Waituna Lagoon Mechanical Opening Site Assessment

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1. Executive Summary

The Waituna Lagoon is manually opened to the Southern Ocean at Toetoes Bay, primarily for the purposes of improving the effectiveness of farm drainage.

The ecological effects of mechanical openings of the Waituna Lagoon are very complex, involving many variables, most of which are not yet quantified. The openings reflect a type of ecological 'trade off' between flushing nutrient laden water and sediment out of the lagoon in order to prevent eutrophic effects, versus the adverse ecological impacts which occur when the lagoon is opened such as of loss of vegetative habitat through drying, desiccation and sand intrusion.

Following an opening, the lagoon closes naturally due to sediment build-up. This can occur over a period of anywhere between a few weeks to over a year depending on a number of factors including wind direction and speed, tides, etc. Current understanding of the near shore environment is limited due to its inherently chaotic nature. This makes it very difficult, if not impossible, to predict when mouth closures will occur with any level of certainty. The monitoring record of opening/closing cycles is also very limited with knowledge based largely on anecdotal evidence and historical openings at only one of the four opening locations.

The objective of this report is to describe the benefits and risks of mechanical opening at four locations in Waituna Lagoon. Both positive and negative ecological effects are considered with a primary focus on *maximising the removal of nutrient laden water and sediment, whist minimising stress to macrophyte beds*. This report is intended to provide supporting information for the Lagoon Technical Group and should not be used in isolation when considering lagoon opening management or likely negative ecological effects from mechanical openings.

The advantages and disadvantages of each location considered are summarised below.

Walker's Bay

- Good flushing potential due to lagoon bed channels, but offset by longer opening period and sand intrusion which is filling the bay;
- Overall cost is same as Charlie's Bay, but both sites double the cost of the Eastern End; and,
- Little physical scouring of macrophytes in bay as cover generally low but offset by un-favourable growing habitats and higher salinities in main body of lagoon which hinder recovery.

Charlie's Bay

- Currently moderate flushing potential but offset by requiring several more openings to 'train' lagoon channels to maximise the flushing ability;
- Cost of opening same as Walker's but double that of eastern end sites;
- Physical scouring effect outside the bay will be limited, but offset by compete removal of macrophytes inside the Bay;
- Saline waters takes 2-3 weeks to reach far western end of the lagoon but offset by very high salinities in the central and eastern macrophyte area; and,
- Return to low salinity conditions same as Walker's Bay even though further from freshwater inputs.

The Fence and Far Eastern End

- Local evidence suggests flushing potential to be large but offset by site not having been utilized since mid-1970's;
- Historically had quick mouth closures but this would require several 'trials' to verify;
- Digger cost cheaper than Charlie's and Walker's Bays but is offset by both sites requiring multiple openings to remove localised sediment build-up;
- The Far Eastern End site is likely to be only site of the four to trial assisted 'pitch' mouth closure;
- Macrophyte scouring is likely to be very significant from these two sites;
- Salinities in the main lagoon lower 10-20 ppt (parts per trillion) due to distance, tidal head difference and tide times required but offset by very high salinities 30-35 ppt in the centre and eastern end of the lagoon; and,
- Return to low salinity conditions (<8 ppt) in the shallower edge habitats where macrophytes exist possible < 6 weeks but offset by reduced fetch and wind mixing which leads to salinity stratification in the deeper main channel.

The selection of a single favoured location is difficult because each location has site specific advantages and disadvantages compared to each of the other locations. In addition, the assessment in this report is based on information from, at most, a few opening events at each site with the exception of the Walker's Bay site. It is important to consider the cumulative effects of continual usage of a specific opening location and its wider effect on the remaining lagoon ecology. For example, the continual reliance on the Walker's Bay opening site over the last 20 years has created a well-defined series of lagoon channels. This has then favoured good flushing events but also longer opening durations, marine sand intrusion and no chance of recovery of macrophytes in the central part of Walker's Bay.

Further geomorphological and surveying work may assist in addressing some of the existing knowledge gaps however to accurately determine the optimal time and location for mechanical opening, three locations (Charlie's Bay, The Fence and the Far Eastern End site) will require 'trial' openings.

It is recommended that future management of the Waituna Lagoon openings consider introducing a rolling opening location schedule across all of the four locations. The schedule should consider a range of factors including the condition and combination of:

- Season (winter versus early summer);
- Life-stage of the macrophytes;
- Lagoon turbidity;
- Tide cycle (neap tide versus spring tide); and,
- Wind direction and speed.

2. Introduction

2.1 Background

The Waituna Lagoon is manually opened to the Southern Ocean at Toetoes Bay, primarily for the purposes of improving the effectiveness of farm drainage.

The ecological effects of mechanical openings of the Waituna Lagoon is very complex, involving many variables, most of which are not yet quantified. The openings reflect a type of ecological 'trade off' between flushing nutrient laden water and sediment out of the lagoon in order to prevent eutrophic effects, versus the adverse ecological impacts which occur when the lagoon is opened such as of loss of vegetative habitat through drying, desiccation and sand intrusion.

Following an opening, the lagoon closes naturally due to sediment build-up. This can occur over a period of anywhere between a few weeks to over a year depending on a number of factors including wind direction and speed, tides, etc. Current understanding of the near shore environment is limited due to its inherently chaotic nature. This makes it very difficult, if not impossible, to predict when mouth closures will occur with any level of certainty. The monitoring record of opening/closing cycles is also very limited with knowledge based largely on anecdotal evidence and historical openings at only one of the four opening locations.

The opening locations which are discussed in this report are labelled on Figure 1.

1. The area of Walker's Bay between 2172416E, 5393345N to 2171161E, 5392983N;
2. Charlie's Bay at 2175026E, 5394587N;
3. The area known as The Fence 2177327E, 5395180N to 2176696E, 5395201N; and,
4. The Far Eastern End adjacent to the point 2178111E, 5395451N.

These locations have been historically used for mechanical openings since 1908 (Waghorn R., personal communication).

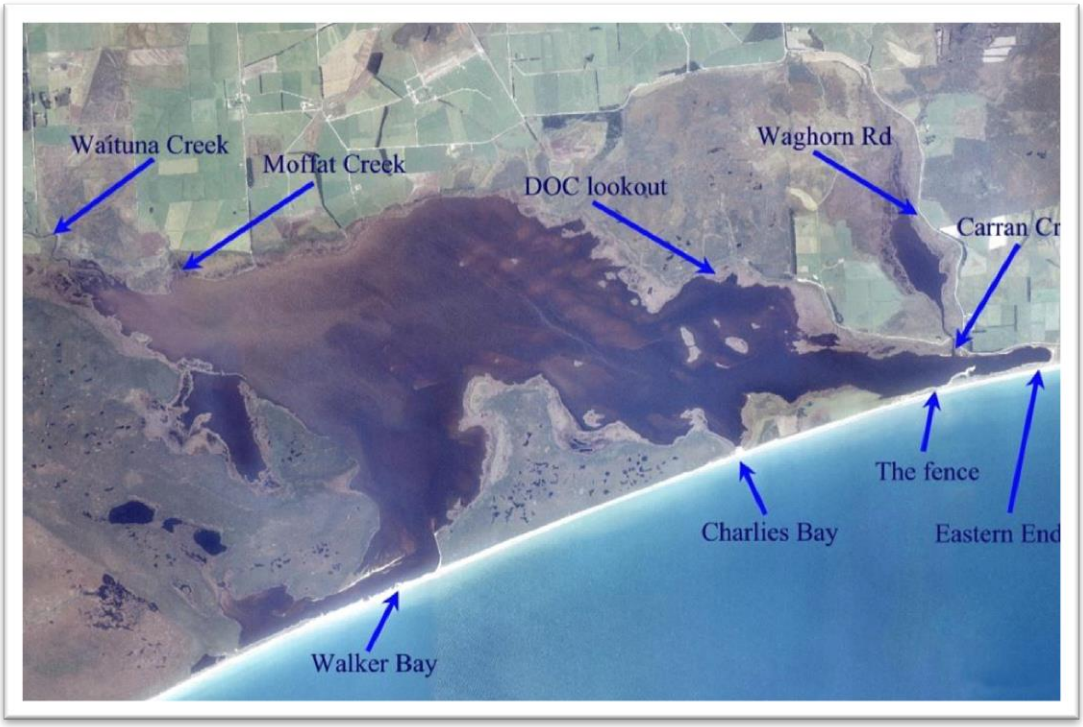

Figure 1: Overview of the Waituna Lagoon and four opening locations

2.2 Objective

The objective of this report is to describe the ecological benefits and risks of four mechanical opening locations in Waituna Lagoon with a primary focus on *maximising the removal of nutrient laden water and sediment, whist minimising stress to macrophyte beds*. The four locations represent current, historic and proposed opening sites.

The following criteria have been used to evaluate the success or failure of each of the given locations:

- Proximity to macrophyte beds and whether these areas are likey to be physically scoured during a opening event. Macrophyte beds include *Ruppia megacarpa* and *Ruppia polycarpa, Myriophyllum triphyllum* and the Charophyte *Lamprothanium macropogon spp*.;
- Salinity intrusion to the lagoon and recovery time after closure to optimal *Ruppia* germination salinities (<8 ppt);
- Chance of closure within 1 month, 3 month, 1 year (previously covered in OPUS International Urgent Measures Report);
- Nutrient and sediment exports during openings (previously published by C. Jenkins, Environment Southland Senior Hydrologist, Appendix B);
- The estimated cost of mechanical opening, including access for machinery;
- Lagoon channel morphology adjacent to opening site;
- Coastal environment - wave roundup/longshore drift observations/swell window/sea bathymetry (still awaiting final bathymetry data);

- Dominant sediment in lagoon adjacent to opening location; and,
- Possible erosion during opening and tidal phase of areas other than macrophyte beds i.e. access points, farm road, visual impacts.

This report has been commissioned by Environment Southland (ES) to support information requirements by the Lagoon Technical Group during its review of the '*Interim recommendations to reduce the risk of Waituna Lagoon flipping to an algal-dominated state*' (Robertson et al, 2011). The information contained within this report should not be used in isolation from other reports.

3. Opening Locations

3.1 Walker's Bay

Walker's Bay is located in the south-west corner of Waituna Lagoon. The bay is exposed to winds from the north and north-west, and is slightly protected from the predominately westerly wind of 271 degrees due to its orientation. The bay forms a 'Y' shape with an elongated tail spreading toward Awarua Bay in the west. There are several small coves and inlets on both sides of the bay, and around in the far west of the bay past the opening sites.

Walker's Bay bathymetry is largely modified and trained by successive openings of the sea barrier over the last 38 years. Figure 2 clearly shows the bottom contours of the bay with a pronounced main channel on the western edge of the bay running NW-SE in direction. There is a second smaller channel on the eastern margin of the bay, which runs N-S. The area between the two channels is approximately 300m^2 and relative level at 0.25 msl. Anecdotal evidence suggests the bed level has increased in height over the last 20 years (Perrin, C. Owen, personal observations 2012) and analysis of aerial photographs indicates the area has increased in horizontal extent (ES aerial images, 1954-2012).

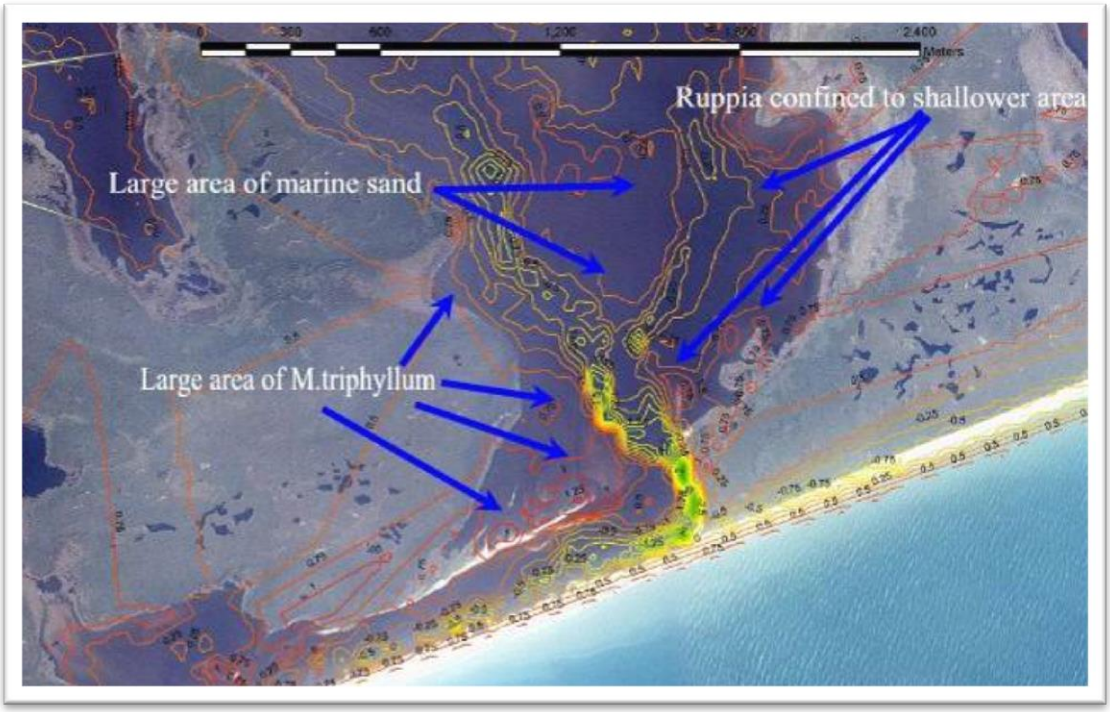

Figure 2: Walker's Bay Bathymetry

The dominant sediment on this elevated section is coarse marine sand sourced from sand intrusion during repeated openings at this location. The two channels then join and have a pronounced 'S' shape toward the barrier. It is in this section of channel that the deepest parts of the lagoon are located where several "holes" of -3.0 msl

exist. The channel then sweeps to the west running parallel between the barrier and Bird Island and across the various historical opening sites. The location of historical openings can be seen in the lagoon bathymetry as there is a series of successive deep holes between -0.5 to -1.0 msl. The remaining parts of the far western end of Walker's Bay is sinuous channel leading to a central basin of 160m^2 at 0.5 msl. There is also a series of over-wash fans created by the sea overtopping the barrier berm during high tides and storm events. These fans range from 70-100 m^2 in size. In 2011 and 2012 the barrier height at Walker's Bay was reduced compared to the height along the remaining barrier, so much so that overtopping is now a regular event at high tide.

The structures and features of Bird Island are largely determined by tidal influences. Evidence of this is the marine sand barrier island/spit structures on the south side of Bird Island, which have been formed by littoral drift when the lagoon is open to the sea. Local observations suggest these structures have been increasing in size, height and extent and are now impeding higher flows at opening time, therefore leading to less flushing. In all probability these observations are valid, however, it has been the continual reliance on Walker's Bay over the last 20 years as the favoured spot which has lead to these negative aspects occurring, as the lagoon is open longer and then prone to more marine-estuarine influences. Future usage of Walker's Bay as the optimal location for a large flush may then change and diminish if it is continues to be used repeatedly.

Environment Southland (ES) has a long term water quality monitoring site in the middle of Walker's Bay at 2171691E, 5394136N. ES has also been undertaking sediment quality monitoring at this site since 2009 . Sediment quality at this site is often degraded with elevated sediment anoxia represented by shallow RPD layers 1-3 mm, and often thick black muddy sediments (ES monitoring data, 2011).

Figure 3: Typical sediment conditions in the northern part of Walker's Bay

Figure 4: The central elevated basin of Walker's Bay, February 2011. The lagoon had been opened at this location for 5 ½ months.
Note: the smothering of *Ruppia* seedlings by marine sand and tufts of Bachelotia anterillium appearing.

4.2.1 Macrophyte populations in Walker's Bay

In 2009, 2010 and 2011, the central basin of Walker's Bay was largely devoid of extensive macrophyte beds except in the shallower margins. The Department of Conservation (DOC) macrophyte monitoring transects are on the western and eastern margins of the bay (transect points 8.5, 8.6, 7.5, 7.6 & 7.7), and therefore cannot be used to assess the central basin's macrophyte cover. However, in 2007 Wriggle Coastal Consulting estimated the *Ruppia spp.* cover in the 1-10% range. This estimate is consistent with observations by ES science staff and the ES boating contractor in 2011, with sparse cover of small plants less than 20 cm long in the <10 % cover range (C. Owen , personal observations 2011-12). The reasons for the consistently low coverage of macrophytes in central Walker's Bay relates to the constant loss of habitat from prolonged lagoon openings. This continual stress hinders recovery and combined with large areas of course sands at optimal macrophyte growing depths, makes future recovery conditions unfavourable if this location continues to be utilised.

The edge habitat of Walker's Bay did recover well after the Charlie's Bay opening in 2011, however, the central deeper areas were still in the <10% cover range of *Ruppia spp*. In early 2012, there was over 1km^2 of *M. triphyllum* in the area immediately north of Bird Island with most of the cover in the >80% range

Macrophyte cover in the far western end of Walker's Bay has historically been good. In 2007 the western end of the bay had *Ruppia megacarpa* cover at 80-100%. Unfortunately the DOC monitoring transect (T9) is located away from a lot of the *Ruppia*, which is between the monitoring transects in this section of the Bay. *Ruppia spp.* cover north of the DOC ransect 9.7 in late 2011 and 2012

had cover in the range of 5-10% (Environment Southland monitoring data, 2011 & 2012).

3.2 Charlie's Bay

Charlie's Bay is located in the central eastern part of Waituna Lagoon and is largely sheltered and only exposed to winds from the north. The bay covers about 1.8 km^2 and is shaped in a 'V' with one main channel running north to south down the bay. Prior to the mechanical opening here in 2011, the bay was last used in 1974 and hence the channels were largely unmodified by opening's (Waghorn R., and Crack D., personal communication, 2011). The bay was the focus of activity in the mid 1970s by Southland Catchment Board members who tried (in vain) to enhance the channel structure with heavy machinery to create a better opening site.

Before the July 2011 opening, the bay was relatively shallow and dominated by moderately large areas of soft to very soft deep muds (0.5-1m deep). Unlike Walker's Bay the basement bed material is mudstone, which has well defined ridge crests and troughs running NNE/SSW (Environment Southland survey data, 2011). The ridge and trough systems were thought to extend into the marine environment, where initially it was considered the sill structure provided a basement anchor for gravel material which assisted in quick mouth closures. However a site inspection of the bay after the July 2011 opening revealed the mudstone sill had been eroded by high flow velocities after channel incision during the opening.

Subsequent surveying and diving of the bay revealed all of the soft to very soft muds had been removed down to the now exposed mudstone (Environment Southland survey and dive data, 2011 & 2012). Currently, the outer parts of the bay are between 0.5- to 0 MSL then rise up to 0.25 MSL, this slight crest created a weir-like structure during the July opening (Figures 5 and 6).

In all likelihood the localised erosion accounts for the large amount of sediment which was removed during the July 2011 opening (C. Jenkins , Appendix B) when compared to previous years at Walker's Bay. Therefore, just as Walker's Bay channel morphology has been trained with successive openings, Charlie's Bay is likely to follow a similar pattern of more clearly defined channel structure adjacent to the opening point. It is feasible that with successive openings at this site more sediment and nutrient will be moved from outside the Charlie's Bay area, than just the localised bed removal that occurred during the 2011 opening.

Figure 5: The weir-like terrace and eroded mudstones in the bathymetry of Charlie's Bay

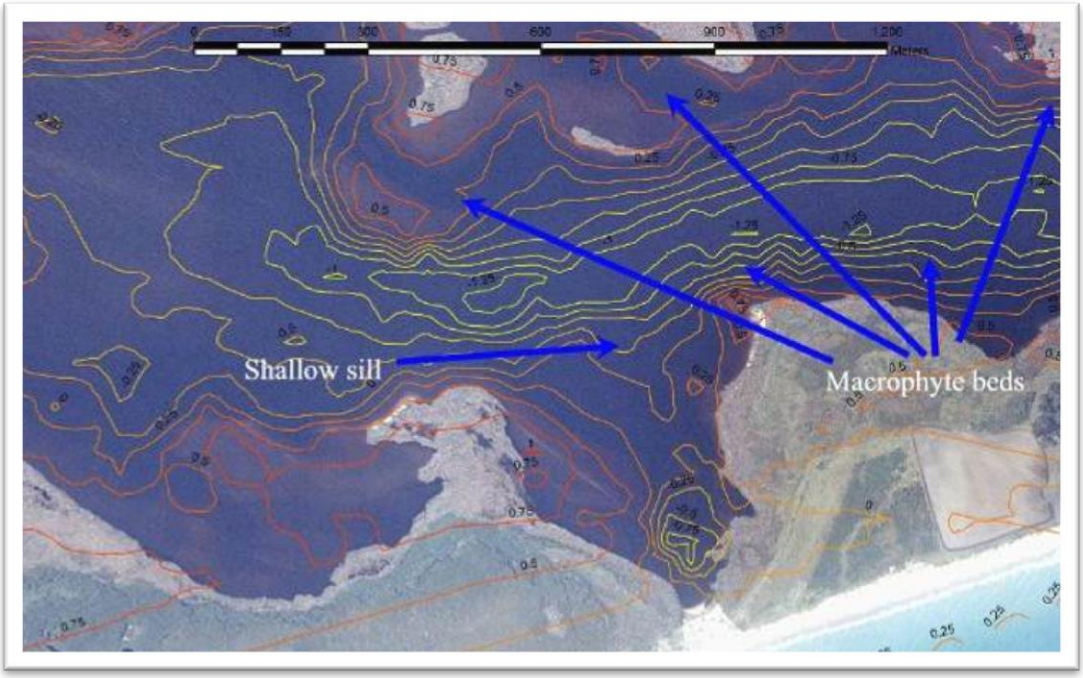

Figure 6: Bathymetry of Charlie's Bay

3.2.1 Macrophyte populations in Charlie's Bay (and nearby)

Charlie's Bay has historically had moderate to good levels of macrophytes. In 2007, Wriggle Coastal Consulting recorded cover in the 50-80% range with a large section of the inner bay at 80-100%. As the bay is shallow and sheltered from the predominant wind growing conditions for macrophytes is optimal.

However, over the successive macrophyte surveys in 2009-2010 cover in the bay decreased to 5-15% cover range with thick *Bachelotia* covering most of the bay. In May 2011, ES science staff dived the bay and one 50m^2 area of *Ruppia polycarpa* at 80-100% cover remained, whereas the rest of the bay was largely devoid of cover. The patch of *Ruppia* was 160m from the opening site. After the July 2011 opening, all the *Ruppia* cover was scoured and removed, and repeat dive surveys revealed a barren hard mudstone bed. The reason for this is the current speeds in this region during channel incision were in excess of 3 m/sec (ES hydrological staff observations, 2011).

The shallower and sheltered edge of the bay did start to show some recovery after the opening (Figure 7). By late 2011 and early 2012, the bay was showing good sign of growth with *Ruppia polycarpa* at 20-60% and about 10-30 cm long.

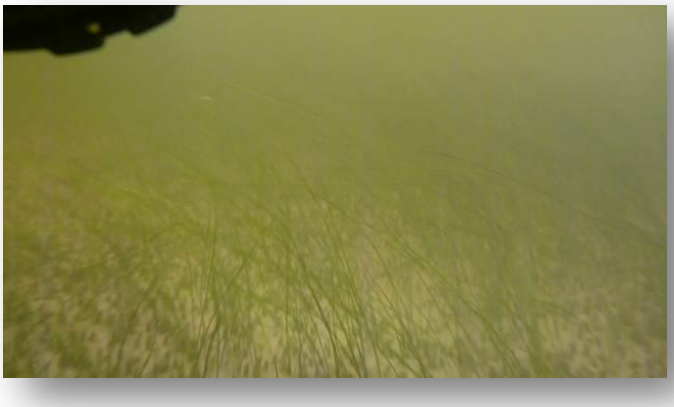

Figure 7: *Ruppia* seedlings (10cm) recovering in Charlie's Bay post-opening

Macrophyte vegetation close to Charlie's Bay is largely away from the DOC monitoring transects. Heading to the east, the lagoon becomes more channelized with a single channel. In this section of the lagoon between DOC transects 2 and 4 there are two distinct bands of both *R. megacarpa, R. polycarpa and M. tripyllum*, which are most prevalent in cover in the depth of 0.25- to 0 msl on either side of the lagoon. This area of macrophyte cover is less than 500m east of Charlie's Bay and runs almost continuous to the Carran Creek mouth. The physical effects of scouring from the last opening at Charlie's Bay appear to have had little effect on these areas of macrophyte, as current speeds were not fast enough to create bed movement or physical removal of the vegetation. Consequently the current and future risks to macrophyte cover from scouring in the wider area is low, but offset by the very high risk to macrophyte cover within several hundred metres of the opening.

3.3 The Fence

The historical opening site at The Fence is directly opposite the Carran Creek mouth in the eastern end of the lagoon. The Fence is visible from Waituna Lagoon Road as two un-vegetative strips of gravel 60m apart. The last time this location was used as an opening site was in 1972, when it stayed opened for 11 days (Waghorn R., personal communication, 2010). The lagoon channel bed immediately west of The Fence is deeper than -0.25 msl, with two deep holes of -1.25msl immediately in front of The Fence (Figure 8). However, there are several larger shoals of fine mud to the north and west as well as the built-up outwash fan at the mouth of Carran Creek (Figure 8).

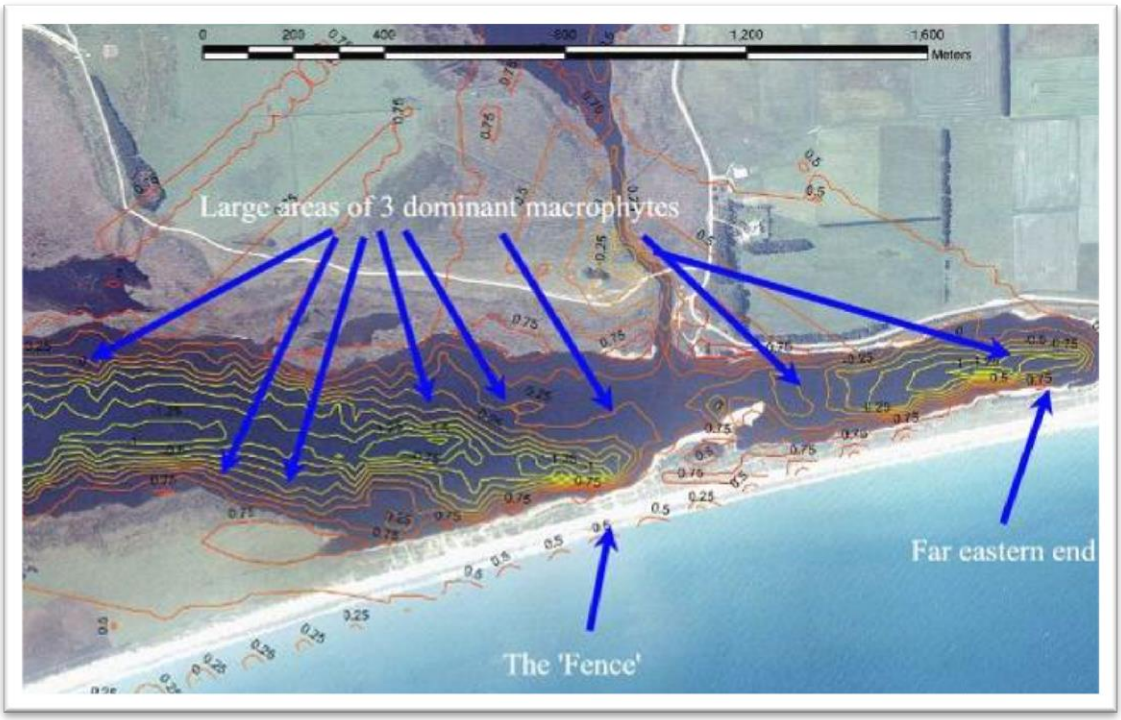

Figure 8: Waituna Lagoon bathymetry in front of The Fence and the Far Eastern End

Since this location has not been used since 1972, its ability to remove sediment and nutrient laden lagoon water from the main body of the lagoon would be reduced compared to Walker's Bay and Charlie's Bay. This would be the case until with successive openings or with mechanical intervention channel shape and structure was more clearly defined adjacent to the opening. However, an opening at this site would remove a large amount of localised sediment, similar to the opening at Charlie's Bay in July 2011.

The dominant sediment adjacent to The Fence is a mixture of soft to very soft mud in the main channel, moving up to firmer mud and gravel on the channel edges. The very soft mud in the main channel is up to 50 cm deep in places.

Immediately east of the mouth of Carran Creek is a large gravel fan which has built out into the lagoon towards the east. This fan has been created by littoral drift from the predominant westerly wind. The location of this however, may prove beneficial if an assisted closure trial was ever to be undertaken in the lagoon. The fan could be used as a 'pitch point' for a mouth which is opened 350m away to the east. A similar hydraulic setup has been engineered at Lake Forsyth in Canterbury where the closure point is located back inside the lagoon away from the coast. The reason for this is the reduction in flow and tidal velocities away from the opening at the coast, therefore less hydraulic energy is required to be overcome to mechanically close the breach.

3.2.1 Macrophyte populations nearby to The Fence

The areas both immediately west and east of The Fence historically and currently have good coverage of all the three dominant macrophyte species in the lagoon. The edges of the central basin again have two bands of macrophytes with cover ranging from 50-80 %. This part of the lagoon is important for macrophyte species as it one of the few areas which does not dry out when the lagoon is tidal, or with low lagoon water levels. The site is also has the Carran Creek adjacent to it and therefore it has more freshwater inputs to the site even when the lagoon is open to the sea.

The macrophytes on the northern edge of the lagoon are within 200-350m of The Fence, whereas the macrophytes on the southern edge of the lagoon are between 0-350m. If this opening location was to be used in the future, careful consideration would be required to determine the likelihood of macrophyte recovery as all macrophytes within 200m of The Fence would be scoured and removed. Lake Waituna Control Association (LWCA) members believe a large opening can be created at this location, which suggests current speeds above what can be achieved at Walker's Bay (i.e. greater than 3 m/s). If this was the case, macrophytes may be scoured to a greater extent as the dominant soft mud in the main channel has a high rate of physical entrainment in currents over 0.1 m per sec (Edwards S., 2011).

The success at removing large amounts of sediment from this location would also depend on successive openings, therefore the current and future risk to macrophytes is high, due to their proximity to the opening site.

3.4 The Far Eastern End

The historical opening at the Far Eastern End of Waituna Lagoon is located adjacent to the Fish and Game carpark. Historical records of usage of this sites are limited, however, it was the original opening site in 1908 (Waghorn R, personal communication, 2010). The site was manually shovelled in 1954 and remained open

for 18 days (Figure 9). Anecdotal evidence suggests that a moderate wind from the west is required to push the lagoon flow towards the opening, and a spring tide to create the largest flush at this location. LWCA members suggest a very large opening event can be created here as the potential head gradient is larger than the other locations (see Figure 21 for barrier slopes).

The majority of the eastern end basin has depths greater than <0.0m msl with the deepest sections at -1.25msl in front of the old opening site (Figure 8). The main channel is uniform in shape, however, there is a gravel/sand spit between here and The Fence which provides a natural constriction in the channel (as described above).

Figure 9: Local farmers and community members shovelling out the Far Eastern End in 1954. Photo courtesy of Ray Waghorn.

Sediment characteristics in the far eastern end of the lagoon are soft to very soft muds with depths averaging 20-40 cm but in the sheltered areas behind the gravel spit up to 1.5 m deep.

As this site has not been utilised since 1954, there has been significant sediment accumulation in the area adjacent to Carran Creek. The outwash fan at the Carran Creek mouth rises to 0.5 msl compared to the two deeper holes on each side of the fan which are at 0 to -1.25 msl. The higher elevation parts of the fan are firmer muddy sands, whereas the deeper parts on either side of the fan are soft to very soft deep muds. The firmer parts of the fan may create a significant barrier to enhanced flow rates the next time this location is utilised. Therefore, similar to Charlie's Bay and The Fence where until the localised sediment source is removed by successive openings, it would be difficult to maximise sediment and nutrient laden water removal.

3.2.1 Macrophyte populations in the Far Eastern End

Macrophyte cover in the Far Eastern End of the lagoon has historically been very good with cover in the range of 50-80% with pockets of 80-100%. The cover has been dominated by *R. megacarpa,* with *M. tripyllum* in the shallow edges of the

lagoon. However, only one DOC monitoring site exists in the eastern end of the lagoon, and it is up to 400m from the greatest amounts of cover of *R. megacarpa*. The area behind the gravel spit in between the Far Eastern End and The Fence has around 800m^2 of *R. megarcarpa* (ES monitoring data and aerial photos, 2012).

The *R. megacarpa* in this part of the lagoon is also covered by water when the lagoon is tidal or with low lagoon levels. The *R. megacarpa* in several places has a predatory colonial Entoproct cronea (Gordon, D, personal observation, 2012). This species is invasive throughout New Zealand but has only been identified in the eastern end of the lagoon in the middle of 2011, However, by the 2nd July 2012 the Ectoproct was spread throughout the lagoon and very conspicuous on *Ruppia* leaves.

Again any proposed openings at this location must be carefully considered as the large areas of macrophyte are likely to be directly affected by the physical scouring from the opening. Therefore, the current and future risk to this area is high for similar reasons to The Fence.

4. Salinity Effects from the Four Opening Sites

Although only the last two successive openings have been comprehensively studied (Charlie's Bay July 2011 and Walker's Bay July 2012) they still give valuable insight into salinity intrusion, hydrodynamics as well as the recovery to low salinity conditions from different opening locations. This assessment has used DOC spot measurement across the lagoon and two in-situ salinity loggers; one located 580m east of Carran Creek; and the other located in Walker's Bay 150m of the consented opening location. This assessment also includes spot measurements undertaken by ES staff and ES contractors over the month following the opening at Walker's Bay in early July 2012.

4.1 Salinity ingress from the Charlie's Bay opening 2011

The effects of bottom water salinity ingress between the western and eastern parts of the lagoon can be seen in Figures 10 and 11. When the lagoon was opened at Charlie's Bay, salinity was moderately high (15.0 to 32 ppt) between early and mid-August, but was highly variable due to the localised input of Carran Creek via Little Lake. High levels of salinity between 15-33 ppt were evident even in the Far Eastern End of the lagoon. The spot measurements undertaken by DOC scientists (Figure 10) clearly show salinity stratification in the deeper eastern end of the lagoon. Wind speeds over this period (recorded at the Waituna Lagoon hydrological site) were generally low in the order of 0-5 m/s and predominantly from the northern quarter. Wind from this direction reduced the fetch in eastern and central parts of the lagoon so wind mixing was reduced. In all likelihood the only mixing occurring was from the small tidal amplitude in the lagoon. Upon lagoon mouth closure on the 18th August 2012, salinity ranged from 10-15 ppt and within 6 weeks levels had dropped to below 8 ppt where it slowly decreased to 5 ppt by the 15th November 2012.

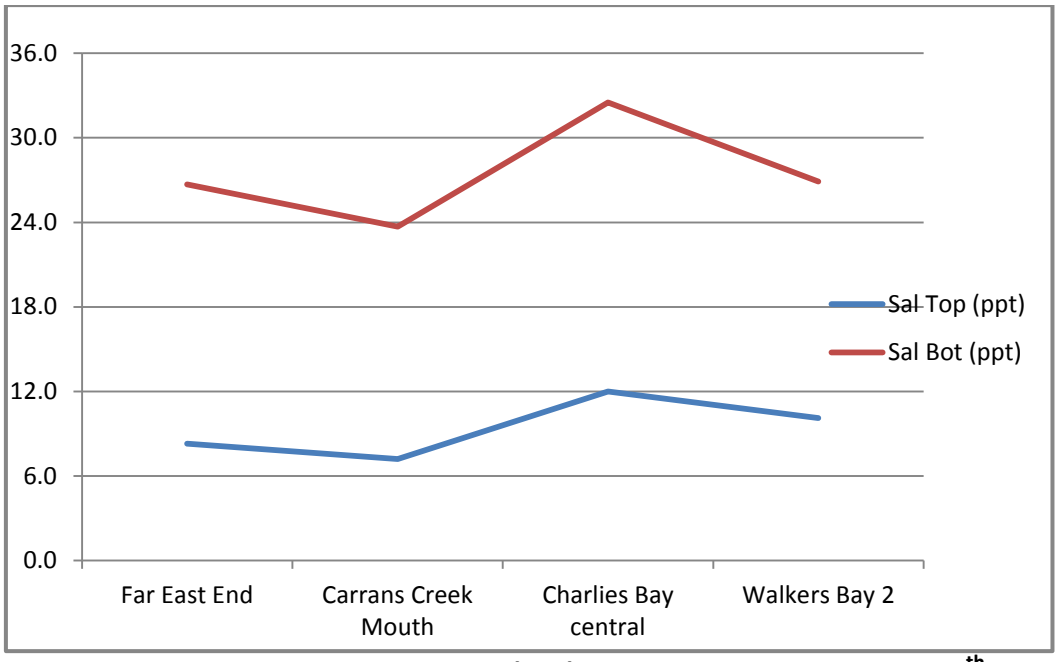

Figure 10: Salinity spot measurements (ppt) across Waituna Lagoon on 5th August 2011

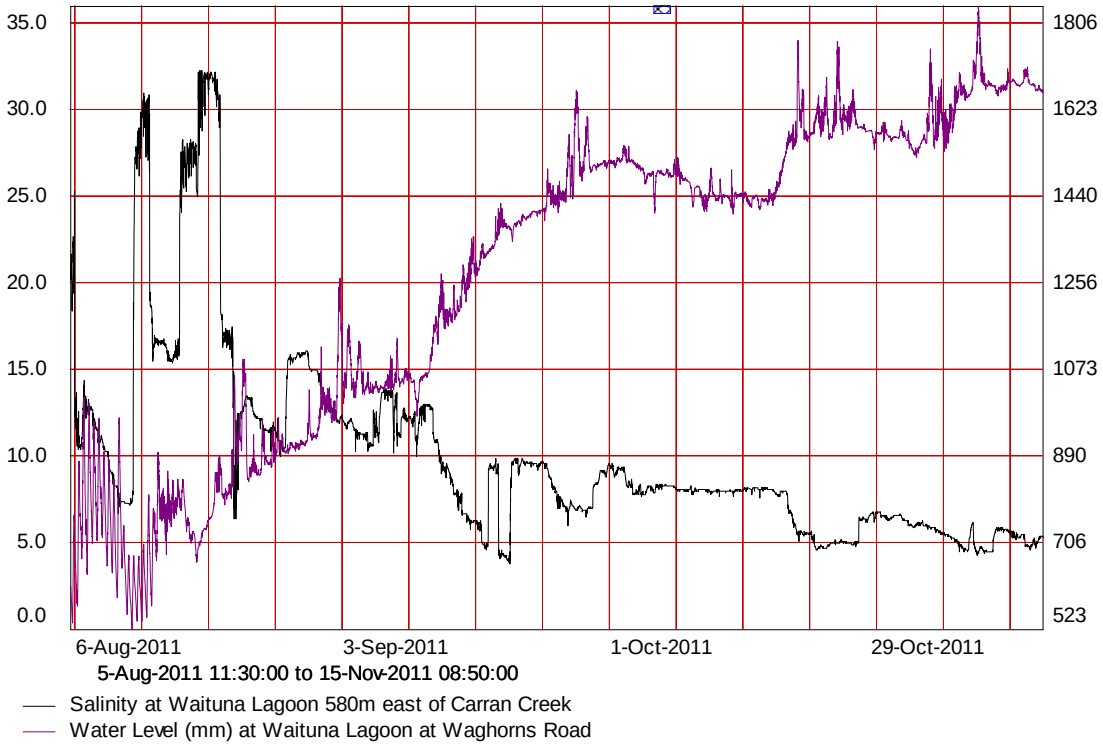

Figure 11: The Waituna Lagoon water level at Waghorn Road and a DOC salinity logger adjacent to Carran Creek mouth

Arrow denotes lagoon closure date on 18th August 2012 (Charlie's Bay opening) and the blue box indicates the period of return to salinities below 8 ppt.

Bottom water salinities behaved similarly at Walker's Bay as they did at Charlie's Bay even though it was further from the opening site at Charlie's Bay, however, the salinity range was reduced. Tidal salinities in Walker's Bay ranged from 10-20 ppt,

with the peak of the salinities coinciding with the largest tidal range, and therefore increased water levels in the lagoon between the 14-15th of August 2012. Severe barrier overtopping can be seen in the data at the end of September with salinities spiking to 25 ppt, this resulted in slight salinity stratification in Walker's Bay.

After lagoon closure the bottom water salinities in Walker's Bay also took around 6 weeks to decrease to below 8 ppt, similar to the eastern end. This suggests that in the last two years there has there has been no difference between the two locations in the time lagoon water took to return to low salinity conditions after mouth closure. In the 12 months prior in the Waituna catchment there had been a period of settled winds with lower than usual rainfall, which resulted in steady filling of the lagoon. Therefore, under a 'wet' or 'typical' year, the time period to return to lower salinities may be shorter than the 6-8 weeks as experienced in the last two openings as freshwater inflows will be greater.

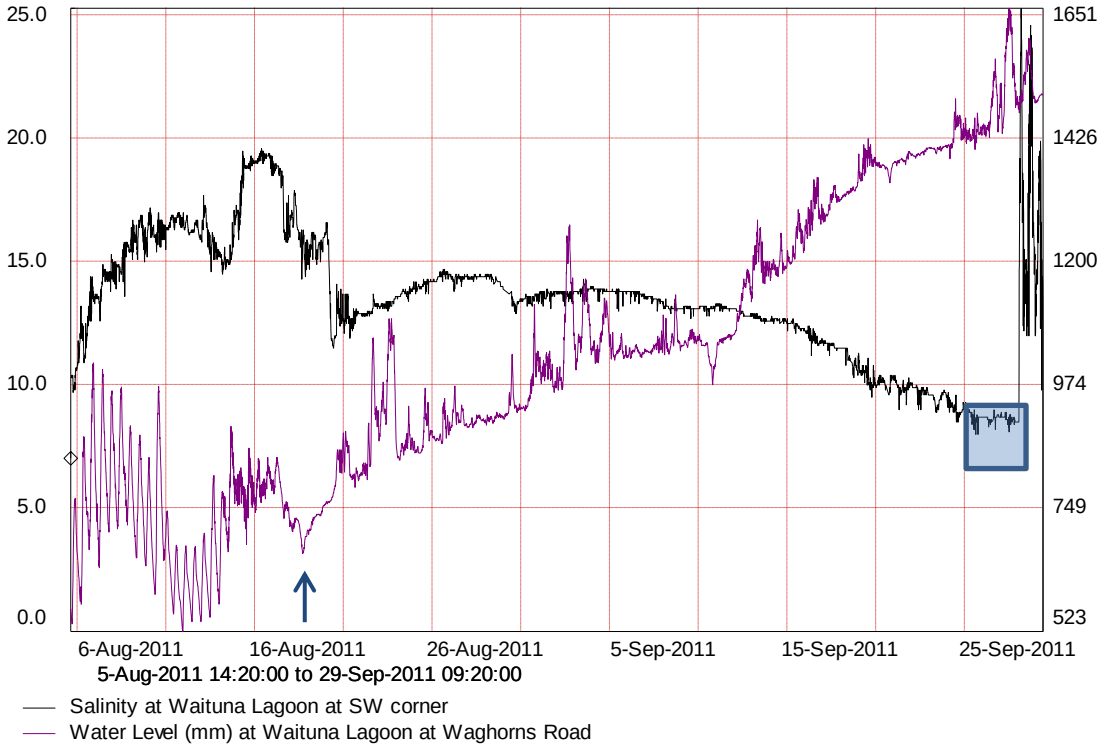

Figure 12: Walker's Bay salinity profile and Waghorn Road water level.
Arrow denotes lagoon closure date on 18th August 2012 (Charlie's Bay opening).

4.2 Salinity ingress from the Walker's Bay opening 2012 and historical data

Following the Walker's Bay opening (2nd July 2012) saline water entered the lagoon with successive tides and by the 9th July 2012 had reached everywhere in the lagoon except the area east of Carran Creek. Salinities of 11 ppt had reached beyond the Carran Creek mouth by the 16th July even though the smaller neap tides (less tidal

power) were on the 13th July. Several researchers have suggested the eastern end of the lagoon may be a 'freshwater refuge' from the effects of salinity. This is likely to be only the case for a Walker's Bay opening that closes in less than two weeks, and where there are sufficient flows in Carran Creek to push against the tide (see Appendix E). If the opening period is longer than two weeks the whole lagoon will be filled with moderate to high levels of saline water.

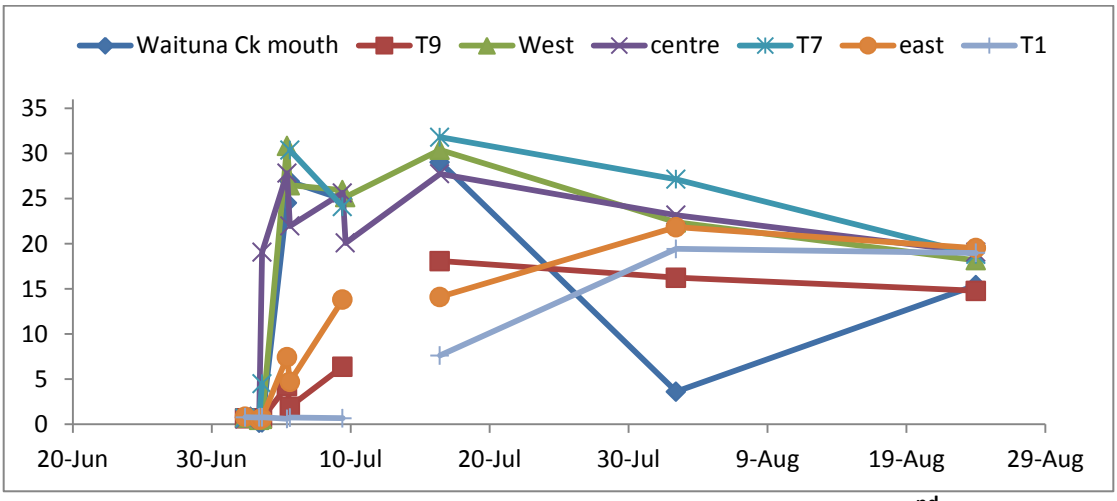

Figure 13: Salinity spot measurements across Waituna Lagoon pre-2nd July opening to 24th August 2012.

The Walker's Bay mouth closed on 24th July 2012 and in the following two weeks bottom water salinities decreased across the lagoon at all sites, except the two sites east of Charlie's Bay towards Carran Creek. As occurred in 2011, these eastern areas of the lagoon recorded salinity stratification in deeper channels and holes. Winds over this period were generally light-moderate (0.5-6 m/sec) and from the northern quarter as in 2011. From 2nd August to the end of August, salinities across the lagoon stabilised and became uniform, with all sites in the range of 14-19 ppt. Flows in the Waituna Creek over the last two weeks of July were all above median.

Interestingly with the latest opening at Walker's Bay, salinities in Shand's Bay remained below 18 ppt given its close proximity to the opening. Examination of the bathymetry of the two entrances to Shand's Bay revealed two shallow sills at 0.5 msl, which possibly account for the lack of tidal penetration into the rest of the bay.

4.3 SOE data and recovery to low salinity conditions

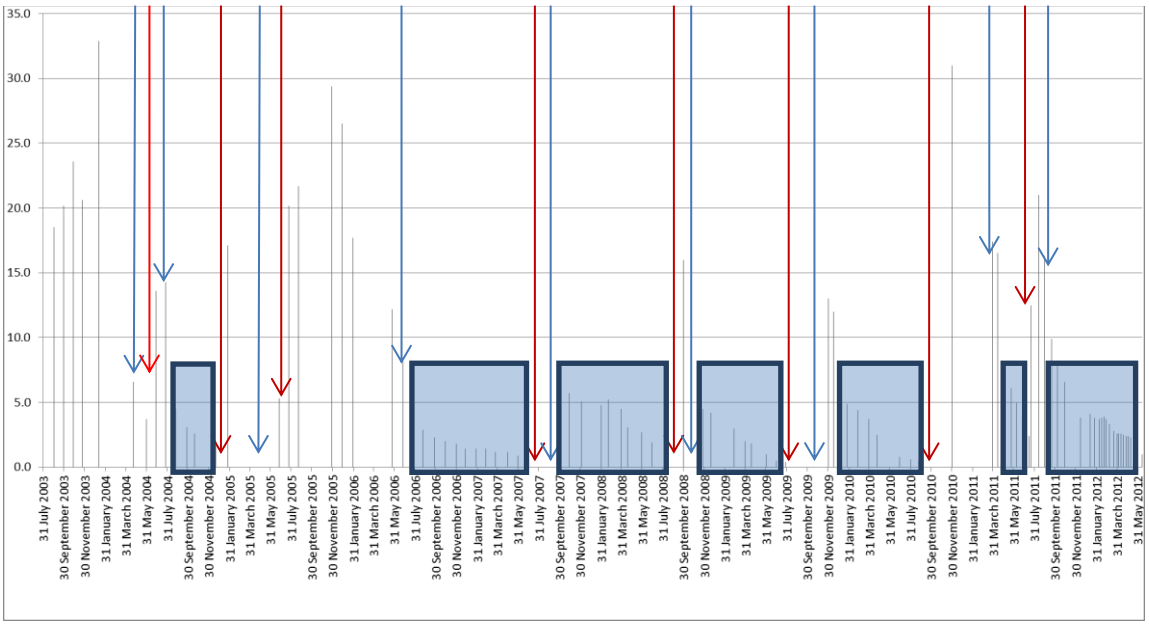

Figure 14: Salinity ingress and return period to low salinity (<8ppt) at the Waituna Lagoon east water quality site.

Note: Red line denotes lagoon openings and blue line is lagoon closing dates. Data is monthly SOE results from the east site, with all but the last year of data for the Walker's Bay openings.

Figure 14 above depicts the recovery of Waituna Lagoon to low salinity conditions below 8 ppt in the last nine years. Again the pattern of recovery is similar to the last opening at Charlie's Bay with low salinities conditions returning in less than two months, and often quicker than this such as occurred in 2006, 2007 and 2008.

Bearing in mind that for a Walker's Bay opening periods in winter averages three months the selection of the opening location then has little impact on salinity intrusion (unless a guaranteed mouth closure is possible within 2 weeks). Therefore, post closure recovery to low salinities conditions is just as important to consider when selecting a location for opening. However, these preliminary findings suggest that the selection of a opening location has little bearing on the return to low salinity (<8ppt) conditions as the timing is consistent between the far west of the lagoon and the central east of the lagoon at Charlie's Bay.

Until an opening can be trialled at the sites in the Far Eastern End, estimating saline intrusion and recovery is difficult for these two sites. However, based on the tide travel times from Waghorn Road and a Walker's Bay opening (being 3.5 hrs) in all likelihood saline water would still penetrate to all areas in the lagoon after 2-3 weeks similar to the other locations. Therefore, until a quick mouth closure can be guaranteed all saline intrusion must be treated equal for four locations, as with the recovery to low salinity conditions.

5. Coastal Environment

Toetoes Bay in front of the Waituna Lagoon is a steep reflective coastline. The beach is made of coarse 'pea gravel' (5-7 mm) which has occasional layers of coarse sand (Edwards Sl., 2011). The section of beach from Bushy Point to several hundred metres east of Charlie's Bay is very uniform. This stretch of coast is very straight with little or no curvature, unlike the coast from the eastern end of the lagoon to the Fortrose Harbour which has a pronounced bend away to the south-east. The dominant swell direction is a deflected south swell (around Stewart Island) at 176 degrees, which has largely shaped Toetoes Bay (McComb, 2009). Wave heights are observably higher towards the Toetoes Harbour end of the bay as opposed to the Bushy Point end of the bay (Larkin G, personal observations 2007-2012).

Until specific bathymetry is undertaken (in progress) in the near shore environment along the barrier, accurate information on seabed data is limited. However, from examining the Marine Chart (NZ 681) there is a noticeable depth gradient which changes along the barrier from east to west. In the area adjacent to Fortrose Harbour mouth depths are shallow in the 1-1.2m range. Moving west towards the historical openings in front of the Far Eastern End and The Fence depths range from 2-3.4m, whereas moving beyond here past Charlie's Bay and Walker's Bay depths appear to be in the order of 3.4-8.2 m. There is deeper water far closer to the shore adjacent to the Waituna beach than further east towards Fortrose Harbour.

Boat tracks run from Toetoes Harbour along to Walker's Bay also suggest a significant change in bed profile between the eastern end of the lagoon and Walker's Bay. The spot bed depths at 2.5 to 3.0 m were only 45-50m from the low tide shoreline opposite The Fence, whereas at Charlie's Bay the distance increased to 74-114m. At Walker's Bay the 2.5-3.0m bed level was *** from the shoreline. (Environment Southland Bathymetry Spot Heights, unpublished data, 2012). Greater water depths and steeper beach profiles on the Waituna beach would result in increased wave power closer to shore, thereby enhancing gravel mobilisation via longshore drift. Care should be taken interpreting these spot heights until a full side scan sonar survey is undertaken so that a full bed profile can be gained.

Observations by ES staff over the last two years have recorded a large accumulation and movement of gravels, particularly on the coast immediately east of Waituna Lagoon towards Bushy Point (Bradley D, personal observations, 2010-2012). The photos series in Figures 15-19 clearly show the increases in gravel east of Waituna Lagoon, and the movement from east to west as demonstrated by removal of material around the pipe which increases towards the further west Bushy Point light house. These rates of gravel movements and accumulation may help explain the quick lagoon mouth closures in the last two years. Sea conditions over the period of the opening this year, were dominated by calm seaS and winds from the Southern quarter. Winds and swell from this direction are aligned with the dominant longshore drift in Toetoes Bay, which would have enhanced gravel movement along the coast past the LAGOON mouth.

Based on LWCA member's notes, the lagoon mouth often closes in calm stable weather, and sometimes in cool frosty conditions (Waghorn R. and Crack D., personal notes, 1972-2011). These types of conditions are consistent with weather patterns in Southland where swell is minimal (<1m) but winds from the S/SE. Under these conditions the sea state favours gravel movement via longshore drift, which then prepares the lagoon mouth for closure. It is therefore recommended, that a summary report be undertaken to ascertain possible drivers or key variables involved in lagoon mouth closure.

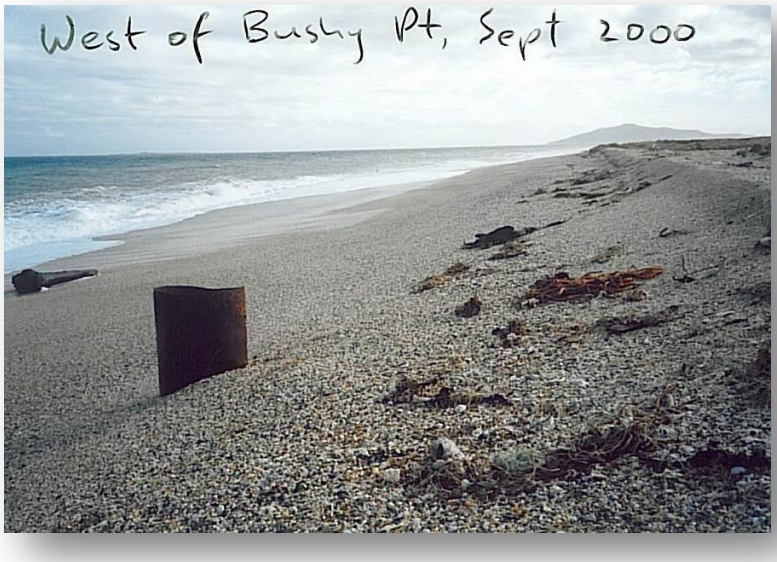

Figure 15: Waituna – Bushy Point beach facing west towards Bluff Hill, 2000.

Figure 16: Waituna – Bushy Point beach August 2011 showing the massive aggradation around the steel pipe.

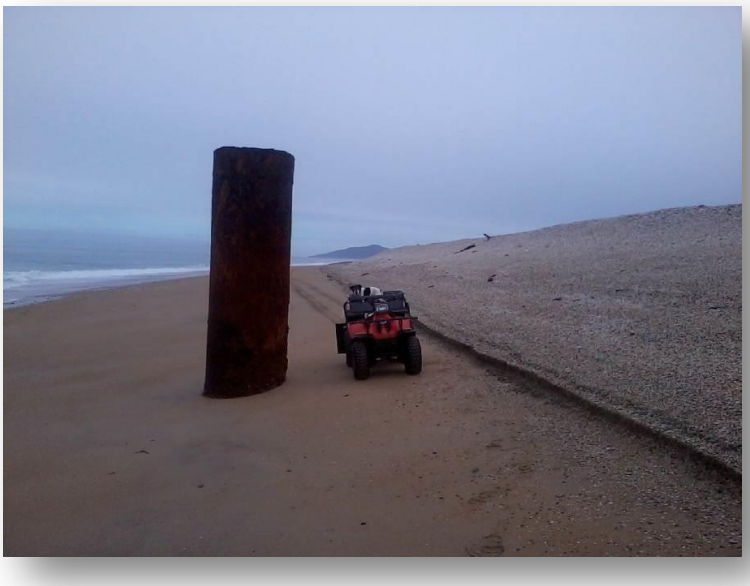

Figure 17: Waituna – Bushy Point beach August 2011 showing the removal of material west along the beach towards the Bushy Point lighthouse.

Figure 18: Bushy Point lighthouse foreshore facing east towards Waituna Lagoon, May 2009.

Figure 19: Bushy Point lighthouse foreshore facing east towards Waituna Lagoon, July 2011 showing the gravel accumulation on the upper beach.

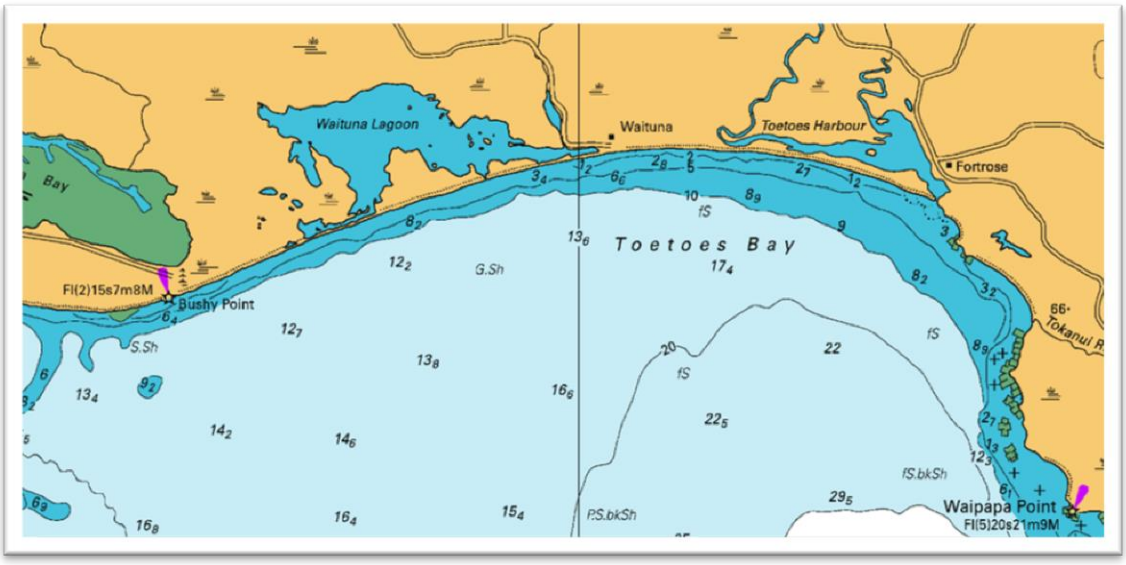

Figure 20: Toetoes Bay bathymetry.

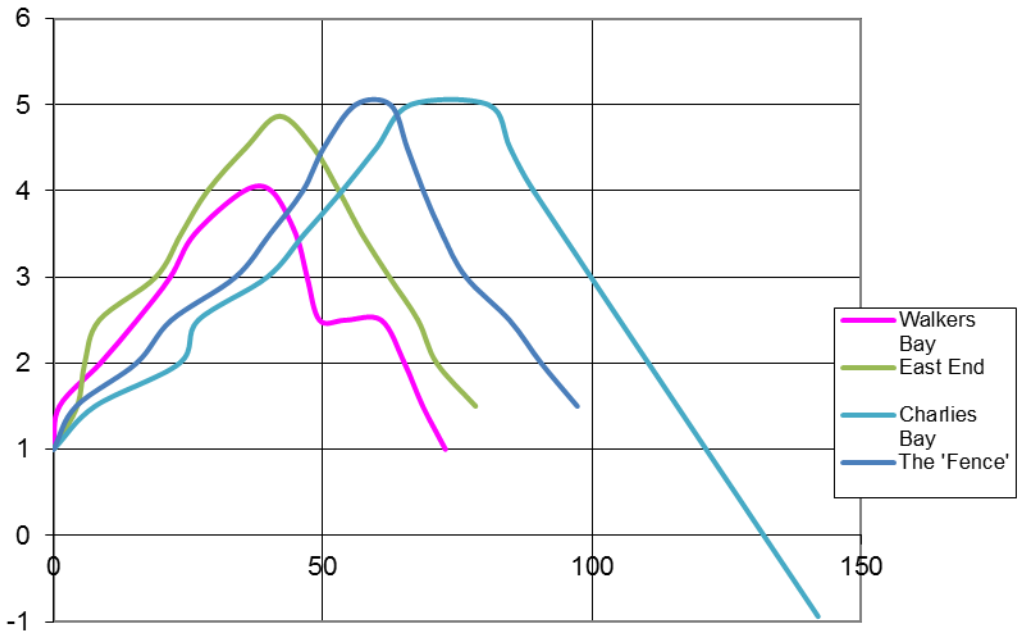

Figure 21: Barrier profiles of the four opening locations.
Note: the horizontal axis is distance from the lagoon to the sea whereas the vertical axis is height in MSL

6. Opening Costs

Although the amount of material which was required to be removed to open the lagoon at Charlie's Bay in July 2011 was far higher than would be necessary at Walker's Bay, the costs incurred from digger time and labour cost weere similar. The reason for this was walking the diggers to the site at Walker's Bay down the barrier can take as long as 2 hours. Therefore the cost of $3000-$4000 for each of the mechanical breaches is similar so neither locality has a financial benefit in terms of time or labour over the other.

As The Fence or the Far Eastern End locations have not been utilised for a significant amount of time, the expected costs of an opening here are largely estimates (Hinton, N., personal communication, 2012). However, as access is excellent and a lot of the barrier material is a mix of sand and pea gravel with vegetation on the surface the digging would be fairly easy and therefore quick. This is because the vertical batter of the slopes in the cut would be steeper. The costs for digger time and labour if using the Far Eastern End is then in the order of $1000 as opposed to the cost of $4000 at Walker's or Charlie's Bay. However, these costs for mechanically opening Waituna Lagoon are still very small in comparison to the $170,000 annual cost to open Te Waihora/Ellesmere in Canterbury (Environment Canterbury website 2012).

7. Summary and Recommendations

The selection of a single favoured location is difficult because each location has site specific advantages and disadvantages compared to each of the other locations. In addition, the assessment in this report is based on information from, at most, a few opening events at each site with the exception of the Walker's Bay site. The following table contains a summary of the benefits and risks of the four opening locations assessed in this report:

Site	Benefits	Risks
Walker's Bay	**Flushing -potential to generate medium to large outflows (600-1200 cumecs)** A. Removes up to 5000 tonnes of sediment B. Removes up to 18 tonnes of Total Phosphorus (TP) C. Removes up to 100 of Total Nitrogen (TN) Note: the bay has increased likelihood of exceeding these removal rates over the other 3 locations due to the 'trained' natural of the channel morphology. The continual use of the bay also means the barrier is now very porous and has no interstitial sand so at higher lagoon water levels large volume of water 5-20 cumecs leak through the barrier.	**Mouth opening period averages 120 days** A. Often creates a large stable mouth, which favours marine sand intrusion into central Walker's Bay, results in smothering of *Ruppia*, hinders recovery B. Large intertidal sand flat at 0.25 msl in central bay, building up in extent and height C. The area of Bird Island is also building in extent, local evidence suggests this is impeding larger outflows (July 2012) At low water levels, localised erosion occurs on both sides of Walker's Bay
	Cost- digger time and labour The overall cost is similar to Charlie's Bay ($3000-$4000), as the barrier is smaller at 60m wide, however, this is offset by the 2-3 hours it takes to walk the diggers to the site	**Cost- digger time and labour** A. The cost of both sites at the eastern end is estimated at $1000 (with far better access to the sites as well as minimal digger time required)
	Macrophyte effects-physical scouring, salinity and recovery to low salinity conditions A. The overall risk to macrophytes from physical scouring in Walker's Bay is generally low as few macophytes are within 200m. The reason for this is the bay has historically poor coverage of macrophytes. Note: if the there is a shift to utilising the eastern end opening sites, it is envisaged that Walker's Bay macrophytes would recover. Therefore the future risk to macrophytes from not only scouring may become higher. B. Salinity intrusion to the central and eastern end of the lagoon takes 2-3 weeks, so if Walker's Bay closes sooner there will be a lower risk to macrophytes.	**Macrophyte effects-physical scouring, salinity and recovery to low salinity conditions** A. There is no respite from desiccation and possible salinity stress in Walker's Bay, as saline water enters the bay immediately on the first incoming tide after opening and reaches the central State Of the Environment water quality sites within 1-2 days. Note: with an opening at Walker's Bay it can take up to 2-3 weeks before saline water reaches the far eastern end of the lagoon. However, this location still has a moderate to high risk of negative effects on macrophytes due to the average opening period of 120 days (Hicks A, 2010 and Edwards S., 2011).

Charlie's Bay	**Flushing – potential to generate moderate to large outflow events (600 cumecs)** with flow velocities estimated >3m/sec in the July 2012 opening (ES monitoring data, 2012) A. Removed 7000 tonnes of sediment B. Removed 65 tonnes of Total Phosphorus (TP) C. Removed 8 tonnes of Total Nitrogen (TN) D. Opening periods for this site* 1974- 1 and 21 days 2011- 31 days* preliminary indication as potential site for shorter opening period. This site requires further trials and investigation before being definitive.	**Flushing-** to get the greatest flushing ability at this location it will require several more openings before the lagoon channel morphology is 'trained'. Note: the basement substrate is mudstone in the bay and at the bay edge with a weir-like sill at the bay entrance, this combined with the longer flatter lagoon to sea gradient/head differential may reduce the likelihood of large to very large (>1200 cumecs) outflows.
	Cost- digger time and labour A. Requires less time for digger to access site, so cost is equal to Walker's Bay	**Cost- digger time and labour** A. Requires more digging time as barrier width is 100m at Charlie's Bay compared to 40-60m at Walker's Bay, and 60m at The Fence and the Far Eastern End
	Macrophyte effects- scouring, salinity and recovery to low salinity conditions A. Physical scouring outside bay limited- beyond 200m B. Salinity intrusion - saline water takes longer (2-3 weeks) to get to the far western end and salinity values are generally low (10-20ppt) as opposed to 36ppt in the central and eastern areas, this allows the west of the lagoon slight respite from salinity dieback. C. Return to low salinity conditions across all locations took 6-8 weeks from a Charlie's Bay opening	**Macrophyte effects- scouring, salinity and recovery to low salinity conditions** A. Inside Charlie's Bay complete removal of macrophytes within 200m B. Salinity Intrusion - faster ingress of higher salinity to eastern and central parts of lagoon i.e. large area of macrophytes exposed to high levels of salinity, C. Return to low salinity conditions across all locations took 6-8 weeks from a Charlie's Bay opening
The Fence and Far Eastern End	**Flushing Potential*-** based largely on anecdotal/local evidence A. Potential for large flushing event due to wind setup on lagoon water level, shape of lagoon, and steep head differential from lagoon to sea B. Potential to remove large areas of soft to very soft mud as current speeds are likely to be far in excess of 0.1 m/sec required to mobilise soft muds. C. Historically closed quicker (and therefore was seen as an unfavourable location)	**Flushing Potential*-** No quantitative assessments A. Large areas of shallow shoals adjacent to both locations which would slow the flushing ability, this would require successive openings (up to 3 times) to train the channels upstream of opening; digger and labour costs then become more in-line with Walker's Bay. B. B. Erosion affects on the Carran Creek mouth, east end carpark and Murray Waghorn's farm access are largely unknown*.
	Cost- digger time and Labour A. Both locations estimated to be $1000 due to excellent access and ease of digging. Note the sea regularly overtops The Fence's two parallel cuts and as such less material may need to be removed if the lagoon overtopping fans are small. These two sites offer the best opportunity to trial an assisted breach closure	**Cost- digger time and Labour** A. Although not related to digging costs, an opening close to public observation could possibly create positive or negative visual and aesthetic effects

	due to good access for a stockpile of material.	
	Macrophyte effects- scouring, salinity and recovery to low salinity conditions A. Scouring- no positive effects from these two locations. B. Salinity intrusion into the larger main body of the central and far western areas of the lagoon could possibly take longer than three weeks. This could be due to distance, tidal head and timing require to push the 7km through a series of narrow lagoon channels and obstructions*. C. Recovery to low salinity effects after opening at these locations * largely unknown, but once tidal influence is lost this location has the potential to return the eastern end of lagoon back to LS in less than 6 weeks if Carran Creek inflows are sufficient.	**Macrophyte effects- scouring, salinity and recovery to low salinity conditions** A. Scouring- complete removal of moderately large areas of *R. megacarpa* & macrophyte from 0-200m from both sites. Note: this preliminary assessment is based on flow velocities of 2-3 m/sec 'ground truthed' by diving in Charlie's Bay post July 2011. If anecdotal evidence is correct very large outflow events can be generated here so macrophytes up to 300-400m away may be affected as the lagoon is only several hundreds metres wide at these two opening points and dominated by very fine soft muds. B. Salinity intrusion into the eastern end will occur very quickly (within 24 hours) and salinity values likely to equal that of marine water (36ppt) even with the close proximity of Carran Creek as tidal power will far exceed creek flow. C. Post lagoon closure raises the probability of salinity stratification in the singular deep channel with numerous parts of -1.0 to 1.5 msl. Note: This is already evident in the ES monitoring data post Walker's Bay opening July 2012. The extent of the stratification will depend on the level of wind mixing in the more sheltered eastern end and Carran Creek inflows. The redox state in these deep light devoid holes is often poor, with shallow RPD in very soft muds (DOC Transect 3 middle). Therefore, the possibility of low DO2 is more likely with a persistent (>3 week) stratification event.

Note: The Fence and the Far Eastern End locations are grouped together in this summary, because parts of their assessment are still preliminary and the issues effecting one locale also affect the other.

* signifies preliminary assessment and requires further assessment

The mechanical opening of Waituna Lagoon is a tradeoff between providing farm drainage, flushing nutrients and sediment, and negative effects incurred from successive openings. The selection of a favoured opening site is also a tradeoff between benefits of one site versus negative effects upon the whole lagoon.

Our current level of understanding of coastal dynamics and lagoon mouth behaviour does not yet allow accurate prediction of the time to mouth closure. Therefore, until this gap in our understanding is narrowed a proactive but cautious approach should be used in selection of a favourable opening location. For example, the relative predictable effects of an opening at Walker's Bay should not discourage another opening at Charlie's Bay or a winter trial at the Far Eastern End. Whist trialling other locations at sensitive periods in the macrophyte life stage should be undertaken with extreme caution, the information gained from monitoring and observing these trial openings is at present one of the best options for narrowing the gaps in our knowledge of these processes.

It is then recommended that a rolling opening schedule be developed for all four locations taking into consideration elements which maximise the protection of lagoon ecology. The factors and variables to be considered also depend largely where the greatest emphasis or weighting is placed for the given ecological state of the lagoon. For example, is enhancing the flushing and removal of sediment a greater value than limiting macrophyte scouring or sand intrusion for a lagoon opening in late summer which has a good biomass of macrophytes? The weightings for each factor are also complex in that they change for repeated openings for a single location, where the effectiveness or benefits from using that one location may diminish the more it used as an opening site (see Appendix D for two examples).

The rolling schedule should also include elements not discussed in this report such as season, macrophyte life stage, tide and current lagoon water quality.

It is also recommended that the following considerations should be included in that rolling schedule:

- Only trial the eastern end sites in autumn to early-winter (May, June, July), and only with good coverage of macrophytes (20-50% cover) in the main body of the lagoon, around Charlie's Bay and in Shand's Bay.

- Trial the use of Charlie's Bay in summer over that of Walker's Bay, (next opening if required).

- Favour the use of Walker's Bay over all other locations to mitigate a sustained algal bloom, no matter the season or life stage.

- If possible coincide openings with elevated lagoon turbidity and winds from the north-west direction when the lagoon is clear and still (as was the case in 2012).

- Trial all sites with a neap tide opening and <u>not</u> the standard spring tide opening.

Recommendations for further work include:

- Undertake a scoping exercise to assess the possibility of an assisted ‘pitch closure’ between The Fence and the Far Eastern End.

- Undertake GPS drogue deployments during the next opening as to determine surface flows and likely shear forces on macrophyte bed.

8. Acknowledgements

Thank you to the following organisations and people:

- Environment Southland and the Department of Conservation for providing the majority of the data used in this report;

- Chris Jenkins (Environment Southland) for his estimates of lagoon opening nutrient and sediment load losses;

- Keith Hamill (while at Opus Consulting), Dr David Hamilton (University of Waikato), Dr Andy Hicks and Karen Wilson (Environment Southland) for providing useful feedback on the draft versions of this report.

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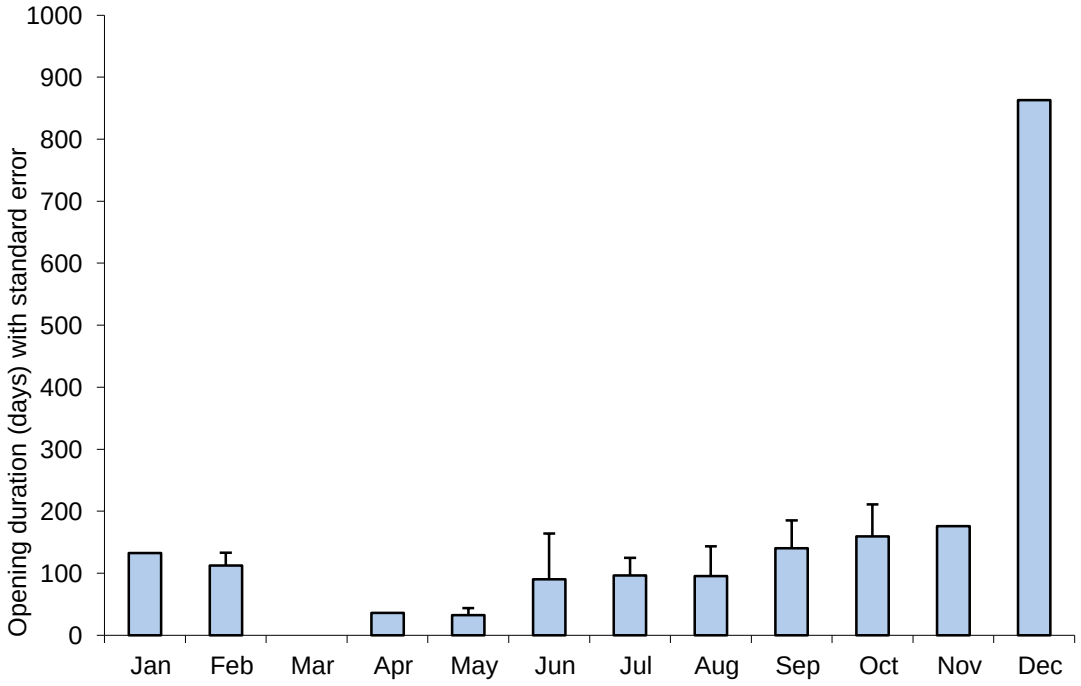
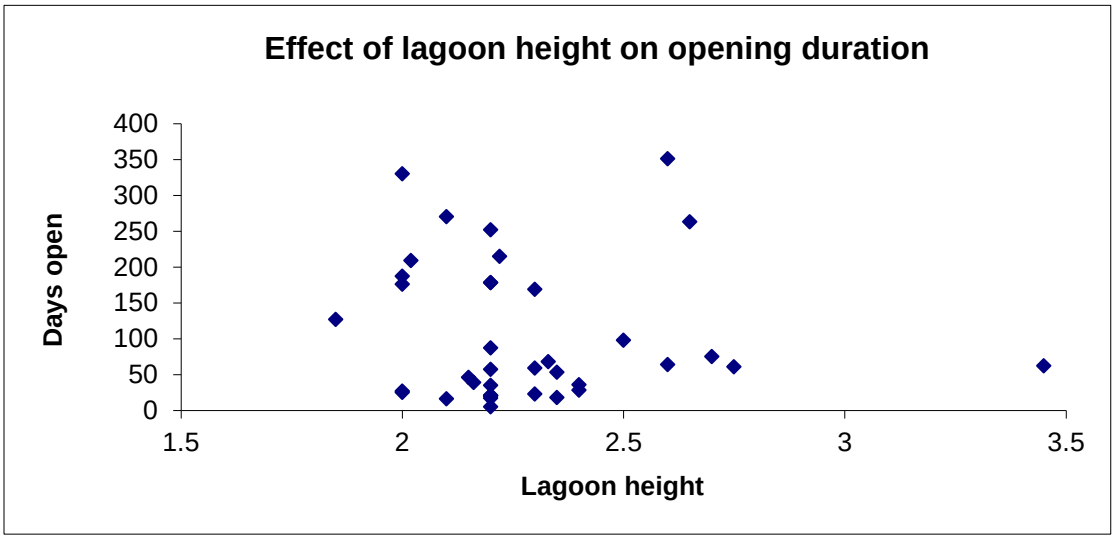
10. Appendices

Appendix A: Opening Durations of Waituna Lagoon

[Source: Dr A Hicks, Environment Southland, 2011]





Appendix B: Data Sources

Environment Southland monitoring data

- Includes Hilltop.hts files from Hydrological and Climate Stations in the Waituna Catchment on Waituna Creek at Marshall Road and Carran Creek.
- Waituna Lagoon Water Level site at Waghorn Road Bridge.
- Macroalgae and macrophyte dive transects from 2011-2012.
- Waituna Lagoon Bathymetry Survey, 2012, GIS contours.
- Charlie's Bay Bathymetry, 2011, pre-opening survey.
- Toetoes Bay bathymetry, 2012 still in progress.

Peer reviewed reports

- Department of Conservation Macrophyte Mapping report (2007-2012), Published by Wriggle Coastal Management and NIWA.
- Waituna Lagoon Broad Scale Mapping and Ecological Vunlerability report, 2007, Wriggle Coastal Management.
- Waituna Lagoon urgent measures report, 2011, Prepared for Environment Southland by OPUS International Consulting.

Expert consultation

- Personal communication with Chris Jenkins, Senior Hydrologist at Environment Southland, who has been studying the hydrological aspects of the lagoon for 10 years.
- Also consulted with Dr Andy Hicks, Environmental Scientist (Aquatic Ecology) at Environment Southland, to ensure nothing was missed in terms of other data sources or any unpublished data.

Other data sources

- Department of Conservation, CTD loggers deployed and maintained by ES technical staff
- Personal notes from Lake Waituna Control Association members Ray Waghorn and Darrin Crack
- Consultation with Noel Hinton, Environment Southland Catchment Division Manager, responsible for two mechanical openings in 2011 and 2012
- Personal observations of Chris Owen, boating contractor for Environment Southland.

Appendix C: Waituna Lagoon Sediment and Nutrient Exports

	TN (tonnes)	TP (tonnes)	TSS (tonnes)	Water Output (cumecs)	Location
2010	101.2	17.3	5,248.2	25,934,601	Walker's Bay
2011	64.5	8.3	7,048.3	29,881,982	Charlie's Bay
2012	42.7	1.6	257.5	17,616,615	Walker's Bay

Appendix D: Site Selection Calculator

10 = low risk, low cost very successful as management option
5= moderate risk to ecology, partially successful, not yet a full assessment available
1= high risk to ecology or unsuccessful as management option

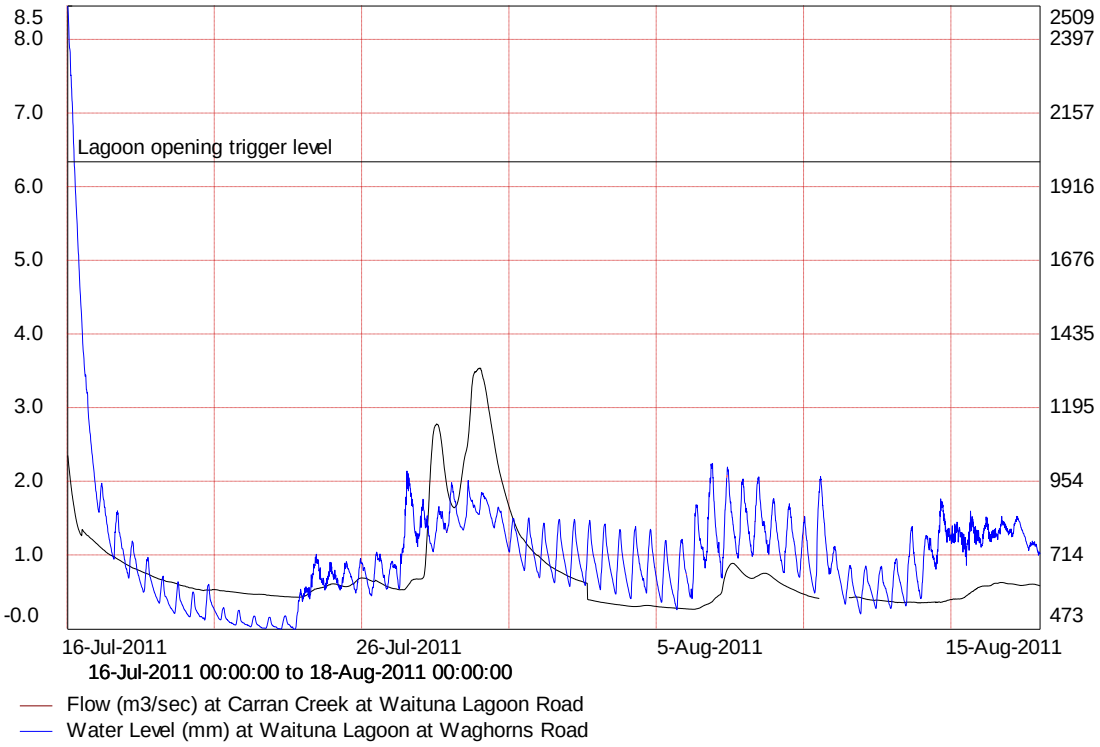
A weighted factor table for a single future opening

Factor	Factor Weight	Walker's Bay	Walk_score	Charlie's Bay	Char_score	The Fence	Fenc_score	Far Eastern End	East_score
Closure timing	15	3	45	8	120	5	75	5	75
Dessication stress/loss of habitat	15	1	15	1	15	5	75	5	75
Flushing TP	15	7	105	7	105	5	75	5	75
Flushing TN	15	8	120	8	120	5	75	5	75
Flushing TSS from lagoon	15	7	105	5	75	5	75	5	75
Flushing TSS from site	5	2	10	5	25	10	50	8	40
Macrophyte scouring at site	5	10	50	5	25	1	5	1	5
Salinity ingress over 2-3 weeks	5	1	5	1	5	1	5	1	5
Low salinity recovery	5	5	25	5	25	5	25	5	25
Season (winter)	15	10	150	10	150	10	150	10	150
Season (late spring-late summer)	15	1	15	7	105	7	105	7	105
Season (autumn)	15	3	45	5	75	5	75	5	75
Cost	2	1	2	1	2	10	20	10	20
Sand intrusion	2	1	2	10	20	10	20	10	20
Local erosion near opening	2	3	6	5	10	3	6	5	10
Favourable marine bathymetry	2	5	10	5	10	5	10	5	10
Assisted mouth closure trial	2	1	2	1	2	8	16	10	20
		SCORE	**712**		**889**		**862**		**860**

A weighted factor table of a multiple openings utilising each of these locations over successive years but with emphasis on quick closure, reducing macrophyte stress and not flushing sediment and nutrients

Factor	Factor Weight	Walker's Bay	Walk_score	Charlie's Bay	Char_score	The Fence	Fence_score	Far Eastern End	East_score
Closure timing	30	1	30	7	210	7	210	7	210
Dessication Stress/loss of habitat	30	1	30	1	30	1	30	1	30
Flushing TP	5	7	35	7	35	5	25	5	25
Flushing TN	5	8	40	8	40	5	25	5	25
Flushing TSS from lagoon	5	7	35	7	35	5	25	5	25
Flushing TSS from site	2	2	4	2	4	2	4	2	4
Macrophyte scouring at Site	30	10	300	5	150	1	30	1	30
Salinity ingress over 2-3 weeks	3	1	3	1	3	1	3	1	3
Low salinity recovery	10	5	50	5	50	5	50	5	50
Season (winter)	2	10	20	7	14	5	10	5	10
Season (late spring-late summer)	2	1	2	5	10	5	10	5	10
Season (autumn)	2	3	6	5	10	5	10	5	10
Cost	2	1	2	1	2	10	20	10	20
Sand intrusion	2	1	2	2	4	5	10	5	10
Local erosion near opening	5	3	15	3	15	5	25	5	25
Favourable marine bathymetry	10	5	50	5	50	5	50	5	50
Assisted beach closure trial	5	1	5	1	5	8	40	10	50
		SCORE	**629**		**667**		**577**		**587**

Appendix E: Carran Creek Flow and Effects on Tide in Eastern End (Charlie's Bay Opening 2011)



Carran Creek flow and effects on tide in eastern end (Walker's Bay Opening 2012)
Need the updated data