Appendix 4

Webb, Trevor, *Soil Investigation to Evaluate Capability of Land Surrounding Waihola, Balclutha, Stirling, Kaitangata, Owaka, Clinton, Heriot and Lawrence for Use as Municipal Wastewater Disposal Sites* (Manaaki Whenua Landcare Research, 2007)

(Attached Separately)

Prepared for Clutha District Council
By Ryder Consulting Ltd

Waihola Oxidation Pond Discharge to the Lake Waihola Outflow Channel

Assessment of Environmental Effects
February 2014

ryderconsulting
environment + planning + project management

Prepared for Clutha District Council
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Assessment of Environmental Effects February 2014

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1. INTRODUCTION

1.1 Background

The Waihola oxidation pond is owned and operated by Clutha District Council (CDC). It was built in 1988 and serves a population of 249 (Statistics New Zealand Census 2006) in the nearby township of Waihola, Otago. In March 2003, Otago Regional Council (ORC) issued CDC consent (consent number 2002.046) to discharge oxidation pond effluent to the outflow channel of Lake Waihola. The permit allows a daily discharge of up to 680 m^3 under normal flow conditions and up to 1,020 m^3 under wet weather conditions.

CDC is seeking a long-term renewal of its Waihola oxidation pond discharge permit for a period of approximately 35 years. As part of their application process, CDC must provide an Assessment of Environmental Effects (AEE) based on past, current and future effluent discharges to the receiving waters of the outflow channel. Ryder Consulting Limited was engaged by CDC to prepare documentation to support the resource consent application.

1.2 Report objectives

The objectives of this report are to characterise the water quality and aquatic ecology in the receiving environment of the Lake Waihola outflow channel. The report assesses the actual and potential effects that current and future effluent discharges from the Waihola oxidation pond are likely to have on ecological and recreational values of the receiving environment. It also identifies cultural values listed under the regional water plan.

2. ASSESSMENT TECHNIQUES

A literature and data review was undertaken utilising information from a variety of sources including:

- ORC and CDC reports and monitoring data.
- New Zealand Freshwater Fish Database (NZFFDB).
- Past surveys and reports by Ryder Consulting Limited.

- Published scientific journal articles.

A field survey was also undertaken in November 2013 to characterise the water quality, habitat and biotic communities in the Lake Waihola outflow channel in the vicinity of the oxidation pond discharge.

3. CHARACTERISTICS OF THE LAKE WAIHOLA OUTFLOW CHANNEL

3.1 General

Lake Waihola is a 5.4 km^2 shallow coastal lake located approximately 40 km southwest of Dunedin, Otago (Figure 1). In addition to Lake Waipori and a series of interconnected waterways, Lake Waihola forms part of the 17.5 km^2 wetland system known as the Waipori/Waihola Lake-Wetland Complex (LWC). The LWC is a coastal ecosystem of great ecological importance (Department of Conservation (DOC) 1993) and up until the 1850's it encompassed two thirds of the lower Taieri Plain. Land clearance, drainage schemes and flood protection works have since greatly reduced the LWC to a fraction of its past size. The hydrology and ecology of the system have been heavily modified and agricultural land now dominates the landscape.

Situated only slightly above mean sea level, the LWC is connected to the ocean via a 10 km reach of the Taieri River. As a result, the LWC and its associated water bodies are tidally influenced and subject to complex hydrological interactions between wetlands, lakes, rivers, aquifers and the ocean. As a significant component of both the LWC and Lake Waihola itself, the outflow channel (which receives the oxidation pond discharge) connects Lake Waihola to the Taieri River. This functions as an arterial route for the flow of freshwater, and sometimes saline water, in and out of Lake Waihola.

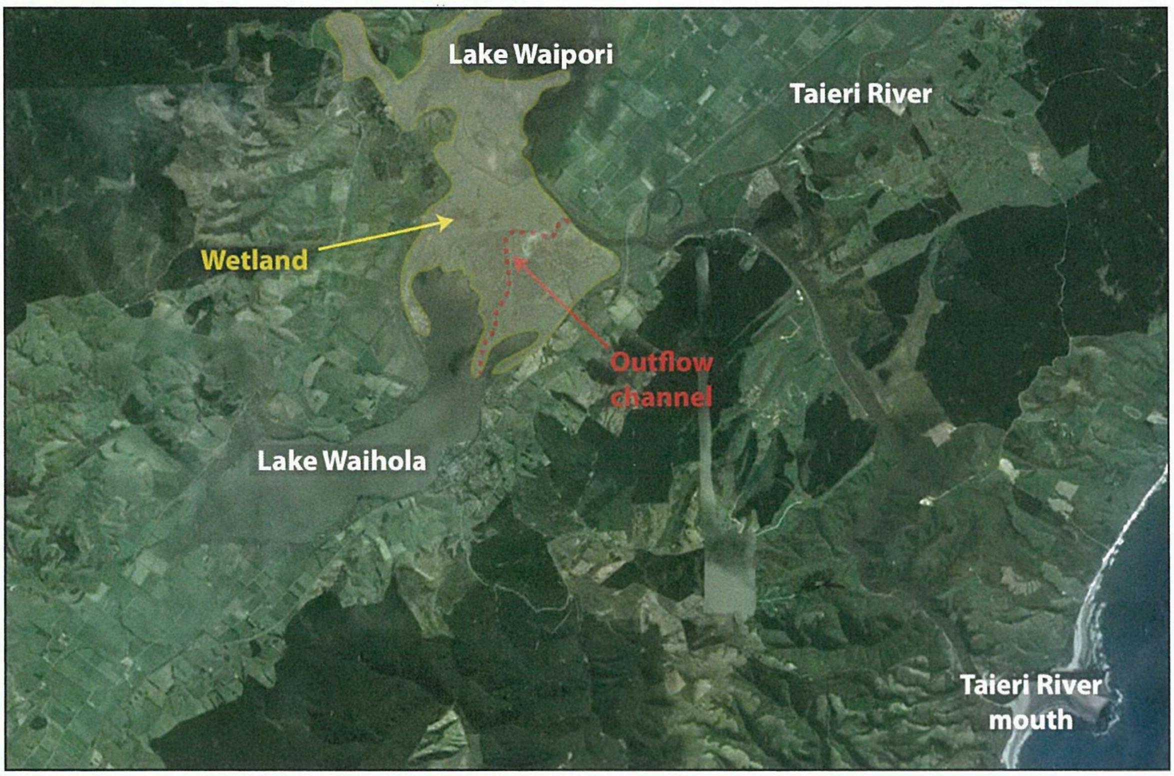

Figure 1 *Map of the Waipori/Waihola Lake-Wetland complex indicating the relative location of the Lake Waihola outflow channel (Google maps).*

3.2 Natural values (ORC Regional Plan: Water)

The ORC Regional Plan: Water for Otago (2013) lists several natural values for Lakes Waipori and Waihola (Table 2). As an integral part of the wetland surrounding Lake Waihola, the outflow channel is likely to share similar natural values. Lakes Waipori and Waihola contain significant areas for the development of trout, a significant presence of eels and a range of indigenous fish and invertebrate species. Riparian vegetation is of significance to aquatic habitats and supports a range of indigenous waterfowl including breeding populations of fernbird (*Bowdleria punctata punctata*) and species threatened with extinction.

Table 2 *Natural values for Lakes Waipori and Waihola as detailed in Schedule 1A, ORC Regional Plan: Water for Otago (2013).*

Water body	Ecosystem values
Lakes Waipori/Waihola	Large water bodies supporting high numbers of particular species, or habitat variety, which can provide for diverse life cycle requirements of a particular species, or a range of species Access within the main stem of a catchment through to the sea or a lake unimpeded by artificial means, such as weirs, and culverts Silt bed composition of importance for resident biota Free of aquatic pest plants (e.g. *Lagarosiphon*) identified in the Pest Management Strategy for Otago 2009. Presence of riparian vegetation of significance to aquatic habitats Significant areas for: • Trout spawning • Development of juvenile trout Significant presence of: • Trout • Eels Presence of a significant range of: • indigenous fish species (including giant kokopu) • indigenous waterfowl (including a breeding population of fernbird) Presence of a significant range of: • indigenous fish species threatened with extinction • indigenous waterfowl threatened with extinction

3.3 Kai Tahu values (ORC Regional Plan: Water)

The ORC Regional Plan: Water for Otago (2013) identifies a variety of mana and access/customary use interests for Lakes Waipori and Waihola (Table 3). The outflow channel is likely to share these same values. Mana interests involve the notions of guardianship, life force, sacred places and treasured interests, which together define the relationship that Kai Tahu have with Lakes Waipori and Waihola. Access and customary use interests include the provision of food resources, the presence of significant spawning and nursery areas for native birds and/or fish, the location of traditional routes, sources of weaving materials and medicines, and sources of water regarded for their healing powers (Table 3).

Table 3 *Kai Tahu values for Lakes Waipori and Waihola, and the Sinclair Wetlands as detailed in Schedule 1D, ORC Regional Plan: Water for Otago (2013).*

	Beliefs, values and uses	**Explanation**
Lakes Waipori and Waihola, Sinclair Wetlands		
Mana interests	MA1: Kaitiakitanga	The exercise of guardianship by Kai Tahu in accordance with tikanga Maori in relation to Otago's natural and physical resources; and includes the ethic of stewardship
	MA2: Mauri	Life force; for example the mauri of a river is most recognisable when there is abundance of water flow and the associated ecosystems are healthy and plentiful; a most important element in the relationship that Kai Tahu have with the water bodies of Otago
	MA3: Waahi tapu and/or Waiwhakaheke	Sacred places; sites, areas and values associated with water bodies that hold spiritual values of importance to Kai Tahu. (Note: Kai Tahu should be consulted regarding the location of these places, sites areas and values for a river identified as MA3)
	MA4: Waahi taoka	Treasured resource; values, sites and resources that are valued and reinforce the special relationship Kai Tahu have with Otago's water resources
Access/customary use interests	MB1: Mahika kai	Places where food is procured or produced
	MB2: Kohanga	Important nursery/spawning areas for native fisheries and/or breeding grounds for birds
	MB3: Trails	Sites and water bodies which formed part of traditional routes
	MB4: Cultural materials	Water bodies that are sources of traditional weaving materials and medicines
	MB5: Waipuna	Sources of water highly regarded for their purity, healing and health-giving powers

3.4 Recreational fishing

The 2007/2008 National Angler's Survey estimates Lake Waihola as having 300 angler days in 2007/2008 (Unwin 2009). This is a decrease from 1,640 angler days in 2001/2002 and 310 angler days in 1994/1995. Lake Waihola, including the outflow channel and waterways interconnected with Lake Waipori, is open to fishing by all legal methods between 1 October and 30 September for the 2103/14 fishing season. A bag limit of six fish per person applies.

3.5 Hydrology

Lakes Waipori and Waihola, and the lower Waipori and Taieri Rivers, are all interconnected via a network of channels that flow through wetlands. With the exception of the Taieri River, the Waipori River is the main source of freshwater flowing into the LWC, which has a regulated flow due to the presence of the Waipori Hydroelectric Power Scheme. Lake Waihola has a mean volume of 7.3 x 10^6 m^3 and an annual non-tidal hydraulic residence time of 153 days (Schallenberg *et al.* 2000 and 2003a).

Water flow within the LWC is affected by tidal flows that are cycled back and forth in the Taieri River. However, net tidal flow is only a small proportion of the overall hydraulic flow within the system. One third of the volume of Lake Waihola is temporarily displaced in a typical tidal cycle and daily net-flow can be either upstream or downstream depending on tides and freshwater inputs. Major saline intrusions resulting from tidal flows have been recorded approximately 2 km upstream of the Waipori River confluence with the Lake Waihola outflow channel as indicated by the dieback of willow trees lining the banks in February 1999 (Sutherland and Closs 2001).

Other sources of water flow into the LWC include discharges from the Taieri Main Drain. The Taieri Main Drain receives water from a network of agricultural drains before it is pumped into Lake Waipori. This and other surface flows are very small compared to tidal and Waipori River inputs to the LWC. Comparatively, the catchment supplying surface water to Lake Waihola is small compared to that of Lake Waipori (Shcallenberg and Burns 2003), however Schallenberg *et al.* (2000) found that significant groundwater also enters the LWC. Although further data and analysis is required to verify the influence of groundwater inputs on the LWC, net groundwater inflow is thought to be as large as the flow of the Waipori River. This flow varies seasonally between 2 and 20 m^3/s and is diffusely spread over the entire wetland complex. Studies on groundwater quality show that it can contain relatively high concentrations of ammoniacal nitrogen (2.2–3.3 mg/L) and is slightly brackish (ORC

2000). Schallenberg *et al.* (2000) found preliminary evidence to suggest that deep channels within the LWC may be areas of groundwater/surface water exchange. This may include channels such as the Lake Waihola outflow channel, which reaches up to 8 m in depth.

3.6 Water quality

3.6.1 General

There is little water quality data for the outflow channel. Schallenberg and Burns (2003) sampled the lower Waipori River approximately 400 m downstream of the confluence of the two channels. However, the lower Waipori River acts as an outflow for the entire LWC and so is heavily influenced by other catchments including Lake Waipori. Therefore, water quality within Lake Waihola is probably the best indication of water quality within the outflow channel.

Land-use intensification, particularly dairy and forestry, has caused concern that water quality is deteriorating in Lake Waihola. In 2000, 68% of the Waihola catchment consisted of pastoral land and 16% planted forest (ORC 2005). In addition, the lake is connected to the lower Waipori River and affected to some extent by the Taieri River and Lake Waipori catchments. Between September 1997 and October 1998, Schallenberg and Burns (2003) investigated the impact of meteorological and hydrological factors on water quality in Lake Waihola. A trophic level monitoring programme set up by the ORC compared their data with that of water quality monitoring carried out at the same sites between October 2002 and August 2004 (ORC 2005) (Appendix One).

The trophic state of a lake refers to the "*life supporting capacity per unit volume of a lake*" (Burns and Bryers 2000). Based on the measurement of four key variables (chlorophyll-α, secchi depth, total phosphorus and total nitrogen), ORC (2005) monitoring found that Lake Waihola had an average trophic level index of 5.03 ± 0.17 between 2002 and 2004, and 5.80 ± 0.42 between 1997 and 1998. This indicates that Lake Waihola is a supertrophic lake saturated in phosphorus and nitrogen.

Excess nutrient contamination can lead to nuisance algal growths in waterways. In particular, shallow supertrophic lakes are prone to algal blooms during settled sunny periods. Typically, the essential nutrients for algal production in New Zealand are the biologically available forms of nitrogen (Nitrite/Nitrate Nitrogen – NNN and Ammoniacal Nitrogen – NH_3-N) and phosphorus (DRP). Lake water quality deteriorated between 1997 and 1998 and was the result of an upward trend in total nitrogen and phosphorus at the time (ORC 2005). A possible explanation for the rise in nitrogen and phosphorus in the lake during 1997 and 1998 is that dairy intensification caused an added influx of ammoniacal nitrogen (ORC 2005). ORC is working with farmers in the lower Taieri catchment to improve effluent disposal, riparian fencing and planting, and drainage.

Phosphorus and nitrogen levels have shown differing trends over recent years in Lake Waihola. State of the environment (SOE) monitoring (Table 4) has found significant increases in total phosphorus between 2006 and 2011 while ammoniacal nitrogen has dropped (Ozanne 2012). DRP levels in Lake Waihola are typically below the New Zealand periphyton guideline limit of 0.026 g/m^3 (Table 4) (Biggs 2000). Likewise, the median NNN concentration is below the guideline limit of 0.295 g/m^3 (Biggs 2000), although individual measurements have occasionally exceeded it (Table 4). A soluble inorganic nitrogen (SIN) : DRP ratio of less than 3 : 1 suggests nitrogen limitation of algae growth in a freshwater environment, unless concentrations of SIN and DRP are well above those expected to saturate growth, in which case neither nutrient is limiting (Wilcock *et al.* 2007). SOE monitoring has revealed that Lake Waihola has a SIN : DRP ratio of 2.70 and is therefore nitrogen limited (Ozanne 2012).

Sediment suspension of Lake Waihola can be common due to its shallowness and vulnerability to the wind. This affects the turbidity of the lake and releases phosphorus previously bound within the sediment into the water. Turbidity in the lake is generally high with a median of 7.8 NTU (Table 4). Between 2006 and 2011, the ANZECC and ARMCANZ (2000) turbidity guideline of 5.6 NTU was exceeded on 72% of sampling occasions (Ozanne 2012). This coincides with significant increases in turbidity in the lake between 2001 and 2011 (Ozanne 2012).

With the exception of total phosphorus, ammoniacal nitrogen and turbidity, measures of water quality have not shown any significant change between SOE reporting periods between 2001 and 2011 (Ozanne 2012). Conductivity is typically high with a median of 512 µs/cm and is reflective of a saline influence and nutrient enrichment in the lake (Table 4). Median temperature is 11.6°C and dissolved oxygen is often greater than 80% saturation.

Table 4 *State of the environment water quality summary data for Lake Waihola between August 2006 and June 2011 (Ozanne 2012).*

Parameter	n	Min	Max	Median	Mean
Total nitrogen (g/m^3)	30	0.190	1.420	0.490	0.563
Nitrite/nitrate nitrogen (g/m^3)	31	0.005	0.592	0.005	0.059
Ammoniacal nitrogen (g/m^3)	30	0.009	0.040	0.009	0.013
Total phosphorus (g/m^3)	30	0.012	0.154	0.046	0.058
Dissolved reactive phosphorus (g/m^3)	31	0.005	0.027	0.005	0.007
Escherichia coli (cfu/100 mL)	31	1	180	30	42
Suspended solids (g/m^3)	30	0.9	135	11	24
Turbidity (NTU)	29	2	79.4	7.8	15.4
Conductivity (µs/cm)	29	6	665	512	1300
Dissolved oxygen (g/m^3)	29	3.2	12.9	8.4	8.6
Dissolved oxygen saturation (%)	29	36.5	105.0	82.7	80.4
pH	30	6.0	9.1	7.4	7.4
Temperature (°C)	30	4.9	21.5	11.6	12.5
Chlorophyll α (g/m^3)	27	0.0017	0.0234	0.0048	0.0076

3.6.2 Faecal contamination

Concentrations of *Escherichia coli* are low in Lake Waihola (Table 4) and therefore inputs from the lake to the outfall channel are also likely to be low. No sample collected between 2006 and 2011 exceeded the Ministry for the Environment's (MfE 2003) guidelines for an acceptable level for *E. coli* in recreational freshwaters (260 cfu/100 mL), or the action/red mode level for *E. coli* (greater than 550 cfu/100 mL). Based on the ORC interpretation of these guidelines, there is therefore no health-risk for swimming in the lake.

3.7 Physical habitat

The Lake Waihola outflow channel is approximately 50 m wide and up to 8 m deep. Shallow bays less than 0.5 m deep exist in some reaches, but depths of 1.5 m or greater are common near to the riverbank. The direction of flow is dependent on tide (see Section 3.5) but is generally slow flowing. Although it is a well defined channel, the outflow channel contains habitat more akin to that of a lake than a typical New Zealand lowland river. The bed is characterised by a thick layer of mud atop tightly packed silts and clay, and gravel and cobble substrates are largely absent. Water clarity is generally poor with high levels of suspended sediment, as is also common in Lake Waihola.

Low-lying wetland habitat characterises the outflow channel banks and consist of a wide range of plant species. These species likely include pukio (*Carex secta*), wire rush/oioi (*Leptocarpus similis*), *Juncus gregiflorus*, New Zealand flax (*Phormium tenax*), mingimingi (*Coprosma propinqua*), raupo (*Typha orientalis*), saltmarsh ribbonwood (*Plagianthus divaricatus*), small-leaved pohuehue (*Muehlenbeckia complexa*), and cabbage tree (*Cordyline australis*). The LWC also contains remnants of mixed shrub and kanuka (*Kunzea ericoides*) forest containing *Coprosma crassifolia*, and korokio (*Corokia cotoneaster*). Exotic plant species include broom (Fabaceae), gorse (*Ulex europaeus*), willow (*Salix fragilis*), and reed sweetgrass (*Glyceria maxima*).

3.8 Aquatic algae

Periphyton or benthic algae is the material that forms slippery surfaces often observed, or at least felt, on upper stone surfaces of lakes, rivers and streams. Under favourable conditions (high nutrients, warm temperatures, high light, and stable flows), these growths flourish and develop into thick layers of varying colour and texture. Periphyton growths represent an important food source for benthic macroinvertebrates (see Section 4.6), but thick growths are typically less palatable and can adversely alter invertebrate habitat as well create a nuisance for lake and river users, and affect the aesthetic character of a waterbody.

There is no historic information on periphyton communities in the outflow channel. However, a lack of suitable bed substrate means that the presence of benthic algae is likely to be minimal or restricted to growing on aquatic macrophytes. Algae that are present in the outflow channel are most likely in the form of free-floating phytoplankton characteristic of lakes and waters with high residence times. Due to its high nutrient levels, Lake Waihola often experiences problems with potentially toxic cyanobacteria blooms. As recently as October 2013, *Anabaena lemmermannii* concentrations were as high as 492 mm^3/L, far exceeding the MfE and MoH (2009) action/red-mode alert-level of 10 mm^3/L.

3.9 Aquatic plants

Aquatic plants (macrophytes) are an important component of lake and river ecosystems. They form a primary component of the food chain, absorb nutrients, provide and consume oxygen, and stabilise sediments by absorbing turbulent energy. Submerged macrophytes act as habitat and feeding ground for invertebrates, fish and waterfowl.

A study in 2002/2003 found a number of aquatic plant species distributed throughout Lake Waihola (Schallenberg and Waite 2004). Stonewort (*Chara corallina*) comprised 73% of all macrophyte cover followed by *Potamogetan ochreatus* (blunt pondweed) (19%). These species were accompanied by lesser amounts of *Elodea canadensis* (Canadian waterweed), *Potamogeton pectinatus* (fennel-leaved pondweed) and *Ruppia polycarpa* (horse's mane weed). However, species distributions were scattered throughout the lake and large densities of *Chara corallina* were mainly confined to the southern end. Ryder (1996) noted that communities at the northern end of Lake Waihola, nearer to the mouth of the outflow channel, were dominated by *Potamogeton ochreatus* and *Myriophyllum triphyllum. Potamogeton ochreatus* is native and common throughout New Zealand. It is tolerant of brackish waters and is a high value habitat for biota (Coffey and Clayton 1988). *Myriophyllum triphyllum* is a native water milfoil distributed widely in New Zealand lakes.

Other species to have been noted to grow at the northern end of Lake Waihola by Ryder (1996) include *Lilaeopsis novae-zelandiae* and *Glossostigma elatinoides*, with *Potamogeton cheesmanii* growing occasionally at greater depths. Floating mats of *Eleocharis acuta* and *Juncus articulatus* have been known to occur at the edges. *Azolla rubra*, *Lemna minor*, *Callitriche stagnalis* and *Cotula coronopifolia* occur in shallow ponds, muddy channels or muddy areas adjacent to wetland ponds (Ryder 1995). Ryder (1996) also notes that mudflats along river deltas are commonly dominated by *Juncus* species. *Cotula coronopifolia*, *Agrostis stolinifera*, *Juncus articulatus* and *Rorippa microphylla* are established in areas of slow moving water.

3.10 Benthic macroinvertebrates

Freshwater benthic macroinvertebrates are small organisms that live on the beds of rivers, lakes and wetlands, have no backbone and are larger than 250 microns (0.25 mm) in size. This broad grouping includes insect larvae (e.g., caddisflies, mayflies, stoneflies), aquatic worms (oligochaetes), snails and crustaceans (e.g., amphipods, isopods and freshwater crayfish).

Macroinvertebrates are important in streams and lakes because they are a primary food item for many freshwater fish species and a number of wetland and riverine bird species. Their ability to transfer primary production (i.e., algae or 'periphyton' growth) into a food source for fish and birds is a fundamental aspect of healthy stream and river ecosystems.

Aquatic macroinvertebrates are also good indicators of ecological change in freshwater environments. Changes in abundance (density or 'numbers') can be influenced by changes in water quality, periphyton biomass and flow history. Because different macroinvertebrate species have different tolerances to instream environmental factors such as dissolved oxygen, temperature, contaminant concentrations, substrate disturbance, fine sediment deposition and periphyton cover, the presence or absence of particular species, and their relative abundance to one another, can provide an indication of water quality and general habitat conditions.

Although some macroinvertebrate (e.g., Schallenberg and Waite 2004) and zooplankton (e.g., Schallenberg *et al.* 2003b) surveys have been carried out within Lake Waihola, none has been carried out in the outflow channel. A macroinvertebrate survey was therefore undertaken in the outfall channel in November 2013 as part of AEE preparation (Section 5.3).

3.11 Fish

The LWC has been identified as a wetland of national importance to fisheries (DOC 1993). The regional water plan for Otago (ORC 2013a, Table 2) identifies it as having a significant presence of trout and eels, a range of indigenous species including those threatened with extinction, and significant areas that support trout spawning and development. Significant populations of giant kokopu (*Galaxias argenteus*) are present while the lakes also support whitebait, commercial eel, brown trout (*Salmo trutta*), and perch (*Perca fluviatilis*) fisheries (Ryder 1996). LWC fisheries also have cultural values (Table 3).

Many fish species that make up the diverse population of Lake Waihola are likely to be present in the outflow channel (Table 5). A study of 25 shallow lakes in New Zealand found that Lake Waihola had a high catch per unit effort (CPUE) and high species diversity (Jeppesen *et al.* 2000). However, of the seven species caught, perch contributed to almost 80% of the catch. Kawahai (*Arripis trutta*) have also been recorded in the lake during periods of high salinity and black flounder (*Rhombosolea retiaria*) populations can be prolific (Ryder 1996). The three species of galaxiid known to reside in the lake are inanga (*Galaxias maculatus*), banded kokopu (*Galaxias fasciatus*) and giant kokopu. Inanga and giant kokopu are classed as threatened and declining on a national scale (Allibone *et al.* 2010). Another species in decline, lamprey (*Geotria australis*), is also commonly found in the lake (Ryder 1996).

In 1998/99, Sutherland and Closs (2001) conducted the only fish survey known to be undertaken in the Lake Waihola outflow channel. Their survey found reasonable numbers of larval inanga in the channel and high densities of juvenile common bullies (*Gobiomorphus cotidianus*). The catch of larval inanga in the channel strongly suggests the importance of the surrounding wetlands and Lake Waihola as inanga spawning ground. DOC supports this notion indicating that whitebait spawning occurs along the banks of the majority of the channel and much of the lower Waipori River (Pete Ravenscroft pers. comm.). Other fish species found in the channel by Sutherland and Closs (2001) were black flounder and the marine fish, smooth leatherjacket (*Parika scaber*). This is thought to be the first record of smooth leatherjacket from a New Zealand estuarine river system.

Table 5 *Fish species identified in past surveys as being present in Lake Waihola. Fish list established from NZFFD data and information provided by ORC, Sutherland and Closs (2001), Jeppesen et al. (2000) and Ryder (1996). Threat status from Allibone et al. (2010) (note that this is only relevant to freshwater fish species).*

Species	Common Name	Native	Migratory	Threat status
Aldrichetta forsteri	Yelloweye mullet	N	Y/N	Not threatened
Anguilla australis	Shortfin eel	Y	Y	Not threatened
Angulla dieffenbachii	Longfin eel	Y	Y	Declining
Arripis trutta	Kawahai	N	n/a	n/a
Galaxias argenteus	Giant kokopu	Y	Y	Declining
Galaxias fasciatus	Banded kokopu	Y	Y	Not threatened
Galaxias maculatus	Inanga	Y	Y	Declining
Geotria australis	Lamprey	Y	Y	Declining
Gobiomorphus cotidianus	Common bully	Y	Y/N	Not threatened
Parika scaber	Smooth leatherjacket	N	n/a	n/a
Perca fluviatilis	Perch	N	N	Introduced and naturalised
Retropinna retropinna	Common smelt	Y	Y	Not threatened
Rhombosolea retiaria	Black flounder	Y	Y	Not threatened
Salmo trutta	Brown trout	N	Y/N	Introduced and naturalised

3.12 Birds

Many bird species use the wetlands as feeding and/or breeding habitat including the 'At risk – declining' South Island fernbird (*Bowdleria punctata punctata*) (Miskelly *et al.* 2008), which has a significant breeding population at Lakes Waipori and Waihola (ORC 2013a). ORC (2013b) lists the common waterfowl likely to be present at the LWC as black swan (*Cygnus atratus*), paradise shelduck (*Tadorna variegata*), grey teal

(*Anas gracilis*), mallard (*A. platyrhynchos*), grey duck (*A. superciliosa superciliosa*), New Zealand shoveller (*A. rhynchotis variegata*) and New Zealand scaup (*Aythya novaeseelandiae*). The grey duck has a threat ranking of 'Threatened – nationally critical' (Miskelly *et al.* 2008).

Swamp birds inhabiting surrounding wetland include Australasian bittern (*Botaurus poiciloptilus*), marsh crake (*Porzana pusilla affinis*), pukeko (*Porphyrio porphyrio melanotus*) and South Island fernbird (*Bowdleria punctata punctata*). Two species of shag (*Phalacrocorax* spp.) breed in the wetland while white-faced heron (*Ardea novaehollandiae*) and southern black-backed gull (*Larus dominicanus dominicanus*) are also present. Shorebirds include pied stilt (*Himantopus himantopus leucocephalus*), South Island pied oystercatcher (*Haematopus finschi*), spur-winged plover (*Vanellus miles novaehollandiae*) and banded dotterel (*Charadrius bicinctus bicinctus*). The Australasian bittern is ranked as 'Threatened – nationally endangered' while the banded dotterel is 'Threatened – Nationally vulnerable' (Miskelly *et al.* 2008). The pied stilt and South Island pied oystercatcher are rated as 'At risk – declining' (Miskelly *et al.* 2008).

Visitors to the LWC include brown teal (*Anas aucklandica aucklandica*), banded rail (*Rallus philippensis assimilis*), spotless crake (*Porzana tabuensis plumbea*), cattle egret (*Bubulcus ibis coromandus*), little egret (*Egretta garzetta*), white heron (*Ardea modesta*) and royal spoonbill (*Platalea regia*). Four species of terns have also been recorded. White heron are 'Threatened – nationally critical' while the brown teal, banded rail and royal spoonbill are ranked as 'At risk – naturally uncommon' (Miskelly *et al.* 2008).

4. WAIHOLA OXIDATION POND

4.1 General

The Waihola sewage treatment system consists of a single-stage oxidation pond and small wetland connected in series that services the nearby township of Waihola (Figures 3 and 4). It is situated on Titri Road and discharges treated effluent via a 1.6 km long pipe to a multiport diffuser located on the bed of the Lake Waihola outflow channel (situated approximately 400 m and 2.4 km from the lower Waipori River and Lake Waihola respectively) (Figure 5). The discharge is operated to some extent by gravity, but is habitually pumped and controlled so as to discharge 2.5 hours either side of high tide with the intention to prevent the flow of effluent into Lake Waihola. The diffuser is 24 m long with seven 40 mm diameter ports drilled 1 m apart, plus an additional port at the end of the pipe. The diffuser acts to disperse effluent to the outflow channel so that dense and highly concentrated effluent plumes are avoided.

The Waihola oxidation pond is small, with a surface area of 0.42 ha and a typical operating depth of 1.2 m. Over the peak summer period, this depth increases to 1.5 m to cope with a temporary increase in residents brought about by an influx of holidaymakers. It has a biological design capacity of 42 kg BOD_5/day, sufficient to treat a population of 630 persons daily. In 2001, the pond served a population of 330 persons representing a loading capacity of 23 kg BOD_5/day (Ryder Consulting 2001). At that time, additional "trade wastes" from a local service station may have been unaccounted for (Hall 2001). The most recent estimate of Waihola's population is 249 persons (Statistics New Zealand 2006 census) and this is unlikely to have increased significantly over the intervening years.

Oxidation ponds are a major means of sewage treatment in New Zealand. In 1991, 40% of communities with populations of 20,000 or greater were served by oxidation pond or lagoon systems (Shields 1991). This number is even greater for small communities between 1,000 and 20,000 people.

Figure 3 *Aerial photograph of the Lake Waihola outflow channel and nearby Waihola oxidation pond, Otago. A dashed red line indicates the approximate path of the oxidation pond discharge pipe (satellite imagery courtesy of Google maps).*

Figure 4 *Waihola oxidation pond, 30th of October 2013. The effluent outflow pipe is situated on the left-hand side of the pond near the end of the jetty. Effluent is discharged from the pond via a submerged pipe through wetland (pictured in the background) to the Lake Waihola (pictured far left) outflow channel.*

Figure 5 *Waihola oxidation pond discharge site as viewed from the centre of the outflow channel (left) and bank (right). The outfall pipe and diffuser are anchored to the bed of the channel.*

4.2 Treatment process

Oxidation ponds operate by stabilising organic wastes by biochemical oxidation. Heterotrophic bacteria degrade organic matter and produce nutrients and minerals that support the growth of algae within the pond. The respiration of algal communities further assists the decomposition of organic wastes by producing oxygen that replenishes heterotrophic bacteria. The net effect of this process is a reduction in the biological oxygen demand (BOD) of effluent and a reduction in oxygen stress on receiving waters. Secondary functions of oxidation ponds also include settling out solid wastes, which prevents the formation of sludge in receiving environments, and the natural disinfection of potentially harmful pathogens.

4.3 Contaminants of concern

Sewage effluents are a source of multiple contaminants that can have a number of ecological, recreational and cultural effects on river environments. The biological treatment process that raw sewage undergoes in wastewater treatment ponds must work effectively and efficiently to minimise these contaminants before treated effluent is discharged to receiving water. This treatment process can be subject to a suite of external factors including retention time in the pond and seasonal variations in light and temperature.

BOD is a measure of the potential for a body of water to lose oxygen. In terms of treated effluent, it can be characterised as the amount of oxygen required for aerobic microorganisms to process organic matter. Effluent streams with high BOD levels have increased potential to decrease dissolved oxygen levels in receiving water environments. Dissolved oxygen is essential to the life of fish, invertebrates, plants and microorganisms, and biological processes in aquatic ecosystems.

Suspended sediments caused by influxes of raw effluent solids are also of concern. Wastewater ponds are typically designed so that solid sewage wastes settle on the bottom of the pond. Increases in suspended sediments are positively correlated with increases in turbidity, and both are correlated with a reduction in the visual clarity of water. Increases in turbidity and reductions in clarity can further decline dissolved oxygen levels in water by inhibiting algal growth. Algal respiration produces oxygen that is a necessary life-source for heterotrophic bacteria to oxidise organic matter. Increased suspended sediments, and hence an increase in turbidity, reduces the ability of sunlight to penetrate the water column which algae requires to grow. Reduced algal densities can result in the decreased efficiency of oxidation ponds to process contaminants such as faecal coliform bacteria. Suspended sediment concentrations can also affect the physicochemical properties of aquatic environments, which can affect plant, invertebrate and fish habitat and survival. High suspended sediment levels can negatively impact human aesthetic, recreational and cultural values.

The availability of sunlight and ultraviolet (UV) radiation is important in the disinfection of potentially hazardous bacteria, viruses and other pathogens that can persist in wastewater ponds. These microorganisms can have implications to human health when discharged at high concentrations to receiving water environments. Such health risks include the possible contraction of waterborne diseases such as salmonella, gastroenteritis, hepatitis and giardia by drinking water, swimming in it or eating food collected there (usually filter-feeding bivalves such as shellfish). Faecal coliform levels are of particular interest when monitoring oxidation ponds. UV light inhibits the growth of faecal bacteria but levels of UV light can once again be influenced by changes in suspended sediment levels, turbidity and clarity. Oxidation ponds are typically designed to be shallow with large surface areas to maximise the UV treatment of microorganisms.

Changes in temperature and pH levels in receiving aquatic environments can also result from effluent discharges. High solar radiation inputs into effluent ponds increases water temperature that can increase the metabolic rate of microorganisms. However, tolerances to temperature are species-specific and high temperatures can impact on survival rates of fish, invertebrates and plants. Like that of temperature, pH can have impacts on freshwater fauna. Specifically, pH and temperature can affect the toxicity of nutrients such as ammonia. Ammonia can be particularly toxic to fish affecting physiological processes including breathing, development and reproduction.

Nutrients such as nitrogen and phosphorus concentrations can be high in treated effluent and can influence nuisance plant and algal growth in receiving aquatic environments. Excessive algal growths can result in a reduction in river ecosystem health. In addition to a loss of aesthetic and recreational values, toxic blue-green algae (or cyanobacteria) can have major health risks for human use and freshwater species. Determining the concentrations of inorganic nitrogen and phosphorus species in water is crucial to establishing whether over-enrichment is occurring. Excessive plant growth is also affected by other factors as mentioned above, i.e. turbidity, clarity, light availability and temperature.

4.4 Proposed consent changes

As a requirement of a new long-term consent, ORC has indicated a likely suite of future effluent quality guidelines to which the Waihola oxidation pond must comply. Consent limits for all measures of effluent quality after renewal of the consent are likely to be reduced with the exception of pH and dissolved oxygen concentrations. Conditions requiring the monitoring of total nitrogen and *E. coli* (*Escherichia coli*) are also likely to be imposed. Table 6 details both current effluent quality guidelines and those proposed under a renewal of the discharge permit.

Table 6 *Consent limits for Waihola oxidation pond effluent quality. Shown are both current limits that will expire on the 1st of September 2017, and proposed limits as indicated by ORC under a long-term renewal of the discharge consent.*

Parameter	**Current limits**		**Proposed limits**
	12-month geometric mean not to exceed	**95% of values not to exceed**	**90% of samples not to exceed (except pH)**
pH	6.5 – 9.0	6.5 – 9.0	6.5 – 9.0
BOD_5	30	50	20
Total suspended solids (g/m^3)	35	120	30
Ammoniacal nitrogen (g/m^3)	20	30	20
Total nitrogen (g/m^3)	-	-	30
Total phosphorus (g/m^3)	12	15	10
Faecal coliforms (cfu/100mL)	1.0×10^3	1.0×10^5	-
Escherichia coli (cfu/100mL)	-	-	260

Dissolved oxygen concentration is set at no less than 2 g/m^3 as measured at the oxidation pond outlet at 9:00am.

4.5 Waihola oxidation pond effluent quality and consent compliance

The CDC has undertaken monitoring of effluent quality in the Waihola oxidation pond up to every three months since July 1985 (Tables 7 and 8). In addition to CDC monitoring, ORC preformed two audit monitoring visits during the peak summer holiday period in January 1999 and February 2000 (Table 7). Summary statistics were available for monitoring data collected between July 1985 and May 2001 (Table 7), and complete data for between February 1998 and June 2013 (Appendix Two, summarised in Table 8). For the purpose of this report, long-term (e.g. 1985–2001) rather than individual yearly geometric means have been used to compare with currently consented "12-month geometric mean" limits.

Between July 1985 and May 2001, geometric means for pH, total phosphorus and ammoniacal nitrogen measured within the current consent guidelines (Table 7). In contrast, BOD_5, faecal coliform and suspended solid concentrations exceeded consented 12-month geometric means. No sample of total phosphorus exceeded maximum guideline limits and all measures of pH remained within the permitted range of 6.5 to 9.0. All other measures of effluent quality in the pond exceeded maximums on at least one occasion with faecal coliform levels peaking at 1.3×10^5 MPN/100 mL.

An investigation assessing the oxidation pond's compliance with a previous discharge permit issued between 1997 and 2002 was undertaken prior to consent renewal in March 2003 (Milne 2000). This followed audit visits by ORC in January 1999 and February 2000. Results found that although dissolved oxygen rarely dropped below the minimum consent limit of 2 g/m^3, BOD_5, total phosphorus and ammoniacal nitrogen exceeded consented limits on the majority of occasions while faecal coliform limits breached annual mean limits occasionally. Between January 1999 and March 2000, effluent quality in the pond was regularly classed as non-compliant. In light of consistent non-compliance, consent renewal in March 2003 required that an artificial wetland be created to provide secondary treatment of pond effluent. The wetland was installed on the south-eastern end of the pond (Figure 3) and construction was completed before new, and the now current, consent limits came into effect on the 1st of May 2004.

Both before and after the completion of the wetland in May 2004, effluent quality in the pond showed similar trends in geometric mean contaminant concentrations (Table 8). Total phosphorus and ammoniacal nitrogen fell within the current consent limits and pH remained within 6.5 – 9.0. In comparison, the geometric means for BOD_5, total suspended solids and faecal coliforms are all greater than those stipulated in the discharge permit. Median total phosphorus has dropped from 8.04 g/m^3 to 7.58 g/m^3 since secondary treatment began. However, median BOD_5, ammoniacal nitrogen, total suspended solids and faecal coliforms have all increased by 8 g/m^3, 2.25 g/m^3, 20 g/m^3 and 1,500 MPN/100 mL respectively. These trends suggest that the addition of a wetland to the Waihola wastewater treatment system has had no effect on improving overall effluent quality.

Since May 2004, the Waihola oxidation pond has never exceeded maximum consent limits for total phosphorus or ammoniacal nitrogen. pH levels complied on 94% of occasions whereas 31% of faecal coliform measurements exceeded maximums. BOD_5 and suspended solid levels complied less than 50% of the time (Table 8).

Table 7 *Summary of CDC monitoring data of effluent collected from Waihola oxidation pond near the discharge outlet between July 1985 and May 2001. Data includes audit monitoring by ORC during January 1999 and February 2000.*

Parameter	**CDC monitoring**					**ORC monitoring**
	Number of samples	**Minimum**	**Maximum**	**Median**	**Geometric mean**	**Mean**
5-day Biochemical Oxygen Demand (BOD_5) (g/m^3)	29	8	82	34	34	69
pH	17	6.8	8.2	7.4	7.4	-
Total phosphorus (g/m^3)	29	3.0	11.3	7.6	7.0	9.3
Faecal coliforms (MPN/100mL)	24	1.1	130000	8000	3253	-
Total suspended solids (g/m^3)	32	8	150	61	47	74
Dissolved reactive phosphorus (g/m^3)	16	1.8	7	4.3	4.0	-
Total dissolved phosphorus (g/m^3)	7	3.2	7.5	5.4	5.1	-
Ammoniacal nitrogen (g/m^3)	29	7.02	35.2	14.8	14.6	10.28
Total nitrogen (g/m^3)	7	12.8	35.0	24.0	23.2	-
Nitrite/nitrate nitrogen (g/m^3)	-	-	-	-	-	0.085
Escherichia coli (no. per 100mL)	1	39000	39000	39000	39000	8900
Enterococci (no. per 100mL)	19	1.1	11000	610	381	-

Proposed conditions for a renewed long-term discharge permit indicate that effluent quality must comply with maximum consented values on 90% of all sampling occasions (Table 6). Initial discussions between CDC and ORC suggest a greater restriction on effluent contaminant character compared to the current consent (Table 6). Under the proposed new conditions, no sample of effluent quality collected since May 2004 would have complied with maximum limits on 90% of occasions. Total phosphorus levels would have the highest order of compliance (81%) while all other metrics would comply on less than half of all sampling occasions. Specifically, not a single effluent sample would comply with the newly proposed suspended solid maximum, while only 6% of samples would comply with the BOD_5 limit. Total nitrogen would comply with a newly consented maximum of 30 g/m^3 on only 22% of occasions.

Table 8 *Summary of CDC monitoring data of effluent discharged from Waihola oxidation pond. Table contains overall summary data for effluent quality before (February 1998 – April 2004) and after (May 2004 – June 2013) the commencement of secondary effluent treatment by a constructed artificial wetland. Parameters highlighted in bold exceed 12-month geometric means as outlined by current consent limits (see Table 6).*

Before Wetland (February 1998 – April 2004)					
Parameter	**Number of samples**	**Minimum**	**Maximum**	**Median**	**Geometric mean**
5-day Biochemical Oxygen Demand (BOD_5) (g/m^3)	24	11	130	45	**43**
pH	8	7.30	8.56	8.04	7.97
Total phosphorus (g/m^3)	23	5.39	11.30	7.93	8.00
Faecal coliforms (MPN/100mL)	23	130	960,000	80,000	**42,429**
Total suspended solids (g/m^3)	24	13	200	67	**62**
Ammoniacal nitrogen (g/m^3)	23	5.55	35.20	18.10	17.09
Total nitrogen (g/m^3)	6	0.03	47.10	35.65	10.25
After Wetland (May 2004 – June 2013)					
Parameter	**Number of samples**	**Minimum**	**Maximum**	**Median**	**Geometric mean**
5-day Biochemical Oxygen Demand (BOD_5) (g/m^3)	32	13	190	53	**52**
pH	32	7.12	9.13	7.58	7.89
Total phosphorus (g/m^3)	32	3.10	11.80	7.09	6.83
Faecal coliforms (MPN/100mL)	32	320	580,000	81,500	**77,075**
Total suspended solids (g/m^3)	32	33	340	87	**91**
Ammoniacal nitrogen (g/m^3)	32	9.64	33.70	20.35	19.51
Total nitrogen (g/m^3)	32	12.00	46.00	34.50	33.07

4.6 Seasonal variation in effluent quality

Effluent quality varies seasonally in the Waihola oxidation pond (Figure 6). Most notably, BOD_5, pH and suspended solids are highest during spring and summer (September – February) while total phosphorus is highest in summer (December – February) and ammoniacal nitrogen in autumn (March – May). Waihola township experiences high numbers of visitors during the summer holiday period. It can therefore be expected that contaminant loadings in the oxidation pond may increase during this time. This is reflected by high concentrations of phosphorus and suspended solids in the effluent.

Faecal bacteria are also expected to increase in summer due to the increased input of organic waste to the pond caused by seasonal population growth. However, faecal coliform numbers are no greater in summer than autumn or winter. This may be due to an offset caused by higher temperature and solar radiation levels during summer. This change in climate and sunlight promotes the growth of algae and increases the metabolic rates of microbes that consume faecal bacteria. Increased oxygen generated the photosynthesis of algae additionally increases the microbe efficiency. In comparison, faecal coliform levels are at their highest during winter when temperature and available sunlight is minimal and microbe metabolism reduced.

The increase in heterotrophic bacteria in the pond during summer is expected to result in a higher demand for oxygen. This is because aerobic bacteria require high levels of oxygen to break down accumulations of organic material (e.g., when population numbers are high). Results of effluent sampling show that BOD_5 levels are highest from spring through to the peak holiday season in summer. Suspended solids also increase during this period as increased levels of organic solid wastes, caused by temporary population growth, enter the pond.

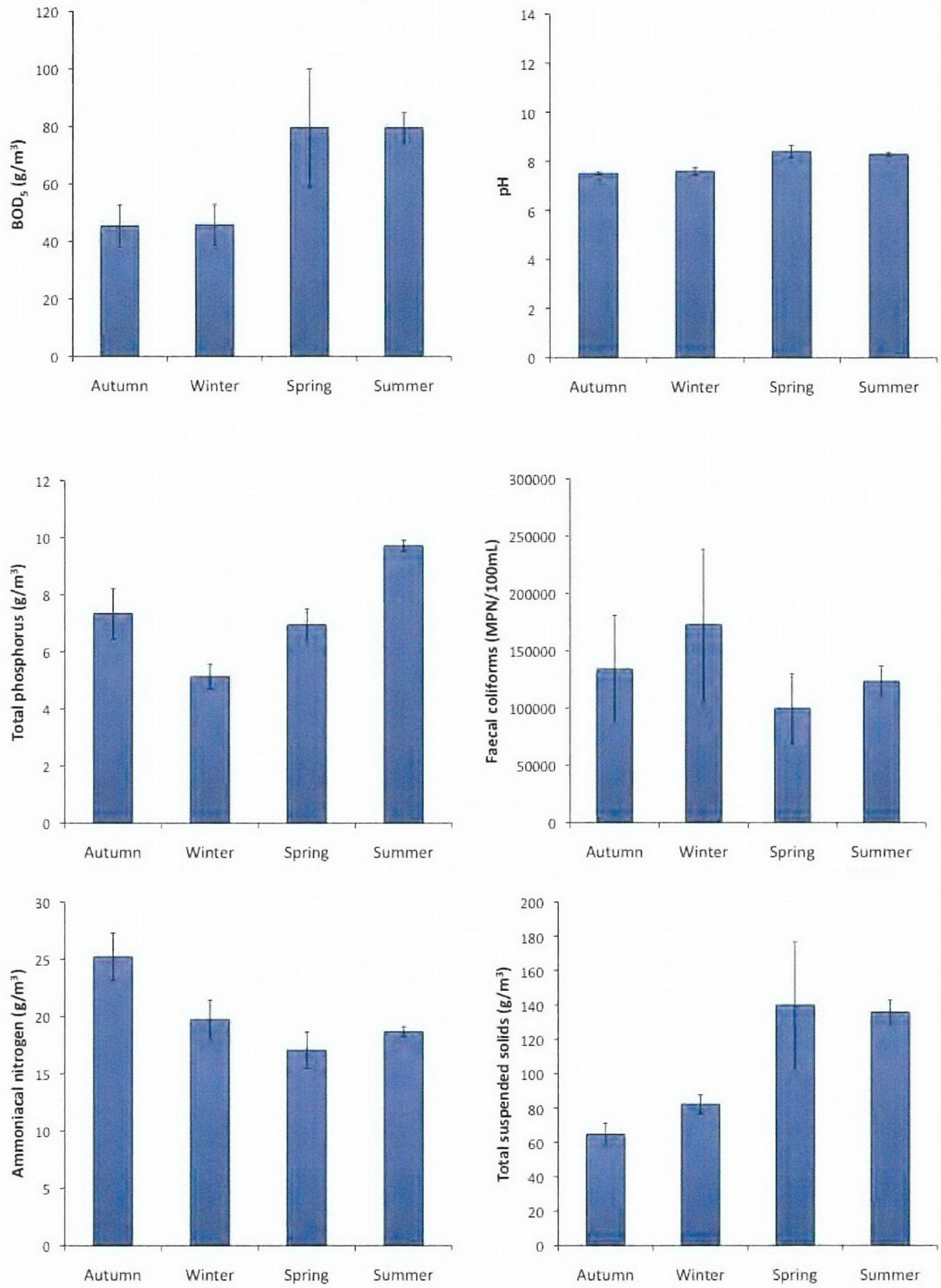

Figure 6 *Seasonal variation in effluent quality at the Waihola oxidation pond between May 2004 and June 2013. Error bars are +/- one standard error.*

4.7 Receiving water quality

Current consent conditions require no monitoring of the receiving water to which oxidation pond effluent is discharged. However, Milne (2000) details the results of water quality sampled in the outfall channel 20 m upstream and 20 m downstream of the discharge between February 1998 and August 1999 (i.e. prior to the addition of the artificial wetland) (Table 9). Results of this data found that faecal coliforms increased slightly from a geometric mean of 70 faecal coliform organisms/100 mL upstream to 99 faecal coliform organisms/100 mL downstream. Enterocooci also marginally increased while BOD_5 and total suspended solids showed minimal change.

ANZECC and ARMCANZ (2000) guidelines recommend median faecal coliform concentrations of no more than 150 faecal coliform organisms/100 mL for primary recreational contact, and 1000 faecal coliform organisms/100 mL for secondary recreational contact. Primary contact includes swimming and direct water-contact sports while secondary contact includes activities such as boating and fishing. Also, a faecal coliform limit of 100 faecal coliform organisms/100 mL is recommended for livestock drinking water (ANZECC and ARMCANZ 2000). Maximum faecal coliform numbers upstream and downstream of the outfall exceeded all these guidelines in February 1998 (see Table 9 maximums). In February 1999, samples also exceeded the ANZECC and ARMCANZ (2000) limit for primary recreational contact upstream.

Table 9 *Summary of Lake Waihola outflow channel water quality monitoring data 20 m upstream and 20 m downstream of the Waihola oxidation pond discharge. Data represent samples collected between February 1998 and August 1999 (Milne 2000).*

Parameter	20 m Upstream				
	Number of samples	Minimum	Maximum	Mean	Geometric mean
5-day Biochemical Oxygen Demand (BOD_5) (g/m^3)	4	< 1	< 3	< 2.3	< 2.1
Faecal coliforms (no./100mL)	4	20	1,300	346	70
Total suspended solids (g/m^3)	4	10	116	57	36
Enterococci (cfu/100 mL)	4	1	90	26	7
Parameter	**20 m Downstream**				
	Number of samples	**Minimum**	**Maximum**	**Mean**	**Geometric mean**
5-day Biochemical Oxygen Demand (BOD_5) (g/m^3)	4	< 1	< 3	< 2.5	< 2.3
Faecal coliforms (no./100mL)	4	< 20	1,100	318	99
Total suspended solids (g/m^3)	4	4	256	80	28
Enterococci (cfu/100 mL)	4	1	95	29	9

5. NOVEMBER 2013 SURVEY

5.1 Sampling locations and character

Monitoring of the Lake Waihola outflow channel was undertaken on the 28th of November 2013. The pumping of effluent from the Waihola oxidation pond takes place 2.5 hours either side of high tide (2.45 pm on the 28th of November). Therefore, water quality samples were collected between 12.35 pm and 1.10 pm in an effort to maximise river flow during sampling during discharge on the incoming tide.

Water quality and benthic surveys took place at three sampling sites in the vicinity of the oxidation pond outfall (Figure 7). A control site was situated 50 m upstream of the effluent outfall while two treatment sites were located 50 m and 100 m downstream. Downstream sites were located lakeside of the discharge (i.e. towards Lake Waihola) and the control site on the opposite side of the discharge as water flows towards Lake Waihola during an incoming tide. Water quality information was also collected at the discharge site, while effluent quality was assessed in the oxidation pond near the pond outlet. Effluent is discharged via a 24 m long multiport diffuser that is anchored to the bed at a depth of up to 6 m. All outlet channel samples were collected by boat at a distance of 20 m from the bank. An additional monitoring site was sampled for *E. coli* at 200 m downstream of the discharge (i.e. towards Lake Waihola).

All three benthic sampling sites were 6–8 m deep with streambeds dominated by a thick mud and silt layer on top of a tightly packed clay bed. Water clarity was poor yet conditions were settled with no wind causing sediment suspension. Low lying wetland habitat and plant species dominated channel banks. Large beds of submerged aquatic plants were sporadically distributed at and between each site and were dominated by *Potamogeton ochreatus* (blunt pondweed) and *Myriophyllum triphyllum* (water milfoil). These growths were confined to within 3 m of the bank where streambed depth was relatively shallow (less than 1.5 m).

Figure 7 *Biological benthic survey site locations in the Lake Waihola outflow channel, 28th of November 2013. Pictured are 50 m upstream (top), 50 m downstream (middle) and 100 m downstream of the Waihola oxidation pond discharge.*

5.2 Water and effluent quality

Monitoring on the 28th of November 2013 recorded a very low suspended solid level (8 g/m³) in the Waihola oxidation pond (Table 10). This represented 9% of the 2004–2013 geometric mean (91 g/m³) (Table 8). In comparison, pH was similar to the 2004–2013 geometric mean, while BOD_5 was slightly lower, and total phosphorus and ammoniacal nitrogen slightly higher (Tables 8 and 10). *E. coli* was not measured in the pond between 1998 and 2013, however faecal coliforms (which are bacteria inclusive of *E. coli*) were generally less than the level of *E. coli* recorded during sampling. These values indicate that the contaminant character of effluent pond was typical with the exception of suspended solids and faecal bacteria.

Water quality monitoring within the outflow channel generally found similar results upstream and downstream of the oxidation pond discharge (Table 11, Figure 10). pH ranged between 7.58 and 7.76 and was relatively consistent both upstream and downstream. Water temperature was similar between sites and dissolved oxygen levels were high, with all measurements above 9.5 g/m³ and saturations of greater than 96%. Nutrient levels also changed little. Dissolved reactive phosphorus, ammoniacal nitrogen, and nitrate/nitrite nitrogen levels were very low measuring less than 0.005, 0.01 and 0.002 g/m³ respectively. Total nitrogen increased from 0.44 g/m³ upstream to 0.51 g/m³ at the outfall site, before returning to upstream levels 50 m downstream.

Conductivity was very high in the outflow channel measuring 860 µs/cm upstream of the outfall (Table 10). It is likely that this was due to high levels of salinity in the water during the incoming tide. Saltwater is a very efficient conductor and willow dieback, as a result of saltwater intrusions, has been documented in the lower Waipori River (Sutherland and Closs 2003). In comparison, conductivity was lower, but still high, downstream of the outfall with measurements between 763 and 801 µs/cm (Table 10).

The turbidity of the outflow channel was naturally high measuring 7.06 NTU upstream of the discharge. This coincided with a high level of suspended solids (8 g/m³) and low water clarity (1.01 m). Turbidity and suspended solids showed small increases at 25 m downstream of the outfall. Turbidity increased to 7.75 NTU while suspended solids peaked at 10 g/m³ before returning to upstream levels 100 m downstream. Water clarity decreased slightly by 5%.

High levels of BOD_5 (50 g/m^3) and *E. coli* (92,000 MPN/100 mL) in oxidation pond effluent meant that concentrations of each were expected to increase immediately below the outfall. *E. coli* numbers were 44% higher 50 m downstream relative to upstream and decreased to 26.5 MPN/100 mL by 100 m downstream. However, BOD_5 was higher upstream (5 g/m^3) than both the 50 m (2 g/m^3) and 100 m (3 g/m^3) downstream sites.

Table 10 *Water quality in the Lake Waihola outflow channel in the vicinity of the Waihola oxidation pond discharge and in the effluent and outfall, 28th of November 2013.*

	Effluent	**Upstream**	**Outfall**	**Downstream 50 m**	**Downstream 100 m**	**Downstream 200 m**
Temperature (°C)	23.3	15.8	15.7	15.7	15.7	-
Dissolved oxygen (%)	123.5	97.4	96.9	97.8	97.6	-
Dissolved oxygen (g/m^3)	10.51	9.84	9.6	9.69	9.67	-
Conductivity (µs/cm)	554	860	801	809	763	-
pH	7.83	7.58	7.63	7.67	7.76	-
Turbidity (NTU)	-	7.06	6.95	7.75	6.93	-
Clarity (m)	-	1.01	0.96	0.97	1	-
5-day Biochemical Oxygen Demand (BOD_5) (g/m^3)	50	5	4	2	3	-
Total Phosphorus (g/m^3)	8.3	0.04	0.03	0.05	0.05	-
Dissolved Reactive Phosphorus (g/m^3)	3.9	0.005	0.005	0.005	0.005	-
Ammoniacal Nitrogen (g/m^3)	22	0.01	0.01	0.01	0.01	-
Total Nitrogen (g/m^3)	44	0.44	0.51	0.44	0.46	-
Nitrate/Nitrite Nitrogen (NNN) (g/m^3)	0.008	0.002	0.002	0.002	0.002	-
Suspended Solids (g/m^3)	8	8	8	10	8	-
E. coli (MPN/100 mL)	92,000	25.3	25.3	43.1	26.5	31.8

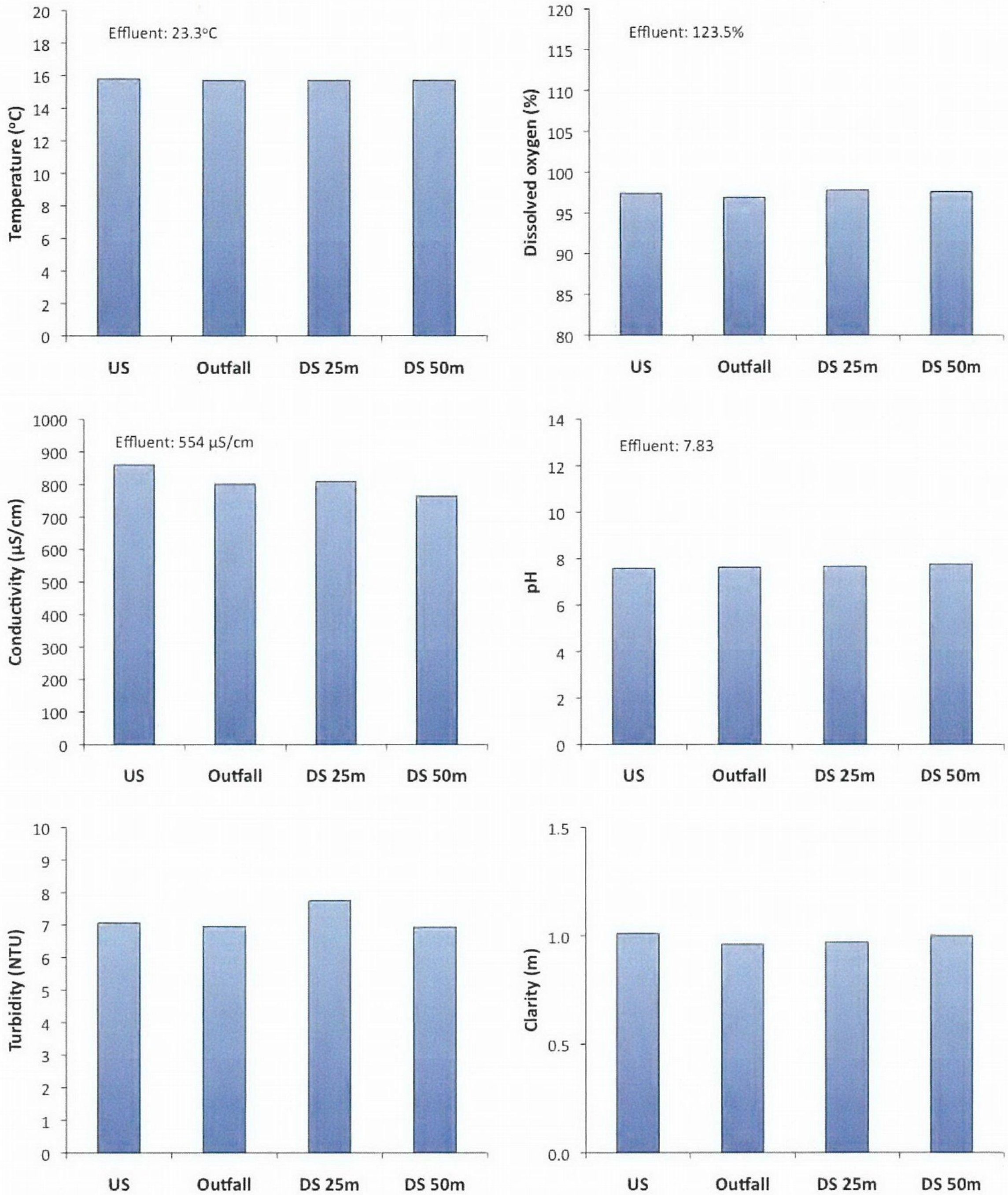

Figure 8 *Graphs of water quality sampled in the Lake Waihola outflow channel in the vicinity of the Waihola oxidation pond discharge, 28th of November 2013. Sampling sites were located upstream of the outfall (US), at the outfall (Outfall), and 25 m (DS 25m), 50 m (DS 50m) and 200 m downstream of the outfall. Where applicable, graphs display effluent quality results collected from the oxidation pond.*

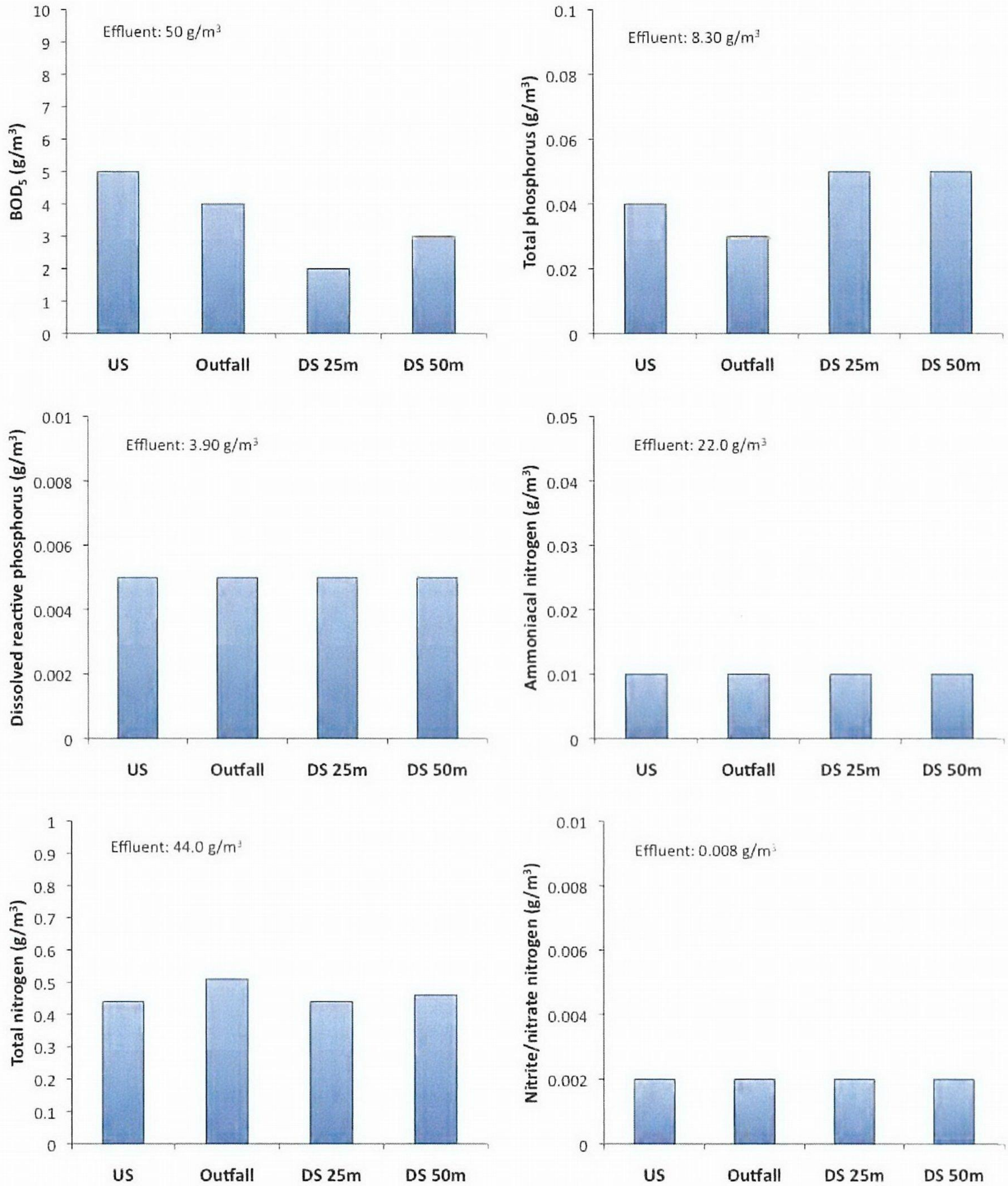

Figure 8 (cont.) *Graphs of water quality sampled in the Lake Waihola outflow channel in the vicinity of the Waihola oxidation pond discharge, 28th of November 2013. Sampling sites were located upstream of the outfall (US), at the outfall (Outfall), and 25 m (DS 25m), 50 m (DS 50m) and 200 m downstream of the outfall. Where applicable, graphs display effluent quality results collected from the oxidation pond.*

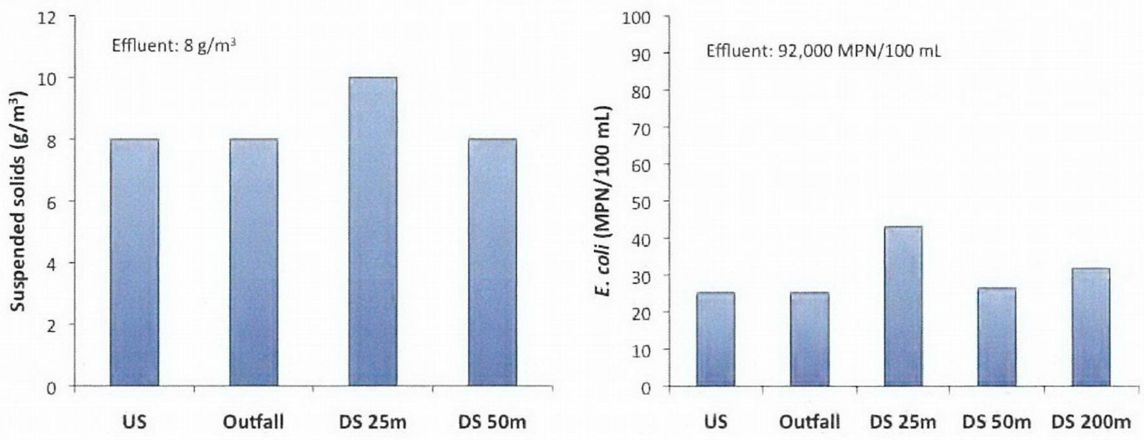

Figure 8 (cont.) *Graphs of water quality sampled in the Lake Waihola outflow channel in the vicinity of the Waihola oxidation pond discharge, 28th of November 2013. Sampling sites were located upstream of the outfall (US), at the outfall (Outfall), and 25 m (DS 25m), 50 m (DS 50m) and 200 m downstream of the outfall. Where applicable, graphs display effluent quality results collected from the oxidation pond.*

5.3 Macroinvertebrates

A total of six macroinvertebrate taxa were identified from nine samples collected in the Lake Waihola outflow channel (Table 11). Taxonomic diversity was very similar between each site with six taxa 100 m downstream of the outfall and five taxa at the remaining two sites. *Paracorophium* amphipods were generally very abundant and dominated the community (Table 11). *Potamopyrgus* snails, *Austridotea* isopods and *Chironomus* midge larvae were generally abundant. Schallenberg and Waite (2004) found snails, midge and caddisfly larvae when sampling Lake Waihola in 2002–2003, however their samples were collected from macrophytes rather than the lake bottom. Overall, taxonomic diversity upstream and downstream of the discharge was markedly lower than the New Zealand median of 18 taxa per river site (Scarsbrook *et al.* 2000).

MCI-sb scores ranged between 74 and 77 (Table 11) and were indicative of 'poor' quality conditions, using Boothroyd and Stark's (2000) narrative terminology (see Appendix Three). In contrast, SQMCI-sb scores ranged between 4.4 and 4.7 and were indicative of 'fair' quality conditions. Although MCI-sb and SQMCI-sb scores were reasonably low, benthic macroinvertebrate communities were typical of the soft-bottomed, lake-like environment present both upstream and downstream of the discharge (mud/silt substrate with slow flowing, deep water).

No significant differences were detected between any of the macroinvertebrate metrics measured upstream and downstream of the Waihola oxidation pond outfall (Table 12).

Table 11 *Macroinvertebrates collected using a ponar grab from the Lake Waihola outflow channel in the vicinity of the Waihola oxidation pond discharge, 28th of November 2013.*

TAXON	MCI-sb score	Upstream			50 m Downstream			100 m Downstream		
		A	B	C	A	B	C	A	B	C
CRUSTACEA										
Austridotea benhami	4.5	C	A	A	A	A	A	A	A	A
Paracorophium species	5.5	VA	VA	VA	VA	VA	VA	A	VA	VVA
DIPTERA										
Chironomus species	3.4	C	A	A	C	A	A	C	A	A
MOLLUSCA										
Potamopyrgus antipodarum	2.1	A	A	A	VA	A	A	A	C	VA
OLIGOCHAETA	3.8	R	R		R	R	R	R	R	R
PLATYHELMINTHES	0.9								R	
Number of taxa		5	5	4	5	5	5	5	6	5
MCI-sb score		77	77	78	77	77	77	77	67	77
SQMCI-sb score		4.8	4.7	4.7	3.9	4.7	4.7	4.0	4.9	4.9
Average MCI-sb score		77			77			74		
Average SQMCI-sb score		4.7			4.4			4.6		

Table 12 *Results of one-factor analysis of variance (ANOVA) tests for differences between macroinvertebrate samples collected from the Lake Waihola outflow channel in the vicinity of the Waihola oxidation pond discharge, 28th of November 2013.*

	$F_{1,4}$	p value
Number of taxa	1.50	0.296
MCI score	1.03	0.412
QMCI score	0.49	0.636

6. POTENTIAL ADVERSE EFFECTS ASSOCIATED WITH DISCHARGE

6.1 General

Treated effluent discharged from the Waihola oxidation pond to the Lake Waihola outflow channel contains a variety of contaminants. These contaminants include faecal bacteria, nutrients and suspended solids. The physicochemical character of the effluent also has the potential to alter receiving water pH, temperature and oxygen levels. The outflow channel in the vicinity of the outfall is already strongly influenced by a variety of external factors such as tidal-induced flow fluctuations, inflow from groundwater and the lower Waipori and Taieri Rivers, agricultural runoff into Lakes Waihola and Waipori, and wind-driven sediment suspension. However, effluent contaminants and physicochemical character have the potential to adversely affect the receiving water quality and ecology if discharged in sufficient quantities.

6.2 Natural and human use values

The discharge of wastewater treatment pond effluent has the potential to adversely affect the natural and human use values of a river or lake. Most notably, potentially harmful bacteria and viruses carry human health risks by affecting drinking water quality and conditions suitable for recreational contact. Some of these risks apply directly to the outflow channel itself, however many are more relevant to Lake Waihola and the lower Waipori and Taieri Rivers between which the channel flows.

Recreational activities that take place within the outflow channel are most likely limited to those that involve secondary contact. The presence of mai-mais (duck shooting shelters) and empty shotgun cartridges shows clear evidence of hunting in the area, while angling, whitebaiting and boating are probably common. Although the concentration of faecal bacteria increases slightly within 50 m downstream of the outfall, the geometric mean between 1998 and 1999 (99 no./100 mL at 20 m downstream) was well below the ANZECC and ARMCANZ (2000) guideline for secondary recreational contact (1000 faecal coliform organisms/100 mL). Similarly, *E. coli* concentrations increased to only 43.1 MPN/100 mL at 50 m downstream during a discharge event in November 2013.

Primary recreational contact within the outflow channel, such as swimming, is uncommon. However, Lake Waihola and the lower Taieri River are popular with locals and holidaymakers. The tidal influence on the LWC means that water may flow in or out of the lake depending on the tide. For this reason, the oxidation pond discharge is timed to occur 2.5 hours before high tide in an attempt to prevent effluent flowing into the lake. Although the mixing zone is well before the channel enters the lake, there is a chance that effluent contaminants may enter the lake on occasions, as daily net-flow can be either upstream or downstream depending on tides and freshwater inputs (Schallenberg *et al.* 2000). For example, a particularly elevated high-tide tide coupled with low river and groundwater levels due to drought would likely increase net-flow upstream into the lake. It is therefore important to assess the discharge's influence on primary contact recreation in context of both Lake Waihola and the lower Taieri River.

A national faecal coliform guideline for swimming and direct water-contact sports is 150 faecal coliform organisms/100 mL (ANZECC and ARMCANZ 2000). As mentioned above, faecal coliforms are generally well below this in the vicinity of the outfall. Faecal coliforms have been measured above this limit on occasions (i.e. February 1998 and 1999), however these measurements were recorded upstream of the discharge. This suggests that high levels were the result of contamination from a source other than the oxidation pond however the tidal conditions during this survey are unknown and it is assumed that samples were collected during an outgoing tide.

Lake Waihola has generally maintained a low level of *E. coli* with a median concentration of 30 cfu/100 mL between 2006 and 2011 (Ozanne 2012). The Ministry for the Environment (MfE 2003) guideline for an acceptable level for *E. coli* in recreational freshwaters is 260 cfu/100 mL whereas its action/red mode level is a single sample greater than 550 cfu/100 mL. The ORC interprets this such that if 550 cfu/100 mL is exceeded, there could be a health-risk for swimming. Between 2006 and 2011, *E. coli* concentrations never exceeded either guideline with a maximum of 180 cfu/100 mL recorded (Ozanne 2012).

ANZECC and ARMCANZ (2000) also suggests a minimum of 1.6 m visual clarity for bathing. Although no long-term monitoring data exists for water quality in the vicinity of the outfall, water clarity is often low in Lake Waihola. Poor water clarity is often caused by wind-driven sediment suspension. November 2013 monitoring found that water clarity in channel is close to 1 m on a calm day with very little wind. This decreased minimally within 50 m downstream of the discharge but returned to 1 m by 100 m downstream. This suggests that, due to the naturally low water clarity, the oxidation pond discharge has little effect on water clarity in the outflow channel, Lake Waihola or lower Taieri River.

National standards for drinking water quality include the guideline value for turbidity of 2.5 NTU, above which the appearance of the water is influenced, as an aesthetic determinant (Ministry of Health 2008). As discussed, sediment suspension due to wind is common, which causes high turbidity in both Lake Waihola and the outflow channel. Turbidity upstream of the oxidation pond outfall in November 2013 measured 7.06 NTU. Discharged effluent caused turbidity to increase slightly at 50 m downstream, but this rapidly reduced within 100 m downstream. This observation suggests that the outfall has no effect on turbidity in Lake Waihola, which shares similarly high levels of turbidity (2006–2011 ORC SOE median: 7.8 NTU (Ozanne 2012). Urban and rural drinking water supply takes are not known to exist either in the lake or outflow channel, or downstream from the channel's confluence with the lower Waipori River. The presence of takes for the purpose of supplying livestock with drinking water is unknown, but median faecal coliform concentrations are such that untreated river water can sometimes be deemed unsuitable for livestock drinking water irrespective of Waihola oxidation pond effluent inputs. Median faecal coliform concentrations measured over 10 times greater than the ANZECC and ARMCANZ (2000) livestock drinking water limit (100 faecal coliforms/100 mL) upstream of the outfall in February 1998 and 1999 indicating that the discharge was not responsible for causing the elevated levels..

Natural values of Lake Waihola (with which the outflow channel shares many attributes) as described in the ORC water plan, notably the 'silt bed composition of importance for resident biota', are unlikely to be affected by the consented discharge. A mud and silt layer on top of tightly packed clay generally dominates bed substrates. In contrast, accumulations of fine organic sediments caused by inputs of suspended solids are usually of most concern in stony-bed rivers. The Waihola oxidation pond is also unlikely to impact on whitebaiting or angling in the channel, lake or lower Waipori and Taieri Rivers. During sampling in November 2013, shoals of whitebait were observed swimming near the outfall site. Reasonable numbers of larval inanga and areas of spawning have also been identified throughout the channel since effluent began discharging over 25 years ago. The effect of the outfall on downstream nutrient and sediment concentrations is very small and unlikely to result in measurable increases of nuisance algae or plants (see Section 6.5), or adversely affect food sources (see Section 6.6) or fish directly (see Section 6.7).

6.3 Benthic habitat

Significant inputs of suspended solids can saturate riverbeds and create accumulations of sludge near discharge outfalls. However, increased sedimentation and smothering of the bed is not an issue in the vicinity of the Waihola oxidation pond outfall. As previously noted, bed substrates already consist of a thick mud and silt layer on top of a tightly clay bed whereas the impact of sedimentation typically occurs in rivers with stony substrates. Furthermore, background suspended sediment levels are already very high and often affected by wind, which creates turbulence stirring up bottom sediments. Likewise, no accumulations of silt or sludge are generated near the outfall or stream banks. Therefore, wetland plant species along channel banks, and the many bird species that inhabit them, are not affected by the discharge.

6.4 Water quality

Since 1998, the Waihola oxidation pond has often failed to comply with consent conditions for effluent quality. Specifically, BOD_5, faecal coliforms and suspended solids have all failed to meet consented maximums and geometric means. In contrast, nutrient levels are low in the pond and have been compliant on all sampling occasions. These contaminants have had varying impacts on receiving water quality.

The discharge's greatest measured effect on water quality in the outflow channel is an increase in faecal bacteria numbers. Results of November 2013 monitoring found that effluent discharge can account for up to 18 MPN/100 mL of *E. coli* 50 m downstream. This increase is relatively small and *E. coli* concentrations become considerably more diluted by 100 m downstream. However, results are inconsistent and monitoring undertaken by ORC between 1998 and 1999 (see Table 9) found that faecal coliform concentrations were often similar or greater upstream of the outfall. Faecal coliform bacteria have implications for human health and significant increases can on occasion exceed guidelines for contact recreation in the vicinity of the outfall (see Section 6.2).

Oxidation pond effluent has shown little to no impact on dissolved oxygen, BOD_5, pH or nutrient levels (total phosphorus, dissolved reactive phosphorus, ammoniacal nitrogen, total nitrogen and nitrate/nitrite nitrogen) in the outflow channel. Monitoring downstream of the outfall indicates that values for each of these water quality parameters are similar to those measured upstream. Measures for nutrients in the channel were particularly low in November 2013 with total phosphorus (<0.033 g/m^3) and ammoniacal nitrogen (<0.01 g/m^3) measuring well below the ANZECC and ARMCANZ (2000) guideline values of 0.614 g/m^3 and 0.021 g/m^3 respectively. Total nitrogen levels peaked at the outfall site (0.51 g/m^3) but still measured less than the lowland river guideline of 0.614 g/m^3 (ANZECC and ARMCANZ 2000). In comparison, turbidity, suspended solids and clarity all showed very small changes downstream (see Sections 6.2 and 6.3).

A growth in population during peak holiday seasons in Waihola may result in increased contaminant inputs to the outflow channel. Seasonal monitoring data of effluent contaminants found that BOD_5, suspended solids and total phosphorus increase in the treatment pond during spring/summer. It is therefore expected that these contaminants may also increase in the receiving environment. Faecal coliforms in the pond remain relatively consistent throughout the year as high solar radiation and temperature levels offset increased solid waste inputs (see Section 4.6).

Contaminants from the Waihola oxidation pond are rapidly diluted in the outflow channel. However, the poorly understood and complicated hydrology of the LWC (see Section 3.5) makes it difficult to assess precise dilution ratios. One third of Lake Waihola can be displaced in a day as tidal flow is cycled backwards and forwards in the channel. This is coupled with extensive, yet empirically unknown, inputs of groundwater, and multiple waterways that interconnect the lake, outflow channel and surrounding wetland. With a hydraulic residence time of 153 days, and daily net-flows alternating upstream and downstream, effluent from the Waihola oxidation pond is likely to persist in a highly diluted state for extended periods of time before being flushed out to sea.

Greater restrictions on allowable BOD_5, suspended solid, nutrient and faecal indicator bacteria levels within the oxidation pond are expected under a new long-term discharge consent (see Table 6). Monitoring results since 2004 suggest that only pH would comply under new conditions proposed by the ORC. Total phosphorus would be expected to comply on only 81% of occasions while remaining measures of effluent quality would comply less than 50% of the time. The new limit for *E. coli* is that pond effluent is not to exceed the MfE (2003) guideline of 260 cfu/100 mL. In November 2013, pond *E. coli* measured over 350 times this limit.

Schedule 15 of the ORC Regional Plan: Water for Otago (2013) contains receiving water quality standards for lakes and rivers to be met by March 2025 (Table 13). The receiving water quality standards for Lakes Waipori and Waihola are 5-year 80th percentile values at all times. No long-term data has been collected in the vicinity of the outfall, however data collected by ORC at Lake Waihola (see Table 4 of this report) shows that median *E. coli*, dissolved reactive phosphorus, ammoniacal nitrogen and nitrate-nitrite nitrogen concentrations, met the plan standards. In contrast, turbidity exceed standards outlined by the plan. It is likely that, with the possible exception of turbidity, these water quality parameters would continue to meet the plan Schedule 15 standards 50 m downstream of the outfall with the current effluent quality.

Table 13 *Water quality standards from schedules 15 of the ORC Regional Plan: Water for Otago (2013). Timeframe for each parameter in brackets.*

	Nitrate-nitrite nitrogen (mg/l)	**Dissolved reactive phosphorus (mg/l)**	**Ammoniacal nitrogen (mg/l)**	***Escherichia coli* (cfu/100 ml)**	**Turbidity (NTU)**
Receiving water: Lake Waipori and Waihola	0.55 (31 March 2025)	0.033 (31 March 2025)	0.1 (31 March 2012)	126 (31 March 2012)	5 (31 March 2025)

6.5 Aquatic algae and plants

Lake Waihola has historically experienced heightened levels of plantonic cyanobacteria growth. During spring and summer, these sometimes reach potentially toxic levels (e.g., October 2013). However, nuisance growths of benthic periphyton are likely to be rare due to a lack of stony substrates within the lake and channel. Macrophytes in the vicinity of the outfall are dominated by *Potamogeton ochreatus* and *Myriophyllum triphyllum.*

Increases in nutrient concentrations can greatly influence the growth and composition of algae and plant communities. Since 1998, Waihola oxidation pond effluent has complied with consented limits for measures of phosphorus and nitrogen.

November 2013 sampling revealed that the discharge has resulted in no detectable increase in phosphorus or nitrogen in the channel downstream of the outfall. It is therefore unlikely that algae and aquatic plant growth will be exacerbated by the discharge.

6.6 Benthic macroinvertebrates

Elevated ammonia concentrations can be toxic to macroinvertebrates and fish. Ammonia is highly soluble in water and is more readily available in the form of ammonium (NH_4^+), which is relatively harmless to animals. Temperature and pH levels must be high in order for ammonia to persist in aquatic environments. At room temperature (25°C) and at a pH of around 8.0, the proportion of ammoniacal nitrogen as represented by ammonia is only 10% or less (Sawyer 2008). Downstream of the oxidation pond outfall, ammoniacal nitrogen concentrations are significantly lower than ANZECC and ARMCANZ (2000) guideline levels for ammonia toxicity (< 0.9 g/m^3). pH levels are also generally between the ANZECC and ARMCANZ (2000) guideline level of 7.2 – 7.8, while water temperatures were measured at less than 16°C (during a sunny November day between 12.35 pm and 1.10 pm). Therefore, ammonia toxicity is not an issue for benthic macroinvertebrates or other aquatic organisms such as fish.

Suspended sediments can settle out in low velocity environments, potentially smothering benthic communities. Siltation affects aquatic invertebrates by reducing light penetration, abrasion, adsorbed toxicants, changes in substrate character, and reducing food quality. The Lake Waihola outflow channel naturally contains a soft-sediment bed characteristic of a wetland water body. It is therefore unlikely to experience a change in substrate composition. Invertebrate communities in the channel are dominated by soft-sediment taxa, such as snails and crustaceans. These occur both upstream and downstream of the outfall, however this does have the added caveat that both communities are exposed to effluent disposal during different tides. Nonetheless, ammoniacal nitrogen levels are well below those indicative of potential toxicity, and the channel is naturally very turbid regardless of the outfall.

6.7 Fish

BOD characterises the necessary level of oxygen required by aerobic organisms to process organic wastes in wastewater effluent. Increased levels of organic waste are correlated with increased levels of BOD_5 and a greater potential for microbes in effluent streams to consume oxygen in a receiving environment. Trout are regarded as the fish species most sensitive to a reduction in dissolved oxygen saturation, with a minimum standard of 80% recommended for lowland river environments (Third Schedule of the Resource Management Act 1991, Dean and Richardson 1999). Historically, BOD_5 levels have exceeded consented limits in the Waihola oxidation pond. However, surveys in 1998/99 (Milne 2000) and November 2013 found that the high BOD_5 levels in the oxidation pond have little influence on downstream BOD_5 levels in the outflow channel. Furthermore, dissolved oxygen saturation has been recorded at levels well above the 80% minimum standard for trout.

Effects of elevated suspended solid concentrations on fish can include direct effects such as the avoidance of turbid water by some fish, lower growth rates, impairment to visual feeding and clogging of gills resulting in death (Ryan 1991, Alabaster and Lloyd 1982, Newcombe and McDonald 1991). Indirect effects can include a reduction in the invertebrate food source, avoidance of silted gravels for spawning by adult fish, and egg mortality due to reduced oxygen conditions in gravel caused by silt deposition.

The effects of suspended sediment on New Zealand fish species are highly variable. For example, banded kokopu displayed a 50% avoidance response at 17-25 NTU, while koaro and inanga were found to be less sensitive, with a 50% avoidance response at 70 and 420 NTU respectively (Boubée *et al.* 1997). Shortfin and longfin elvers and redfin bullies showed no avoidance behaviour, even at the highest turbidities tested (1,100 NTU) (Boubée *et al.* 1997). Rowe *et al.* (2004) determined the maximum turbidity levels that could be tolerated by four native fish species over a 24 hour period. Juvenile banded kokopu and adult redfin bullies were able to tolerate turbidity levels of up to 38,000 NTU with low mortality. In contrast, smelt and inanga were much more sensitive to high turbidity levels. Fifty per cent mortality rates ranged from 1,700 to 3,000 NTU for smelt, and 17,500 to 21,000 NTU for inanga (Rowe *et al.* 2004).

Turbidity measurements in the outflow channel on the 28th of November 2013 ranged between 6.95 and 7.75 NTU. This is similar to Lake Waihola 2006–2011 median of 7.8 NTU, although levels in the lake have been recorded as high as 79.4 NTU (Ozanne 2012). Fish behaviour may be influenced by increased turbidity during high tributary flow events and periods of bed disturbance caused by high winds. However, generally turbidity levels are such that they are not likely to affect fish behaviour and are well below levels where fish mortality would be expected. November 2013 monitoring showed that the Waihola oxidation pond discharge only has a localised impact on suspended solid concentrations in the outflow channel. Regardless, fish behaviour is such that any suspended sediment plume would be able to be avoided.

As already noted, ammoniacal nitrogen levels in the vicinity of the Waihola oxidation pond discharge are well below those regarded as being toxic to freshwater fish (see Sections 6.4 and 6.6).

7. CONCLUSION

The discharge of effluent from the Waihola oxidation pond to the outflow channel of Lake Waihola has a minor effect on water quality that is restricted to a localised area immediately downstream of the discharge point. This effect is temporary and shifts with the changing tide. The discharge does not appear to adversely affect aquatic plant, benthic macroinvertebrate, fish or bird communities. The minor and localised effect of the discharge on water quality in the outflow channel is expected to have minimal, if any, effects on water quality and aquatic communities in Lake Waihola, the surrounding wetland, or the lower Waipori and Taieri Rivers.

The Waihola oxidation pond has a history of contaminant non-compliance and often exceeds maximum guideline values. The proposal of more stringent contaminant guidelines under a new long-term discharge permit means that if new guidelines are met, any effects on the receiving water will be further reduced or eliminated. As it currently stands, only pH levels would comply with the proposed guidelines. Therefore, significant improvements to treatment facilities would be necessary for BOD_5, nutrients, faecal bacteria and suspended solid levels to comply.

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9. APPENDICES

Appendix One

Summary results for water quality monitoring undertaken in Lake Waihola between September 1997 and October 1998 (Schallenberg and Burns 2003a), and October 2002 and August 2004 (ORC 2005). They include total nitrogen, total phosphorous, chlorophyll-α and secchi depth, which are the four key variables required to calculate the trophic status of the lakes.

Parameter	**September 1997 – October 1998**											
	Waihola South				Waihola Mid				Waihola North			
	n	min	max	med	n	min	max	med	n	min	max	med
Total phosphorus (g/m^3)	23	0.036	0.196	0.082	24	0.030	0.207	0.067	24	0.027	0.124	0.053
Total nitrogen (g/m^3)	23	0.299	1.153	0.674	24	0.222	1.183	0.456	24	0.222	0.851	0.42825
Chlorophyll-a	23	0.0014	0.0397	0.0126	24	0.0012	0.0333	0.0086	24	0.0026	0.0640	0.0099
Nitrate (g/m^3)	23	0.002	0.212	0.025	24	0.000	0.113	0.024	24	0.000	0.103	0.025
Ammoniacal nitrogen (g/m^3)	23	0.000	0.077	0.029	24	0.001	0.055	0.027	24	0.006	0.060	0.031
Dissolved reactive phosphorus (g/m^3)	23	0.005	0.037	0.015	24	0.003	0.024	0.008	24	0.004	0.021	0.008
Turbidity (NTU)	23	1.1	80.0	12.8	24	2.1	74.0	16.3	24	3.1	43.0	11.7
pH	19	7.02	9.66	8.04	19	7.00	8.20	7.47	19	6.90	8.13	7.42
Conductivity (µs/cm)	23	164	5700	1531	24	128	6220	2011	24	122	6800	1931
Parameter	**October 2002 – August 2004**											
	Waihola South				Waihola Mid				Waihola North			
	n	min	max	med	n	min	max	med	n	min	max	med
Total phosphorus (g/m^3)	20	0.003	0.163	0.048	20	0.003	0.121	0.037	17	0.003	0.237	0.047
Total nitrogen (g/m^3)	20	0.380	1.760	0.888	20	0.260	1.140	0.591	17	0.350	1.030	0.571
Chlorophyll-a	20	0.0010	0.3950	0.0324	20	0.0015	0.0370	0.0070	17	0.0016	0.0065	0.0040
Nitrate (g/m^3)	20	0.003	0.243	0.035	20	0.003	0.034	0.011	17	0.003	0.080	0.030
Ammoniacal nitrogen (g/m^3)	20	0.005	0.100	0.046	20	0.005	0.140	0.040	17	0.005	0.110	0.050
Dissolved reactive phosphorus (g/m^3)	20	0.003	0.017	0.004	20	0.003	0.006	0.003	17	0.003	0.006	0.004
Turbidity (NTU)	20	1.2	28.0	7.4	20	2.6	28.0	9.9	17	4.4	23.0	9.3
pH	16	6.98	9.24	7.90	15	7.07	8.17	7.54	15	7.13	8.03	7.40
Conductivity (µs/cm)	20	0	12710	2999	20	183	13140	2829	17	167	12510	2692
Total suspended solids (g/m^3)	20	2	67	15	20	6	82	23	17	6	72	26
Inorganic suspended solids (g/m^3)	20	1	57	10	20	3	75	19	17	3	66	23

Appendix Two

CDC monitoring data of effluent collected from Waihola oxidation pond between February 1998 and June 2013.

Date	5-day biochemical oxygen demand (g/m^3)	pH	Total phosphorus (g/m^3)	Faecal coliforms (MPN/100mL)	Ammoniacal nitrogen (g/m^3)	Total nitrogen (g/m^3)	Total suspended solids (g/m^3)
10 February 1998	11	-	8.63	130	14	-	13
12 May 1998	23	-	8.9	130000	21.2	-	13
11 August 1998	60	-	8.31	210000	29.6	-	39
10 November 1998	30	-	7.58	80000	18.4	-	18
4 February 1999	82	-	11.3	8000	14	-	77
19 May 1999	58	-	11.2	8000	35.2	0.025	70
24 August 1999	26	-	6.54	50000	18.1	-	110
10 November 1999	33	-	7.52	130000	16.7	-	54
8 February 2000	65	8.2	7.6	6800	11	20	80
16 February 2000	54	-	7.02	50000	11.2	-	120
16 May 2000	42	-	7.86	130000	23.4	-	61
10 August 2000	39	-	6.77	30000	20.3	-	46
7 November 2000	45	-	5.69	30000	13.7	-	81
12 February 2001	54	-	8.74	82000	22	-	58
8 May 2001	45	-	8.48	1700	21.7	-	41
9 August 2001	30	-	5.73	95000	15	-	63
13 February 2002	38	7.39	7	5600	8.19	-	110
12 September 2002	27	7.3	5.39	210000	15.3	-	35
11 February 2003	57	8.41	9.44	320000	5.55	-	160
6 May 2003	130	7.92	10.2	240000	18	38.2	200
23 May 2003	51	-	-	-	-	-	100
13 August 2003	28	7.96	7.93	46000	22.9	33.1	55
8 December 2003	48	8.56	8.99	110000	27.2	39	74
18 February 2004	78	8.12	11	960000	20.9	47.1	150
17 May 2005	32	7.41	8.72	24000	30.3	42.4	59
9 August 2005	36	7.12	7.49	72000	25.5	35	73
9 November 2005	86	7.33	9.55	270000	21.4	42	100
15 February 2006	31	8.4	10.8	310000	15.6	36.6	150

Date	5-day biochemical oxygen demand (g/m^3)	pH	Total phosphorus (g/m^3)	Faecal coliforms (MPN/100mL)	Ammoniacal nitrogen (g/m^3)	Total nitrogen (g/m^3)	Total suspended solids (g/m^3)
11 May 2006	29	7.17	5.9	130000	18.3	27	43
10 August 2006	39	7.5	6.53	89000	20.8	32	86
12 February 2007	88	7.36	10.5	100000	20	38	140
15 May 2007	80	7.52	11.6	250000	33.7	46	88
9 August 2007	49	8.62	4.46	75000	13.4	23	85
6 November 2007	76	7.78	6.91	46000	12.4	33	160
13 February 2008	55	8.88	11.3	70000	14.8	31	72
12 May 2008	57	7.7	8.51	49000	24.9	36	80
19 August 2008	17	7.89	3.1	31000	9.64	12	54
11 November 2008	50	9.13	7.24	34000	15.9	31	96
3 February 2009	95	9.04	11.8	82000	25.5	43	100
19 May 2009	44	7.5	5.47	31000	20.3	27	58
4 August 2009	35	7.46	4.29	23000	21.3	29	76
11 November 2009	87	8.74	6.93	81000	17.6	38	150
3 February 2010	190	8.7	10.3	26000	16.9	43	280
10 May 2010	51	7.46	8.56	400000	31.5	43	56
5 August 2010	86	7.27	5.77	580000	20.5	34	110
10 November 2010	40	8.95	5.15	94000	15.5	21	33
2 February 2011	58	8.81	7.38	88000	15.3	33	140
17 May 2011	13	7.67	3.76	48000	20.4	25	46
2 August 2011	27	7.47	5.04	44000	24.3	36	85
1 November 2011	190	8.63	7.46	72000	12.9	40	340
9 February 2012	49	7.48	8.31	320	22.4	33	74
8 May 2012	57	7.57	6.22	140000	22.3	37	87
1 August 2012	64	7.44	4.71	420000	20.2	32	100
1 November 2012	28	8.25	5.4	100000	23.6	34	100
5 February 2013	70	7.55	7.32	310000	18.7	36	130
6 June 2013	59	7.59	4.77	220000	21.9	40	70

Appendix Three

November 2013 sampling techniques

Water and effluent quality

Water quality was sampled at three sites in the outflow channel (see Section 5.1) and effluent quality from the oxidation pond. A handheld YSI Professional Plus multi-probe field meter was used to measure temperature, pH, dissolved oxygen saturation and concentration, and conductivity. Water clarity was measured using a transmissometer, an instrument that measures light transmittance through water. Turbidity was measured using a Hach 2100Q turbidimeter. Grab-water samples were also collected and sent to Citilab Dunedin to be tested for BOD_5, total phosphorus, dissolved reactive phosphorus, total nitrogen, ammoniacal nitrogen, nitrate-nitrite nitrogen, suspended solids and *E. coli*. An additional sampling site 200 m downstream of the outfall was tested solely for *E. coli*.

Macroinvertebrates

Field collection and laboratory processing

Due to the great depth of the outflow channel, benthic macroinvertebrates were collected at each sampling site using a ponar grab. The ponar grab was released into the water and retrieved by rope after disengaging on the streambed. Its contents were then sieved through 500 µm mesh and preserved in 70% ethanol to be returned to the laboratory for processing.

In the laboratory, macroinvertebrate samples were processed for taxa identification and relative abundance according to the semi-quantitative protocol 'P1: Coded abundance' as outlined in the Ministry for the Environment's "Protocols for sampling macroinvertebrates in wadeable streams" (Stark *et al.* 2001). Preserved samples were passed through a 500 µm sieve to remove fine material. Contents of the sieve were then placed in a white tray for macroinvertebrates identification. Each taxon present in the sample was assigned to one of five coded abundance categories (Table A3.1). Up to 20 individuals representative of each taxon were removed from each sample to confirm identifications under a dissecting microscope (10-40x) using criteria from Winterbourn *et al.* (2006).

Table A3.1 *Coded abundance scores used to summarise macroinvertebrate data (after Stark 1998).*

Abundance	Coded Abundance	Weighting factor
1 - 4	Rare (R)	1
5 - 19	Common (C)	5
20 - 99	Abundant (A)	20
100 - 499	Very abundant (VA)	100
> 500	Very very abundant (VVA)	500

Analyses

For each site, benthic macroinvertebrate community health was assessed by determining the following characteristics:

Number of taxa: A measurement of the number of taxa present.

Macroinvertebrate Community Index for soft-bottomed streams (MCI-sb) and semi-quantitative MCI for soft-bottomed streams (SQMCI-sb) (Stark and Maxted 2007): These biotic indices have recently been developed specifically for use in soft-bottomed streams. The original MCI and SQMCI were developed for use in hard-bottomed streams based on sampling macroinvertebrates from riffle or run habitats, however their use has often been extended through a wide range of habitats including soft-bottomed areas. The soft-bottomed indices use the same principles as the hard-bottomed MCI and SQMCI indices, however new taxon-specific tolerance scores (between 1 and 10) have been derived specifically for soft-bottomed streams (Stark and Maxted 2007).

The MCI-sb site score is obtained by summing the scores of individual taxa and dividing this total by the number of taxa present at the site.

$$\text{MCI-sb} = \left(\frac{\text{Sum of taxa scores}}{\text{Number of scoring taxa}}\right) \times 20$$

The SQMCI-sb uses the same approach as the MCI-sb but weights each taxa score based on how abundant the taxa is within the community. Abundance of each taxon is converted into one of five coded abundance scores using the codes established by Stark (1998) (Table A3.1).

$$\text{SQMCI-sb} = \frac{\text{Sum of (Taxa coded abundance x Taxa score)}}{\text{Sum of coded abundances for sample}}$$

As for MCI and SQMCI, MCI-sb and SQMCI-sb scores can be interpreted in the context of national standards (Table A3.2).

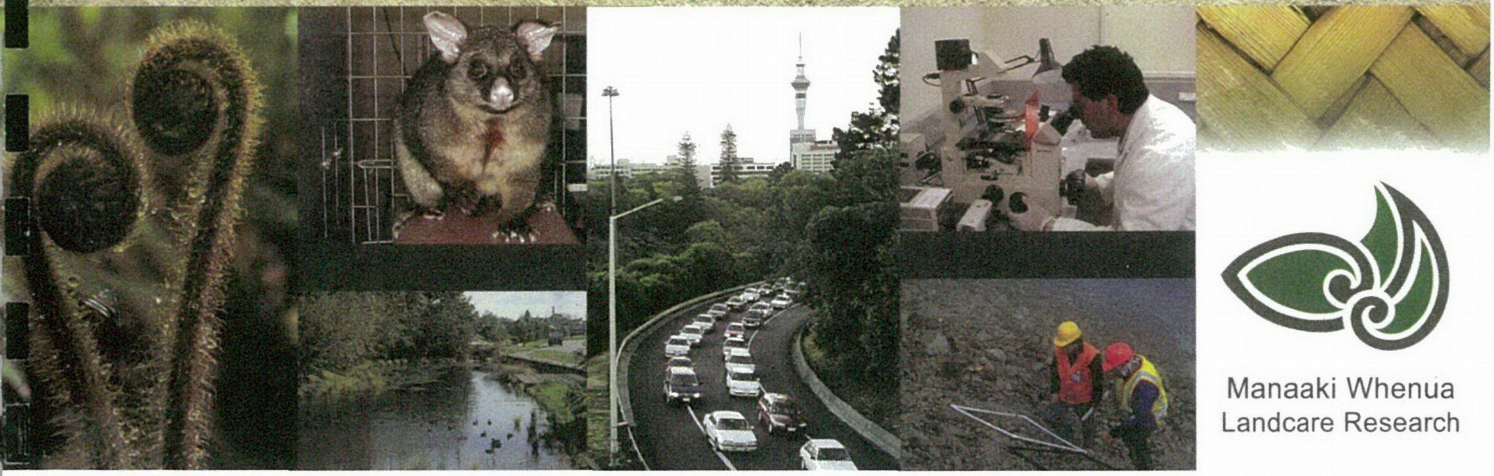
Table A3.2 *Interpretation of macroinvertebrate community index values from Boothroyd and Stark (2000) (Quality class A) and Stark and Maxted (2007) (Quality class B).*

Quality Class A	Quality Class B	MCI-sb	SQMCI-sb
Clean water	Excellent	≥ 120	≥ 6.00
Doubtful quality	Good	100 – 119	5.00 – 5.99
Probable moderate pollution	Fair	80 – 99	4.00 – 4.99
Probable severe pollution	Poor	< 80	< 4.00

Values for macroinvertebrate metrics were compared between the three sampling locations using a one-factor analysis of variance (ANOVA) in the statistical package DataDesk®. In these tests a 'p' value of <0.05 indicates a statistically significant difference between the three sites. If an ANOVA test indicated a significant difference in invertebrate communities between sampling sites, Bonferroni post-hoc tests were used to test for differences in individual, one-on-one site comparisons.

Soil Investigation to Evaluate Capability of Land Surrounding Waihola, Balclutha, Stirling, Kaitangata, Owaka, Clinton, Heriot and Lawrence for Use as Municipal Wastewater Disposal Sites

Trevor H. Webb



Manaaki Whenua
Landcare Research

CDC ID A46844

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Contents

Summary

Project and Client

Soils surrounding Waihola, Balclutha, Stirling, Kaitangata, Owaka, Clinton, Heriot and Lawrence were investigated by Landcare Research to evaluate their capability for use as municipal wastewater disposal sites. This report was prepared for Clutha District Council for comment in June–July 2006.

Objectives

- To evaluate the suitability of soils for land-based wastewater disposal within defined areas surrounding eight townships in Clutha District.
- To identify the location of land considered suitable for wastewater disposal.
- To estimate the area of land required for wastewater disposal under 'best practice' on each soil/landscape considered to contain suitable soils.

Results

- Soil profile descriptions were made for soils at 6 sites at Waihola, 24 sites at Balclutha-Stirling-Kaitangata vicinity, 6 sites at Owaka, 5 sites at Clinton, 6 sites at Heriot and 9 sites at Lawrence.
- Land considered to be potentially suitable for year-round wastewater disposal was located within the target zone at Balclutha, Stirling, Kaitangata, Owaka, and Clinton and just beyond the target zone at Waihola. However, for some towns, it is uncertain whether a sufficient area of land can be found within target areas.
- It is less likely that land suitable for year-round wastewater disposal can be found at either Heriot or Lawrence.
- Maps are presented showing location of land potentially suitable for wastewater disposal.
- Estimates are given of hydraulic loading capacity for each soil/landscape based on the matching of soil morphological descriptions with soil water assessments made on similar soils from Canterbury.
- It is suggested that pasture under spray irrigation is the most suitable disposal method on flat to undulating land and trickle irrigation under forest is the most suitable disposal method on hilly to steep land.
- Recommendations are made for soil testing to be carried out on specific sites proposed for wastewater disposal.
- Recommended hydraulic loadings are made with the assumption that sufficient capacity will be available for storage of wastewater during periods of sustained rainfall.
- Assessment of nutrient loadings is based upon land disposal systems designed to accommodate hydraulic loads. Nitrogen loadings are well below pasture uptake requirements and phosphorus loadings either meet potential pasture uptake values or are below potential pasture uptake values.

1. Introduction

1.1 Brief

This report has been prepared by Landcare Research to provide an analysis of land suitability for wastewater disposal from Waihola, Balclutha, Stirling, Kaitangata, Owaka, Clinton, Heriot and Lawrence townships. The report is written in response to a request from Clutha District Council and was prepared during June–July 2006.

The brief received from Clutha District Council (2005) described the scope of the work and subsequent reporting as follows:

> 'This engagement is for Professional Services to evaluate the viability of land based sewage disposal to serve Clutha District communities with communal sewage treatment and disposal systems.
>
> To achieve this, the following tasks will be required. This list is not intended to be exhaustive as it identifies tasks at a high level.
>
> a) Review any Clutha District Council documentation as necessary.
>
> b) Review soils mapping information to identify soil characteristics and suitability for sewage disposal.
>
> c) Determine disposal parameters applicable to sites in each location.
>
> d) Identify disposal mechanism and estimate areas required for each location.
>
> Prepare a draft report to Council for comment summarising the findings from b) – d) above, commenting specifically on the viability of land-based disposal in each location.
>
> Receive any comment from Council and incorporate them in a final report.
>
> The report is to enable Council to verify the area of land required at each location and have estimates of capital and operating costs prepared.'

1.2 Location

The target investigative area was based upon the following radii from each town, as provided by Clutha District Council:

Waihola	3.75 km
Balclutha	15.0 km
Stirling	2.25 km
Kaitangata	6.0 km
Owaka	3.0 km
Clinton	2.25 km
Heriot	1.0 km
Lawrence	4.5 km

1.3 Treated wastewater volumes and characteristics

Average daily wastewater volumes were derived from estimates provided by Clutha District Council by email on 27 June 2006. The nutrient concentrations of treated wastewater were derived from 'Issues and Options' reports on each town (MWH 2001a,b,c, 2002a,b,c,d). Average daily wastewater volumes were used to calculate land areas required for land disposal. Average nutrient concentrations were used to estimate annual phosphorus and nitrogen loadings.

1.4 Reliability of soil maps and permeability estimates

It is intended that the information contained in this report and accompanying maps is sufficiently accurate to form a basis for costing alternative land-based wastewater disposal systems at each town. The maps provide a sound basis for indicating areas with greatest potential for land disposal sites. Further soil investigation may locate other suitable sites. Further investigation will also be necessary to quantify soil permeability and pore volumes at any sites proposed for use as land disposal areas. From these measurements a more site-specific estimate may be made of hydraulic loading potential and thence irrigation scheduling. Also a daily water balance analysis needs to be undertaken in relation to a proposed irrigation schedule to determine the size of wastewater storage required at each site.

2. Methods

2.1 Review of previous reports

Previous studies of land disposal of wastewater had been prepared for each of the sites by Montgomery Watson Harza in 2001 and 2002. These reports were used as background information and relevant parts are commented on in this report.

2.2 Soil survey

Soil maps from GrowOtago were used as a basis for selecting sampling sites and to provide an initial understanding of soil type distribution. Soil characteristics were determined at selected sites by use of a hand-operated 75-mm-diameter auger, road cuts, drainage cuts, and by excavating pits. Seventy percent of the profile observations were made on road verges, with the remainder made along transects through farmland. At soil observation points, soils were subdivided into horizons and described in terms of texture, colour, mottle patterns, consistence, root density and estimates of soil permeability. Most profile observations were made to 1 m depth and in places to 2–3 m depth. Information on soil profiles was supplemented by the 110 observations made for Milton, Kaka Point and Tapanui (Webb 2006).

The amount of soil information obtained at any point was necessarily a compromise between investigating the array of soils contained in the large areas designated in the brief, while obtaining adequate soil morphology descriptions at each site. There was insufficient time to investigate soil conditions over all the area designated surrounding the towns. However, extrapolation based on GrowOtago maps provides a reasonable estimate of the possible extent of suitable land.

In general the GrowOtago maps were found to be a good reflection of soil drainage conditions and proved very helpful in stratifying sampling.

2.3 Estimates of irrigation capacity

Irrigation scheduling needs to be based upon soil characteristics, including the permeability of soil horizons and air-filled pore volume at field capacity and wilting point. No measurements of pore volumes or permeability were undertaken as part of this study so these characteristics have been estimated by matching soil morphology with similar soils for which data are available.

Permeability can be estimated into classes from soil morphology with a fair degree of accuracy when soil density and soil structure are measured in soil pits (Griffiths et al. 1999). The time available and scope of this project precluded detailed measurement of soil morphology. However, the author has wide experience of estimating soil permeability from profile morphology and has assigned permeability classes to profiles. Recommendations are made as to the need for quantification/verification of permeability by subsequent field measurement at specific sites.

Estimates of drainage capacity were made on the basis of modelling the drainage curve using the LEACHM model (Hutson & Wagenet 1992) for similar soils in Canterbury.

3. Results

3.1 General aspects of wastewater disposal

Overall objective

The methods of wastewater disposal recommended in this report are based upon best practice as discussed in Robb & Barkle (2000) and NZLTC (2000). Best practice aims to provide sustainable wastewater disposal systems. Sustainability for wastewater disposal requires land to be capable of:

- Assimilating daily volumes of treated wastewater onto the soils without surface ponding
- Providing for uptake of biological and chemical constituents and senescence of microbes
- Minimising adverse impacts on the environment.

Note: This report makes a number of recommendations for irrigation rates and scheduling. These recommendations need to be seen as estimates based on a number of assumptions in relation to estimated soil permeability and unspecified wastewater storage capacity. Recommendations are made to enable Clutha District Council to estimate likely land areas required for land disposal of wastewater and to estimate 'ballpark' costs for setting up and running irrigation systems.

Soil drainage characteristics

No drainage measurements have been made for these soils and no hydraulic conductivity data are available for soils of the Clutha District. However, measurements for similar soils in Canterbury are used to estimate likely drainage characteristics. Data for Waimakariri soils (Weathered Orthic Recent soils) are used to simulate soils on the older floodplains and Templeton soils (Immature Pallic soils) are used to simulate soils on the fans and steeplands. It is likely that the soils in Canterbury will have slower permeability and lower pore volumes that the soils in Clutha District, so estimates based on these soils are likely to be more conservative in terms of irrigation capacity.

Irrigation application for each soil

Irrigation scheduling that applies water at a rate lower than the infiltration rate, and in an amount that is less than the air-filled pore space, maximises opportunity for nutrient uptake and microbial removal.

Irrigation application rate (application rate under a sprinkler or trickle-wetted area) needs to be at a rate that accords with soil hydraulic characteristics:

The application rate must be matched to the capacity of the soil to absorb and transmit water. The limiting value is the smaller of the surface infiltration rate and the near-saturated vertical hydraulic conductivity of the least permeable soil layer (Robb & Barkle 2000).

Rate of irrigation needs to be based upon measurements of unsaturated hydraulic conductivity of the least permeable soil layers within soils on potential sites. These measurements need to be made after potential sites are selected.

Irrigation application frequency and quantity need to accord with soil hydraulic characteristics:

To keep soils below saturation and to make some allowance for rainfall, preliminary data analysis suggests soil should be irrigated to about half of the available pore space that is not already filled with water. In other words about half the pore volume between saturated water content and field capacity (NZLTC 2000, section 2).

Application quantity and frequency determine amounts of wastewater that may be applied and consequently the amount of land required for land disposal. These factors therefore need to be estimated to *enable Council to verify the area of land required at each location and have estimates of capital and operating costs prepared.*

Frequency of irrigation is determined by the need to provide adequate time for soil to become well aerated so the biological activity (above and below ground) will have suitable conditions and sufficient time to renovate/absorb nutrients and contaminants. Determining this frequency is somewhat subjective, but I favour allowing a minimum of 10 days between irrigation events. If soils are very permeable (as occurs on parts of the older floodplains) the interval may be reduced to 7 days but treatment of wastewater will not be as effective.

1. Soils of the older floodplains
Drainage from saturation over 10 days = 56 mm
Recommended irrigation application = half the drained pore volume = 28 mm

2. Soils of the fans with moderately slow permeability
Drainage from saturation over 10 days = 46 mm
Recommended irrigation application = half the drained pore volume = 23 mm

3. Soils of the fans with slow permeability
Drainage from saturation over 10 days = 36 mm
Recommended irrigation application = half the drained pore volume = 18 mm

4. Moderately deep soils on steep slopes
Drainage from saturation over 10 days = 36 mm
Recommended irrigation application = half the drained pore volume = 18 mm

5. Shallow soils on steep slopes
Drainage from saturation over 10 days = 20 mm
Recommended irrigation application = half the drained pore volume = 10 mm

6. Most hilly and steep lands have a mix of moderately deep and shallow soils and the recommended irrigation application for these areas is 12 mm every 10 days

Possible irrigation schedule based on drainage and rainfall

The following irrigation scheduling rules are presented to provide an understanding of the kind of scheduling that may be needed to run the irrigation system.

SUMMER
After irrigation, wait 10 days,
1. If no rainfall >20 mm over 3 days –
    Apply half the drained pore volume plus any soil water deficit (ET – RF).

2. If rainfall of >40 mm occurs over 3 days –
   Wait for an additional 7 days after the rainfall event then irrigate as per rule 1.
3. If rainfall between 20 and 40 mm occurs over 3 days –
   Wait for an additional 3 days after the rainfall event then irrigate as per rule 1.

WINTER
After irrigation, wait 10 days,
1. If no rainfall >20 mm over 3 days –
   Apply half the drained pore volume.
2. If rainfall of >40 mm occurs over 3 days –
   Wait for an additional 10 days after the rainfall event then irrigate as per rule 1.
3. If rainfall between 20 and 40 mm occurs over 3 days –
   Wait for an additional 7 days after the rainfall event then irrigate as per rule 1.

Rainfall is greater in summer so periods of rest because of rainfall will be more frequent. However, evapotranspiration is greater so the average amount of wastewater able to be applied at each irrigation will be greater. These factors will tend to balance out. I will therefore assume that for irrigation in summer, the half-pore-volume may be undertaken every 10 days.

Rainfall is lower in winter so periods of rest because of rainfall will be less frequent. However, evapotranspiration is much lower so amounts of wastewater able to be applied at each irrigation event will be lower. The lower evapotranspiration is likely to be a major constraint to wastewater application, so applying the 10-day schedule will require storage of wastewater over greater periods than in summer.

Irrigation system

Best practice would include tertiary treatment of sewage. However, I have not made any assumptions regarding upgrading of the treatment system, as this is uncertain and is beyond the scope of this report. I have assumed that wastewater characteristics will accord with those provided in reports provided. Generally the design of an irrigation system, under the soils and climate of Clutha District, will be at a rate that will enable the soil to achieve an acceptable level of renovation of nutrients and microbial contaminants.

Two systems of wastewater disposal are considered: low-application-rate spray irrigation onto pasture, and trickle irrigation under forest.

Flat to undulating land: Sprinkler irrigation onto pasture is the recommended system of land disposal. The hardware system of irrigation is beyond the brief of this report and can be any system that attains the appropriate application rate without generating hazardous aerosols. (It is suggested that recommended irrigation rate is likely to be between 5 and 12 mm/hour.)

Hilly land: I have limited experience of wastewater application to hilly land. I have heard reports of spray irrigation on hilly land causing damage to wood quality as a consequence of wastewater being sprayed onto tree trunks. I understanding that surface drip irrigation under forest may be a suitable method of application for hilly land. Forests are needed for slope stability because tree roots will penetrate into subsurface rocky material. A buffer zone of 10–20 m may need to be provided at the base of longer slopes to absorb any runoff from upslope.

I am uncertain of the most appropriate scheduling of drip irrigation. I favour slow application rates so that water can infiltrate with limited lateral flow, and about 10 days between applications to facilitate through drainage of excess water and to allow the soil to be well aerated. Some experimental work will be needed to establish most appropriate irrigation scheduling.

Need for storage

During periods of sustained rainfall, irrigation needs to be turned off because soils need time to drain before recommencing irrigation applications. Volumes of wastewater discharge also tend to increase in periods of higher rainfall. The size of storage needed to sustain land disposal will need to be determined after a wastewater application schedule is developed. This schedule will then need to be run in computer simulation with daily climate data to determine the length of rest periods and amounts of wastewater that can be applied. The length of rest periods will largely determine the area of storage required.

Key factors in irrigation design

Hydraulic loading: The required land area is determined from the hydraulic loading (wastewater loading plus climatic water balance). A water balance study has not been undertaken so the estimates of land area are based upon an assumption of applying half of the air-filled pore volume of wastewater every 10 days. The estimated land area and associated irrigation schedules require a large storage capacity to store wastewater through wet winter periods. If wastewater volumes are greater or less than those quoted, then areas of land required may be adjusted on a simple proportional basis.

Nitrogen uptake: Pasture yield is expected to be between 15 000 and 18 000 kg dry matter/ha/yr. Herbage will contain about 4.5% of N. If all the herbage is taken for hay or silage, between 675 and 810 kg/ha/yr (depending on pasture yield) of N will be removed from the site per annum.

Phosphorus uptake: Herbage will contain at least 0.4% of P. If all the herbage is taken for hay or silage, between 60 and 72 kg/ha/yr of P (depending on pasture yield) will be removed from the site.

Most soil profiles (other than small areas on steep slopes) are composed of thick mantles of fine-textured material and therefore have relatively high phosphate adsorption capacity per hectare even though the soil's adsorption capacity is expected to be moderate to low.

Fate of percolation water

Land under wastewater disposal systems will have excess water draining for most of the year. Consideration needs to be given to the fate of this water.

On flat to undulating land, percolating water will eventually seep into surface streams or aquifers. Under the irrigation practices recommended in this report, environmental effects of this percolation are expected to be minimal.

On hilly to steep land, percolating water can pose risks of soil erosion (wherever excess water drains into concave areas or along slow-permeability barriers). There will also be a significant increase in water draining to the base of the slope and this may require construction of drainage ditches.

Analysis of these effects are beyond the scope of this report.

3.2 Waihola

Previous reports

Previous analysis of land disposal of wastewater was undertaken by MWH (2001a). They suggested that land near the oxidation pond 'is moderately permeable and suitable for irrigation of the pond effluent'. On the basis of an irrigation rate of 'no more than 3 mm/day', they estimated a need for 3 ha of land for land disposal.

Soil descriptions

Soil profiles were described at six sites: three on fans and three on steep slopes within hilly land. Observation sites and land areas are depicted in Fig. 1. I did not investigate the specific area of land designated by MWH, as this was depicted on the GrowOtago map as containing poorly drained Fragic Perch-Gley Pallic soils.

Fans: GrowOtago maps identify Taieri (Typic Orthic Gley) soils and deep, poorly drained Otokia soils (Fragic Perch-Gley Pallic) on fans. Surface conditions on fans closest to Waihola township indicated that these fans have drainage impediments. However, fans to the southeast, just beyond the 3.75 km perimeter, contained shallow to moderately deep, well-drained, silty soils with inclusions of imperfectly drained soils. I have estimated that subsoils have slow permeability but not very slow permeability. However, in places the fan alluvium is likely to overlie older fan alluvium that has impeded drainage. There are similar fans 1 km north-east of the oxidation pond that were not investigated and these fans may contain similar soils. These areas on depicted on Fig. 1.

Rolling lands: GrowOtago maps identify deep, poorly drained Otokia (Fragic Perch-Gley Pallic) and deep, imperfectly drained Warepa (Mottled Fragic Pallic) soils on rolling land. General observations of road cuts around Waihola and inspection of land to the east of the oxidation ponds, confirm the presence of fragipans with very slow permeability underlying soils mapped on rolling land. These areas are unsuited to year-round wastewater irrigation. This land is suitable only for deficit irrigation.

Hilly lands: GrowOtago maps identify Kaitangata (Typic Immature Pallic) and Henley (Mottled Immature Pallic) soils on hilly land. General observations indicated that most of this land contains shallow to deep, imperfectly drained, silt loam to stony silt-loam-textured soils with slowly permeable subsoils. I inspected steep slopes under native bush to the east of the oxidation ponds as this appeared to have the best chance of free drainage. Even on steep slopes, the soil profiles had dense stony subsoils with indication of slow permeability. These lands are therefore generally unsuitable for year-round wastewater irrigation.

Land disposal options

I am not confident of finding land with permeable soils within the 3.75-km radius. The fans 4 km to the south-east of Waihola have similar soils to the fans described for Milton (Webb 2006) and would have similar hydraulic loading capacity. This seems to be the most likely prospect for land disposal at Waihola but this land is about 6 km from the current oxidation pond. It is likely that these soils will cope with an application schedule of around 23 mm applied every 10 days.

Minimum land area required based on hydraulic loading

On the basis of an average discharge of 85 m^3/day and an application rate of 2.3 mm/day, a land area of 3.7 ha would be required for wastewater disposal on fan soils.

Nutrient loading

Fan soils are expected to have moderate phosphate adsorption potential. Nitrogen loadings for the minimum land area are well below uptake values for vigorous pasture growth and phosphorus loadings are just below uptake values by vigorous pasture growth (Table 1).

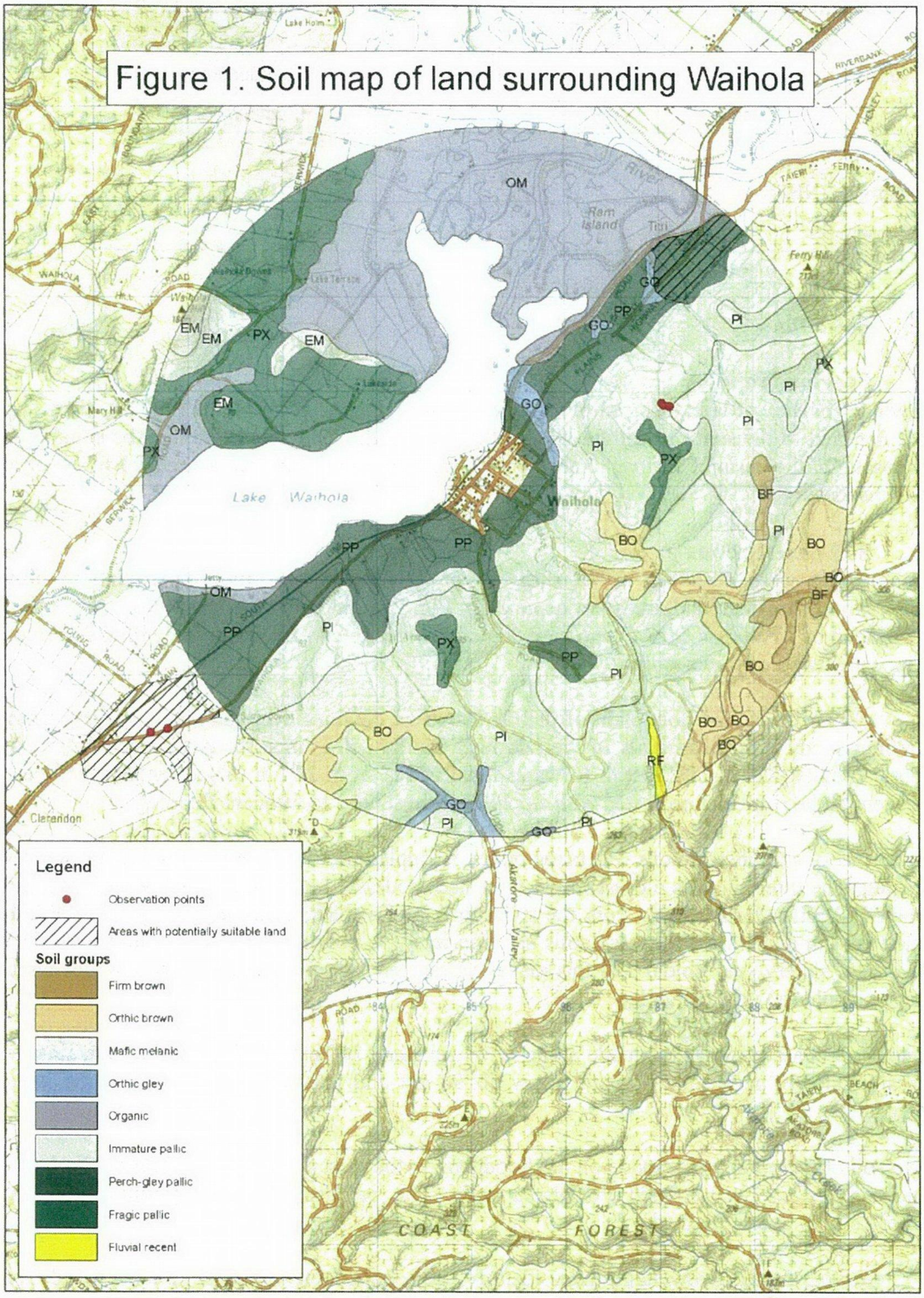
Figure 1. Soil map of land surrounding Waihola
Legend
Observation points
Areas with potentially suitable land
Soil groups
Firm brown
Orthic brown
Mafic melanic
Orthic gley
Organic
Immature pallic
Perch-gley pallic
Fragic pallic
Fluvial recent
Lake Waihola
Waihola
COAST FOREST
Clarendon

Table 1 Calculation of annual nutrient loading based on an average discharge of 85 m^3/day, and a land area of 3.7 ha for fans. Nutrient concentrations are derived from consent values as no monitoring data were available.

Nutrient	Discharge concentration (g/m^3)	Nutrient loading (kg/ha/yr)
Fans		
Nitrogen (NH_4)	15	126
Phosphorus	7	59

3.3 Balclutha

Previous reports

Previous analysis of land disposal of wastewater was undertaken by MWH (2002a). They suggested that flat land to the south or rolling hills to the west of the oxidation pond may be suitable for land disposal. On the basis of an irrigation rate of 3 mm/day, they estimated a need for 67 ha of land for land disposal.

Soil descriptions

Soil profiles were described at 22 sites: 14 on floodplains and eight on rolling to hilly land. Observation sites and land areas are depicted in Fig. 2. I did not investigate the area of rolling hills designated by MWH, as GrowOtago map depict this area to contain imperfectly drained Fragic Pallic soils with very slow permeability.

Floodplains: The floodplain of the Clutha River contains deep silty soils varying from freely draining sandy Pomahaka soils to well-drained Clutha soils, imperfectly drained Matau soils and poorly drained Koau soils. Depth to water table varies from 30 cm to greater than 150 cm. Areas adjacent to the river, not protected with stopbanks, are subject to frequent flooding.

A transect of soil observations was taken on the floodplain north of the river and to the south-west of Stirling. The three profiles closest to the river had moderate permeability and were moderately well drained. Profiles further back from the river contained a thick, massive, slowly permeable horizon below 50 cm and I assessed these soils as imperfectly to poorly drained. Alluvium from the Clutha River is a silvery grey colour and this makes assessment of soil drainage (based on development of grey soil colours) very difficult.

Three soil observations were made along Lawsons Road in Inch Clutha. Profiles contained a thick, massive, slowly permeable horizon below 50–90 cm and I assessed these soils to be imperfectly drained.

Two soil observations were made on the floodplain to the west of the western branch Clutha River on land mapped as well-drained Pomahaka soils. The profiles had slow permeability and were imperfectly to poorly drained.

Rolling lands: GrowOtago maps identify deep, imperfectly drained Te Houka and Clydevale (Mottled Fragic Pallic) soils on rolling land to the east and west of Balclutha. General observations of road cuts around Balclutha confirm the presence of fragipans with very slow permeability underlying soils mapped as Te Houka soils. These areas are unsuited to year-round wastewater irrigation and are suited only for deficit irrigation. However, at least part of the landscape mapped as Clydevale soils has moderately well drained soils that lack fragipans. These profiles have low clay content and have clay-enriched horizons with slow permeability below 80 cm depth.

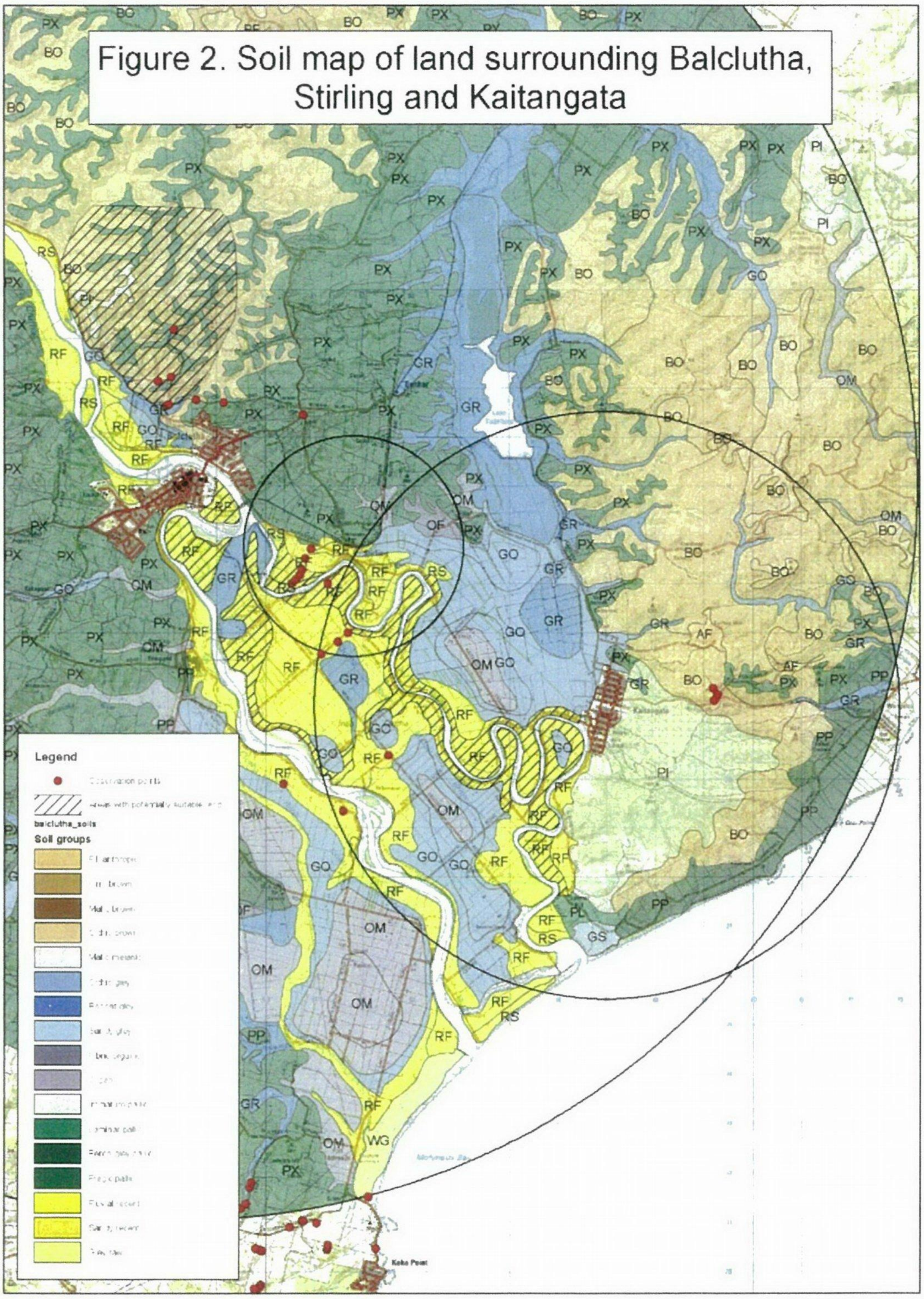

Figure 2. Soil map of land surrounding Balclutha, Stirling and Kaitangata

Hilly lands: On hilly land to the north of Balclutha, GrowOtago maps identify Tuapeka (Acidic Orthic Brown) soils on hilly land with Clydevale (Mottled Fragic Pallic) occupying rolling crests. Profile observations indicated a range of soil types in this area. Gentle ridges were coated with silty loess with low clay content and contained soils that were moderately well to imperfectly drained. These soils are better classified as Otama (Mottled Laminar Pallic) soils. These soils lacked fragipans but had significant clay accumulation in subsoils below 60 cm depth. Clay-enriched horizons have slow permeability but overlie more permeable horizons below 100–120 cm. Moderately sloping hills contained moderately well drained, shallow to moderately deep, silty soils. These soils are classified as Immature Pallic and Argillic Pallic soils. The soils overlie moderately weathered shattered rock. These soils are assessed as having moderately slow permeability. Water and tree roots penetrate into rocky substrates.

Land disposal options

Floodplains: Most of the land on the floodplain of the Clutha appears to have drainage limitations related to shallow depth to water table or to slowly permeable subsoils and would be marginally suitable for wastewater disposal. Areas of land most suitable for wastewater disposal can be found closest to the river, particularly along the eastern branch of the river. These areas are depicted on Fig 2. However, the area of land is limited and it would be difficult to find enough land to receive the amount of wastewater from Balclutha.

These soils are generally well suited to land disposal but have moderately slow to slow permeability in subsoils and overlie groundwater within silty or sandy alluvium. There would need to be careful site investigation of permeability, depth to water table, and transmissivity of aquifers before an estimate of loading capacity could be made. At best this land will cope with an application schedule of around 28 mm applied every 10 days.

Hilly land: Hilly land to the north of Balclutha has potential for wastewater disposal. Undulating to rolling ridges could be spray-irrigated for pasture and these slopes together with upper hill slopes could be trickle-irrigated under forest. The hill slopes are suitable for wastewater disposal but steeper slopes pose risks of runoff and erosion. I estimate that undulating land could cope with an application schedule of around 18 mm applied every 10 days and hill slopes could cope with an application schedule of around 15 mm applied every 10 days.

Minimum land area required based on hydraulic loading

On the basis of an average discharge of 2000 m^3/day and an application rate of 2.8 mm/day, a land area of 71 ha would be required for wastewater disposal on floodplain soils. On the basis of an average discharge of 2000 m^3/day and an application rate of 1.8 mm/day, a land area of 111 ha would be required for wastewater disposal on undulating land. On the basis of an average discharge of 2000 m^3/day and an application rate of 1.5 mm/day, a land area of 133 ha would be required for wastewater disposal on hilly land.

Nutrient loading

Floodplain soils are expected to have low phosphate adsorption potential. Nitrogen loadings for the minimum land area are well below uptake values for vigorous pasture growth and phosphorus loadings are within uptake values by vigorous pasture growth (Table 2). Soils on undulating and hilly land are expected to have moderate to low phosphate adsorption potential. Nitrogen loadings for the minimum land area for these landforms are well below uptake values for vigorous pasture growth and phosphorus loadings are below uptake values by vigorous pasture growth (Table 2).

Table 2 Calculation of annual nutrient loading based on an average discharge of 2000 m^3/day, and a land area of 71 ha for floodplains, 111 ha for undulating land, and 133 ha for hilly lands.

Nutrient	Discharge concentration (g/m^3)	Nutrient loading (kg/ha/yr)
Floodplains		
Nitrogen (NH_4)	15	153
Phosphorus	7	72
Undulating lands		
Nitrogen (NH_4)	15	99
Phosphorus	7	46
Hilly lands		
Nitrogen (NH_4)	15	82
Phosphorus	7	38

3.4 Kaitangata

Previous reports

Previous analysis of land disposal of wastewater was undertaken by MWH (2002b). They suggested that flat land adjacent to the oxidation pond may be used for this purpose. They noted that the soil was 'low lying' and may be of low permeability. On the basis of an irrigation rate of 3 mm/day, they estimated a need for 12 ha of land for land disposal.

Soil descriptions

Soil profiles were described at three sites on hilly land to the east of Kaitangata. Observation sites and land areas are depicted in Fig. 2.

Floodplains: The floodplain of the Clutha River contains deep silty soils varying from freely draining sandy Pomahaka soils to well-drained Clutha soils, imperfectly drained Matau soils and poorly drained Koau soils. Depth to water table varies from 30 cm to greater than 150 cm. Areas adjacent to the river, not protected with stopbanks, are subject to frequent flooding.

No soil profiles were described on floodplains in the vicinity of Kaitangata. Soil descriptions for the Balclutha areas may be applied to this area.

Hilly lands: GrowOtago maps identify Kaitangata (Typic Immature Pallic) and Tarata (Acidic Orthic Brown) soils on hilly land and Otama (Mottled Laminar Pallic) soils on rolling crests of hilly land to the east of Kaitangata. Limited observations were made in this area. Profiles all had slowly permeable subsoils and were not suited to wastewater disposal. I did not observe Laminar Pallic soils on ridges. This area is underlain by weathered sandstone and is likely to have slow permeability over much of the landscape.

Land disposal options

Floodplains: Most of the land on the floodplain of the Clutha appears to have drainage limitations related to shallow depth to water table or to slowly permeable subsoils and would be marginally suitable for wastewater disposal. Areas of land most suitable for wastewater disposal can be found closest to the river. These areas are depicted on Fig. 2. It is likely that a sufficient area of suitable land may be found within 3 km of Kaitangata.

These soils are generally well suited to land disposal but have moderately slow to slow permeability in subsoils and overlie groundwater within silty or sandy alluvium. There would need to be careful site investigation of permeability and depth and transmissivity of water tables before an estimate of loading capacity could be made. It is likely that these soils will cope with an application schedule of around 28 mm applied every 10 days.

Hilly land: Hilly land to the east of Kaitangata appears to be unsuited to wastewater disposal. However, the soil types, as identified on the GrowOtago soil map, indicate that suitable land should occur within this area.

Minimum land area required based on hydraulic loading

On the basis of an average discharge of 320 m^3/day and an application rate of 2.8 mm/day, a land area of 11.4 ha would be required for wastewater disposal on floodplain soils.

Nutrient loading

Floodplain soils are expected to have low phosphate adsorption potential. Nitrogen loadings for the minimum land area are well below uptake values for vigorous pasture growth and phosphorus loadings are within uptake values by vigorous pasture growth (Table 3).

Table 3 Calculation of annual nutrient loading based on an average discharge of 320 m^3/day, and a land area of 11.4 ha for floodplains.

Nutrient	Discharge concentration (g/m^3)	Nutrient loading (kg/ha/yr)
Floodplains		
Nitrogen (NH_4)	16	164
Phosphorus	7	72

3.5 Stirling

Previous reports

Previous analysis of land disposal of wastewater was undertaken by MWH (2002c). They suggested that flat land adjacent to the oxidation pond may be used for this purpose. They noted that land adjacent to the pond is 'moderately permeable and suitable for irrigation of the pond effluent. On the basis of an irrigation rate of 3 mm/day, they estimated a need for 6 ha of land for land disposal.

Soil descriptions

Soil profiles were described at 10 sites on floodplains to the west and south of Stirling. Observation sites and land areas are depicted in Fig. 2.

Floodplains: The floodplain of the Clutha River contains deep silty soils varying from freely draining sandy Pomahaka soils to well-drained Clutha soils, imperfectly drained Matau soils and poorly drained Koau soils. Depth to water table varies from 30 cm to greater than 150 cm. Areas adjacent to the river, not protected with stopbanks, are subject to frequent flooding. Soil descriptions are the same as reported for Balclutha.

Rolling lands: GrowOtago maps identify Clydevale and Te Houka (Mottled Fragic Pallic) soils on rolling land to the north-west of Stirling. These soils have fragipan horizons with very slow permeability and are unsuited to year-round irrigation. However, no observations were made in this area, and from observations made of soils to the north of Balclutha, it is probable that some of this landscape will contain Otama (Mottled Laminar Pallic) soils. Otama soils are formed from silty loess with low clay content and are moderately well to imperfectly drained. These soils lack fragipans but have significant clay accumulation in subsoils below 60 cm depth.

Land disposal options

Floodplains: Most of the land on the floodplain of the Clutha appears to have drainage limitations related to shallow depth to water table or to slowly permeable subsoils and would be marginally suitable for wastewater disposal. Areas of land most suitable for wastewater disposal can be found closest to the river. These areas are depicted on Fig. 2. It is likely that a sufficient area of suitable land may be found within 2 km of Stirling.

These soils are generally well suited to land disposal but have moderately slow to slow permeability in subsoils and overlie groundwater within silty or sandy alluvium. There would need to be careful site investigation of permeability and depth and transmissivity of water tables before an estimate of loading capacity could be made. It is likely that these soils will cope with an application schedule of around 28 mm applied every 10 days.

Rolling land: Rolling land to the north-west of Stirling may have potential for wastewater disposal. Undulating to rolling ridges could be spray-irrigated for pasture and trickle-irrigated under forest. Further investigation would be necessary to establish soil characteristics in this area.

Minimum land area required based on hydraulic loading

On the basis of an average discharge of 130 m^3/day and an application rate of 2.8 mm/day, a land area of 4.6 ha would be required for wastewater disposal on floodplain soils.

Nutrient loading

Floodplain soils are expected to have low phosphate adsorption potential. Nitrogen loadings for the minimum land area are well below uptake values for vigorous pasture growth and phosphorus loadings are somewhat below uptake values for vigorous pasture growth (Table 4).

Table 4 Calculation of annual nutrient loading based on an average discharge of 130 m^3/day, and a land area of 4.6 ha for floodplains.

Nutrient	Discharge concentration (g/m^3)	Nutrient loading (kg/ha/yr)
Floodplains		
Nitrogen (NH_4)	13	133
Phosphorus	5	51

3.6 Owaka

Previous reports

Previous analysis of land disposal of wastewater was undertaken by MWH (2002d). They noted that land around the oxidation ponds was subject to flooding and was unsuited to wastewater disposal but that suitable flat land could be found to the west of the oxidation ponds. On the basis of an irrigation rate of 'no more than 3 mm/day', they estimated a need for 5 ha of land for land disposal.

Soil descriptions

Soil profiles were described at six sites: four on fans and two on rolling land. Observation sites and land areas are depicted in Fig. 3.

GrowOtago maps for Owaka are based on the *General Survey of the Soils of South Island* (NZ Soil Bureau 1968). These maps identify Owaka (Typic Firm brown), Chaslands (Mottled Firm Brown) and Waimahaka (Acidic Firm Brown) soils on fans and hills surrounding Owaka. My observations (Fig. 3) indicated that low-lying surfaces, including the land around the oxidation pond, are composed of poorly drained soils. Soils on rolling to hilly land contained profiles with thick, firm, slowly permeable subsoils. Undulating fans along Owaka Valley Road contained moderately well drained Brown soils with a thin firm subsoil with slow to moderately slow permeability.

Land disposal options

Land suitable for wastewater disposal can be found on Brown soils on fans within 1–2 km to the west of the oxidation ponds and may occur on other similar fans to the west and north of Owaka. There would need to be careful site investigation of soil permeability before a confident estimate of loading capacity could be made. It is likely that these soils will cope with an application schedule of around 18 mm applied every 10 days. Higher rainfall would require greater storage capacity to withhold wastewater during periods of sustained wet weather.

Minimum land area required based on hydraulic loading

On the basis of an average discharge of 260 m^3/day and an application rate of 1.8 mm/day, a land area of 14.4 ha would be required for wastewater disposal on floodplain soils.

Nutrient loading

Fan soils are expected to have moderate phosphate adsorption potential. Nitrogen and phosphorus loadings are well below uptake values for vigorous pasture growth (Table 5).

Table 5 Calculation of annual nutrient loading based on an average discharge of 260 m^3/day, and a land area of 14.4 ha for fans.

Nutrient	Discharge concentration (g/m^3)	Nutrient loading (kg/ha/yr)
Fans		
Nitrogen (NH_4)	12	79
Phosphorus	5	33

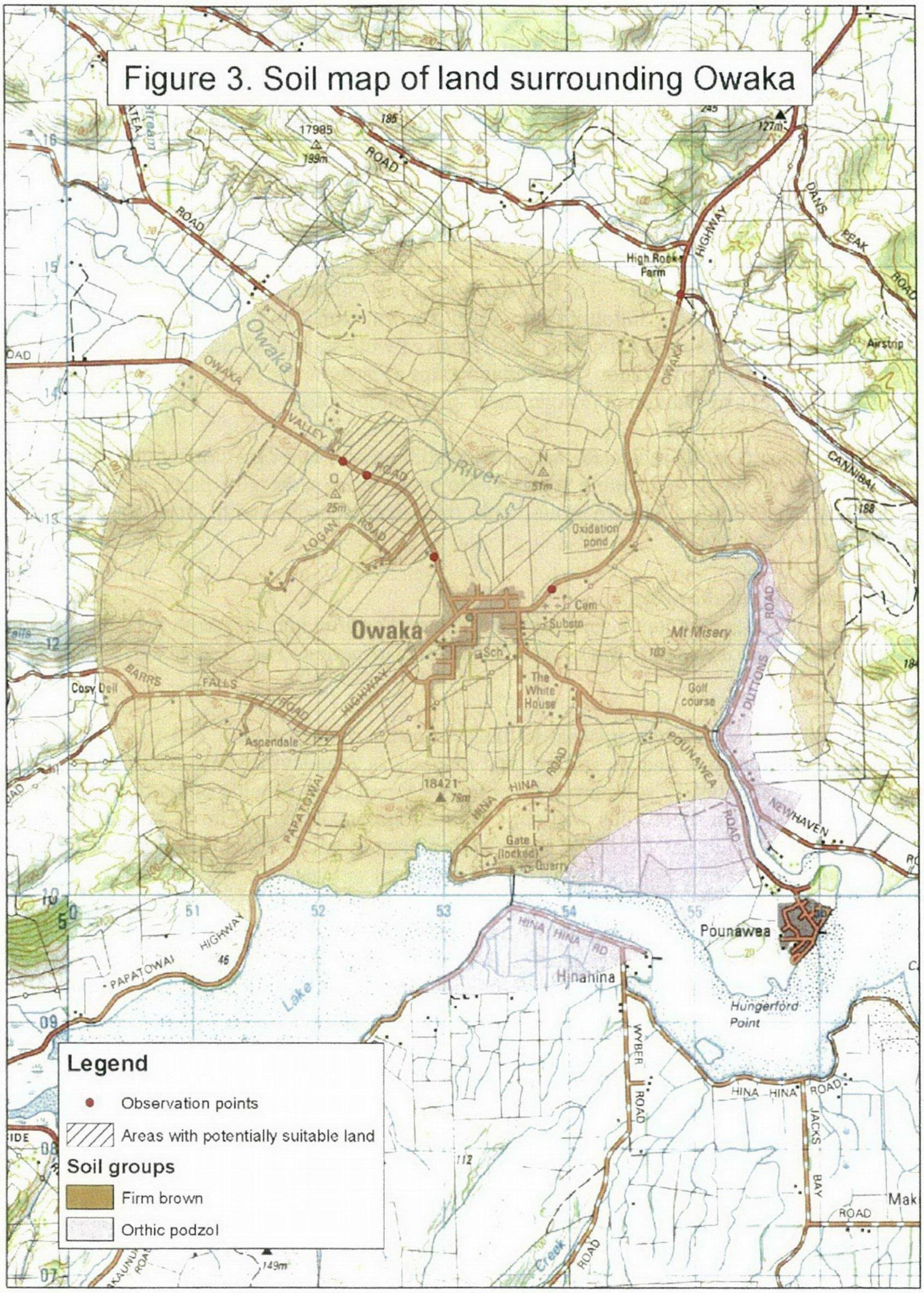

Figure 3. Soil map of land surrounding Owaka

3.7 Clinton

Previous reports

No analysis of land disposal of wastewater was undertaken for Clinton.

Soil descriptions

Soil profiles were described at five sites: three on fans and one on rolling land. Observation sites and land areas are depicted in Fig. 4.

Floodplains: GrowOtago maps identify poorly drained Jacobstown (Acidic Orthic Gley) and Fleming (Perch Gley Pallic) soils on floodplains and river terraces.

Rolling lands and fans: To the south-west of Clinton, GrowOtago maps identify deep, moderately well drained Clinton (Typic Firm Brown) soils and imperfectly drained Arthurton (Mottled-pallic Firm Brown) soils with small areas of well-drained Mandeville (Typic Mafic Brown) soils. To the north-east of Clinton, GrowOtago maps identify deep, poorly drained Hokonui (Argillic Perch-gley Pallic) and Waikoikoi (Fragic Perch-gley Pallic) soils.

My observations (Fig. 4) indicated that soils on rolling land and fans commonly contained profiles with thick, firm, slowly permeable subsoils. However, there were also parts of fans that contained moderately well drained Brown soils with thin firm subsoils with slow to moderately slow permeability.

Land disposal options

Land to the north-east contains soils with fragipans or argillic horizons with very slow permeability and these areas are unsuited to year-round wastewater irrigation. This land is suitable only for deficit irrigation.

Land suitable for wastewater disposal is likely to occur on fans within 1–2 km of Clinton on land mapped as Clinton soils and on rolling land mapped as Mandeville soils. There would need to be careful site investigation of soil permeability before a confident estimate of loading capacity could be made. It is likely that these soils will cope with an application schedule of around 18 mm applied every 10 days. Clinton has oxidation ponds with a large storage capacity that should be adequate to withhold wastewater disposal during periods of sustained wet weather.

Minimum land area required based on hydraulic loading

On the basis of an average discharge of 250 m^3/day and application rate of 1.8 mm/day, 13.9 ha of land would be required for wastewater disposal on suitable parts of the Clinton and Mandeville soils.

Nutrient loading

Clinton and Mandeville soils are expected to have moderate phosphate adsorption potential. Nitrogen and phosphorus loadings are below uptake values for vigorous pasture growth (Table 6).

Table 6 Calculation of annual nutrient loading based on an average discharge of 250 m^3/day, and a land area of 13.9 ha for fan.

Nutrient	Discharge concentration (g/m^3)	Nutrient loading (kg/ha/yr)
Fans		
Nitrogen (NH_4)	6	125
Phosphorus	11	58

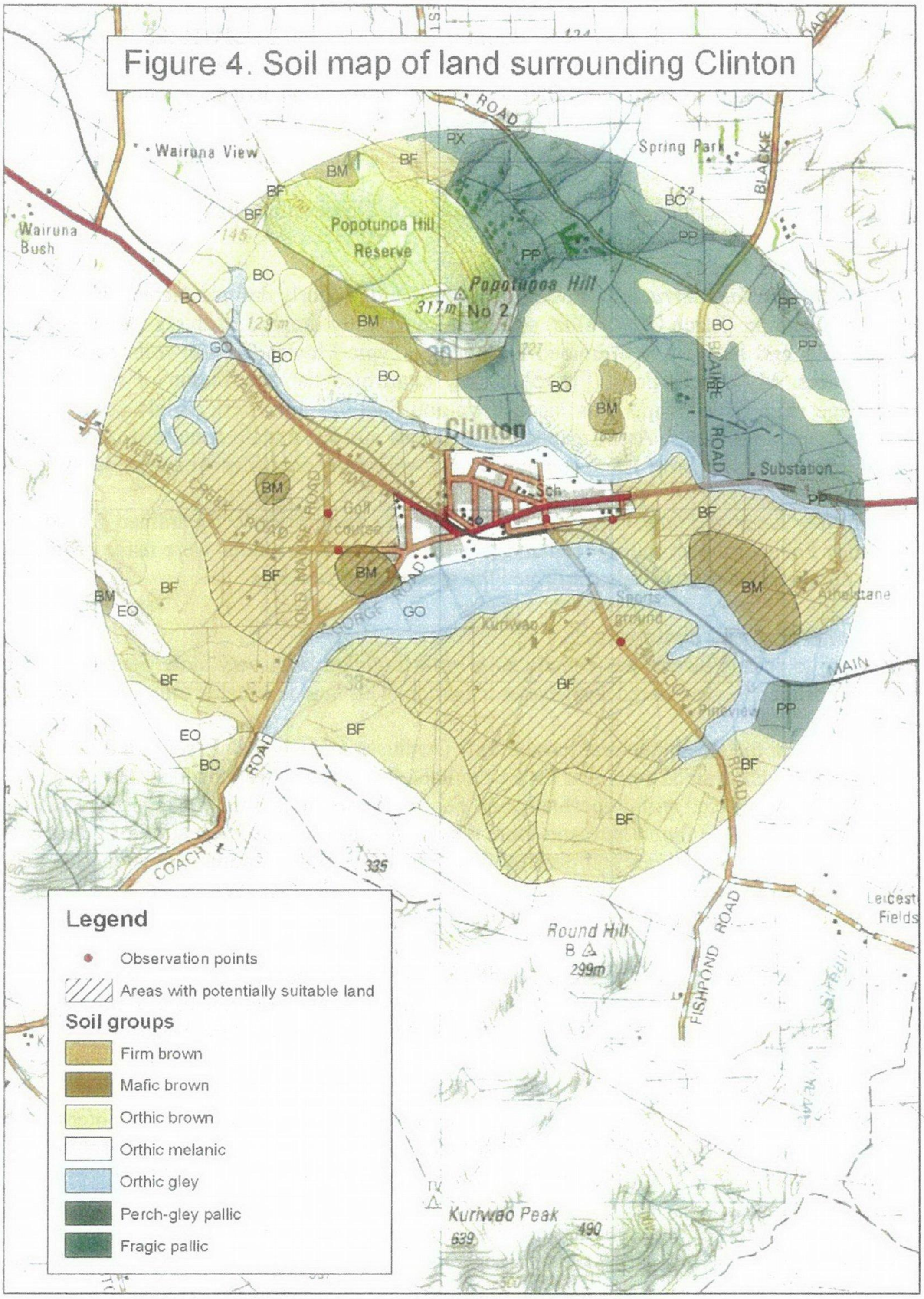

Figure 4. Soil map of land surrounding Clinton

3.8 Heriot

Previous reports

Previous analysis of land disposal of wastewater was undertaken by MWH (2001b). They suggested that flat land to the north of the oxidation pond contains soils that are 'moderately permeable and suitable for irrigation of the pond effluent'. On the basis of an irrigation rate of 3 mm/day, they estimated a need for 5 ha of land for land disposal.

Soil descriptions

Soil profiles were described at six sites on terrace land. Observation sites and land areas are depicted in Fig. 5.

Floodplains and terraces: GrowOtago maps identify poorly drained Jacobstown (Acidic Orthic Gley) and Fleming (Perch Gley Pallic) soils and imperfectly drained Ardlussa (Mottled-pallic Orthic Brown) soils and shallow well-drained Riversdale (Typic Fluvial Recent) soils on floodplains and river terraces. My observations (Fig. 5) largely confirmed the distribution of soils shown on the GrowOtago map. Areas mapped as Jacobstown and Fleming soils were mainly poorly drained with slowly permeable subsoils. Areas mapped as Ardlussa and Riversdale contained imperfectly drained soils with water tables above 1.5 m and moderately well drained profiles with gravels within 2 m.

Rolling lands and fans: GrowOtago maps identify deep, imperfectly drained Waikoikoi (Fragic Perch-gley Pallic) soils on rolling land and fans. No profile descriptions were made of these soils but general observations of road cuts confirmed the presence of fragipans.

Land disposal options

Undulating to rolling landscapes contain soils with fragipans with very slow permeability and these areas are unsuited to year-round wastewater irrigation. This land is suitable only for deficit irrigation.

Observations on the floodplain and terrace soils (Ardlussa and Riversdale soils) indicate the presence of moderately well drained soils that may be suitable for wastewater irrigation. However, these soils appear to be interspersed with imperfectly and poorly drained soils. It is unlikely that a sufficient area of suitable land will be found here and there would need to be a site evaluation of this area to locate suitable land and to investigate soil permeability before a confident estimate of suitability and loading capacity could be made. If land is found here it is unlikely that these soils would cope with an application schedule of more than 18 mm applied every 10 days.

Minimum land area required based on hydraulic loading

On the basis of an average discharge of 90 m^3/day and an application rate of 1.8 mm/day, a land area of 5.0 ha would be required for wastewater disposal on floodplain and terrace soils.

Nutrient loading

Floodplain and terrace soils are expected to have low phosphate adsorption potential. Nitrogen loadings for the minimum land area are well below uptake values for vigorous pasture growth and phosphorus loadings are below uptake values for vigorous pasture growth (Table 7).

Table 7 Calculation of annual nutrient loading based on an average discharge of 90 m^3/day, and a land area of 5.0 ha for floodplains and terraces.

Nutrient	Discharge concentration (g/m^3)	Nutrient loading (kg/ha/yr)
Floodplains & terraces		
Nitrogen (NH_4)	11	72
Phosphorus	7	46

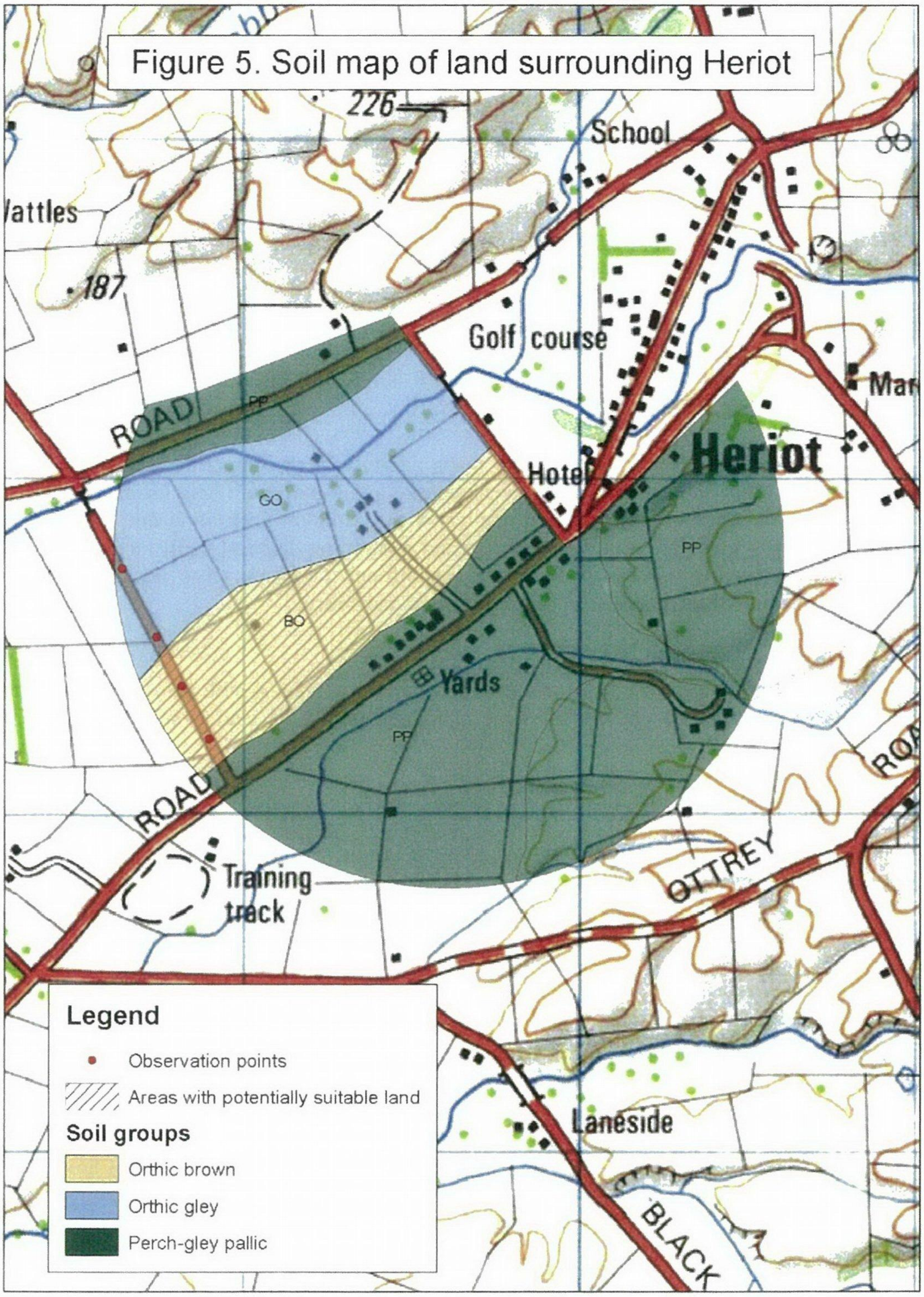

Figure 5. Soil map of land surrounding Heriot

3.9 Lawrence

Previous reports

Previous analysis of land disposal of wastewater was undertaken by MWH (2001c). They suggested that flat land to the north of the oxidation pond contains soil that is 'moderately permeable and suitable for irrigation of the pond effluent'. On the basis of an irrigation rate of 3 mm/day, they estimated a need for 5 ha of land for land disposal.

Soil descriptions

Soil profiles were described at nine sites: four on floodplains, two on rolling land and three on hills. Observation sites and land areas are depicted in Fig. 6.

Floodplains: GrowOtago maps identify Tailings (Stony-tailing, Fill Anthropic) soils on floodplains and river terraces. Profiles described here consisted of imperfectly to poorly drained silty (low clay content) soils with variable stone content. Some subsoil horizons had slow permeability. It is unknown what strata underlie this landform but it is likely to have compact subsurface materials causing perched water tables.

Rolling land and hills: GrowOtago maps identify deep, imperfectly drained Waitahuna (Mottled Fragic Pallic) soils and well-drained Tuapeka and Pukekoma (Acid Orthic Brown) soils on rolling land and hills. Profile descriptions indicated that soils on undulating and rolling landforms contained fragipans and were unsuited to year-round wastewater disposal. Hilly slopes had some soils with moderately well drained profiles but it was difficult to locate areas that did not contain a significant inclusion of soils with slow or very slow permeability.

Land disposal options

Soils on undulating to rolling landscapes contain soils with fragipans with very slow permeability so these areas are unsuited to year-round wastewater irrigation. This land is suitable only for deficit irrigation.

There are two possible options (both of which are unlikely) for land disposal within the target land area for Lawrence. There may be some land suited to year-round wastewater disposal on the floodplain mapped as Tailings (Fill Anthropic; Fig. 6). There may also be suitable land on moderately sloping land on areas to the north of Lawrence. There would need to be site evaluation of these areas to locate a suitable land parcel plus investigation of soil permeability before a confident estimate of suitability and loading capacity could be made. If land is found here, it is unlikely that these soils would cope with an application schedule of more than 18 mm applied every 10 days.

Minimum land area required based on hydraulic loading

On the basis of an average discharge of 140 m^3/day and an application rate of 1.8 mm day, a land area of 7.8 ha would be required for wastewater disposal on floodplain soils.

Nutrient loading

Floodplain soils are expected to have low phosphate adsorption potential and rolling land and hills to have moderate permeability. Nitrogen loadings for the minimum land area are well below uptake values for vigorous pasture growth and phosphorus loadings are near the upper limit of uptake values for vigorous pasture growth (Table 8).

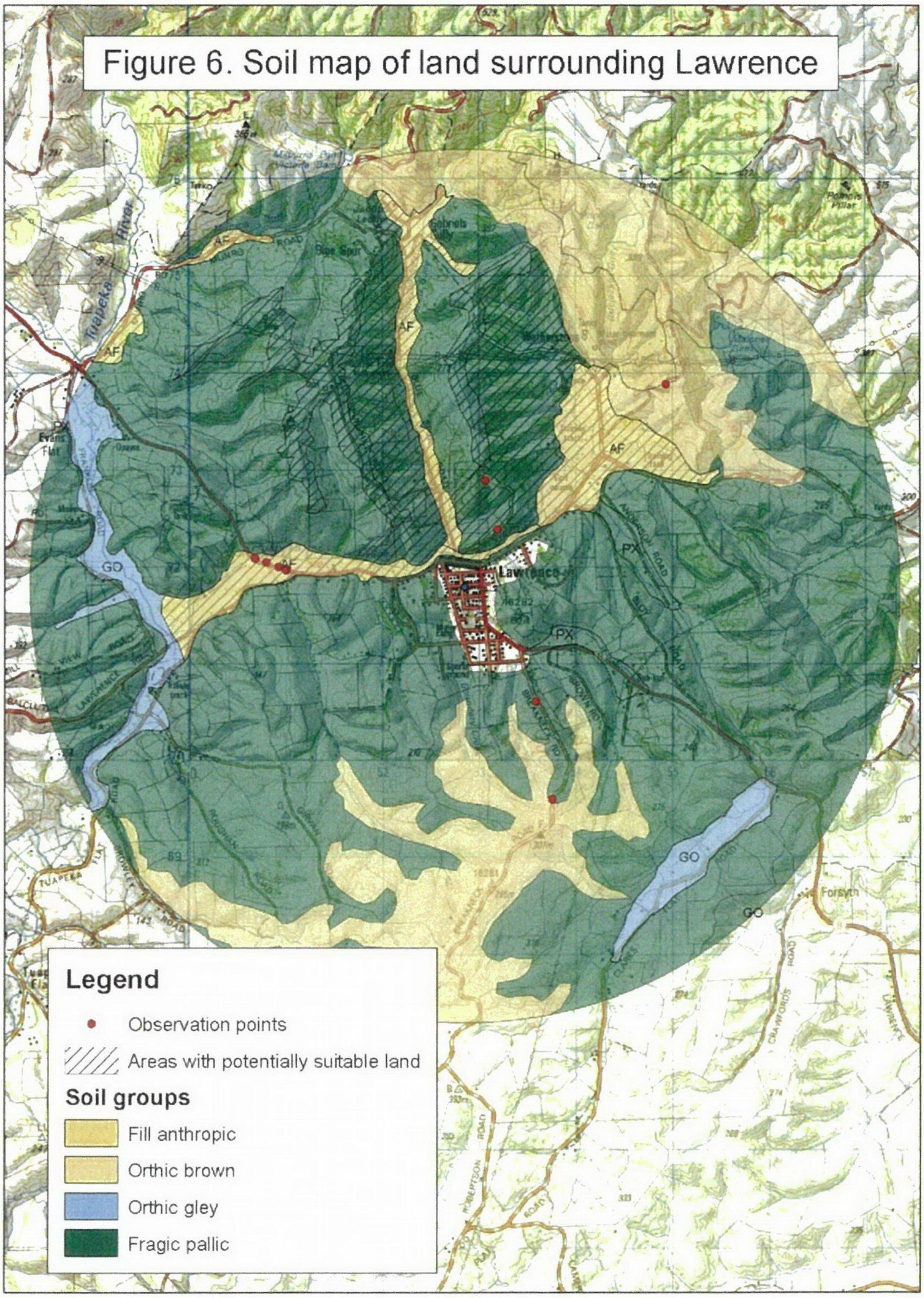
Figure 6. Soil map of land surrounding Lawrence
Legend
Observation points
Areas with potentially suitable land
Soil groups
Fill anthropic
Orthic brown
Orthic gley
Fragic pallic
AF
GO
PX
Lawrence
Tuapeka River
Blue Spur
Forsyth

Table 8 Calculation of annual nutrient loading based on an average discharge of 140 m^3/day, and a land area of 7.8 ha for floodplains.

Nutrient	Discharge concentration (g/m^3)	Nutrient loading (kg/ha/yr)
Floodplains		
Nitrogen (NH_4)	6	112
Phosphorus	11	72

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Manaaki Whenua
Landcare Research

www.landcareresearch.co.nz