subsection had sought to understand the operational effects of ECGIS on local hydrology based on collected data. Considering drain flow without abstraction or augmentation showed Windermere would have ceased flowing at Poplar Road for periods of October and November 2018, and the first quarter of 2019. Similar situations would have arisen in Home Paddock and Poplar Drains. Regarding considered water quality parameters, operation of ECGIS can be attributed to lower DO, EC, and nitrate-N medians across the irrigation season. Elevated temperature, DRP and *E. Coli* across the same period is likely most attributable to environmental and land use factors and not ECGIS operation.

4.2.5 Summary

This Section first explored investigation data to understand the hydrological setting of ECGIS. Correlation between piezo data within the arrays of Newtons, Boundary, and Surveyors suggests at these arrays the dominant driver of groundwater level was groundwater pressure gradients. At Poplar and Lower Beach drivers appear to be a balance between groundwater and surface water pressure gradients. Water quality data was considered against target values. When considering ANZECC (2000) guidelines for irrigation suitability, Scheme bores and Surveyors piezos were the only sites not at risk of exceeding total nitrogen trigger values; Poplar Bed Piezo was the only site at risk of exceeding TP trigger values, and; suitability based on *E. Coli* decreased in drain water with distance downgradient. When considering LWRP 2035 targets for nitrate-N, most sites are not on track to meet these. When considering both water quality and quantity data Newtons, Boundary, and Surveyors arrays were identified as gaining reaches where groundwater discharged to surface water. Poplar and Lower Beach arrays were identified as possibly losing reaches where surface water discharged to groundwater.

This Section then explored investigation data to understand operational effects of ECGIS. Without ECGIS augmentation of drain flow, Windermere Drain would likely have ceased flowing for up to a quarter of the investigation period. ECGIS also likely contributed to lower DO, EC and nitrate-N medians during the irrigation season.

4.3 Objective 3: Identify Values Associated with the Hinds Drains

21 interviews were conducted with ECGIS members and other community members to identify values associated with the Hinds Drains. Each interviewee had an individual association with the drains area; most for over 20 years. For some, this was by virtue of living nearby, for others it was through employment, and for others it was through personal interest. Because the community of ECGIS and the wider Hinds Drains area is well established, there is an apparent social hierarchy whereby certain community members and leaders are implicitly trusted to act on behalf of the whole. In the Hinds Drains Working Party process community leaders acted to identify acceptable changes that would enhance drain flow and associated values, while not limiting the viability of farming operations. These community members were also seen as acting on behalf of their community through the larger-scale Plan Change 2 to the LWRP process.

People's association with an area, such as the Hinds Drains, can be enhanced or inhibited by factors both within and outside of their control. For example, enhanced riparian planting by a bankside landowner can reduce potential for contamination, and so reduce the operational effects of their farm on the environment. This can also contribute to achieving good management practice and thus be a factor in limiting compliance costs. The same riparian planting can increase bank stability, offer habitat for birdlife, and provide shade for the drain, creating more favourable aquatic habitat. One management choice can have a raft of consequences. Through the conducted interviews, riparian landowners identified a desire to improve their margins in such a manner. They had not done so due to uncertainties as to whether such action was permitted as the Flood Protection and Drainage Bylaw (Environment Canterbury, 2013)prevents unauthorised land management within 7.5 m of a drain bank. Landowners were unsure whether such investment would be worthwhile, both financially and in terms of time involved in getting permissions and managing the plantings. They were also not sure whether any plantings be approved, or whether they would be damaged by drain clearance and spraying. Landowners expressed a desire to do the right thing by the environment but did not know where to find answers to such questions, and therefore had not proceeded with such measures.

4.3.1 Changes Over Time

Interviewees acknowledged environmental decline in the Hinds Drains area. This was mainly in the form of the drains not flowing as consistently as they had historically, with many running dry in recent years. Reduction in fish abundance was attributed to this lack of flow in waterways, as well as poor water quality. There were conflicting views on whether declining water quantity and quality was a symptom of generally inadequate water management, or whether it was a result of drought conditions. Interviewees wanted to see this decline reversed, but felt it was out of their control. Whether lack of flow is due to increased upgradient groundwater use, or a lack of rainfall recharge, such factors are indeed out of the control of Hinds Drains residents, but not necessarily outside the influence of the winder Hinds Plains community. As per Section 4.2.4 there appears to be stream depletion effects from pumping on flow in ECGIS drains. Understanding the relative scale of these impacts are outside the scope of this investigation but would help to better understand factors impacting Hinds Drains flows.

A common theme identified among Other Interviewees (non-ECGIS members) was that of changed intercommunity relationships (between different interest groups and with councils). This theme was not raised by ECGIS members. This is likely because they relied on their community leaders and were not directly engaged in the processes surrounding Plan Change 2 to the LWRP as Other Interviewees were. It is possible that the reliance on the informal community hierarchy could insulate members from this wider social change. Equally it is possible that effective communication via this structure enables facilitation of social change in an unconfrontational way through a trusted intermediary. Without trusted community leaders it is possible that some ECGIS members would have been more involved in the LWRP processes. Others would have been just as engaged as they were. With an ECGIS member now Chair of the Ashburton Zone Committee, it is suggested that dissatisfaction with how the LWRP process played out has been a catalyst for greater participation by community members in wider processes.

4.3.2 Perceptions of Eiffelton Community Group Irrigation Scheme

All interviewees viewed ECGIS positively. Perhaps the most unexpected value that interviewees associated with ECGIS was related to community. Many identified the importance of ECGIS in terms of knowing the people around them, having a strong social and support structure, and being better informed and aware of things that have the potential to impact individual situations.

Those who had been involved in water management in the Ashburton District expressed an appreciation for what ECGIS does in keeping the drains 'alive' by voluntarily ensuring they have year-round flow. During the recent drought many interviewees participated in fish rescues, relocating fish from dry drains to those used by ECGIS to reduce fish mortality. The Hinds Drains are home to both native fish and sport fish. That the operation of ECGIS creates suitable habitat for both is seen as a win-win for the environment. Some questioned the value of providing only pockets of suitable habitat, while others believed that 'something is better than nothing'. That ECGIS can maintain year-round aquatic habitat where it would otherwise disappear is surely a positive. Ecological refuges, and pockets of biota gives hope that repopulation of other drains could occur with return of flow.

There is apparent understanding within the wider community of how ECGIS operates and how this is of benefit to the environment. This may reflect the intergenerational nature of the Eiffelton area; stronger connections with better sharing of information. It may also reflect Ashburton's development as a service town for the agricultural industry, and the towns reliance on successful and profitable farming to support associated industries. Perhaps it is also a function of small-town life; everyone knowing each other's business before they know it themselves. Or it could simply be that interviewees were all either ECGIS members or identified by their association with water management in Ashburton. Those who are engaged in the water management process in Ashburton evidently take the time to understand their communities, pressures on natural resources, and management successes. They demonstrated an understanding that agriculture and the environment are not mutually exclusive, and that successful land management also means good environmental outcomes.

4.3.3 Values

The most common value interviewees associated with the Hinds Drains was their function; keeping the water table low and the land farmable. This likely reflected the fact that most interviewees lived within the Hinds Drains area and so benefitted directly from this primary function of the drains. Because most interviewees within the Hinds Drains area were also ECGIS members, drain function as a water conveyance mechanism was also a facet of this value. The value placed on the drainage and conveyance function of the drains can also relate to the collective memory of the community. That there are so many intergenerational farmers within ECGIS and the wider Hinds Drains area means that they have first- or second-hand knowledge of the impacts that the underperforming drainage system (as identified in Section 1.6) had on land and livelihoods in the past and could have in the future.

Other values expressed by interviewees related to the provision of aquatic habitat (especially for native species), and recreational benefits of the Hinds Drains environment. This again perhaps reflects the long association of many interviewees with the area. Interviewees remember what the Drains used to be, and how they used to use them (e.g. swimming, fishing), and have fond memories. This is reflected in the responses given for values they would like to see enhanced in the Drains. Most interviewees identified restoration of native species as the most desired outcome. Many commented that while it would be nice to see greater biodiversity in the area, developing the drainage network to support such things should not come at the expense of drain function. Because most interviewees had long association with the area, many discussed the potential for drain restoration to what they remember from childhood; where the drains functioned as intended, had good flow, and plentiful fish.

4.3.4 Summary

Interviewees acknowledged environmental decline in the Hinds Drains area. This was mainly in the form of the drains not flowing as consistently as they had historically, with many running dry in recent years. Interviewees wanted to see this decline reversed, but felt it was out of their control. Interviewees expressed an appreciation for what ECGIS does in keeping the drains 'alive' by voluntarily ensuring they have year-round flow.

The most common value interviewees associated with the Hinds Drains was their function; keeping the water table low and the land farmable. This likely reflects a long association and collective memory of the impacts of drainage failures. The second most common value associated with the drains was native fish. Again, this is likely to stem from a long association and desire for restoration to what the drains used to be.

4.4 Objective 4: Determine How Values Could Be Met Using an Integrated Framework

Section 3.3.4 identified maintaining drainage function as the main community priority for the Hinds Drains, and provision of native fish as a secondary value. This Section will discuss how these two key values could be better met by adopting an integrative management framework. Section 1.4 introduced five such frameworks and identified that each can inform integrated management and positive environmental outcomes given appropriate support. This Section will address how IWRM could be used to enhance both drainage function and habitat for native fish using the framework presented by Liu et al. (2008) (Figure 4-12). Because drainage and native fish habitat require consideration of different aspects of the same natural resource (water) IWRM was selected as the most appropriate framework to apply. IWRM shows the strong feedbacks between understanding and action; better understanding leading to increasingly effective action on the ground to achieve desired outcomes. That IWRM was chosen for application in this instance does not preclude parallel or alternative employment of one of the other frameworks.

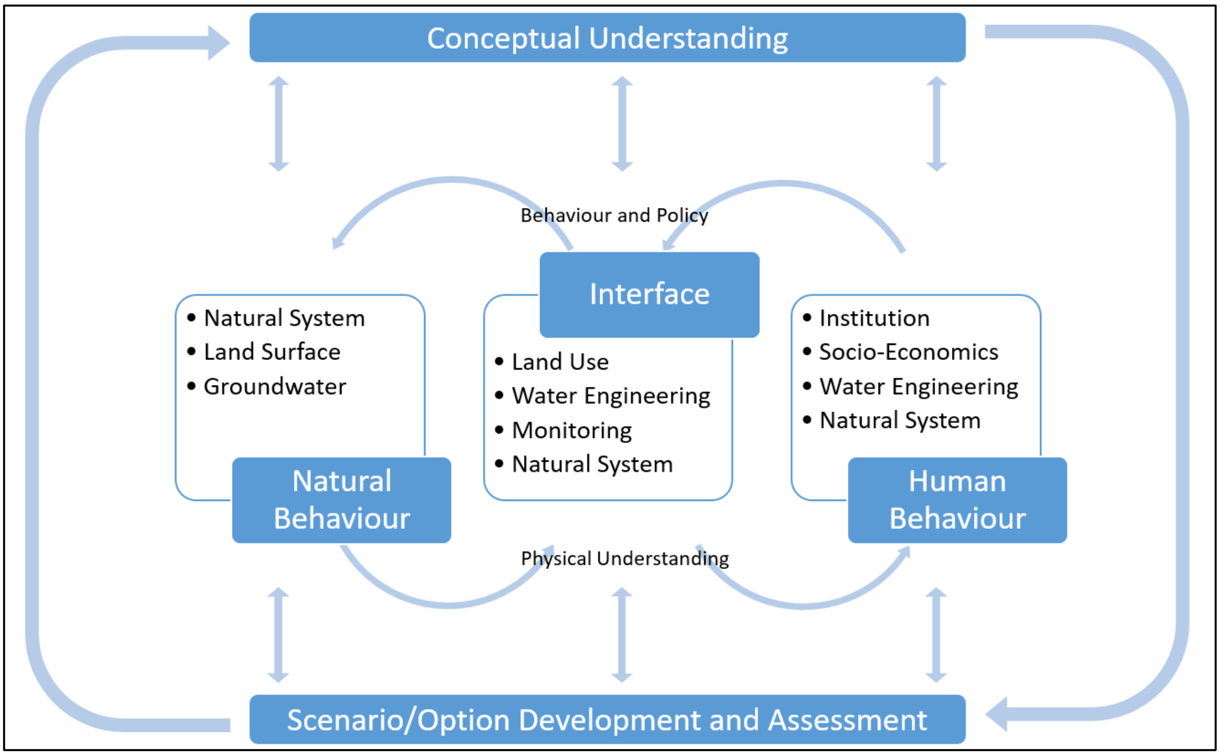

Figure 4-12 Integrated Water Resource Management Framework Adapted from Liu et al. (2008)

4.4.1 The Status Quo

Drainage

Drains fall within the scope of the Flood and Drainage Byaw (Environment Canterbury, 2013). The Bylaw defines controlled activities, landowner responsibilities, and the powers of Environment Canterbury. The purpose of the Bylaw is to:

> "*…manage, regulate and protect flood protection and flood control works (including drainage networks) belonging to or under the control of the Canterbury Regional Council from damage or misuse. This Bylaw only controls activities that may affect the integrity or effective operation and maintenance of the flood protection and flood control works.*"

The Bylaw controls activities within drains and within 7.5 m of the top of a drain bank. It seeks to maintain drains in their current state (no widening or deepening) while ensuring access for maintenance and inspection purposes. The Hinds Drains Working Party made recommendations for improving drain and riparian management within the Hinds Drains area (Hinds Drains Working Party, 2016). This includes limiting herbicide use; excluding livestock from main and secondary drains ,and stock and cultivation from no less than 0.3 m from the point that the land slope 'changes significantly down the side of the drain'; planting and maintaining riparian vegetation that provides shade, limits weed growth, does not compromise drainage, provides bank stability, is easily maintained, is stable in floods, will not restrict capacity, and will not cause blockages, and; recognising and mitigating overland flow paths and their potential to introduce sediment.

Native Fish Habitat

Figure 4-13 shows which Windermere Drain reaches are suited to supporting different native fish species as defined by the Hinds Drains Working Party. The entire length of Windermere Drain is considered suitable for both Longfin and Shortfin eels and the Upland Bully. The lower reaches of Windermere Drain are considered suitable for both Īnanga and the Common Bully. Table 4-10 shows habitat statistics for the native species identified in Figure 4-13 based on descriptions in Jowett and Richardson (2008). Jowett and Richardson (2008) present other variables for habitat suitability. These were excluded as no relevant data was collected.

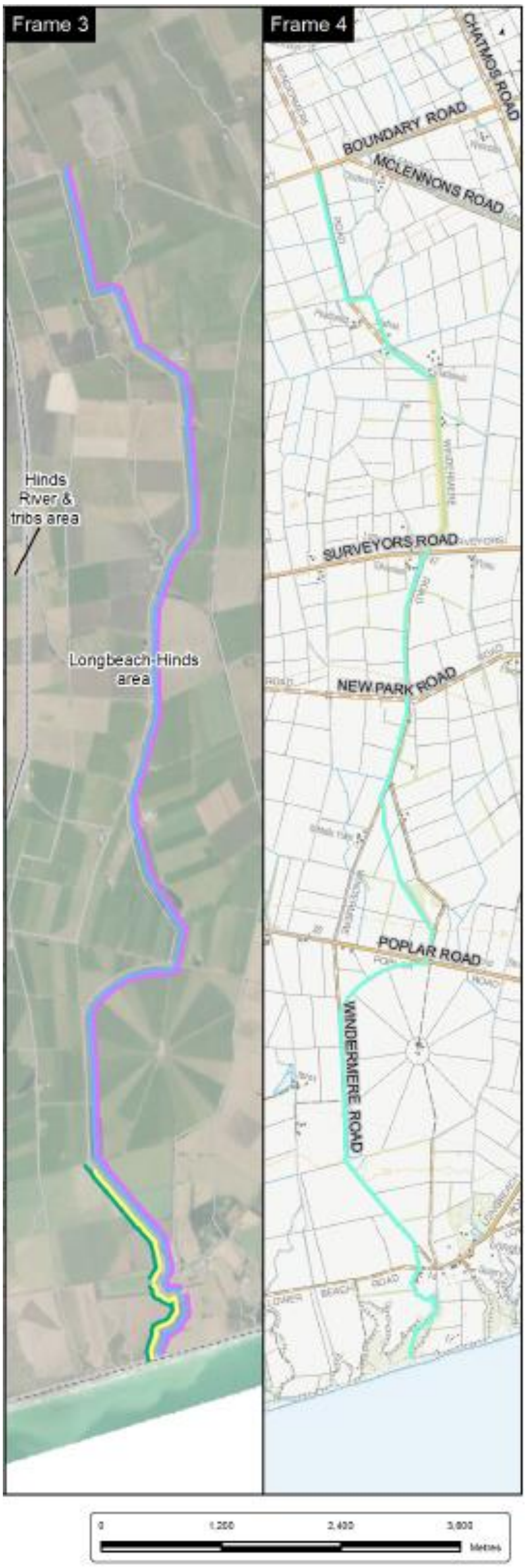

Figure 4-13 Hinds Drains Working Party (2016) Information for Windermere Drain. Frame 3 Shows Potential for Native Migratory Fish: Purple is Shortfin Eel, Blue is Longfin Eel, Yellow is Common Bully, Green is Īnanga. Frame 4 Shows Potential for Native Non-Migratory Fish: Yellow is Habitat Enhancement, Green is Upland Bully

Table 4-10 Habitat Statistics for Native Species Identified In Figure 4-13 (Adapted from Jowett and Richardson (2008))

	Velocity (m/s)			Depth (m)		
	Min	**Max**	**Avg**	**Min**	**Max**	**Avg**
Īnanga	0	0.18	0.05	0.08	2.0	0.30
Common Bully	0	1.07	0.35	0.05	0.67	0.21
Upland Bully	0	1.09	0.40	0.03	0.69	0.19
Longfin Eel	0	1.39	0.40	0.04	0.8	0.21
Shortfin Eel	0	1.34	0.28	0.04	1.2	0.22

Table 4-11 presents the percentages of investigation gauging data that met average velocity and depth requirements for each species. Minimum was not considered as all gaugings had parts of their cross sections that exceeded these values. Bully were seen at Boundary, Poplar and Lower Beach during some site visits. Their presence at other sites and on other visits, and that of other species, cannot be precluded as they were not a facet of investigation; noting of native fish species was chance observation. All species except the Upland Bully are migratory fish; they spend part of their life at sea. Suitability along the drain length must be a consideration. If native fish habitat can only be provided in isolated pockets, populations will inevitability age; losing their juvenile components if they do not encounter appropriately timed flows to complete migration.

Table 4-11 Percentage of Gauging Data with Suitable Average Habitat Statistics (As Defined by Jowett and Richardson (2008)) for Native Species By Site. Blank Cells Are 0%

		Newtons	Boundary	Surveyors	Poplar	Lower Beach
Suitable Velocity and Depth	Īnanga	64%			50%	
	Common Bully			14%		50%
	Upland Bully			14%		50%
	Longfin Eel			14%		50%
	Shortfin Eel	14%		36%		36%
Suitable Velocity Only	Īnanga	21%	86%	93%	43%	93%
	Common Bully			7%		14%
	Upland Bully					7%
	Longfin Eel					7%
	Shortfin Eel			14%		36%
Suitable Depth Only	Īnanga	14%			7%	
	Common Bully	100%		50%	100%	7%
	Upland Bully	100%	14%	79%	100%	7%
	Longfin Eel	100%		50%	100%	7%
	Shortfin Eel	86%		21%	93%	7%

When considering average suitability in terms of both velocity and depth, there was generally poor suitability (Table 4-11). Newtons Drain had average values for both velocity and depth that met average habitat requirements for Īnanga at 64% of visits. Boundary did not meet average habitat requirements for both velocity and depth on any visits. Surveyors generally had low suitable combined velocity and depth for all species, with a great range in suitability across velocity and depth (when considered in isolation) for species. Poplar met average requirements for both velocity and depth for Īnanga 50% of the time. Lower Beach had average values for both velocity and depth that met habitat requirements for both Bully species and the Longfin Eel 50% of the time. Average depth requirements were generally met at all sites for some of the time for all species except at Boundary. Average velocity requirements were met less frequently except at Lower Beach and for Īnanga.

4.4.2 Applying Integrated Water Management to Enhance Drainage and Native Fish Habitat

Liu et al. (2008) IWRM model (Figure 4-12) was adapted for application to Windermere Drain to enhance drainage and native fish habitat (Figure 4-14). As the approach is integrative rather than comprehensive, not all facets and factors are considered. Considered were those that impact drainage maintenance and management, and/or native fish habitat. 'Natural Behaviour' identified factors of the Windermere Drain locale and environmental conditions that could influence drainage and provision of native fish habitat. Here 'Natural' was not considered as reflecting an unaltered state but as factors arising from nature. This is because none of Windermere Drain nor its catchment can be considered 'natural' as it is a highly modified area. 'Human Behaviour' described factors that influence the relative importance of drainage and native fish habitat in enabling desired behaviours. This included understanding of the environment and associated responses, interaction with the environment, and drivers of that influence interaction. 'Interface' intersects the two and tied the practicalities of human behaviour to natural function. For example, Windermere Drain is known for its trout population. If enhancing native fish populations is a priority, fish barriers should be installed to prevent predation by trout.

Drainage and Drain Discharge Management

Drainage

Section 1.3.2 discussed controlled drainage. That is, actively managing subsurface drainage water to enhance its use within the soil profile (without causing pooling), while ensuring surface drainage remains within system capacity. Retrofitting such a system was identified as being of limited benefit to water quality, but no mention could be found relating to water quantity. Ensuring water is more effectively used within the soil profile could see less tile drain discharge and less need for irrigation. It could be considered that such an approach would dampen flood peaks, but managers would have to be careful to avoid negative impacts on productivity. Controlled drainage is best used in a dendritic system rather than a disconnected system of tiles working in isolation, as is the case in the Hinds Drains area, thus such a solution is likely not practically implemented here.

It was identified during interviews that many landowners knew their property contained tile drains. Many landowners did not know exactly where they were, how many there were, or if they still functioned properly. To enhance drainage, perhaps an appropriate starting point would be to better understand existing drainage infrastructure. It should be known what surface and subsurface drainage infrastructure exists, what state this is in (e.g. blocked/collapsed tile drains), what its capacity is (e.g. whether subsurface capacity exceeds surface capacity), and what maintenance needs to be done to restore any areas identified as poorly performing. If better management of drainage is desired, mapping tile drains, understanding their contributions to drain flow, and influences on their discharge could be an appropriate place to begin. Knowing where tile drains discharge to surface drains can help identify areas most susceptible to receiving large inflows of water and contaminants.

Greer et al. (2012) identified that drain scraping and other traditional clearance methods were detrimental to native fish populations. This method of drain clearance is largely relied on for management of the Hinds Drains (1.3.3). If wanting to enhance drain management for native fish species, management actions that do not disturb potential habitat would be more appropriate. It is suggested that an adaptive management approach is undertaken to trial interventions that would increase passive management of the drains. Passive approaches, such as enhancing riparian planting to decrease the quantity of contaminants entering the drains, could decrease the need for active management. Cessation of drain scraping, and spraying would create stable habitat for native fish and better enable establishment of populations. It would also reduce the costs associated with drain maintenance and enable resources to be targeted elsewhere over time.

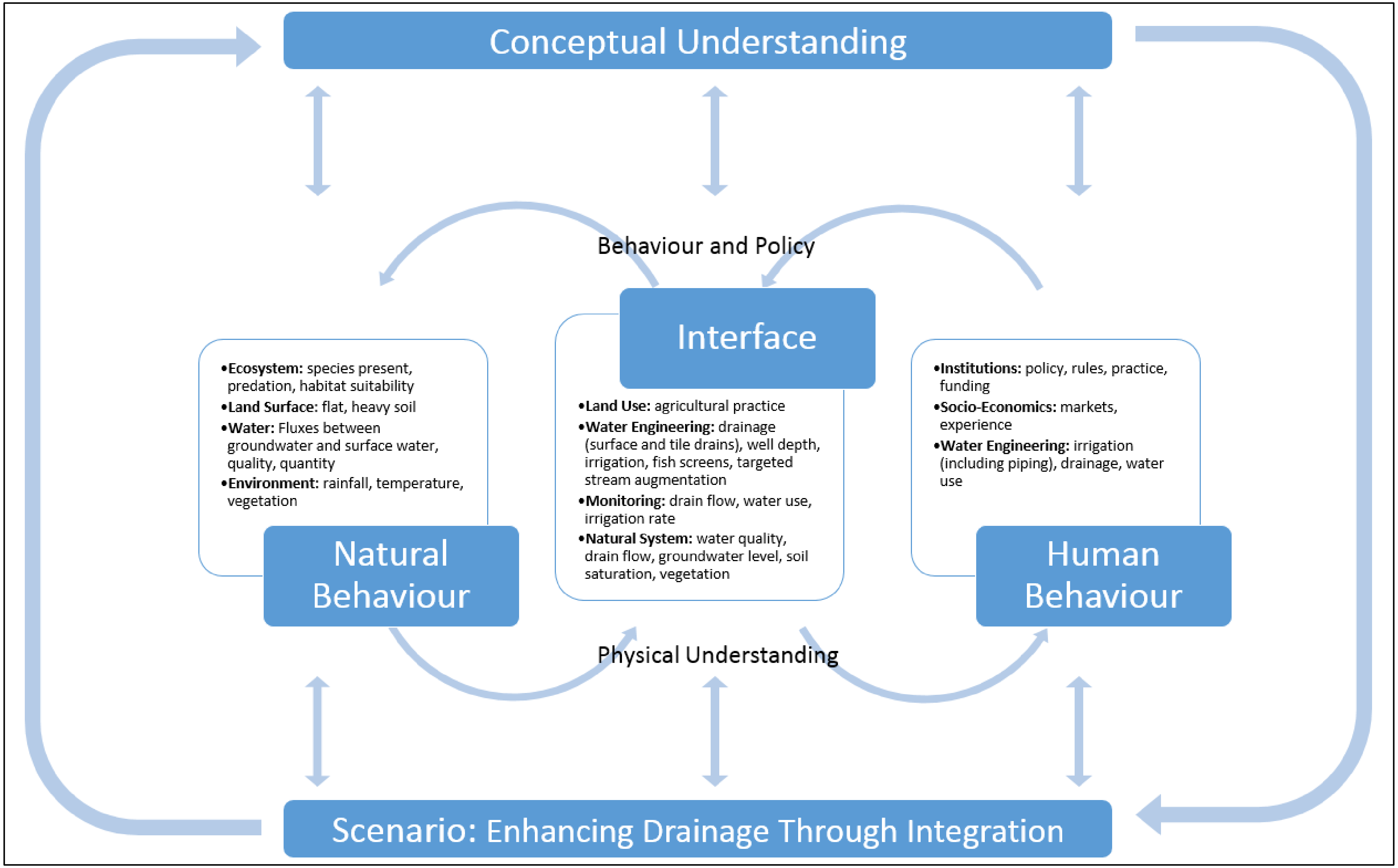

Figure 4-14 Applying Liu et al. (2008) Framework to Windermere Drain to Identify Opportunities to Enhance Drainage and Native Fish Habitat

Drain Discharge

There is no requirement for ECGIS to guarantee flow in Windermere Drain to Lower Beach Road. Despite this, Lower Beach had the greatest potential for native species habitat (4.4.1). This suggests that if wanting to enhance habitat for native fish, perhaps the easiest 'wins' could be made at this site. A voluntary or legislated minimum flow during ECGIS operation could ensure Windermere Drain discharge at Lower Beach Road meets native fish habitat requirements. An environmental flow regime may be more desirable than a fixed minimum flow. The success of the current Boundary Drain trial (another of the Hinds Drains) would inform whether implement of such a regime was viable. Choosing to ensure sufficient flows at Lower Beach to support native fish species could perhaps have the greatest benefit for native species for the least cost as:

a) Velocity and depth requirements are already being met up to half of the time under existing management so topping up the balance would be required less often than at other sites

b) It is the closest site to the coast so could enhance migration potential of native species, further enhancing populations

c) As identified in interviews, the lowest reaches of Windermere Drain had the greatest ecological value. Ensuring adequate flows at Lower Beach Road could further enhance this value

d) It would provide benefit to a range of native species

e) It could be eligible for Immediate Steps[12] or alternative funding, reducing the burden of operational costs.

Ensuring flow at Lower Beach could be achieved by two identified mechanisms. The first is targeted stream augmentation; operating ECGIS in a manner that provides the required flow. It could also be achieved by ensuring a properly functioning and maintained drainage system. Data from this investigation suggests that Windermere Drain may be losing flow to groundwater at this array (3.2.3). Would increasing augmentation actually provide greater flows, or would it see greater groundwater recharge? An adaptive management strategy may be an appropriate tool to resolve this uncertainty.

Conditions at Newtons, Boundary, and Poplar are generally unsuited to supporting the identified native species when considering both velocity and depth (Table 4-11). When considering velocity and depth in isolation Boundary remains unsuitable in both instances, while Newtons and Poplar have suitable depth to support most species most of the time. This suggests sluggish flow as the factor limiting habitat suitability. At Newtons there was persistent macrophyte growth. Excessive macrophyte growth is recognised as restricting water flow and decreasing drain capacity. Ensuring low macrophyte cover may be an effective tool for increasing flow velocity and thus habitat suitability for native fish species. Poplar had the widest drain reach which may be the reason for sluggish flow at this site. Narrowing the drain here would increase velocity and could increase suitability. This would also decrease capacity, and not be in keeping with the premises of the Flood and Drainage Bylaw (Environment Canterbury, 2013). Targeted stream augmentation to increase flow at Poplar could increase flow, as could ensuring a properly functioning subsurface drainage system. The Poplar array faces the same issues as Lower Beach in that investigation data suggest it could be a losing reach. Would these interventions achieve the desired outcomes? Adaptive management could again be an appropriate solution.

Vegetation Management

Vegetation and vegetation management can impact both drain function and native fish habitat. Excessive macrophyte growth can restrict drain flow and limit habitat suitable for native fish species. The Flood and Drainage Bylaw (Environment Canterbury, 2013) identified plant growth as a factor that can inhibit drain function and drain maintenance identified in each of the behaviours in Figure 4-14. Appendix 2 shows photos of Windermere Drain at each array during site visits. Macrophyte growth was prominent in Newtons and Boundary arrays. The lower arrays did not have macrophyte growth. Newtons Drain had little shade cover. Windermere Drain at Poplar Road was similarly unshaded. Boundary, Surveyors, and Lower Beach sites all had moderate shading. Minimum recorded water temperatures from Newtons and Boundary arrays were consistent with those from Scheme bores and generally had minimum temperatures that were 25% higher than minimum temperatures from the remaining arrays.

[12] Immediate Steps is funding from Environment Canterbury is available annually for protection and restoration of biodiversity on private and public land.

Median and maximum temperatures were better aligned across all investigation sites. This suggests that partial shading did not significantly alter water temperature. It could suggest that lower water temperatures at down-gradient arrays may limit macrophyte growth. Both Newtons and Boundary arrays generally have higher nitrate-N concentrations but lower DRP concentrations than the remaining arrays. This suggests that nitrate-N may be the limiting factor in macrophyte growth at the lower sites, rather than DRP, which is generally the case in Canterbury.

Riparian Planting
One way to reduce macrophyte growth, provide a level of water quality enhancement, and create suitable habitat for native fish is via effective riparian planting and management. The Canterbury Waterway Rehabilitation Experiment (CAREX) conducted trials to evaluate rehabilitation tools to improve lowland agricultural waterways. Tools identified during this experiment included preventing macrophyte growth (Collins et al., 2018), *E. coli* contamination (Devane et al., 2018) and nitrate-N contamination (Goeller et al., 2018), and; rebattering of drain banks (Harding et al., 2018). Bank rebattering is a tool to reduce sediments entering the waterway by removing sources along the bank, such as over-steepened or eroding banks. Bank rebattering involves earthworks to reduce the slope and stabilise the bank. This stops bank collapse, reduces erosion, and also increases the flood capacity of the waterway. As part of CAREX, (Collins and Ison, 2010) recommended combining tools for maximum effectiveness; providing immediate control by using weed mat, herbicide spray or hand weeding until sufficient shading can be achieved through riparian planting. (Goeller et al., 2018) found effective riparian planting increased nitrate attenuation in low flow conditions. They emphasised that tools should not be considered in isolation, but as part of better land-based nutrient management, especially in catchments with poor conditions for denitrification or attenuation in groundwater, as is the case in the Hinds Drains area. Figure 4-15 gives example of a CAREX rehabilitation site where rebattering and replanting (with interim measures as described above) was used to improve the state of a lowland agricultural waterway. The success of CAREX gives example of how effective riparian management could reduce need for active drain management while maintaining drain function and enhancing native fish habitat.

4.4.3 Summary

Drainage and native fish habitat were considered within Liu et al. (2008) IWRM framework. This enabled identification of interventions that could enhance one or both values. Considered native fish were those previously identified by the HDWP as having suitable habitat within Windermere Drain. Better understanding the subsurface drainage system is identified as a mechanism to ensure drain function. Knowing the capacity of the tile drain system and where it is failing can help identify susceptible areas for remediation to ensure the drainage system can properly convey water. Vegetation management is identified as a tool for ensuring drain function and provision of stable native fish habitat. CAREX demonstrated transferrable lessons for how riparian management can reduce macrophyte growth, maintain drain capacity, and reduce contaminant load entering drains. Investigation data indicated that not all drain sites had sufficient velocity and/or depth to be suited to native fish habitat provision. Targeting stream augmentation to increase velocity was suggested as a potential solution, as was ensuring the efficiency of the existing drainage system. Lower Beach had the greatest habitat suitability when considering both velocity and depth. It is considered that intervention at this location could result in the most benefits.

Figure 4-15 Example of Canterbury Waterway Rehabilitation Experiment (CAREX) Rehabilitation (Febria et al., 2018)

5 Conclusions

The aim of this investigation was to understand the operation and operational effects of ECGIS. This was achieved by addressing four objectives. This Section is structured to present how this investigation has addressed each objective, limitations associated with findings, and recommendations to improve the status quo.

5.1 Objective 1: Document the Operation of Eiffelton Community Group Irrigation Scheme and How Operational Decisions Are Made

Objective 1 was achieved by conducting semi-structured interviews with ECGIS members and considering resource consent information. 11 of 17 ECGIS members were interviewed. As interviews captured most ECGIS members and most of the ECGIS Board, it is considered that documented operation and operational decision making reflects an appropriate understanding of ECGIS.

5.1.1 Operation of Eiffelton Community Group Irrigation Scheme

ECGIS consists of 4,000 ha of land, 58 km of drains, and 20 production bores. ECGIS pumps water from the production bores into Deals, Windermere and Home Paddock drains to convey water for irrigation to its members. Bores are pumped into the closest drain, except HP1 which is pumped into Windermere Drain, with Home Paddock Drain not flowing till below Smiths Drain. Member access to water is proportional to their relative share of land within the ECGIS footprint.

ECGIS is operated to provide irrigation water to members in as cost-efficient manner as possible while ensuring compliance to consent conditions, including: pumping rates from production bores, abstraction rates by members, and low flow conditions at Poplar Road. Low flow conditions must be met if a member is taking water. Depending on irrigation demand and drain flow, at times members can take water without affecting compliance to low flow conditions.

Members are required to advise ECGIS management of their intent to irrigate 24 hours before doing so to ensure sufficient water to meet irrigation demand and low flow conditions. This does not always occur and members who have done the right thing can run out of water, and management must rush to provide additional augmentation to both meet irrigation demand and minimum flow requirements. Technically, more water can be abstracted from the drains by members than can be supplied by ECGIS production bores, but each drain has a minimum flow rate which must be complied with whenever a member is irrigating.

Below the minimum flow sites there is no requirement for ECGIS to maintain drain flow. However, ECGIS members value the ecological values provided by the drains, so maintenance of drain flow is actively practiced, including outside of irrigation. Members below the Poplar Road minimum flow sites all have large storage ponds. This enables them to divert and capture flow for their own irrigation purposes. Diversions for filling ponds are operated 'as needed' to top up the ponds when the storage has been depleted by irrigation. These members can struggle to get enough water, meaning extra work for ECGIS management to maintain equitable access to water.

Production bores, irrigation takes, and low flow sites are all telemetered. All members have access to all telemetry data via a web platform. This is one way in which ECGIS management ensures enough flow in the drains and encourages social responsibility between members. Failures in the electrics and electronics of ECGIS is a problem faced by ECGIS management. Power supply can be unreliable during peak irrigation season due to high regional demand. This leads to temporary power failures, and so cessation of pumping. Power failures do not affect ECGIS uniformly due to the distribution of the network.

Community is a big part of ECGIS. ECGIS has provided for stronger relationships between neighbours and direct conflict resolution. ECGIS has brought members closer together so that members better understand one another and what is happening beyond their farm gate. ECGIS has fostered a sense of social responsibility to one another and to the environment within which ECGIS is situated. ECGIS members value the drains for the inherent values (ecological, aesthetic, drainage) they provide, as well as for a means of water conveyance. This is potentially enhanced by the presence of many intergenerational families.

Good communication was identified as a fundamental to the success of ECGIS. Successful operation of ECGIS is inherently dependent upon timely and effective communication among its members. ECGIS Members must communicate to ECGIS management their intent to begin irrigation prior to doing so to ensure sufficient drain flow to meet both irrigation demands and minimum flows. ECGIS Leadership must communicate their decisions to members. They must also communicate with external parties to ensure ECGIS's continued operation. Effective communication is not guaranteed. Barriers to communication have (or have the potential to) become pressure points in the operation of ECGIS.

Despite operating under a system of targeted stream augmentation for over 30 years, ECGIS does not meet the conditions to operate as a restricted discretionary activity under Plan Change 2 to LWRP. Policies introduced in this plan change would mean that targeted stream augmentation in support of irrigation would no longer be viable. Rules introduced in Plan Change 2 do give scope for ECGIS to apply for a discretionary consent to overcome this. ECGIS is of the understanding that Plan Change 7 to the LWRP includes a regime to meet Policy 13.4.23 and enable ECGIS to continue to operate in the same manner. ECGIS leadership is anxious to see whether this is indeed the case.

5.1.2 Operational Decision Making

The Race Manager and Assistant Race Manager are responsible for the day-to-day operation of ECGIS. Both are ECGIS members. The ECGIS Chair, also an ECGIS member, is responsible for ensuring an appropriate democratic process for wider ECGIS operation. Proposed changes to ECGIS are put to members to vote on, generally at the AGM. Outside of the AGM, leadership is responsible for making decisions on behalf of members, and for conveying decisions.

ECGIS management make decisions on which production bores to use and how much flow to divert between the drains based on their understanding of ECGIS; capacity of the production bores, requirements of each irrigator, and the hydrology of the ECGIS area. Management operates to a 20 L/s surplus in provided water to prevent non-compliance. Management recognises that some bores have better yield than others, while some have higher operating costs. Because of these factors, there is no set order in which production bores are used. Recent drought illustrated the responsiveness of ECGIS management. If drain flows are unable to be maintained due to poor production bore yield, all members face an equitable relative decrease in their entitlement to ECGIS water. When there is no baseflow in the drains, it can take up to 20% of volume pumped from ECGIS production bores just to keep the drains wet. This is not a cost-effective nor an economically efficient use of water.

5.1.3 Limitations

The only ECGIS infrastructure identified as not being telemetered were diversion gates that transfer water between the drains; from Deals to Windermere, and from Windermere to Home Paddock. As water is regularly transferred from Deals to Windermere this is potentially a significant gap in understanding the operation of ECGIS as the volume of water transferred cannot be quantified. This is a potentially significant knowledge gap in understanding ECGIS operation and the effects thereof. If it is not known how much water is being transferred between drains, the cumulative effect of ECGIS operation on a given drain cannot be definitively determined, nor the influence of augmentation on parameter flux.

5.1.4 Recommendations

As each ECGIS production bore can be operated remotely, so too could each drain abstraction. For example, if an ECGIS member wanted to begin irrigating, they could physically turn their pump on, but no water is abstracted until one of the following conditions is met: 1) minimum flow being exceeded by the sought abstraction rate plus 20% (the buffer volume set by ECGIS management to ensure consent compliance), or 2) if 1) is not occurring, an alert is sent to the ECGIS manager advising of the desire to take. The ECGIS manager provides augmentation sufficient to enable abstraction. Once 1) is occurring abstraction can commence. Such a system would resolve management frustration and ensure fair and equitable access to water.

The remote operation of each production bore occurs in isolation. It is suggested that ECGIS could invest in a single system from which all members can view operations, as per the current Boraman's set up, but also from which ECGIS management can operate bores from a single space. This would streamline operational management of ECGIS. Incorporating the aforementioned alert system into such a space could further increase ease of managing ECGIS. Having a 'one-stop-shop' for management to operate pumps, see diagnostics and status, and for all members to access usage and flow data would improve on the status quo and create a more transparent and user-friendly setup.

Having a backup power supply to each of the production bores could provide temporary power in the event of a power cut. It may not be cost effective to provide a secondary power source to all 20 ECGIS bores, but targeted deployment to those which are most heavily used and/or experience the most unreliability could offset the effects of a power cut. Alternatively, ECGIS could petition Electricity Ashburton to increase network capacity, or provide more fail-safes so that power failures are less of an issue. In terms of maintaining pumping, the existing system alerts ECGIS management when a pump fails so they can rectify the situation. Pump failures are not just due to power losses; there are a host of factors that can cause pumps to fail. It is the responsibility of ECGIS management to investigate each failure and resolve it. Investing in appropriate diagnostic software alongside alert management would reduce the time spent resolving pump failures and could reduce down-time, creating a more efficient system.

There is a general perception by ECGIS members that changes introduced through the LWRP threaten ECGIS's continued existence. It is recommended that friction with external agencies could be resolved by stepping back to a starting position, establishing a common language, and ensuring everyone is working from the same rulebook.

5.2 Objective 2: Understand the Hydrological Setting of ECGIS and How Scheme Operation Impacts Measured Parameters

This objective was addressed by undertaking field investigation on the largest and centremost drain utilised by ECGIS; Windermere Drain. This enabled deployment of resources that told a more comprehensive story. The aim of this field investigation was to collect sufficient data, both spatially and temporally, and from surface and groundwater, to draw conclusions regarding the hydrological setting of ECGIS and effects of its operation on measured parameters. To complement this data, ECGIS pumping and flow data, and rainfall data were also obtained.

5.2.1 Eiffelton Community Group Irrigation Scheme Hydrological Setting

Gauging results showed increases in flow towards the coast across 2018, while in 2019 flows increased to Surveyors and again fell. Piezo level logger data showed influence from rainfall at all arrays, though limited at Surveyors. Another influence was evident in the hydrographs for Surveyors piezos, and Poplar Bank Piezo. No array had the same relation between sites as another. At the top and bottom of ECGIS arrays had similar hydrograph profiles, while in the middle similarities only existed between the piezos. There was an overall decrease in water elevation with proximity to the coast. In examining relationships between hydrologic data, correlation between piezo data within the arrays of Newtons, Boundary, and Surveyors suggests at these arrays, the dominant driver of groundwater level was groundwater pressure gradients. At Poplar and Lower Beach drivers appear to be a balance between groundwater and surface water pressure gradients. Continuous flow logger data had the strongest correlation with rainfall.

In considering water quality parameters, Newtons and Boundary arrays had the highest concentrations of nitrogen species, including nitrate-N. At each array the drain site generally had the highest concentrations of nitrate-N. Scheme bores and Surveyors piezos had nitrate-N concentrations much lower than the other sites. Scheme bores had the lowest phosphorus concentrations. Highest DRP concentrations were found in Poplar and Lower Beach piezos. Drain sites generally had the highest DO concentrations. Most sites had decreases in DO during irrigation season. There were no significant differences in EC concentrations across arrays, most samples ranging 25-35 mS/m. Scheme bores had noticeably lower concentrations at around 15 mS/m. *E. coli* detections were lowest at the top of ECGIS. Lower Beach and Poplar arrays, Surveyors Bed Piezo, and all drain sites had the highest concentrations.

Water quality data was considered against ANZECC (2000) standards and LWRP (Environment Canterbury, 2014) target values. Regarding ANZECC (2000) irrigation standards, all samples had electrical conductivities within the tolerance for sensitive crops. The suitability of drain water for irrigation use decreased with distance down-gradient, especially regarding *E. Coli*. Given ECGIS takes from Windermere Drain this is a potential area for concern. It raises questions regarding the sources of *E. Coli*, the adequacy of the riparian area of Windermere Drain for capturing/treating overland flow, and whether the subsurface drainage is providing a quick flow path (as in Section 1.3.1), preventing biological processes from providing an ecosystem service by reducing the *E. Coli* count. The ANZECC (2000) guidelines also define trigger values that offer 95% species protection for freshwater ecosystems. Scheme bores and Surveyors array had least exceedances. Drain sites in the lowermost arrays had the least exceedances of ecological triggers, while inland they had the most. Down-catchment piezos had the most exceedances overall. Scheme bores and Surveyors and Poplar piezos had medians that met the 2035 LWRP median target for nitrate-N. These and Poplar piezos also met the 2035 95th percentile target for nitrate-N. Groundwater at the top of ECGIS had higher nitrate-N concentrations than those further down-catchment. This suggests that elevated nitrate-N concentrations along the length of Windermere Drain could be a relic of groundwater inflow from the upper reaches, or an alternate source.

Each array was characterised based on water quality and quantity information. It was considered that the Newtons array represents a gaining stream with some localised disconnection. It also likely receives additional inflows of water and contaminants, as suggested by elevated *E. coli* and phosphorus concentrations relative to groundwater. It was considered that the Boundary array consists of a well-connected gaining reach, with some contribution of additional overland inflow accounting for elevated *E. coli* and phosphorus. It was considered that the Surveyors array is a gaining reach. However, the local setting is more hydrogeologically complex than that at the up-gradient sites, with dynamic concentrations of nitrogen species. It was considered that the Poplar array consists a losing reach, with groundwater elevation decreasing with distance from the drain, and a settling of sediments with attached contaminants. This may contribute to elevated contaminant concentrations in groundwater through hyporheic exchange of sediment. It was considered that the Lower Beach array consists a generally losing reach but that it may gain from lateral groundwater flow.

5.2.2 Eiffelton Community Group Irrigation Scheme Operational Effects

To understand ECGIS effects on drain flow, provided continuous flow data from Poplar Road was compared to what could reasonably be expected without ECGIS operation. This was done by removing the volumes of production bore contribution to, and irrigation take abstraction from each drain. Three scenarios were considered; each ECGIS drain operating in isolation, D1 and D2 discharging to Windermere Drain instead of Deals Drain, and W8 and W9 discharging to Home Paddock Drain instead of Windermere Drain. The latter two scenarios were to reflect potential impact of ECGIS management on flows. When considering each drain as being augmented and abstracted from in isolation there were significant periods of deficit in each drain. The most significant in Windermere Drain. When assuming D1 and D2 were discharging to Windermere Drain, Deals Drain did not flow dry as it assumes a greater proportion of baseflow than contribution. D1 and D2 discharging to Windermere Drain enhanced the projected deficits noticeably in October 2018, and to a lesser extent in 2019. When assuming W8 and W9 were discharging to Home Paddock Drain this had no impact on the 2018 deficits in Windermere Drain, but reduced the 2019 deficits. W8 and W9 discharging to Home Paddock Drain saw deficit occur in October 2018 where it previously did not and enhanced the 2019 deficit.

To further understand the impacts of ECGIS on drain flow, annual average discharge estimates were compared to estimates from pre-ECGIS. Annual average discharge as estimated using all gauging data saw less discharge at Newtons (-38%) and more discharge at Boundary (+128%), Surveyors (41%), Poplar (33%), and Lower Beach (4%), than estimated by Middleditch (1983). When annual average discharge was calculated from pre-irrigation data, all sites had 40-80% greater discharge than estimated by Middleditch (1983). When annual average discharge was calculated from irrigation season data Newtons, Boundary, and Surveyors had greater flow than estimated by Middleditch, while Poplar and Lower Beach had lesser flow. This may suggest the minimum flow at Poplar Road is lower than historic discharge. The significant difference at Lower Beach (-61%) likely reflects that ECGIS is not bound to a minimum discharge at this site.

DO medians generally decreased during irrigation season compared to preceding data, with a handful of sites having no meaningful difference and Scheme Middle increasing. This decrease in DO concentrations may reflect the introduction of deeper, lower DO water from ECGIS production bores to the drains and shallow groundwater. EC similarly had lower median values during irrigation season compared to prior across most sites. The exception was Scheme bores which all had higher EC during irrigation season. Only Scheme Top 2 also saw a higher median nitrate-N during irrigation season, meaning the increase in median EC across Scheme bores was likely due to an increase in other ions. Changes in median EC during the 2018-19 irrigation season generally reflected changes in median nitrate-N across other investigation sites. The most notable feature of the water quality pattern was the reduction in nitrate-N concentrations due to the dilution with augmentation water from lower nitrate ECGIS production bores. DRP and *E. Coli* concentrations generally either increased or had no significant difference on pre-irrigation season values. As Scheme bore of these parameters were generally lower than that at other investigation sites, this suggests an external contribution across this period, most likely land use.

5.2.3 Limitations

In understanding ECGIS setting and its effects on the local hydrological setting values were taken as absolute; conclusions drawn reflect collected data. External factors were largely disregarded. Losses and gains in drain flow were not considered. Other groundwater takes were not accounted for, nor were any stream depletion effects. Data acknowledges changes in flows between arrays, and that stream depletion effects are likely. It is possible that the estimated discharge deficits (4.2.4) overestimate the effects of ECGIS on drain flow.

Effluent discharge was discounted as a cause of elevated nitrate-N and *E. coli* concentrations. It was acknowledged that this information was likely incomplete. Having comprehensive information may challenge this conclusion.

5.2.4 Recommendations

Both *E. coli* and nitrate-N were identified as contaminants of concern. This aligns with current understanding. Identification and mitigation of sources of contamination of drain water occurs to ensure water is suitable for use. Riparian planting and minimising the cumulative effects of tile drain discharge into the drains could mitigate these factors and improve drain water quality. Mapping of effluent discharges is recommended to see if this better explains elevated nitrate-N and *E. Coli*. Regarding irrigation water quality findings, it is recommended that ECGIS members consider these relative to their operation to determine if further intervention is necessary.

5.3 Objective 3: Identify Values Associated with the Hinds Drains

Objective 3 was achieved by conducting semi-structured interviews with ECGIS members and other parties involved in Hinds Plains water management. 21 interviews were conducted consisting 11 ECGIS Members and 11 Other Interviewees. Most interviewees had association with the Hinds Drains area of >20 years. The largest change in the Hinds Drains area identified by ECGIS Members, and the second largest change identified by Other Interviewees, over their association was a reduction in the flowing length of waterways. Interviewees identified that many of the Hinds Drains had dried completely in recent years, and a reduction in perennial flow. Reduction in fish abundance was attributed to this reduction of flow in waterways and to reduced water quality limiting available habitat. The change in the Hinds Drains area mentioned most by Other Interviewees was MAR and the perceived benefits this practice would eventually have on both water quality and quantity.

Interviewees acknowledged environmental decline in the Hinds Drains area. This was mainly in the form of the drains not flowing as consistently as they had historically. Reduction in fish abundance was attributed to this lack of flow in waterways, as well as poor water quality. Those who had been involved in water management in the Ashburton District expressed an appreciation for what ECGIS does in keeping the drains 'alive' by voluntarily ensuring they have year-round flow. The Hinds Drains are home to both native fish and sport fish. That the operation of ECGIS creates suitable habitat for both is seen as a win-win for the environment. Some questioned the value of providing only pockets of suitable habitat, while others believed that 'something is better than nothing'. That ECGIS can maintain year-round aquatic habitat where it would otherwise disappear is surely a positive. Ecological refuges, and pockets of biota gives hope that repopulation of other drains could occur with return of flow. There is apparent understanding within the wider community of how ECGIS operates and how this is of benefit to the environment. Those who are engaged in the water management process in Ashburton evidently take the time to understand their communities, pressures on natural resources, and management successes. They demonstrated an understanding that agriculture and the environment are not mutually exclusive, and that successful land management also means good environmental outcomes.

5.3.1 Hinds Drains Values

The most common value associated with the Hinds Drains by ECGIS Members was their function as drains and keeping their land farmable. This likely reflected the fact that most interviewees lived within the Hinds Drains area and so benefitted directly from this primary function of the drains. Recreation (e.g. swimming, fishing) was the value most associated with the Hinds Drains by Other Interviewees. Presence of introduced and native fish was equally valued by ECGIS Members, but introduced fish were less valued by Other Interviewees. Interviewees were asked what they would like to see the Hinds Drains used for in a 'perfect world'. Most interviewees identified restoration to provide for native fish. Many wanted to maintain drain function (to enabled continued agricultural land use), while a smaller number wanted to see the trout population restored. Many interviewees commented that while it would be nice to see greater biodiversity in the area, developing the drainage network to support such things should not come at the expense of their drainage function. The value placed on the drainage and conveyance function of the drains can also relate to the collective memory of the community. That there are so many intergenerational farmers within ECGIS and the wider Hinds Drains area means that they have first- or second-hand knowledge of the impacts that the underperforming drainage system had on land and livelihoods in the past and could have in the future.

Riparian landowners identified a desire to improve their margins. Landowners were unsure whether such investment would be worthwhile, both financially and in terms of time involved in getting permissions and managing the plantings. They were also not sure whether any plantings be approved, or whether they would be damaged by drain clearance and spraying. Landowners expressed a desire to do the right thing by the environment but did not know where to find answers to such questions, and therefore had not proceeded with such measures.

When asked whether they viewed ECGIS positively or negatively, 100% of interviewees indicated they viewed it positively. The largest factor was that ECGIS was seen as having a positive effect on maintaining aquatic ecosystems and thus promoting greater biodiversity because it maintains flow in the drains it uses. That ECGIS operates in a manner that provides for values the community does and had associated with the Hinds Drains surely sets example of a replicable practice.

5.3.2 Limitations

As targeted interviewees were ECGIS members and those involved in Ashburton water management, the values and rationale reflect an informed understanding of the Hinds Drains area and ECGIS. They are members of or have relationships with ECGIS. They had time prior to interviews for this investigation to form opinions relating to the Hinds Drains, ECGIS, and most had long association with the area. Just over half of the interviewees were ECGIS members and most interviewees were residents of the Hinds Drains area. It is likely that these introduced considerable bias in responses. Had interviewees consisted a more diverse interest group it is likely that responses would have varied from those obtained.

5.3.3 Recommendations

If wanting to understand values associated with the Hinds Drains, a wider section of society should be considered rather than the groups targeted in this investigation. This should include landowners above State Highway 1, other interest groups, and a more diverse cross section of society.

5.4 Objective 4: Determine How Values Could Be Met Using an Integrated Framework

Achieving this objective involved incorporating information obtained to address the previous three. By understanding the hydrological setting, the effect of ECGIS on the environment can be better quantified.

By understanding community perception of ECGIS and values associated with the Hinds Drains, it can be identified whether targeted stream augmentation is a tool that could be implemented to enhance values. By understanding the effects of targeted stream augmentation in the Windermere Drain setting, it can be assessed whether it is practical to address community values using this tool. Understanding community values can help inform what changes would be most welcomed by communities, and how such changes could be well-supported.

Section 1.4 introduced five integration frameworks for freshwater management. Adaptive management is a learning by doing approach; ecohydrology, where hydrological and ecological outcomes are equally weighted, considered, and integrated. Ecosystem services is where the benefits society derives from nature are highlighted to better promote management for social and ecological outcomes. IWRM seeks integrated consideration of all aspects of the hydrosphere and its demands, while also recognising the impacts of land use and adequately providing for societal requirements and development. ICM seeks to give equal consideration to land, water, people, and their interactions and interdependencies. Each has similarities. They require an enabling environment, decentralised management, adequate governance, multi-level decision making, resourcing, and stakeholder participation and buy-in to be successful. The choice to use one approach over another is dependent on the situation at hand.

Drainage function was identified as the main value for the Hinds Drains with native fish as a secondary value. IWRM using Liu et al. (2008) model was chosen to identify opportunities to enhance drainage and improve opportunity for native fish. As the approach is integrative rather than comprehensive, not all facets and factors are considered. Considered were those that impact drainage maintenance and management, and/or native fish habitat. Opportunities to enhance these values were considered in two contexts: drain management and vegetation management.

In drain management it was identified that stocktake of existing drainage infrastructure was a prudent place to start to identify opportunities to enhance the status quo as relating to drainage function. Traditional drain clearance methods have been identified in literature as being detrimental to New Zealand native fish populations. If wanting to manage drains to provide for native fish alternative management strategies should be investigated. Also regarding drain management was management of flows. It was identified that the greatest potential for native fish habitat was where ECGIS was not required to provide flow. As this site is already experiencing average required flows for some species most of the time, it would require the least effort to make up the difference.

Vegetation management consists management of in-drain and out-of-drain vegetation management. Excessive macrophyte growth can restrict drain flow and limit habitat suitable for native fish species. Removal of macrophytes, as suggested in the receding paragraph can be undertaken but can also affect native fish habitat. One way to reduce macrophyte growth, provide a level of water quality enhancement, and create suitable habitat for native fish is via effective riparian planting and management. CAREX is used as an example of reach-scale, replicable tools to enhance both drain function and native fish habitat.

5.4.1 Limitations

Implementing actions is limited by their acceptability. it may not be desirable by ECGIS to provide greater flow to Lower Beach road for it to be of no benefit for the ECGIS. It is acknowledged that they have previously undertaken such efforts. Lack of recognition of this voluntary altruism can lead to resentment and reduced likelihood of recurrence. Mechanisms to identify these actions and encourage their continuance need to be investigated by regulatory bodies.

5.4.2 Recommendations

It is again recommended that efforts are undertaken to map tile drains to understand what infrastructure exists and where it could be enhanced. Passive approaches, such as enhancing riparian planting to decrease the quantity of contaminants entering the drains, slow macrophyte growth, and decrease the need for active management. If wanting to enhance drain management for native fish species, management actions that do not disturb potential habitat are desirable. It is suggested that an adaptive management approach is undertaken to trial interventions that would increase passive management of the drains. Cessation of drain scraping, and spraying would create stable habitat for native fish and better enable establishment of populations. It would also reduce the costs associated with drain maintenance and enable resources to be targeted elsewhere over time. A voluntary or legislated minimum flow at Lower Beach Road during ECGIS operation could better provide native fish habitat.

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