

Waituna Lagoon – Pre-feasibility Engineering Scoping for Lagoon Closings/Opening





This report has been prepared under the DHI Business Management System certified by DNV to comply with ISO 9001 (Quality Management)



DNV Business Assurance, Danmark A/S

Waituna Lagoon – Pre-feasibility Engineering Scoping for Lagoon Closings/Opening

Prepared for Environment Southland and DairyNZ
 Represented by Sue Bennett (MWH)



Photo Source: Environment Southland (www.es.govt.nz)

Project manager	Benjamin Tuckey
Project number	44800698
Approval date	03/02/15
Revision	Final 1.0
Classification	Open



CONTENTS

1	Executive Summary	1-1
2	Introduction	2-1
2.1	Objectives of Study	2-1
2.2	Overview of Key Aspects of Lagoon Environment.....	2-2
2.2.1	Salinity and Water Levels	2-2
2.2.2	Nutrients.....	2-2
2.2.3	Sediment.....	2-3
2.3	Overview of Spit Opening Locations.....	2-3
2.4	Overview of Closure of the Spit Openings	2-4
2.5	<i>Ruppia</i> Beds Coverage.....	2-5
3	Proposed Solutions for Management of Lagoon	3-1
3.1	Overview of Solutions	3-1
3.2	Assessment Criteria.....	3-1
3.3	Pilot Model for Preliminary Assessment of Solutions	3-2
3.4	Preliminary Cost Estimate of Options	3-6
3.5	Assessment of Possible Solutions	3-6
3.5.1	Mechanical Opening of the Spit with Un-aided Closure	3-6
3.5.2	Two Mechanical Openings at Same Time with Un-aided Closure	3-18
3.5.3	Mechanical Opening of the Spit with Aided Mechanical Closure	3-23
3.5.4	Mechanical Opening of the Spit with Aided Closure from Temporary Structure	3-26
3.5.5	Internal Dike with a Gate Structure	3-28
3.5.6	Culvert through Spit into Littoral Zone	3-32
3.5.7	Culvert through Spit Extended Beyond Littoral Zone.....	3-33
3.5.8	Canal Connection with Toetoes Harbour	3-35
3.5.9	Canal Connection with Awarua Bay.....	3-38
3.6	Solutions Considered and Not Evaluated in Detail	3-41
3.6.1	Pump and Pipe Network	3-41
3.6.2	Rolling Opening Schedule	3-41
3.6.3	External Breakwaters with a Gate through the Spit	3-41
3.6.4	Two Canals	3-41
4	Recommendations	4-1
5	References.....	5-1

APPENDIX A – Waituna Lagoon Hydraulic Management Options Cost Report

1 Executive Summary

A critical assessment has been carried out for possible options for managing the Waituna Lagoon. The main aim of any solution is to obtain desired water levels and salinity within the lagoon while also encouraging the removal of nutrient rich water and sediment from the lagoon.

Proposed options can be described by one of the following categories:

1. Mechanical opening of the spit at one or more locations with un-aided closure;
2. Mechanical opening of the spit with some type of aided closure; and
3. A permanent control structure with or without mechanical opening.

The perceived advantages and disadvantages were discussed for each option and an un-calibrated pilot model used to assess the appropriateness of each option. Rough order capital and maintenance costs were also calculated.

Further investigation is required to better understand the littoral transport along the Waituna Lagoon coastline and inform on any differences in the associated infilling potential for different opening locations. However with the current information available for a mechanical opening with un-aided closure, we recommend a more western opening in Walker's Bay is considered.

Two types of aided closure for a mechanical opening were discussed, mechanical closure and a temporary internal structure to reduce tidal flows through the spit opening, which should encourage spit closure. More investigation would be required into the practicality of a temporary internal structure before a recommendation on the most appropriate method for aided closure can be provided.

It was concluded that to obtain more control over water levels and salinity within the lagoon, a solution that incorporates a permanent structure would be required. Three types of permanent control structures were assessed:

- A mechanical opening combined with an internal structure;
- A structure through the spit; and
- A canal to an adjacent body of water.

Of the permanent structure options investigated, we believe that an internal dike with gate structure located at Hansen's Bay is the most viable solution. Further investigations would be required to carry out the detailed design of such a structure. A canal to Toetoes Harbour is also considered a viable solution, especially since you remove some of the issues that are associated with spit breaching.

There were also several options considered but not evaluated in detail, since we believe they are not viable solutions.

2 Introduction

The Waituna Lagoon in Toetoes Bay, Southland is an ecologically important and highly valued coastal lagoon in New Zealand. Openings of the lagoon have been historically undertaken for fish passage, to artificially manage the water levels in the lagoon to help drainage of agricultural land from the surrounding catchments and also encourage flushing of nutrient rich waters and sediment out of the lagoon.

There is a fine balance between achieving these goals and allowing too much intrusion of ocean water into the lagoon, which increases the salinity of the lagoon and can have a negative effect on the ecological health of the lagoon. This is especially an issue during the spring/summer months when a saline environment can have an effect on *Ruppia* growth within the lagoon (Larkin, 2013). A summer opening is not desired, as one of the two *Ruppia* species present requires a spring/summer freshwater germination phase, although the established *Ruppia* beds have a high salinity tolerance (David Burger, DairyNZ, pers. comm.). Other risks to *Ruppia* growth are the potential drying out of beds if water levels are too low within the lagoon and increased water temperatures in summer due to shallower water depths (Opus, 2011). *Ruppia* is considered a key indicator of the overall health of the lagoon ecosystem.

A contrary benefit to the lagoon being open over summer is that the extensive tidal mudflats form an important habitat for wading birds. However wading birds are also able to utilise other extensive tidal mudflats in the region.

Of late natural closing of the lagoon has become problematic due to concerns about the lagoon and *Ruppia* health, with the lagoon remaining open for prolonged periods. With approximate current catchment nutrient loads, one to three months in winter is considered the optimum opening time to reduce the likelihood of phytoplankton blooms and protect native species (Hamilton et. al., 2012).

2.1 Objectives of Study

DHI have been commissioned by Environment Southland and DairyNZ to carry out a pre-feasibility engineering scoping study to assess the following:

- Possible solutions for closing the lagoon (based on the current opening methodology);
- Different options for managing the lagoon opening including options that encourage better flushing of the lagoon and exchange of water with the open ocean.

Instead of separating the solutions into the two groups outlined above and assessing them separately, we have assessed all solutions used for managing the lagoon together. Possible options can be described by one of the following categories:

1. Mechanical opening of the spit at one or more locations with un-aided closure;
2. Mechanical opening of the spit with some type of aided closure; and
3. A permanent control structure with or without mechanical opening.

The following issues have been identified as critical for assessing the appropriateness of any possible solution.

- Ability to reduce water levels in relation to drainage from surrounding catchment;
- Ability to maintain required water levels within lagoon for coverage of *Ruppia* beds;

- Ability to flush nutrient rich water and sediment from the lagoon;
- Potential for controlling saline intrusion into the harbour, to ensure salinity are not too high during *Ruppia* growing season and ensure the lagoon doesn't become predominantly freshwater;
- Potential for damaging plants roots of lagoon vegetation especially *Ruppia* due to high current speeds; and
- Likely capital and maintenance costs.

2.2 Overview of Key Aspects of Lagoon Environment

2.2.1 Salinity and Water Levels

Larkin (2013) presents a detailed analysis of how salinity conditions change within the lagoon. When the lagoon is closed to the sea, there are typically low salinity conditions (< 8 PSU) within the lagoon. Salinities will continue to decrease for prolonged periods between lagoon openings.

Periodically the decision is made to open the lagoon to the sea for the main purpose of improving drainage from farmland in the surrounding catchments of the lagoon. Water levels within the lagoon before opening are typically between 2 m to 2.5 m MSL but can reach up to 3 m MSL. An interesting feature of the lagoon is that the frequent westerly wind at the study site can generate wind set up and water level differences between the east and west of lagoon of up to 0.5 m (Hamilton et. al., 2012).

When the spit is opened there is an immediate decrease in lagoon water levels within a period of hours. Once open to the sea, lagoon water levels are very dependent on freshwater inflows and the tide. Water levels have been collected from the mid lagoon from June 2012 and during this time water levels as low as 0.2 m MSL have been observed when the lagoon is open to the sea. Once open to the sea, saline intrusion commences into the lagoon as sea water enters the lagoon on subsequent flood tides.

The amount of saline intrusion that occurs and the resulting salinities within the lagoon is ultimately dependant on the length of time the lagoon is open to the sea. When Walker's Bay was open for two weeks in July 2012, salinities of approximately 30 PSU were measured in the west of the lagoon and 11 PSU were measured in the east of the lagoon. By the end of August 2012 over a month after the mouth of lagoon had closed, salinities had stabilised across the whole lagoon to approximately 14 – 19 PSU. It can be assumed that the longer the lagoon is open to the sea the higher the resulting salinities within the lagoon. It has been observed that a return to low salinity conditions can take up to two months but is often much quicker (Larkin, 2013). This is dependent on how long the lagoon was open to the sea and the freshwater inflows to the lagoon.

2.2.2 Nutrients

The catchments surrounding the lagoon currently contribute a large amount of nutrients (nitrogen and phosphorus) to the lagoon. Although some nutrients are essential to the ecology of the lagoon, if loads are too high problems can start to occur. High nutrient levels within the lagoon can lead to algae and phytoplankton growth, eutrophication and in the worst case the lagoon may experience a 'regime shift'. That is, a change from having clear water and an aquatic environment dominated by aquatic macrophyte plants such as *Ruppia*, to one which has turbid and murky water dominated by algal slime and other suspended phytoplankton.

Opening the lagoon to the sea allows the flushing of nutrient rich waters out of the lagoon and the intrusion of sea water with a lower nutrient load, which ultimately reduces nutrient levels within the lagoon. Currently one to three months per winter is considered the optimum opening time to reduce the likelihood of phytoplankton blooms and protect native species with the approximate current catchment nutrient loads (Hamilton et. al., 2012).

2.2.3 Sediment

There are currently high sediment loads to the lagoon, of which a large fraction is derived from bank-side and in-stream erosion processes (AgResearch, 2013). Too much sediment can have a negative impact on *Ruppia* especially if it smothers it. Opening the lagoon to the sea allows the flushing of some of this sediment (predominately mud) out of the lagoon (Opus, 2011).

2.3 Overview of Spit Opening Locations

Four different breach locations have historically been used and are presented in Figure 2-1.



Figure 2-1 Overview of four potential opening locations.

In recent history, lagoon opening has occurred at Walker's Bay in the western part of the lagoon. To initiate an opening a suitable period is selected when water levels are elevated within the lagoon and during a spring tide (to produce the highest head difference between the sea and the lagoon at low tide). An initial cut is then dug with an excavator through the spit, which normally will develop into a breach channel within six hours (Opus, 2011).

The bathymetry at Walker's Bay has been modified by repeated openings due to the ingress of marine sand through the mouth which has deposited within the lagoon. A main channel exists along the western edge of the bay which connects with the main body of the lagoon.

Hansen's Bay is located in the central eastern part of the lagoon. A trial opening was carried out here in 2011. Prior to this the bay was last opened in 1974 (Larkin, 2013). An interesting feature of this site is the mudstone sill that was known to exist within the bay and was eroded during the

2011 breach to approximately 0 – 0.25 m MSL. The beach at Hansen’s Bay is wider than other locations along the spit, 90 m compared with 50 m, or approximately 50% wider (Opus, 2011).

Two other eastern locations within the lagoon where openings have occurred historically are The Fence and the Eastern End. The Fence has not been used since 1972 and the Eastern End was last used in 1954 (Larkin, 2013).

The spit is composed of what is locally described as pea gravel with a diameter of approximately 6 to 8 mm. This material is non-cohesive and highly mobile (Opus, 2011).

2.4 Overview of Closure of the Spit Openings

Once a breach of the spit has been initiated, a channel is scoured out over a matter of hours. The width and depth of the initial channel will depend on a number of factors including but not limited to:

- The difference in water level across the spit – breaching can thus be timed with the tide to provide a smaller or larger initial breach channel.
- The length of the channel (local width of the spit) with a wider spit leading to both a lower water level gradient along the channel and a larger volume of sediment to be scoured out.
- The resistance to erosion of the spit. The spit mainly consists of loose sediments, but an underlying layer has been reported for the breach at Hansen’s Bay (Noel Hinton, Environment Southland, pers. comm.)
- Bathymetry and flow resistance within Waituna Lagoon which will affect the head loss across the spit. There is for instance a sill across Hansen’s Bay which may limit the total volume of water available for the initial scouring of the channel after breaching.

Subsequent to the initial breach, a highly dynamic balance is established between the tidal and catchment runoff induced flows through the channel trying to keep it flushed open and the littoral sediment transport trying to close it up. For tidal inlets, the flushing will typically work towards channel dimensions that lead to maximum current speeds in the order of 1 m/s (Bruun, 1968 and 1990). The tidal induced flushing is lower during neap tide, and the channel is thus more likely to close during neap tide. However, there will be times of minimal flow on each tidal cycle as the flow reverses, which leaves a shorter window for closure under the right littoral transport conditions. The littoral transport is mainly dependent on wave height and direction, with higher transport rates generated by higher waves at an angle to the coastline being favourable for closure.

Observations from historical closures are briefly summarised below.

The period over which opening and closing of the spit at Walker’s Bay occurs, can range anywhere between a few weeks to over a year depending on wind, waves and tides (Larkin, 2013).

Observations of Walker’s Bay mouth closures are that in favourable wave conditions a bar of gravel will start to extend over the mouth (due to the littoral transport of sediment) until it extends across the mouth of the opening to form a berm, which is then increased in height as more material accumulates on the berm due to gravel transported by wave run up (Larkin, 2013). It can be assumed closures at other opening locations would close in a similar fashion.

A closure is more likely to commence close to a neap tide when the tidal flow through the mouth of lagoon is the smallest, however this is not always the case and the mouth has been observed to close for a variety of states of the tide (Larkin, 2013). Inflows to the lagoon also have a role in

closure of the lagoon mouth with low catchment inflows being favourable. A closure of the mouth has been observed to be disrupted if there is an increase in the catchment inflows.

An opinion is that the Hansen's Bay location is likely to close quicker than the other opening locations due to the wide section of beach and abundant local beach material (Opus, 2011). In general the littoral drift along the coastline of Toetoes Bay is from east to west, although the direction of transport may change with different wave conditions. The majority of sediment along this coastline is sourced from gravel beds and cliffs to the east, while sediment sources from the west are considered limited. For this reason it is speculated the openings to the east are also likely to close more quickly than Walker's Bay (Opus, 2011). However we do not believe there is enough understanding of littoral transport along this coastline to support this claim.

2.5 *Ruppia* Beds Coverage

Ruppia is an important aquatic plant for the lagoon and is considered an indicator of lagoon ecosystem health. It absorbs nutrients, stabilises sediments by holding its roots in the sediment and therefore reduces turbidity. It also provides habitat and food for aquatic species within the lagoon.

To determine the impact that different lagoon management solutions will have on the *Ruppia* beds within the lagoon it is important to have an understanding of the main locations where *Ruppia* beds are abundant within the lagoon. In 2007, Wriggle mapped the percentage cover of *Ruppia* within the lagoon (Wriggle, 2007) as shown in Figure 2-2. Subsequent monitoring at selected locations within the lagoon has indicated a further decline in *Ruppia* coverage (NIWA, 2014), however as an indication of the areas where *Ruppia* beds are most abundant, we believe the 2007 survey is adequate. At this time there was only 1 – 10% cover of *Ruppia* beds within the western lagoon. It has been concluded that one of the reasons there is such a low coverage for this area is a consequence of the repeated openings of the spit at Walker's Bay. This is a result of continual stress on these areas due to physical scouring of the beds, drying out of the beds and large areas of coarse sands at optimal growing depths (Larkin, 2013). The majority of the main *Ruppia* beds are located within the eastern lagoon where there is as high as 50 – 80% coverage for significant areas.

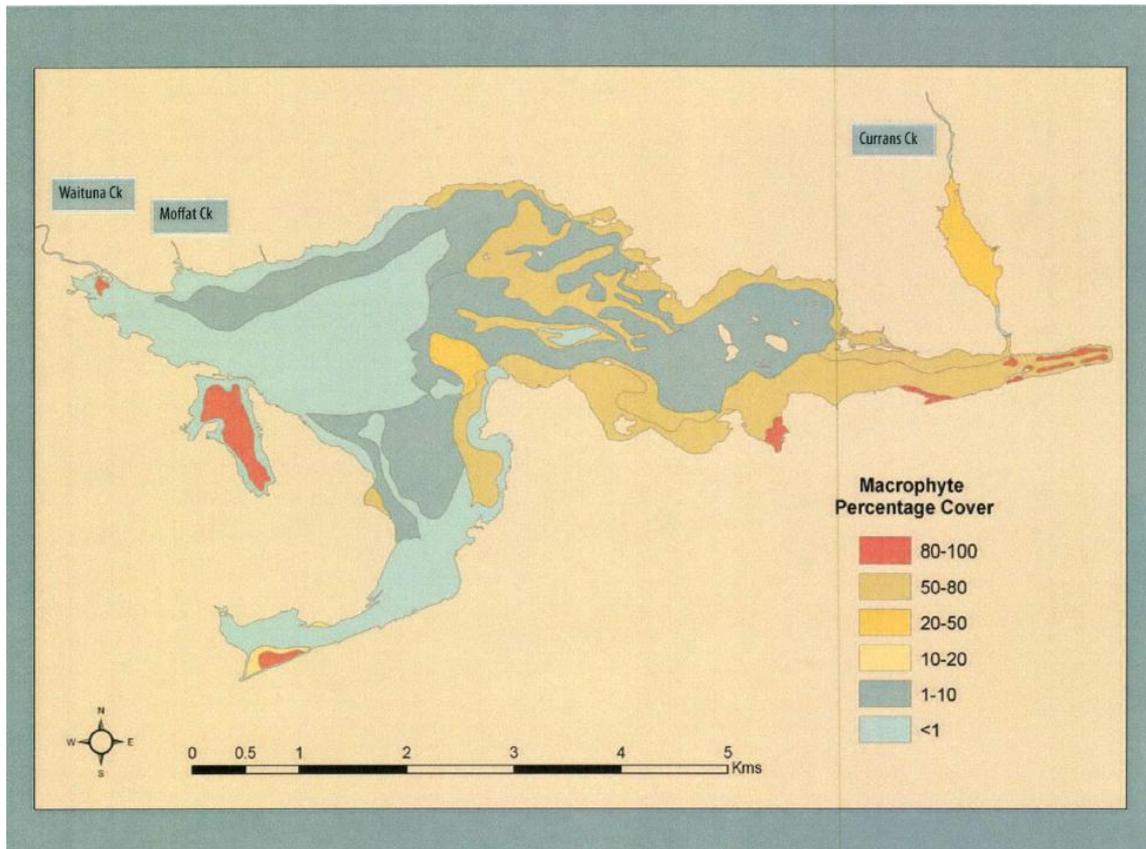


Figure 2-2 *Ruppia* cover in 2007 (source: Wriggle, 2007).

3 Proposed Solutions for Management of Lagoon

An assessment of different solutions for better managing the lagoon has been carried out. The aim of any solution is to obtain desired water levels and salinity within the lagoon while also encouraging the removal of nutrient rich water and sediment from the lagoon. The assessment included determining the perceived advantages and disadvantages for each option. An un-calibrated pilot model was set up to better quantify the performance of options with regard to the critical issues which determine the appropriateness of the option. Rough order capital and maintenance costs were also calculated for each option.

3.1 Overview of Solutions

The types of options that have been evaluated in detail cover the following five categories:

- Mechanical opening of the spit at one or more locations with un-aided closure;
- Mechanical opening of the spit with some type of aided closure;
- A mechanical opening combined with an internal structure;
- A structure through the spit; and
- A canal to an adjacent body of water.

Mechanical opening of the spit has been investigated in previous studies ((Opus 2011), (Larkin, 2013) (Hamilton *et. al.*, 2012)), however we have used an un-calibrated hydrodynamic model to supplement the findings from these previous studies.

3.2 Assessment Criteria

Each of the possible solutions has been assessed and the following produced:

- A brief description of the option;
- Perceived advantages and disadvantages of the option;
- Rough order capital and maintenance costs;
- Where required a preliminary assessment of the option using a pilot model has been carried out to assess the option for an important issue; and
- Conclusion with DHI's opinion on the suitability of the option.

We note that the assessment of what is good and bad is complex and the connectivity to the ecology is not necessarily well understood at this stage. Flushing out of nutrients and some sediments is considered beneficial but too much flushing and too high salinity can have negative impacts. Higher current velocities during flushing may be beneficial in terms of flushing of excessive sediments from the lagoon, but may damage *Ruppia* beds. It has not been possible or within the scope of the present study to establish a clear assessment matrix, and the model results are open to interpretation. We have also not considered the impact of light limitation (linked to water level, turbidity and re-suspension) on health of the *Ruppia* health as this process is very complex and outside the scope of this study.

3.3 Pilot Model for Preliminary Assessment of Solutions

A pilot (un-calibrated) hydrodynamic model has been set up to help with assessing a number of the options with regard to some of the critical issues which determine the appropriateness of the option. Interpretation of the model results should take the limited data and time into consideration and the model results are intended for preliminary guidance only. The data and model setup is outlined in the present section with results for the individual options under the respective sub-sections in Section 3.5.

Bathymetry data for the hydrodynamic model was obtained from three sources:

- C-Map™, which is a world electronic chart database. This data was used for model domain outside of the lagoon.
- LiDAR data collected in March 2012 and provided by Environment Southland. This data was used for the bathymetry within the lagoon above approximately 0.6 m MSL.
- Single beam survey data collected in December 2011 and provided by Environment Southland. This data was used for the bathymetry within the lagoon below approximately 0.6 m MSL.

An example of the whole model domain and bathymetry is provided in Figure 3-1 while an example of the model bathymetry and mesh for only the lagoon is shown in Figure 3-2. A flexible mesh of triangular and quadrangular elements has been used which allows high resolution in areas of most importance and a lower resolution for areas of less significance (i.e. open ocean).

We emphasise that the model results are highly dependent upon the bathymetry in the model and the dynamic nature of the spit openings was not simulated. There was no consideration of the influence of forcing from wind or waves on the hydrodynamics of the lagoon and only short periods (i.e. a neap spring tidal cycle) were simulated. For all these reasons the results from the un-calibrated pilot model are to be considered rough indications only.

For the spit openings, a bathymetry was created for the openings so that the throat of the opening would not be the determining factor in the volume of water that would flow into and out of the lagoon during a tidal cycle (i.e. the throat would not be a major constriction for tidal flow), instead this is determined by the bathymetry of the lagoon itself. For Walker's Bay and The Fence a channel of 100 m width with -1 m MSL depth was assumed, while for Hansen's Bay a channel width of 70 m with -1 m MSL depth was assumed based on the wider spit at this location. For Walker's Bay, after one to two days of a breach, the opening will generally be 70 – 100 m in width (Noel Hinton, Environment Southland, pers. comm.). This supports the assumed bathymetry for the preliminary modelling. A sill of approximately 0 m MSL was included within Hansen's Bay to represent the mudstone sill that exists at this location.

Yearly flow volumes for significant freshwater inflows to the lagoon were provided in Hamilton *et al.*, (2012). From these values a mean flow was calculated (see Table 3-1) and has been included as a constant inflow at appropriate locations within the model.

Table 3-1 Annual flow for significant freshwater inflows to lagoon (Hamilton *et. al.*, 2012) and calculated mean flow.

Inflow	Annual Flow (m ³ /yr)	Mean Flow (m ³ /s)
Waituna Creek	50,888,000	1.61
Moffat Creek	10,310,000	0.33
Carran Creek	12,839,000	0.41
Carran Creek tributary/Craws Creek	4,076,000	0.13
Groundwater	43,822,000	1.39

Simulations were carried out for 18 days to include a neap spring tide cycle. The open ocean boundary condition for the simulations is presented in Figure 3-3. An initial condition for surface elevation was set so that the surface elevation at the commencement of the simulation was 3 m MSL within the lagoon.

When a spit breach is created there is an initial flush of nutrient rich waters out of the lagoon, however a large volume of lagoon water will remain in the lagoon. While the spit remains open there will then be an exchange and mixing of water from the lagoon with open ocean water through tidal flushing.

To assess the tidal flushing of the lagoon for each option over the neap spring tidal cycle, the flushing of a conservative tracer out of the lagoon was simulated. An initial condition was generated so that the concentration within the lagoon was 1000 (dimensionless unit) and the open ocean was zero. This predicts the tidal flushing of water out of the lagoon and conversely the intrusion of salt water from the open ocean. Lagoon water quality has not been simulated as this requires additional data and adds to the model complexity, and this is not within the scope for the pre-feasibility study.

For areas where significant tidal flushing occurred there is also the potential for fine sediments to be flushed from the lagoon. The physical processes which determine the erosion and deposition of fine sediment are complex (determined by combination of tides (when the entrance is open), wind and waves) and were not assessed in detail for this study, since this is outside the scope of a pre-feasibility study. However for this study it can be assumed that areas where significant tidal flushing occurs over a neap spring tidal cycle may also encourage flushing of fine sediment.

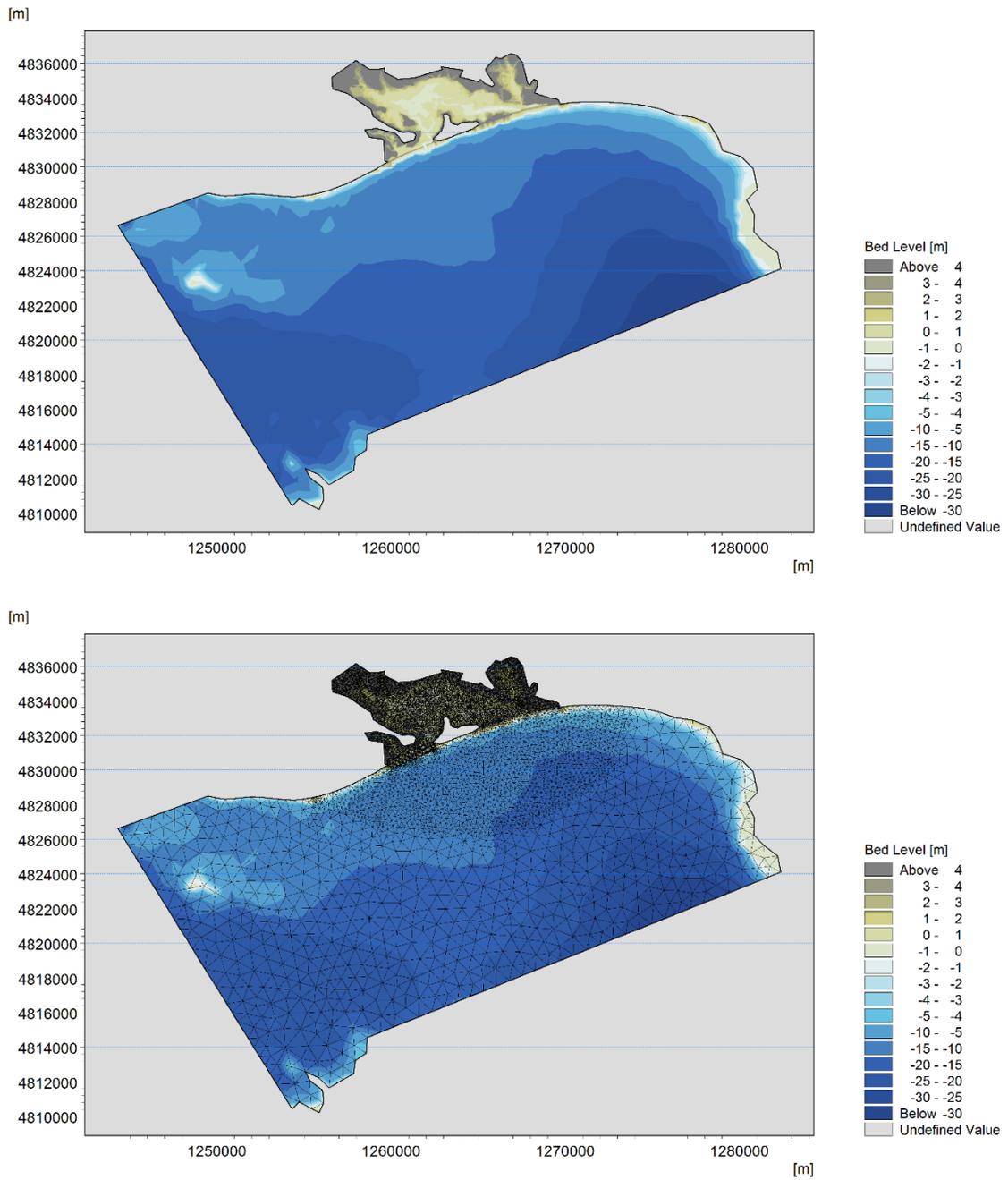


Figure 3-1 Hydrodynamic model extent – bathymetry (top) and mesh (below).

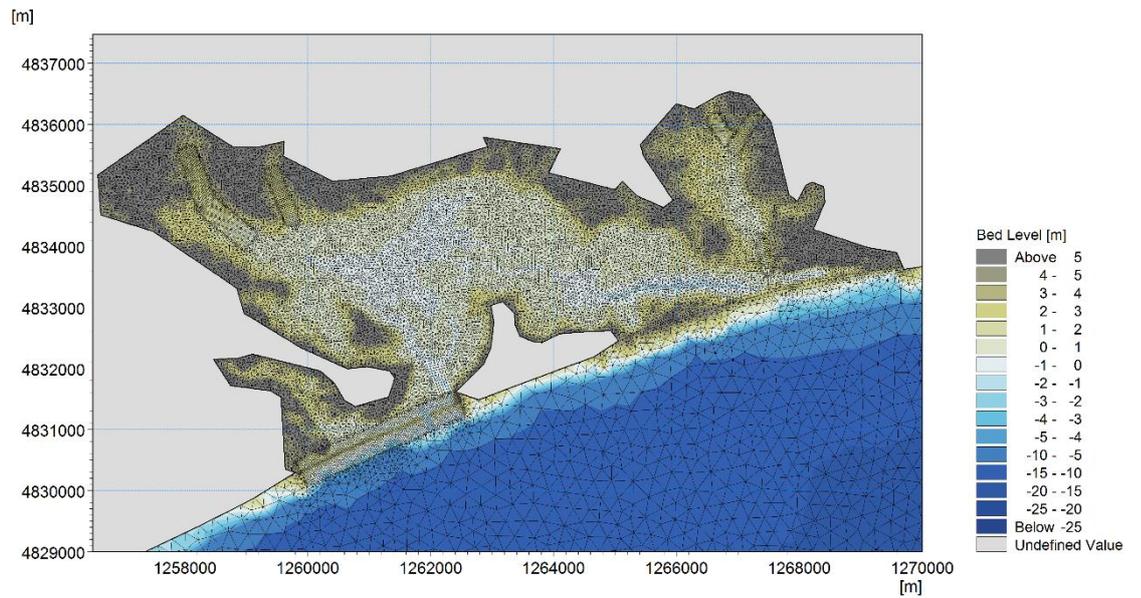
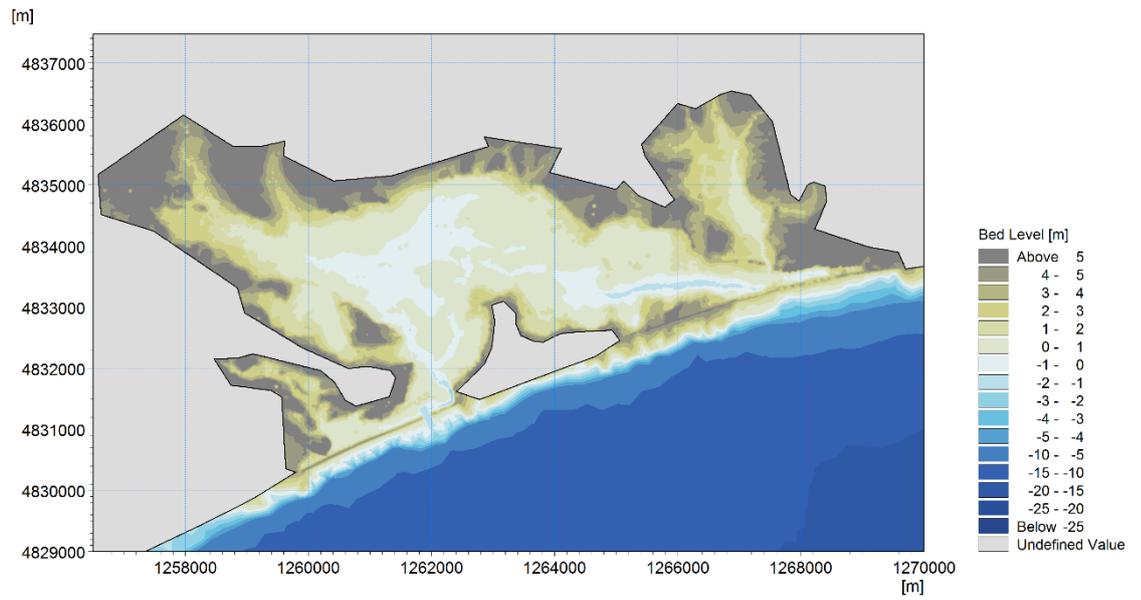


Figure 3-2 Hydrodynamic model lagoon bathymetry (top) and mesh (below).

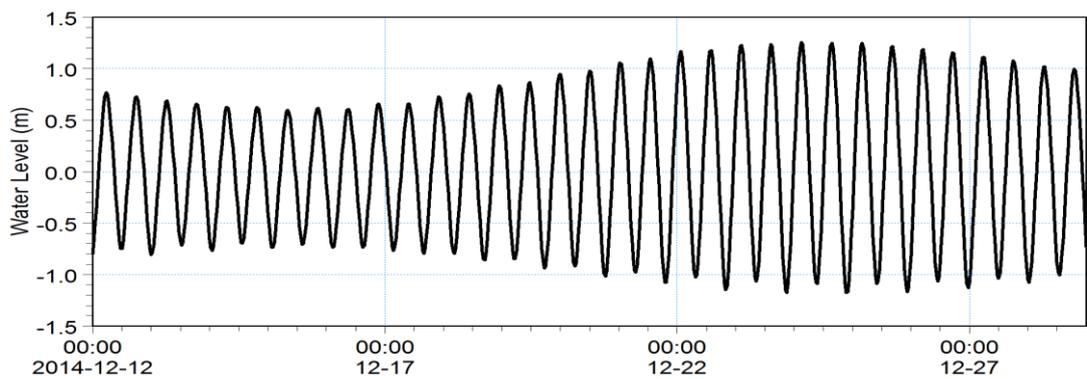


Figure 3-3 Open ocean boundary condition for neap spring tidal cycle.

3.4 Preliminary Cost Estimate of Options

WaterLine has assessed the preliminary costs of the various options, both capital and maintenance costs (WaterLine, 2014). The costs have been prepared on a “rough order of cost” basis and the information provided is not intended to be used for capital expenditure decision making, but is intended to provide information on the relative costs of options.

3.5 Assessment of Possible Solutions

3.5.1 Mechanical Opening of the Spit with Un-aided Closure

Description

Mechanical opening of the spit has in recent history (since 1970's) occurred at the Walker's Bay location with one trial opening at the Hansen's Bay location carried out in 2011. There are also two other locations where other breaches have occurred historically in the eastern part of the lagoon (Larkin, 2013). The breach locations can be generally grouped into the eastern locations (Hansen's Bay, The Fence and Eastern End) and Walker's Bay in the west of the lagoon. At Walker's Bay there is the location where openings predominantly occur at the eastern end of Walker's Bay, however another proposed location is the western end of the spit. The current breach location at Walker's Bay has been observed previously to migrate around 180 – 200 m to the west along coastline after opening (Ewen Pirie, Chairman of the Lake Waituna Control Association, pers. comm). A more western Walker's Bay breach has the potential to migrate a similar distance to the west.

Hansen's Bay is unique due to the fact there is a 0 – 0.25 m MSL mudstone sill that exists across its mouth within the lagoon. This sill was higher until the 2011 opening when significant erosion occurred for this area. This will act as a constriction to the amount of flow that will enter into the lagoon from the sea if a breach is made at Hansen's Bay. Interestingly staff from Environment Southland that were responsible for overseeing the breach at Hansen's Bay in 2011, encountered a mudstone layer when creating the breach. We propose this layer was most likely an extension of the sill within the bay. This layer did not prove much resistance and a digger was able to reasonably quickly break through the layer (Noel Hinton, Environment Southland, pers. comm.). This observation would suggest the sill within the bay is likely to erode further with subsequent openings of Hansen's Bay.

Advantages and Disadvantages

All Breach Locations

The following are the perceived advantages for all breach locations:

- Spit breaching is a relatively straight forward process and can be carried out quickly.
- Will reduce flood levels in lagoon and improve drainage for surrounding catchments.

The following are the perceived disadvantages for all breach locations:

- All breaches may provide insufficient water depth for optimal *Ruppia* growing if the breach remains open for too long after the opening is made or if there is insufficient rainfall after the breach. The risk is lower with Hansen's Bay due to the sill which will maintain higher water levels.

- Potential for a breach to close soon after the spit opening before significant tidal flushing of the lagoon has occurred.
- Significant saline intrusion can occur if the breach remains open for too long. The risk to the existing main *Ruppia* beds is increased for the eastern breach locations. For Walker's Bay the risk is minimised due to the distance from the existing main *Ruppia* beds, however there is still a significant risk if the breach is open for too long.
- Risk of intrusion of marine sediment into the lagoon from wave action. There is a higher risk the longer the breach is open or during periods of high energy wave climate. It appears that the bathymetry within Walker's Bay has been changed drastically by repeated openings.

Walker's Bay Only

The following is a perceived advantage for only the Walker's Bay location:

- When the spit is opened outflow velocities will cause little harm to *Ruppia* due to the distance from the existing main *Ruppia* beds.

The following is a perceived disadvantage for only the Walker's Bay breach location:

- Will not produce good tidal flushing within the existing main *Ruppia* beds.

Eastern Breach Locations Only

The following are the perceived advantages for only the eastern breach locations:

- Breach location close to the existing main *Ruppia* beds to encourage tidal flushing within these areas.
- It is envisioned that with a shift to one of the eastern breach locations, the *Ruppia* beds in the western part of the lagoon may recover.
- The water level increase in the east of the lagoon due to wind set up may facilitate an easier spit breaching.
- For the Eastern End, the breach location is close to little lake/mouth of Carran Creek at Waghorn's Road bridge, which will encourage flushing of sediment from this area.

The following are the perceived disadvantages for only the eastern breach locations:

- There is a risk of erosion to adjacent land in the vicinity of the breach locations due to increased water velocities that would occur in these areas during a breach. This is not seen as a high risk for Walker's Bay since there have already been repeated openings at this location.
- The close location of the opening to the existing main *Ruppia* beds may cause harm due to high outflow velocities when the spit opened. This risk is reduced for Hansen's Bay as the opening is not as close to the existing main *Ruppia* beds.

Hansen's Bay Only

The following are the perceived advantages for only the Hansen's Bay location due to the presence of the mudstone sill across the inside of Hansen's Bay. If the sill were to erode further these advantages over the other breach locations will start to diminish. This is investigated with the pilot model below.

- The natural sill helps to maintain a higher water level within the lagoon compared with other breach locations.
- The sill may reduce the amount of saline intrusion if the breach is open too long.

Comments for All Opening Locations

The amount of tidal flushing or saline intrusion that occurs is very dependent on how long the lagoon mouth remains open. It is difficult to determine at what stage the fact the mouth is open changes from providing positive to negative impacts. However in general, a breach with no means of aiding closure provides no control over tidal flushing or salinity within the lagoon. There is a high dependency on climatic conditions to when the mouth closes and what level of tidal flushing is achieved within the lagoon and the resulting overall salinity.

Capital Cost and Maintenance Cost

\$3,000 to \$4,000 for a mechanical breach at Walker's Bay or Hansen's Bay. Only \$1,000 at The Fence or Eastern End due to the easier access (Larkin, 2013). There is no maintenance cost associated with mechanical breaching.

Preliminary Assessment using Pilot Model

The pilot model has been used to assess the different opening locations for a number of different issues such as tidal flushing, typical flow from the sea to the lagoon through different openings and current speeds within the main *Ruppia* beds in the eastern lagoon. For these assessments, due to the close proximity between The Fence and the Eastern End, only The Fence has been assessed with the pilot model. The Walker's Bay opening has been assessed at the location where the breach predominantly occurs. An interesting feature of bathymetry at Walker's Bay is the sand bank to the west of the main channel inside the spit as shown in Figure 3-4. The pilot model indicates that this is a major constriction to flow through the mouth into the main body of the lagoon.

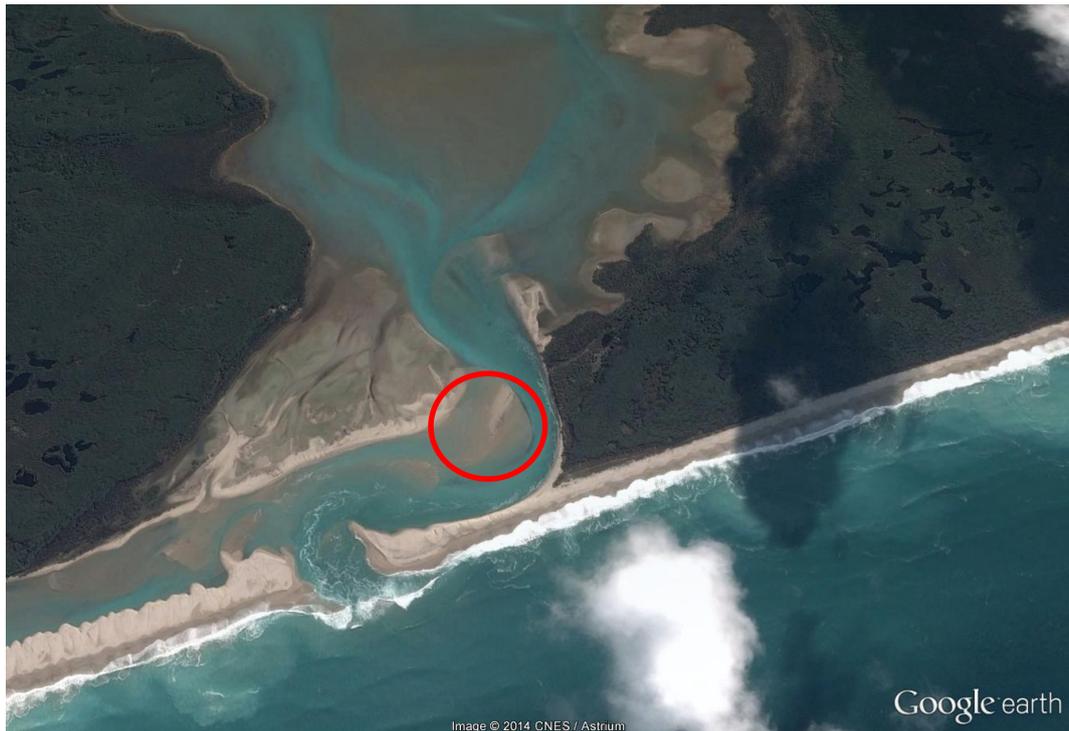


Figure 3-4 Sand bank to west of main channel in Walker's Bay.

The tidal flushing potential for different spit opening locations has been assessed using the pilot model. The final concentration of a conservative tracer after a neap spring tide cycle is presented in Figure 3-5. As expected the eastern locations promote more tidal flushing of water in the eastern part of the lagoon and Walker's Bay more tidal flushing in the western part of the lagoon. The Fence opening has the advantage of flushing the very eastern part of the lagoon. Conversely if the eastern locations remain open for a prolonged period, the main *Ruppia* beds will be exposed to a more saline environment in a shorter time than with the Walker's Bay location.

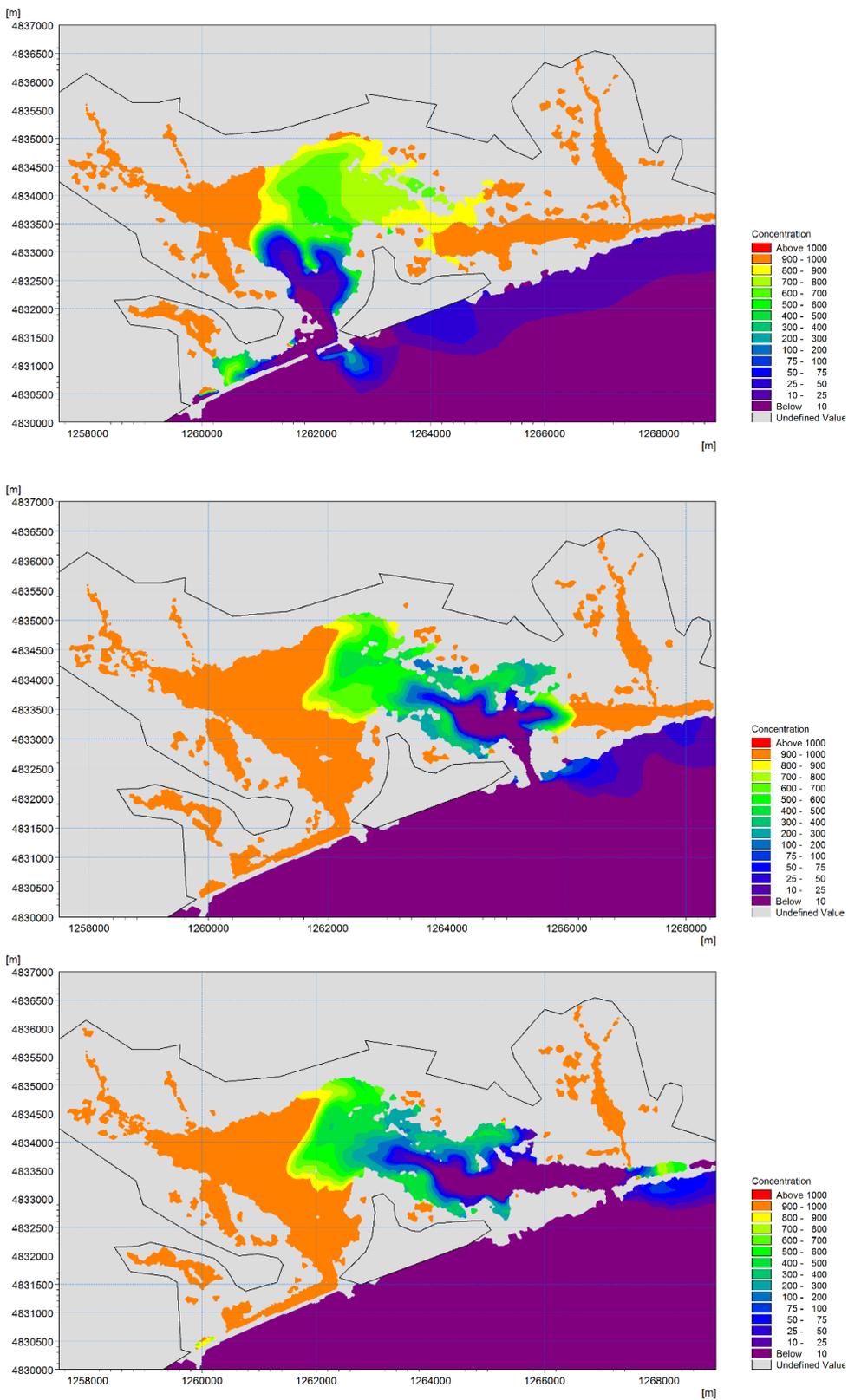


Figure 3-5 Final concentration of a conservative tracer with an initial concentration of 1000 in lagoon and zero in open ocean, to predict the tidal flushing that may occur after a neap spring tide cycle for different spit openings – Walker's Bay (top), Hansen's Bay (middle) and The Fence (bottom).

A comparison of flows through the different spit openings is presented in Figure 3-6. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon. It is interesting to note that the bathymetry of the lagoon creates a larger flow through the opening at The Fence compared with the Walker's Bay and Hansen's openings. The sill at Hansen's Bay impedes the flow through this opening, while as discussed above the sand bank within Walker's Bay also constricts flow.

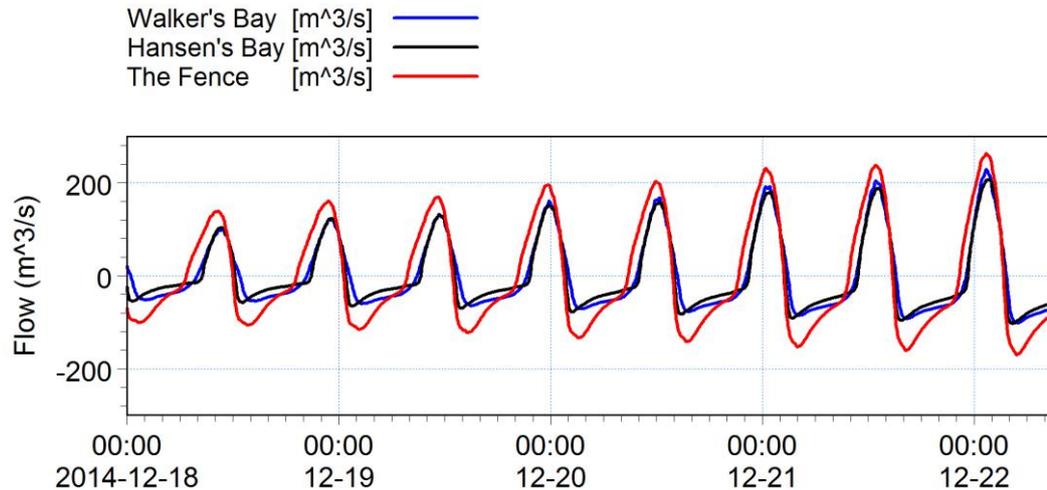


Figure 3-6 Comparison of flow through different spit openings for approximately mean tide. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon.

To assess the impact of the opening locations on the current speeds within the main *Ruppia* beds as water drains from the lagoon after an opening is created, the current speed three hours after commencement of the simulation for the areas with the main *Ruppia* beds are presented in Figure 3-7. As expected the eastern locations generate much larger current speeds within the main *Ruppia* beds compared with Walker's Bay opening, with The Fence generating the highest current speeds over the largest area of the main *Ruppia* beds.

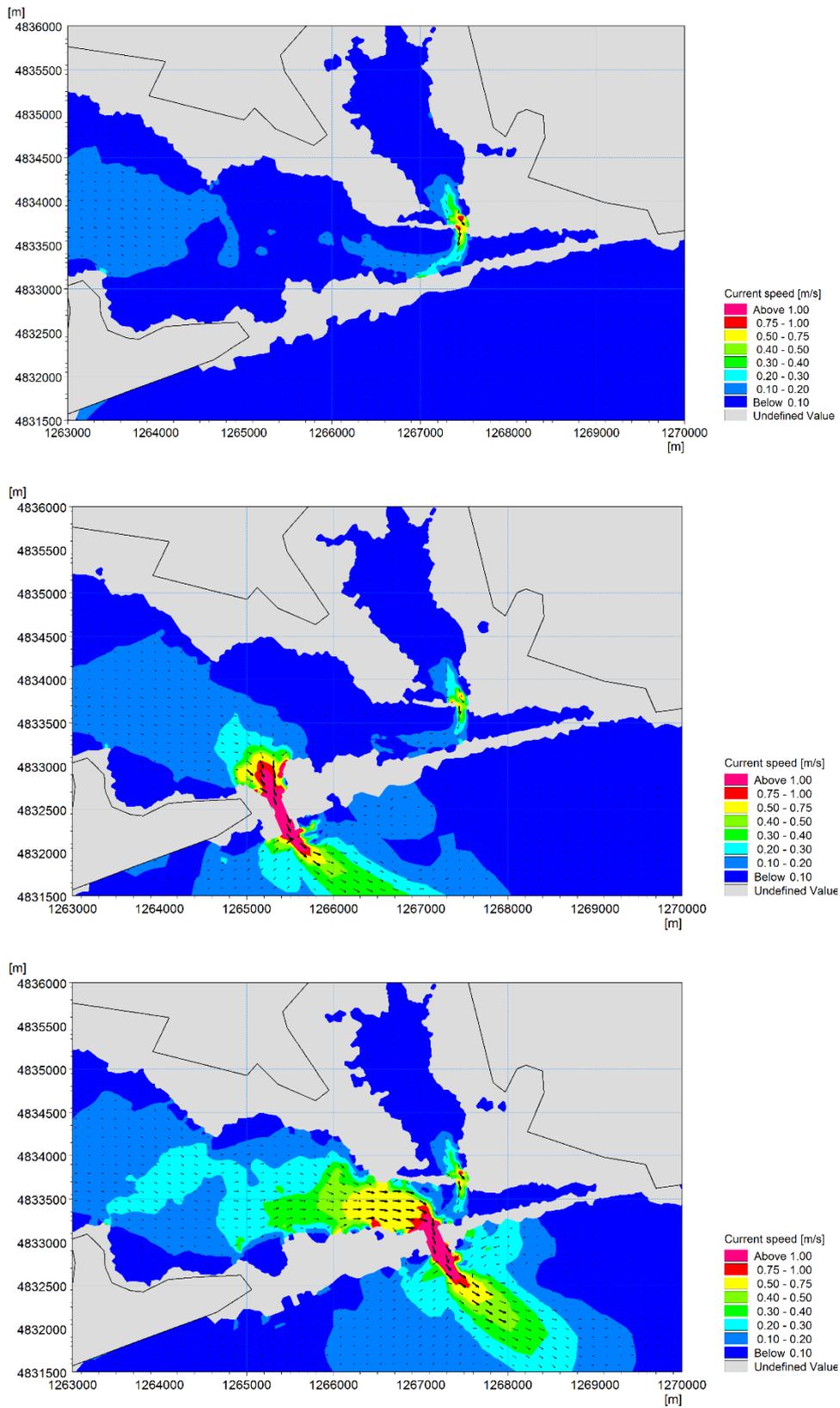


Figure 3-7 Current speed three hours after commencement of simulation for areas with the main *Ruppia* beds as elevated water levels drain out of lagoon with different spit openings – Walkers Bay (top), Hansen's Bay (middle) and The Fence (bottom).

A comparison of the water levels in the lagoon adjacent with Hansen's Bay for different spit openings is presented in Figure 3-8. This location was chosen as it was seen as a suitable location for determining water levels that would occur for the areas within the main *Ruppia* beds. For The Fence opening, water levels are able to drop significantly at low tide. This is obviously dependent on the depth of the assumed cut through the spit. The sill at Hansen's Bay, ensures that water levels are significantly higher during a low tide, a finding which is not dependent on the depth of the cut.

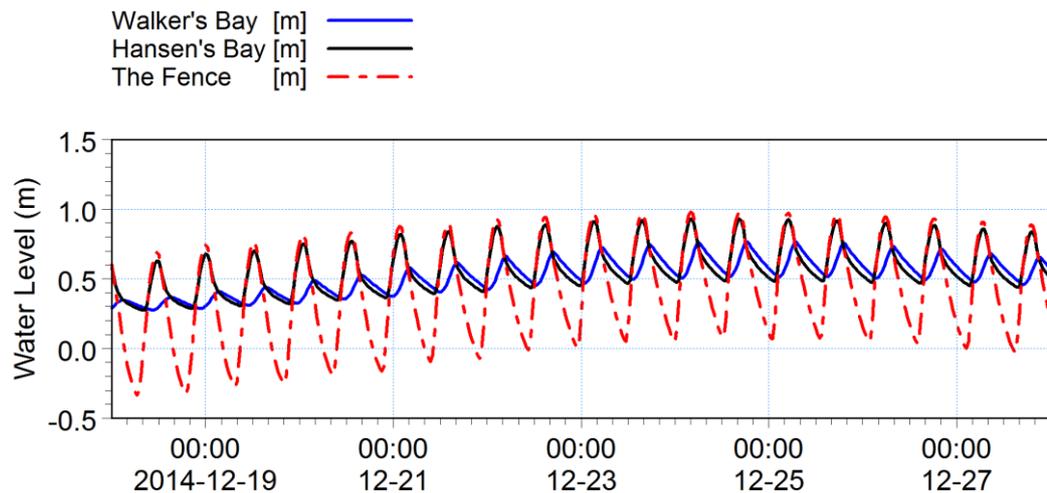


Figure 3-8 Comparison of water levels in the lagoon adjacent with Hansen's Bay for different spit openings.

As discussed above the influence of the mudstone sill that exists inside Hansen's Bay is currently an uncertainty. When Hansen's Bay was opened in 2011, there was significant erosion observed in this area. If this was to continue to erode with subsequent openings of Hansen's Bay this would have a significant impact on the hydrodynamics of the lagoon if the spit was open at Hansen's Bay. The pilot model was utilised to assess the likely change to the flow through the opening if the sill was to erode to an extent where it was no longer a constriction on flow through the mouth.

A comparison of the flow through the mouth at Hansen's Bay with and without the sill is presented in Figure 3-9. There is a significant increase in the volume of water that would enter the lagoon from the sea on the flood tide without the sill. For the simulation with the eroded sill, the depth of the assumed channel through the spit may become an important factor similar to The Fence location, and the limitations of the pilot model obviously have to be considered.

A comparison of the water level in the lagoon adjacent with Hansen's Bay with and without the Hansen's Bay sill is presented in Figure 3-10. Without the sill, water levels are able to drop significantly more for low tides with the assumed depth of the cut through the spit.

For Hansen's Bay without the sill, the current speeds three hours after commencement of the simulation for areas with the main *Ruppia* beds are presented in Figure 3-11. Although the current speeds increase significantly compared with when the sill is present, the current speeds within the main *Ruppia* beds are still lower than with The Fence opening.

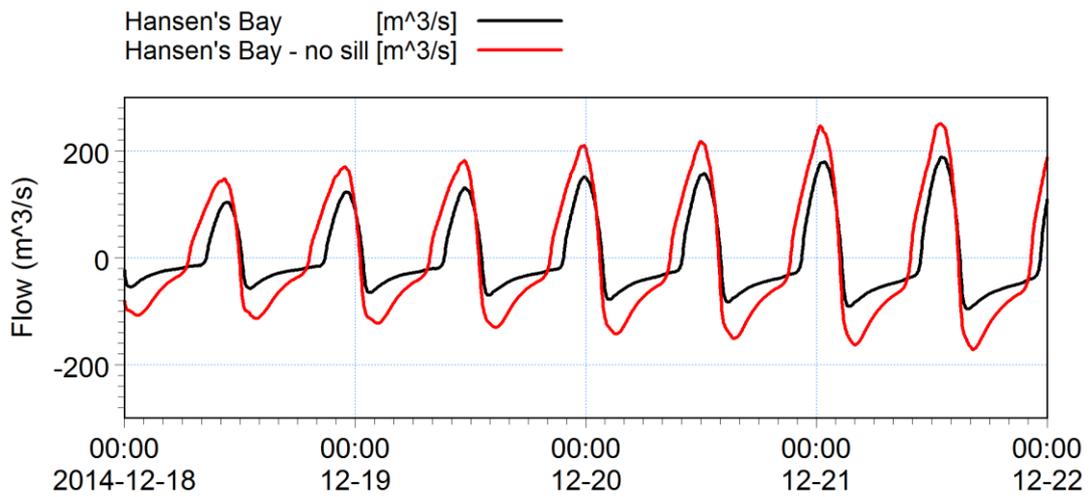


Figure 3-9 Comparison of flow through Hansen's Bay opening with and without the sill for approximately mean tide. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon.

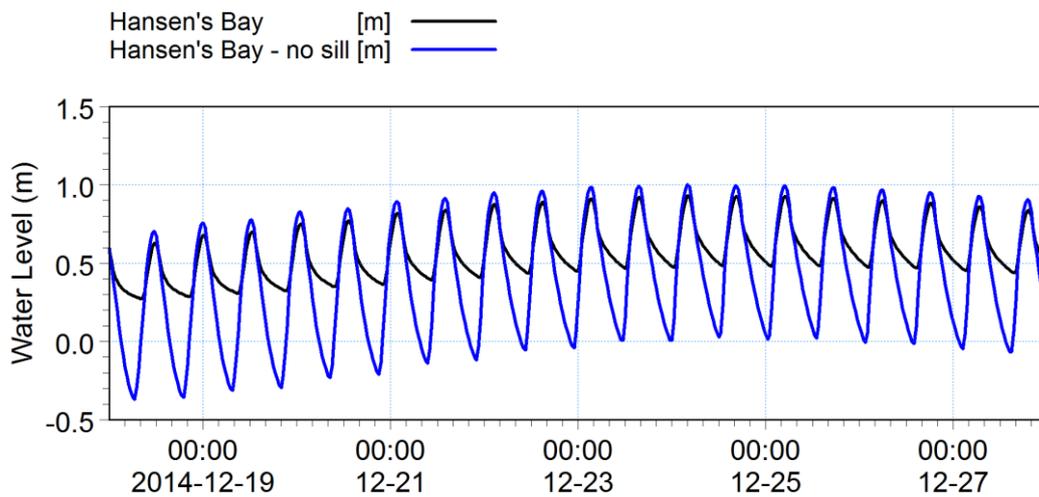


Figure 3-10 Comparison of water level in the lagoon adjacent with Hansen's Bay with and without the Hansen's Bay sill.

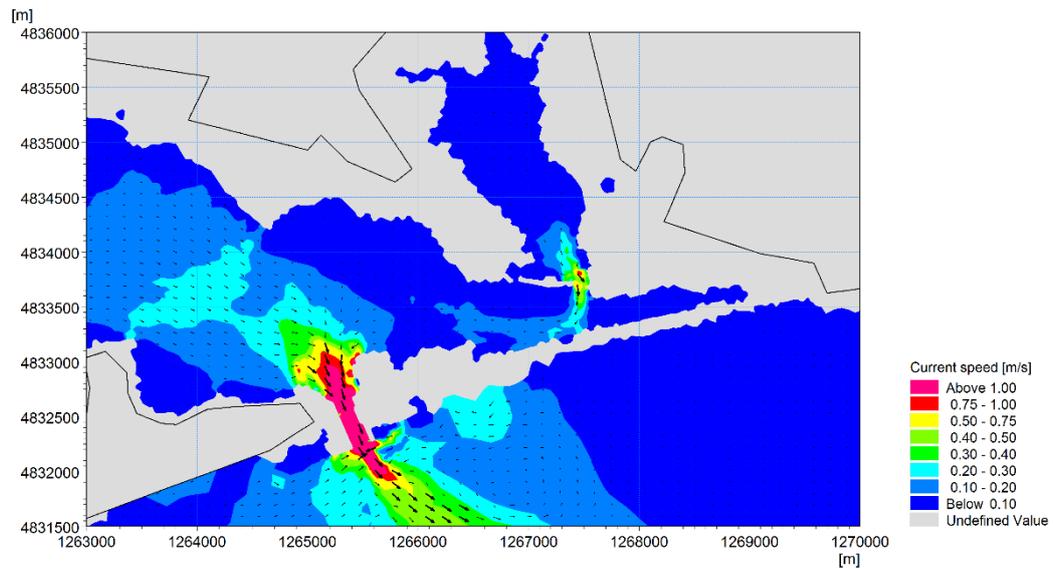


Figure 3-11 Current speed three hours after commencement of simulation for areas with the main *Ruppia* beds as elevated water levels drain out of lagoon for Hansen's Bay with no sill.

The pilot model was also utilised to assess any benefits of a more western location in Walker's Bay. Currently there is not really a defined channel between this western opening location and the main Walker's Bay channel which joins with the main body of lagoon. It can be assumed that a significant channel would form in time if the western location was repeatedly breached, therefore a -1 m MSL deep, 45 m wide channel was incorporated into the bathymetry used for the pilot model as shown in Figure 3-12.

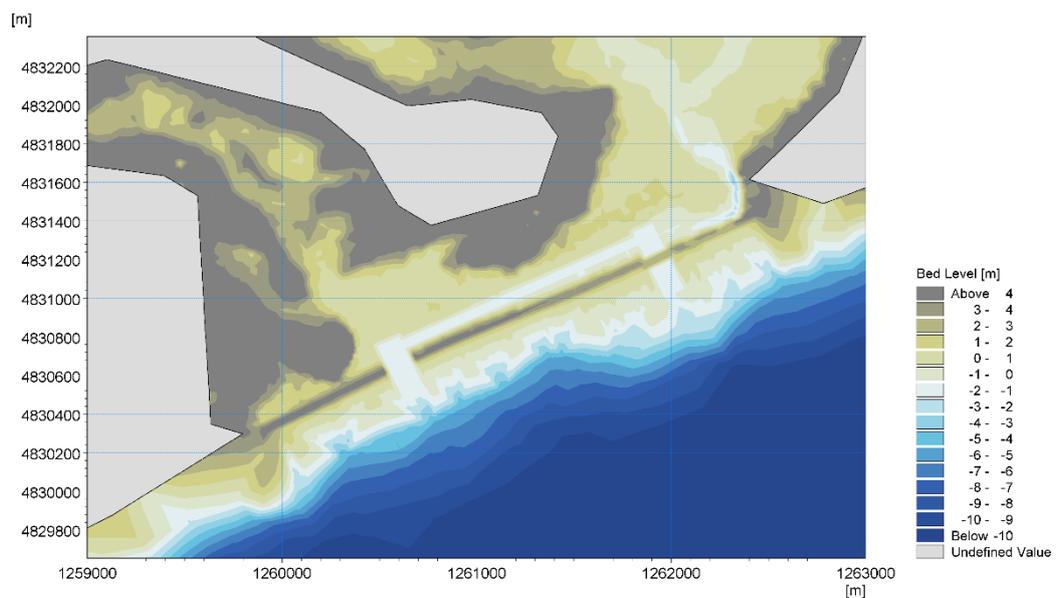


Figure 3-12 Bathymetry for Walker's Bay western opening.

A comparison of the flow through the mouth at Walker's Bay for the current opening location to east and the possible location to the west for neap and mean tides is presented in Figure 3-13 and Figure 3-14. There is an impact on the ebb tide flow, with a reduction in flows by approximately 15 - 20%. We believe this may encourage the earlier formation of the bar across the lagoon mouth compared with the eastern Walker's Bay location in favourable conditions and ultimately a quicker closure of the mouth. However the impact of this decrease in tidal flow is a reduction in tidal flushing of the lagoon as presented in Figure 3-15.

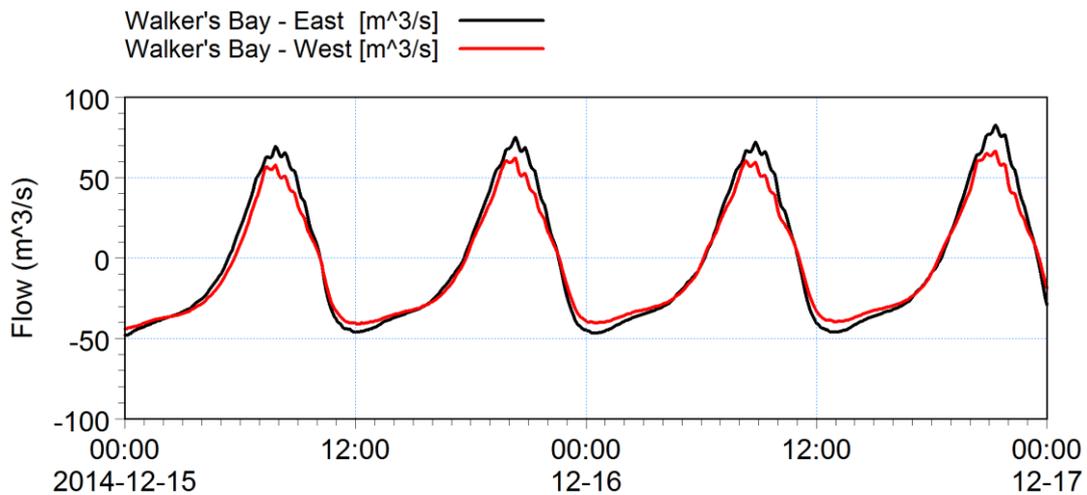


Figure 3-13 Comparison of flow through Walker's Bay opening located to east (current location) or to west for approximately neap tide. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon.

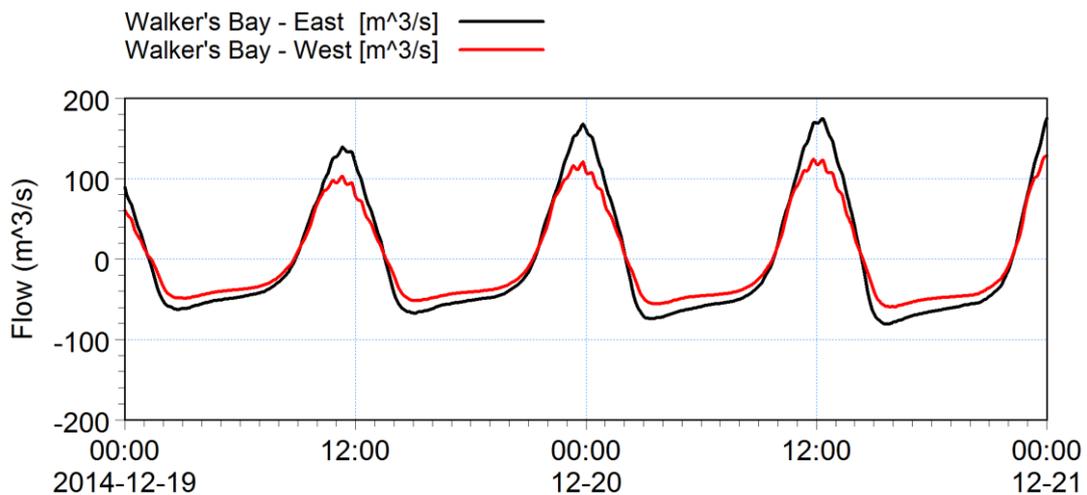


Figure 3-14 Comparison of flow through Walker's Bay opening located to east (current location) or to west for approximately mean tide. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon.

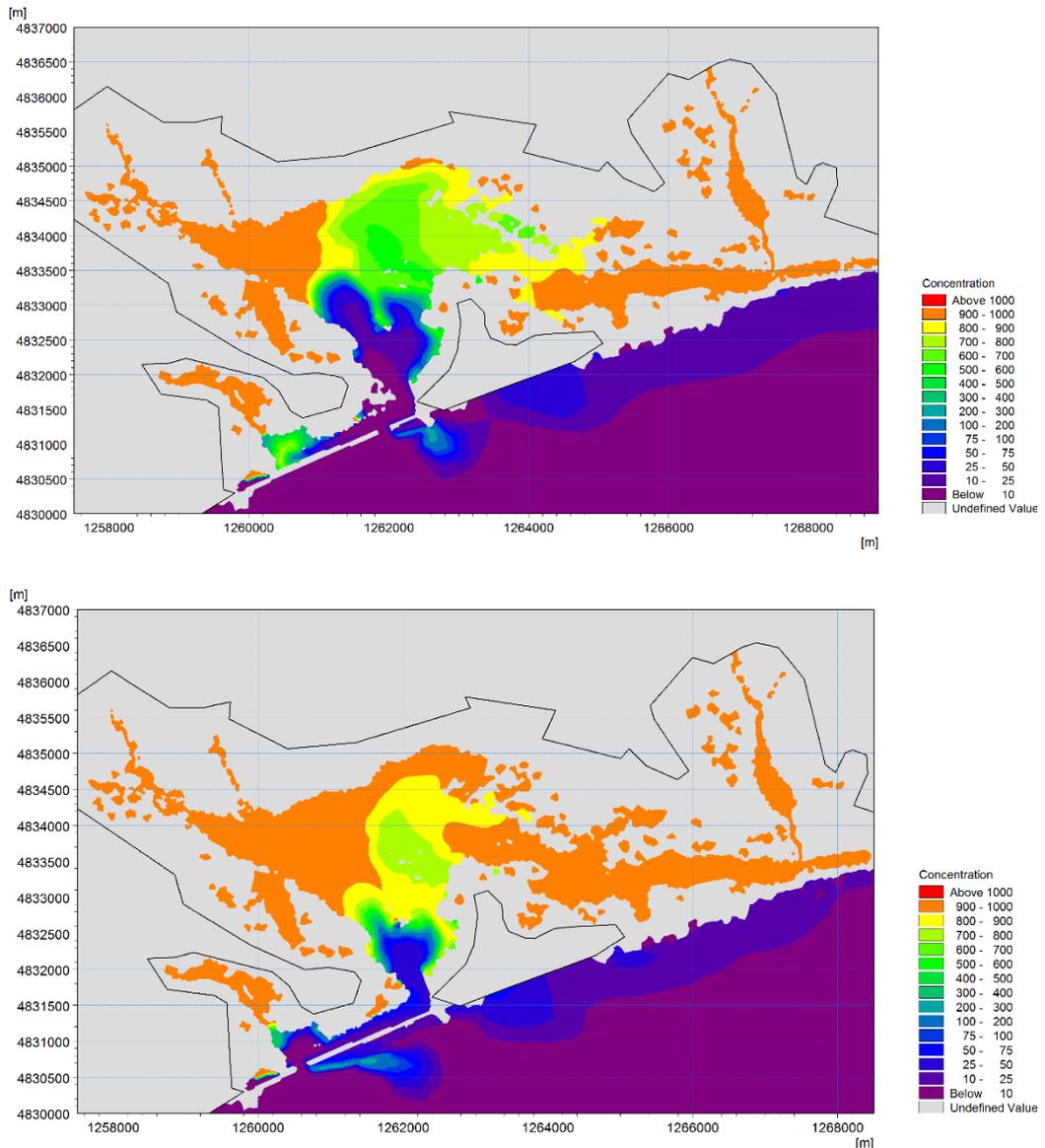


Figure 3-15 Final concentration of a conservative tracer with an initial concentration of 1000 in lagoon and zero in open ocean, to predict the tidal flushing that may occur after a neap spring tide cycle for Walker's Bay opening located to east (top) or to west (bottom).

Conclusion

For a mechanical opening of the spit with unaided closure, we believe that there are two locations which are most suitable for spit breaching, Walker's Bay and Hansen's Bay. All locations will reduce the flood levels within the lagoon when required, however we do not consider that The Fence and Eastern End are suitable locations for opening, mostly due to the increase in risk to the main *Ruppia* beds. It has been concluded previously that the eastern location are likely to close more easily, however we do not believe there is enough understanding of littoral transport along this coastline to support this claim. The fact tidal flows through the eastern part of the lagoon are higher due to the bathymetry within the lagoon, may also negate any possible perceived benefits for the eastern locations with regard to the supply of sediment for infilling of the breach channel.

Hansen's Bay is considered a suitable location for future openings which has the potential to close more quickly than Walker's Bay, however we believe that this is very dependent on the mudstone sill within Hansen's Bay. Should this continue to erode away until it is no longer a constriction to flow, some of the benefits of the Hansen's Bay location will be negated. The increased tidal flow through Hansen's Bay may also result in longer closure times for this location. If Hansen's Bay is opened regularly there is also the risk of significant ingress of marine sediment over time which could impact the main *Ruppia* beds.

A valid alternative to the current Walker's Bay opening location is a breach further to the west. We believe this option should be considered further since the reduction in ebb tide flows may encourage earlier closure of the spit. However it should be noted that the bathymetry along the inside of the spit which would join this new opening to the current channel which connects with the main body of the lagoon would require time to evolve (i.e. deepen and widen) and there is a significant risk that initial openings may close earlier than required before the desired amount of tidal flushing of the lagoon has occurred. A Walker's Bay opening also has the advantage of not being too close to the main *Ruppia* beds and the negative impacts this may include.

3.5.2 Two Mechanical Openings at Same Time with Un-aided Closure

Description

Instead of breaching the spit at only one location, this option consists of breaching the spit at two locations, either Walker's Bay with one of the eastern lagoon breaches or two eastern lagoon locations. The assumption behind this option is that with two openings the initial scouring of the opening will be less, and flow through each of the lagoon mouths will decrease and may encourage earlier closure of the openings.

Advantages and Disadvantages

The following are the perceived advantages for this option:

- Will reduce flood levels in lagoon and improve drainage for surrounding catchments.
- At least one breach location is close to the existing main *Ruppia* beds to encourage tidal flushing within these areas.
- A smaller initial scouring and reduced tidal flow through each opening which may encourage closure of openings.

The following are the perceived disadvantages for this option:

- Spit breaching no longer straight forward. A lot of effort required to time the breach of openings to occur at same time. If one breach occurs before the other there may no longer be enough head to initiate the other breach.
- Risk that two simultaneous breaches will not lead to the desired channel dimensions and they may close up early (especially if large storm events occur) before significant tidal flushing of lagoon has occurred.
- High probability that one opening will close before the other. The added tidal flows through the remaining opening may then inhibit an earlier closure of the remaining opening.

- Risk of intrusion of marine sediment into the lagoon from wave action. There is a higher risk the longer the breaches are open or during periods of high energy wave climate.

Similar to the case with one lagoon opening, the amount of tidal flushing or saline intrusion that occurs is very dependent on how long the lagoon mouth remains open, however it can be assumed that two openings will encourage more tidal flushing and saline intrusion. It is difficult to determine at what stage the fact the mouth is open changes from providing positive impacts to negative impacts. However in general, a breach with no means of aiding closure provides no control over tidal flushing or salinity within the lagoon. There is a high dependency on climatic conditions on when the mouth closes and to what level of tidal flushing is achieved within the lagoon and the resulting overall salinity.

Capital Cost and Maintenance Cost

\$3,000 to \$4,000 for a mechanical breach at Walker's Bay or Hansen's Bay. Only \$1,000 at The Fence or Eastern End due to easier access (Larkin, 2013). There is no maintenance cost associated with mechanical breaching. With two simultaneous breaches, the breaching cost would likely double.

Preliminary Assessment using Pilot Model

The tidal flushing potential for different spit opening locations has been assessed using the pilot model. The final concentration of a conservative tracer after a neap spring tide cycle is presented in Figure 3-16 for the Walker's Bay and Hansen's Bay combined openings and Hansen's Bay and The Fence combined openings. The Walker's Bay and Hansen's Bay opening flushes a much larger area than the combined eastern locations opening.

Interestingly with the Walker's Bay and Hansen's Bay combined opening, there has not been a reduction in the neap ebb tidal flow through the openings as shown in Figure 3-17 and Figure 3-18. Therefore the main perceived advantage of this option is not valid. For the eastern location combined openings there is a reduction in the neap tidal flow through the openings as shown in Figure 3-19 and Figure 3-20, although the tidal ebb flows are still significant.

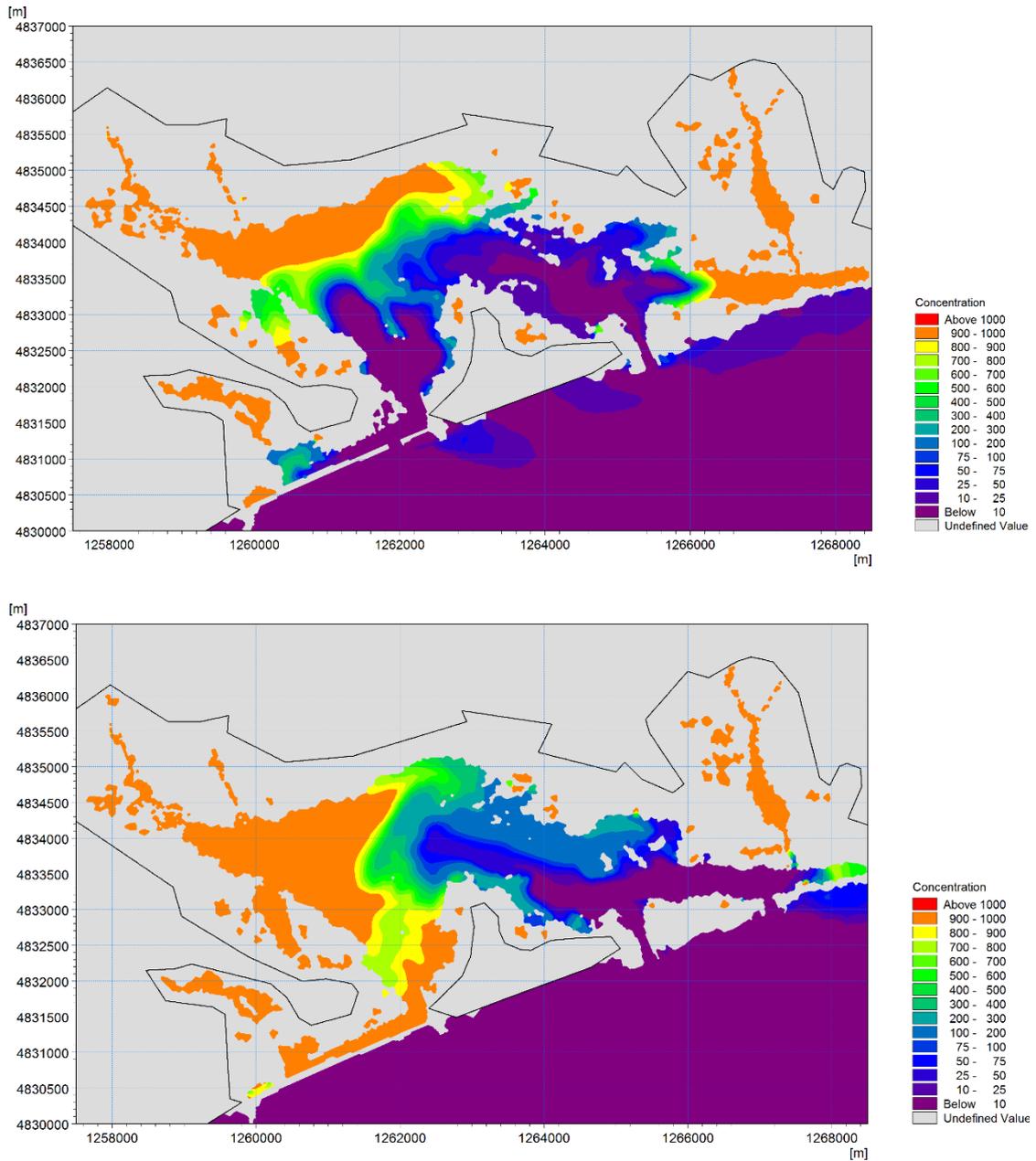


Figure 3-16 Final concentration of a conservative tracer with an initial concentration of 1000 in lagoon and zero in open ocean, to predict the tidal flushing that may occur after a neap spring tide cycle for different combined spit openings – Walker's Bay and Hansen's Bay (top) and Hansen's Bay and The Fence (bottom).

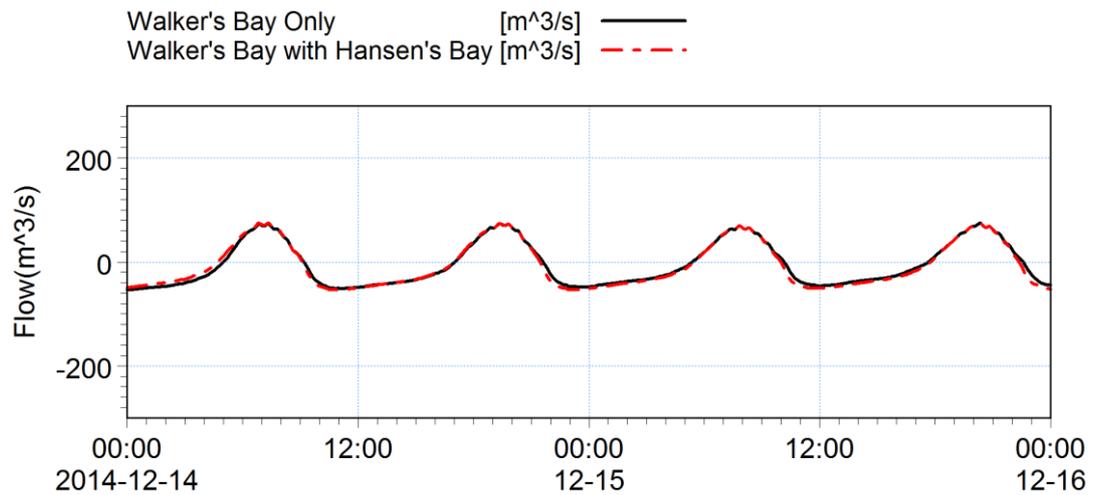


Figure 3-17 Comparison of flow through Walker's Bay spit breach for only Walker's Bay breach and combination of Hansen's Bay and Walker's Bay breaches for approximately neap tide. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon.

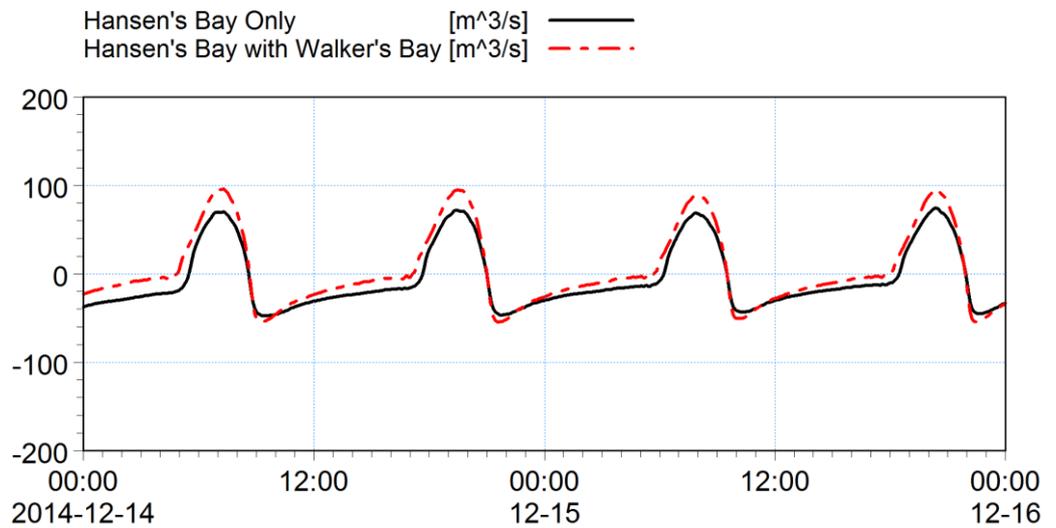


Figure 3-18 Comparison of flow through Hansen's Bay spit breach for only Hansen's Bay breach and combination of Hansen's Bay and Walker's Bay breaches for approximately neap tide. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon.

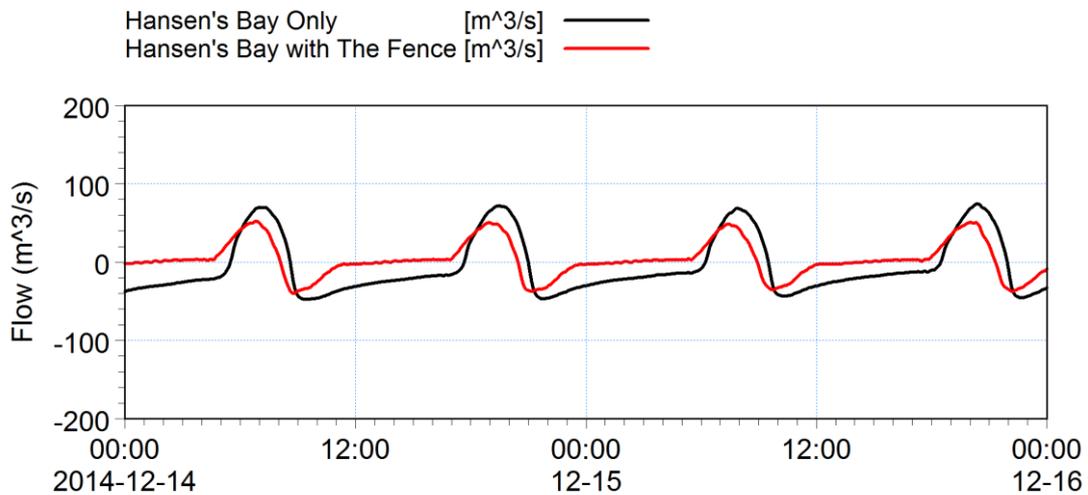


Figure 3-19 Comparison of flow through Hansen's Bay spit breach for only Hansen's Bay breach and combination of Hansen's Bay and The Fence breaches for approximately neap tide. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon.

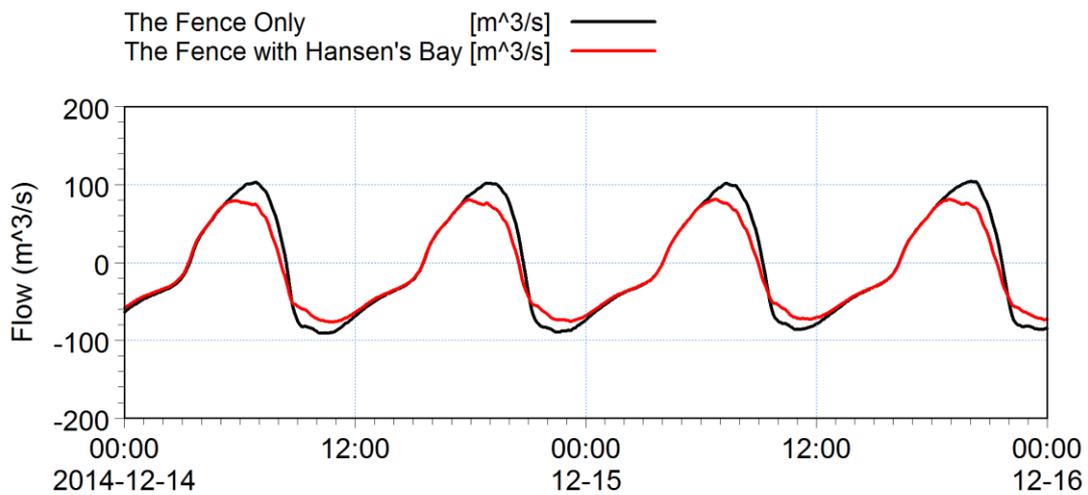


Figure 3-20 Comparison of flow through The Fence spit breach for only The Fence breach and combination of Hansen's Bay and The Fence breaches for approximately neap tide. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon.

Conclusion

We do not believe this is a viable option to consider further, although two eastern openings will reduce the tidal flow through the openings to the lagoon. There is a high risk that an opening may close immediately without achieving a reasonable amount of tidal flushing of the lagoon or that one opening may close earlier than the other opening resulting in only one opening and all the problems associated with this. This option provides no more control over the lagoon flushing and overall salinity than if only one breach was mechanically opened.

3.5.3 Mechanical Opening of the Spit with Aided Mechanical Closure

Description

Mechanical closure of the spit breach has previously been suggested as a viable option to investigate further. A mechanical closure consists of using some type of machinery (most likely a bulldozer) to infill gravel into the opening and encourage it to close. NIWA (2013) recommended that Hansen's Bay was a more suitable location to attempt a closure than Walker's Bay.

This type of closure will still be very dependent on a number of external factors, such as swell and wind conditions, the state of the tide and freshwater inflows to the lagoon. There is no guarantee that this type of forced closure will actually be successful and there is a risk that a significant amount of time and money could be spent without achieving the objective of closing the breach. There is also the health and safety issues that would arise from working in such a dynamic environment.

However we believe the likelihood of success of mechanical closure could be improved through more preparation before creating a breach through the spit. When the decision is made that the spit needs to be breached, while carrying out the excavation to create the breach, the excavated material should be stockpiled to the side of the breach to be used for the infill. Currently when the breach is opened this gravel is most likely transported seaward to form a temporary ebb delta.

By taking this step, when the decision is made to encourage the closure of the breach, there is a ready supply of gravel for infilling the opening. This type of preparation would work best at Hansen's Bay where the breach location is more confined and the breach width and location likely to be more predictable. There is a greater risk at Walker's Bay that the lagoon mouth might migrate and erode the stock piled gravel.

Staff from Environment Southland that have been responsible for overseeing breaches at both Walker's Bay and Hansen's Bay doubt the feasibility of mechanical closure due to the very mobile nature of the gravel at the site (Noel Hinton, Environment Southland, pers. comm.). They believe any gravel in filled into the opening is likely to be transported away from the mouth, before enough gravel can be in filled to encourage closure of the opening.

Advantages and Disadvantages

The advantages and disadvantages of mechanical spit opening are discussed in Section 3.5.1. The idea of mechanical closure of the spit is to minimise the negative impacts of the lagoon open to the sea for a prolonged period.

Mechanical closure attempts to provide some control over the amount of tidal flushing of the lagoon and the overall salinity of the lagoon, however spit closure will likely still be dependent on favourable climatic conditions.

Capital Cost and Maintenance Cost

The preliminary cost estimate for each opening and aided closure is \$12,000.

Preliminary Assessment using Pilot Model

The pilot model was utilised to assess the flow through the mouth and water level within the mouth for a neap tide (when the flow is least and more favourable for closure). Flows and water levels for Walker's Bay and Hansen's Bay (with sill) openings are presented in Figure 3-21. The plots indicate a significant phase lag between tidal elevations and currents with the current reversal taking place on ebb and flood tide rather than during high and low tide. This effect in the model is caused by the flow resistance within the shallow lagoon. It is again stressed that this is an un-calibrated pilot model, and results should be evaluated with caution. Whether a closure would be performed around the current reversal on flood or ebb tide would partly depend on the desired water level within the lagoon after closure, although with the phase lag, the difference in water level between the two scenarios is a lot less than the difference between high and low tide, and the difference further within the lagoon will be even less.

From the perspective of closing the breach, the flows during high tide are significantly higher than during low tide, which is due to the added tidal prism and reduced flow resistance within the lagoon. From this perspective, it is favourable to close the entrance after low tide on flood tide. This also has the advantage that any sediment filled into the channel and washed away is not washed into the lagoon but out to sea. Another important consideration is obviously at what time during the day the current reversals take place as it preferable from a safety perspective to work during daylight.

We envisage that work would start with stockpiling material along the side(s) of the channel well before the time of current reversal in the channel, and as the flow reduces in the channel towards current reversal, the material is gradually bulldozed out across the channel such that by the time the water levels in the lagoon are the same as in the sea and the currents are largely zero, there is only a narrow channel left to fill. This should quickly be filled in and then widened to the sides and built upwards to prevent breaching by the rising tide.

The flow plots indicate that the flow in the channel is less than half of the maximum flow for more than two hours leading up to the flow reversal at Walker's Bay, which indicates that the infilling can start well before the flow reversal, and there are at least 2 - 3 hours available to close the gap before a significant inflow will start.

For Hansen's Bay the flow profile is even more skewed due to the sill close to the entrance. The flows during low tide are weak and provide very favourable conditions for starting the infill of the channel well prior to the current reversal.

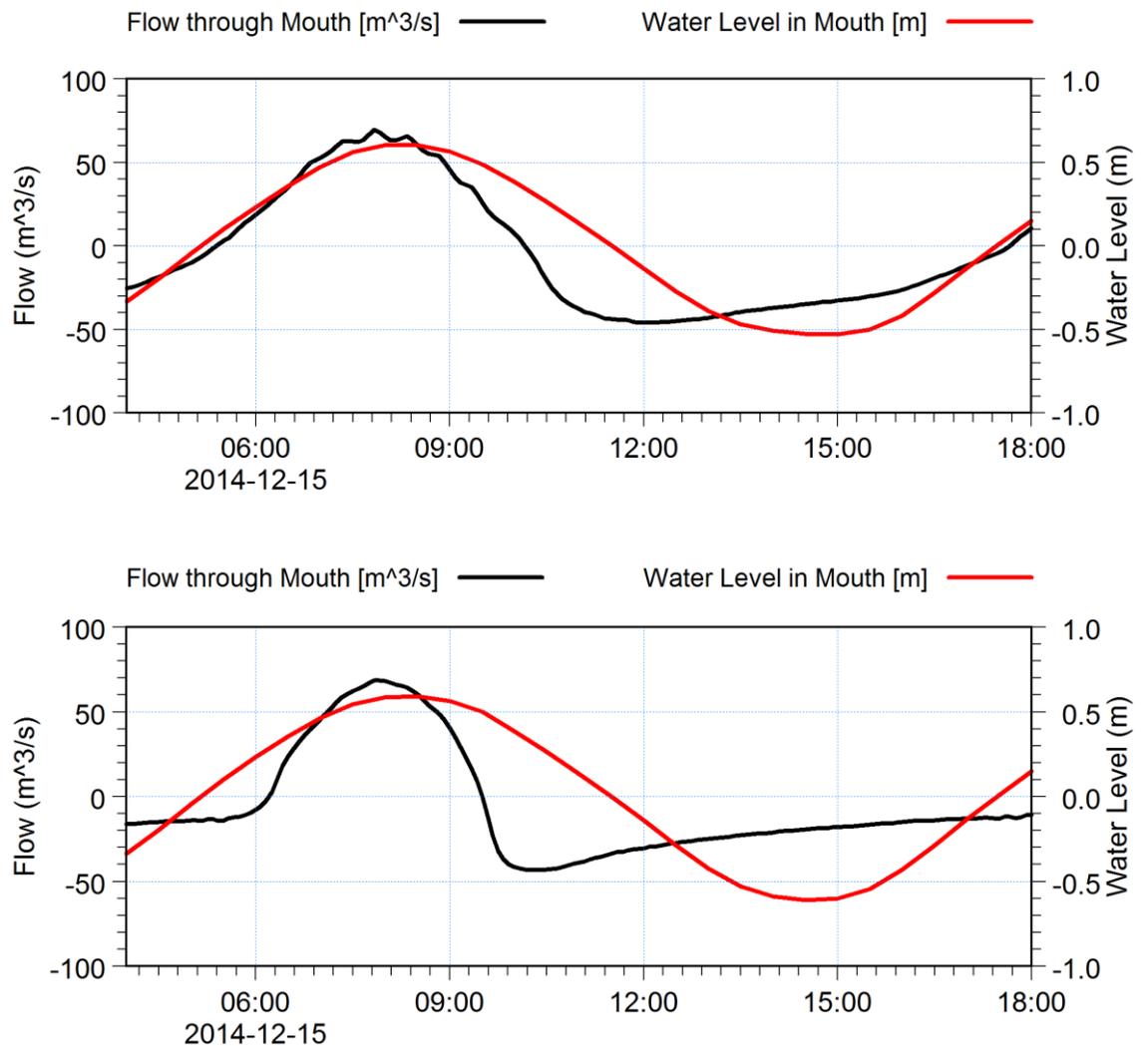


Figure 3-21 Flow through the mouth and water level within the mouth for a neap tide has been assessed for both Walker's Bay (top) and Hansen's Bay - with sill (bottom) openings. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon.

Conclusion

The ability to force a closure would eliminate the negatives associated with a prolonged opening of the breach.

There are numerous uncertainties related to mechanically aided closure, and there will always be some risk of failure. The success will depend on the ability to close the channel with a sufficiently wide "plug" over a limited period of time when the water level difference between the lagoon and the sea is minimal, and thereafter strengthen the plug to ensure that it can withstand higher water level gradients across it and that the rising tides do not wash across it.

The (very preliminary) model results indicate favourable conditions at Hansen's Bay for a potential mechanically aided closure. The internal sill within Hansen's Bay lead to a skewed flow profile through the channel, which would allow the infill to start several hours before current reversal. Given the right climatic conditions that allow the work to be carried out safely, this does

not appear to be an unsurmountable exercise, but there are numerous uncertainties that only a field test can provide full insight into.

3.5.4 Mechanical Opening of the Spit with Aided Closure from Temporary Structure

Description

This option aids closure of spit through the deployment of geotextile tubes filled with sand at an appropriate location within the lagoon. These could potentially be deployed for either Walker's Bay or Hansen's Bay at locations shown in Figure 3-22. It may be possible to deploy the tubes before the decision was made to breach the spit. There would be very limited currents within the channel at this time however much higher water levels which may also provide challenges for deploying the tubes. If the tubes are placed before the breach is made, it may be a challenge to design them to stay in place after the spit is breached. The tubes would be placed across a constriction in the main lagoon channel. Once the spit had been open for a suitable time to reduce water levels and flush the lagoon, the tubes could then be filled on site with locally sourced sand. The filled geotextile tubes would then become a barrier to flow and would basically split the lagoon in two, greatly reducing the tidal flow through the spit breach and encouraging the spit breach to close with favourable conditions. An alternative to filling the tubes with sand, is filling the tubes with water. Water will be easier to source, however this would probably require a different type of geotextile.

It is emphasised that DHI has no practical experience with the application of geotextile tubes in this fashion, and there are numerous uncertainties with respect to the practicality of this that would need to be further investigated before this is considered a viable option. What size would be required, how long would it take to fill it, how durable will it be, are but a few of the obvious questions that have not been considered at this stage.

This solution is a short term variation of the solution presented in Section 3.5.5 which works in the same way to close the breach but allows less control over lagoon water levels and tidal flushing within the lagoon. Section 3.5.5 presents how the solution would work to encourage closure of the mouth.

There is the possibility that the tubes could be deployed after a breach had been mechanically opened. The most appropriate time would be during a neap tide when the peak flows through the opening to the lagoon are smallest (pilot model indicates approximately 45 m³/s for ebb tide and 65 m³/s for flood tide – see Section 3.5.3). It is difficult to ascertain at this time the practicality for deploying tubes within the time available around flow reversal.

Once the lagoon mouth had closed the tubes could be emptied and removed from site, placed in storage ready for next deployment. It is also possible that the bags could remain deployed, however this would be dependent on the amount of sedimentation that may occur on top of the bags and whether this would have an impact on the ability to refill the bags the next time they were required.

It is difficult to establish from aerial photos how easy it would be to access these locations for deploying the tubes. This would have a big implication on the viability of this solution for aiding closure of the spit.

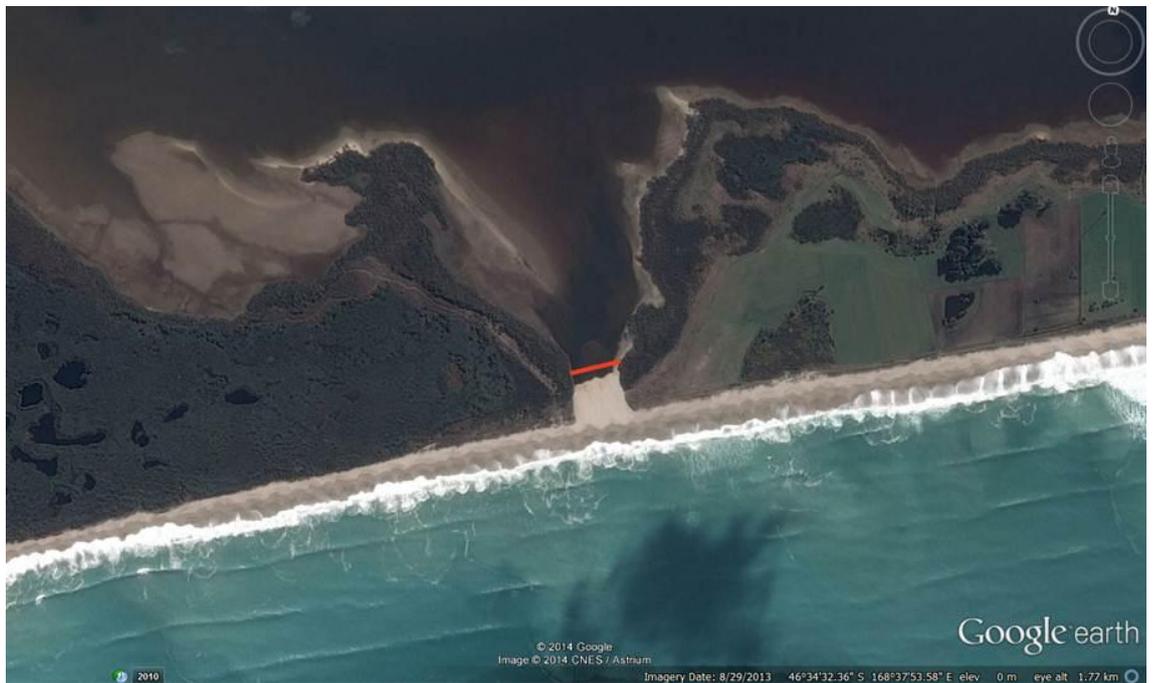


Figure 3-22 Possible locations for deployment of sand bags Walker's Bay (top) and Hansen's Bay (bottom).

Advantages and Disadvantages

The advantages and disadvantages of mechanical spit opening are discussed in Section 3.5.1. The idea of aided closure of the spit with a temporary internal structure is to minimise the negative impacts of the lagoon open to the sea for a prolonged period.

This type of aided closure is likely to be less reliant on climatic conditions compared with mechanical closure of the spit and therefore should provide further control over the amount of tidal flushing of the lagoon and the overall salinity of the lagoon.

Capital Cost and Maintenance Cost

The preliminary capital cost estimate is \$60,000 and the cost estimate for each subsequent opening and aided closure is \$60,000.

Preliminary Assessment using Pilot Model

The pilot model was not used to carry out any specific assessments for this option, instead outputs from assessments for other options were utilised as described above.

Conclusion

This option would require more investigation into the practicality and feasibility of deploying, anchoring and filling geotextile tubes within such a complex and dynamic environment. Access to the site for deploying the tubes also needs to be considered. The concept may be more ideally suited to the Hansen's Bay location as for Walker's Bay there is a risk of breaching of the adjacent sand bank. For both locations there is still uncertainty about how many geotextile tubes would be required to withstand the substantial forces that will be placed on the temporary structure.

3.5.5 Internal Dike with a Gate Structure

Description

This option contains an internal dike (or weir if overtopping of structure was desired) with a gate structure that separates the lagoon into an "inner" lagoon and an "outer" lagoon within the spit. This option would still require periodic breaching of the spit. There are two most obvious locations for this type of structure, Walker's Bay and Hansen's Bay at the locations shown in Figure 3-22. An alternative location for the dike if a more western location was chosen for the breach at Walker's Bay is shown in Figure 3-23. By limiting the tidal prism of the "outer" lagoon to a fraction of the total lagoon, the volume of water through the mouth during a tidal cycle will be greatly reduced which would encourage the spit to close with a favourable wave climate.

The gate structure could be designed to allow a desired amount of ocean water to enter the lagoon when the spit was breached to produce tidal flushing within the lagoon and maintain a desired water level within the lagoon. We envision the dike could be submerged when levels are elevated in the lagoon. The dike and gate would need to be constructed so that the spit could still be easily breached when required, i.e. with a gate structure that does not overly restrict the flow through it.

NIWA have recommended a man-made sill is built within Hansen's Bay to protect water levels around *Ruppia* and reduce sea incursions (NIWA, 2013). We believe that this option incorporates elements of this recommended solution but takes it further by allowing more control over the closure of the spit breach.



Figure 3-23 Alternative possible location for internal dike for more western Walker's Bay opening. The breach shown on the Google image would instead be to the west of the indicated location of a structure.

Advantages and Disadvantages

The following are the perceived advantages for this option:

- Possible to maintain a desired water level within the lagoon.
- Similar to the existing spit mechanical opening with regard to reducing flood levels in lagoon and improve drainage for surrounding catchments
- If required the gate structure can be closed therefore significantly reducing volume through the spit breach during a tidal cycle which should encourage the spit to close with a favourable wave climate.
- Not critical that the spit breach closes quickly as the tidal flushing and minimum water levels within the inner lagoon can be controlled by the dike and gate.
- Salt intrusion into the lagoon can be controlled depending on how the gate structure is operated. Conversely tidal flushing can also be maximised depending on how the gate structure is operated.

The following are the perceived disadvantages for this option:

- Risk of marine sediment intrusion into the lagoon from wave action. There is a higher risk the longer the breach is open or during periods of high energy wave climate.
- May require maintenance to keep the gate structure free of sedimentation.
- Risk there might be an issue with Walker's Bay site if sand bank to west of structure is highly mobile (i.e. channel may just migrate to west of structure through sand bank). The sand bank would probably need to be strengthened to avoid breaching, possibly with geotextile tubes of sand. The land to the east of the structure is also prone to erosion (Warren Tuckey, Environment Southland, pers. comm) and would also require protection. Similar can be assumed if the alternative location for the dike was selected with a more western opening location at Walker's Bay, however for this situation scour through the spit would be the concern.
- There is a risk of erosion to adjacent land in the vicinity of the breach locations due to increased water velocities that would occur in these areas during a breach. This is not seen as a high risk for the current Walker's Bay breach location since there have already been repeated openings at this location.

This option provides full control of spit closure, since the internal structure can be closed at any time. However control over the amount of tidal flushing of the lagoon that occurs and the overall salinity of the lagoon, is still dependant on length of time the breach remains open. This may not be long if climatic conditions favour closure.

Capital Cost and Maintenance Cost

The preliminary capital cost estimate is \$560,000 and annual maintenance cost estimate is \$20,000.

Preliminary Assessment using Pilot Model

The tidal flushing potential for this option has not been assessed with the pilot model, since the amount of tidal flushing would depend on the dimensions of the gate structure and how it was operated.

Instead the pilot model was utilised to determine the impact on current speeds through the spit opening at Walker's Bay if the gate structure was fully closed. This assessment is presented in Figure 3-24. The reduction in flows through the spit opening that would occur with the gate closed is presented in Figure 3-25. This illustrates how reducing the tidal flow through the mouth will encourage closure of the lagoon mouth.

The same has not been assessed for Hansen's Bay since there would not be a significant body of water seaward of the dike and therefore insignificant current speeds would occur through the spit opening.

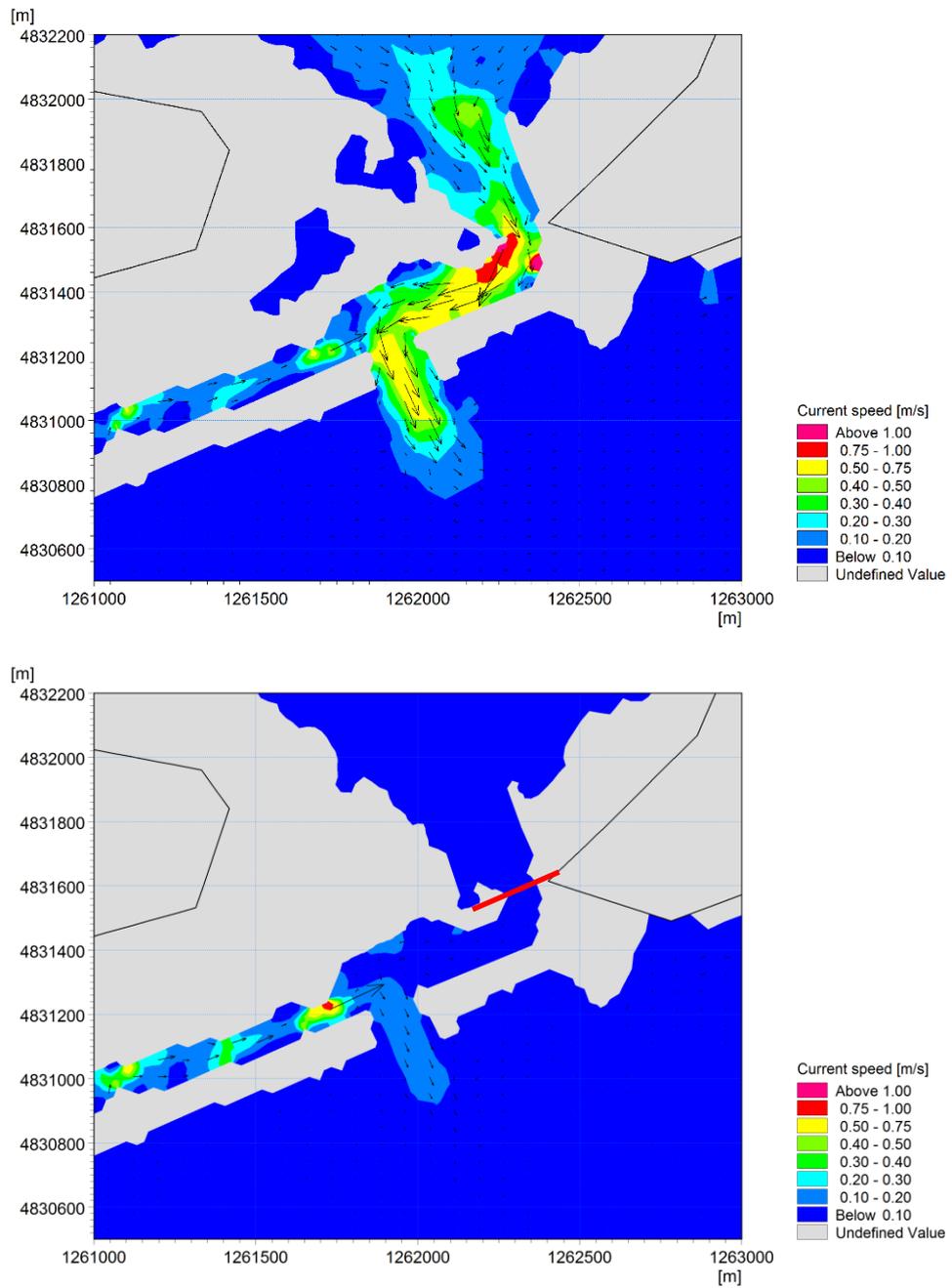


Figure 3-24 Comparison of current speeds for peak ebb tide for a mean tide for Walkers Bay spit opening without (top) and with the internal dike (bottom), indicated by red line.

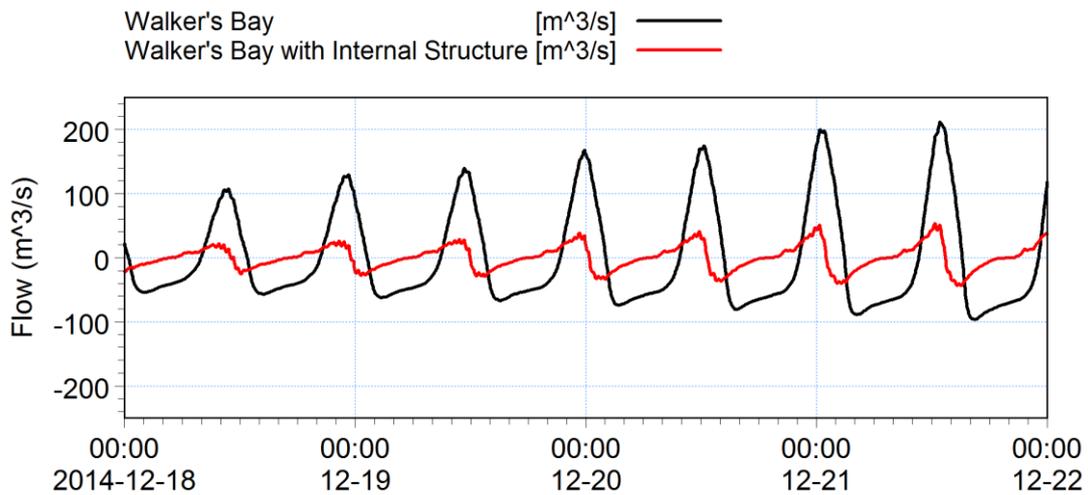


Figure 3-25 Comparison of flow through the Walkers Bay spit opening with and without the internal dike. A positive flow indicates flow into the lagoon while a negative flow indicates flow out of the lagoon.

Conclusion

We believe this is a viable option that should be given further consideration. The option allows flood levels to be reduced in the lagoon and also provides the ability to close the spit when required. The option also delivers some level of control over the amount of sea water that is allowed to enter the lagoon and minimum water levels within the lagoon. The Hansen's Bay location appears most suitable since the length of the dike would be significantly shorter than Walker's Bay and could be tied in with the true land to east and west, instead of mobile sand bank or the spit as would be the case with either proposed locations for a Walker's Bay structure. A risk with the Hansen's Bay location is the proximity to the spit, which may promote sedimentation issues that would need to be carefully considered in the gate design.

3.5.6 Culvert through Spit into Littoral Zone

Description

This option consists of a flap gated culvert through the spit into the surf zone. An example of where a similar concept is employed is the Waihao box, a timber box culvert which reduces the risk of flooding from Waihao River and assists with drainage from the surrounding catchment.

In theory the culvert would open itself when elevated levels occur within the lagoon. The culvert would have to be flap gated to inhibit the transport of gravel from the littoral zone into the culvert, which could ultimately block the culvert. We do not see a feasible way to allow flow from the sea through the culvert into the lagoon as this would likely encourage blockage of the culvert. The culvert could be located at either of the four breach locations described in Section 3.5.1.

Advantages and Disadvantages

The following are the perceived advantages for this option:

- Culvert can be sized to reduce flood levels in lagoon and improve drainage for surrounding catchments.
- The culvert could be designed so that a desired water level is maintained within the lagoon.
- Remove the issue of opening and closing spit breaches.

The following are the perceived disadvantages for this option:

- As flow only allowed out of lagoon the ability to flush the lagoon is removed.
- Littoral transport of sediment into the vicinity of culvert on the ocean side may not allow the culvert to open as desired.
- Lagoon will have minimal saline intrusion and will ultimately become predominantly freshwater.
- Risk that there would be significantly less flushing of fine sediment from lagoon compared with lagoon spit breaching.

Capital Cost and Maintenance Cost

The preliminary capital cost estimate is \$2,300,000 and annual maintenance cost estimate is greater than \$25,000.

Preliminary Assessment using Pilot Model

This option has not been assessed using the pilot model.

Conclusion

This option is not suitable since it does not provide an ability to flush the lagoon and will result in a predominantly freshwater lagoon. Even if the culvert could be designed somehow to provide some seawater to the lagoon, there is also a genuine risk the culvert will be closed by sedimentation on the seaward side of the structure and may not even be able to reduce water levels within the lagoon as required without human intervention to remove the blockage.

3.5.7 Culvert through Spit Extended Beyond Littoral Zone

Description

This option consists of a gated culvert buried below the seabed through the spit with the outlet extended beyond the surf zone. This option would provide the ability to control water levels within the lagoon and could also be designed to allow continuous or regular tidal flushing (controlled by a gate) of the lagoon. Other potential challenges for this option would be the location and design of the seaward opening of the culvert which may still be susceptible to sedimentation during large storms. This would depend on the transport rates in deeper water

beyond the surf zone for which there is currently not a very good understanding. The culvert could be located at either of the four breach locations described in Section 3.5.1.

Advantages and Disadvantages

The following are the perceived advantages for this option:

- Culvert can be sized to reduce flood levels in lagoon and improve drainage for surrounding catchments.
- The culvert could be designed so that a desired water level is maintained within the lagoon.
- Remove the issue of opening and closing spit breaches.
- Allows controlled tidal flushing of the lagoon and ability to control salinity within lagoon throughout the year.
- Removes the ingress of sediments from the sea to the lagoon during spit breaching.

The following are the perceived disadvantages for this option:

- Risk of sedimentation in the culvert and subsequent closure of the culvert during large storm events.
- Risk that there would be significantly less flushing of fine sediment from lagoon compared with lagoon spit breaching.

Capital Cost and Maintenance Cost

The preliminary capital cost estimate is \$4,500,000 and annual maintenance cost estimate is greater than \$10,000.

Preliminary Assessment using Pilot Model

This option has not been assessed using the pilot model. Modelling the tidal flushing with this option would require a long term model rather than a short event based model.

Conclusion

This option would provide the ultimate control in terms of flushing the lagoon with sea water and would maintain required water levels within the lagoon (i.e. reduce flood levels and maintain minimum water levels). The option would be a very expensive option to build and there is still uncertainty for how long the structure would need to be to extend past surf zone and whether it would still be exposed to significant sedimentation during large storm events.

3.5.8 Canal Connection with Toetoes Harbour

Description

This option consists of creating approximately a 4 km length canal between the eastern part of the lagoon and Matura River within Toetoes Harbour as shown in Figure 3-26. The flow through the canal could either be controlled by some type of structure within the channel or allowed to flow unrestricted between the lagoon and the Matura River. Unrestricted flow would probably still require some type of control to not allow flood flow from Matura River into the lagoon which would effect drainage of the catchments surrounding the lagoon.

Opus (2014) have assessed the feasibility of a canal to Toetoes Harbour with the aim of controlling water levels in the lagoon, however the option put forward here would have significantly larger dimensions with the aim of possibly also providing tidal flushing within the lagoon.



Figure 3-26 Canal between eastern lagoon and Matura River.

Advantages and Disadvantages

The following are the perceived advantages for this option:

- The canal could be designed so that a desired water level is maintained within the lagoon.

- Will reduce flood levels in the lagoon and improve drainage for surrounding catchments, however elevated water levels in Mataura River will reduce the effectiveness of this option.
- Elevated flow from Mataura River could be allowed back into the lagoon to encourage flushing of lagoon water. It should be noted that this could be a disadvantage if water quality issues (i.e. high nutrient loads or undesirable aquatic species) from Mataura River were introduced to the lagoon.
- Discharging nutrient rich waters into Mataura River / Toetoes Harbour is unlikely to result in water quality issues as the river is likely to promote quick flushing of nutrient rich waters through the harbour mouth into the open ocean. This is really only an advantage if comparing to discharging to other enclosed water bodies such as Awarua Bay.
- The canal could be constructed utilising existing drains and the canal would be located through farm land.
- Canal entrance to lagoon, close to little lake/mouth of Carran Creek at Waghorn's Road bridge, which may encourage flushing of sediment from this area.
- Will remove the issue of opening and closing spit breaches.
- Will remove the issue of sediment intrusion from the sea to the lagoon during spit breaching.
- Potential to short circuit the flow from Carran Creek away from the lagoon.

The following are the perceived disadvantages for this option:

- A much larger investment for the assessment of environmental effects would be required for a resource consent compared with other options.
- If not controlled there could be a significant flow of water from the Mataura River to lagoon during large flood events which would reduce the drainage and increase the risk of flooding for the catchments surrounding the lagoon.
- Need to ensure that if water was taken from the river to the lagoon, that there wasn't any effect on navigation through the Toetoe harbour mouth. However is probably more likely to improve the harbour entrance as it would work as an increase in tidal prism. Also need to ensure that water quality issues in river (i.e. high nutrient loads or undesirable aquatic species) not introduced to lagoon.
- Risk that there would be significantly less flushing of fine sediment from the lagoon compared with lagoon spit breaching.
- May affect salinity intrusion within the lower Mataura River.
- Hydrodynamics for the eastern end of the lagoon will be significantly altered. The eastern end of lagoon is key habitat for *Ruppia*, which is most likely due to the relative isolation of the eastern end.

There is uncertainty about whether any saline water would be able to enter the lagoon through the canal, since we do not have data or information to determine the extent of the salt wedge that propagates up the Mataura River. If no saline intrusion into the lagoon occurred with this option, the option would not be appropriate since the lagoon would become predominantly freshwater. It is possible that water could only be taken during periods of lower flows within the river when the salt wedge would propagate further upstream.

Capital Cost and Maintenance Cost

The preliminary capital cost estimate is \$2,100,000 and annual maintenance cost estimate is \$25,000.

Preliminary Assessment using Pilot Model

The tidal flushing potential for this option has been assessed using the pilot model. A 40 m wide rectangular channel with depth of -1 m MSL and a length of 4 km connecting to the eastern part of the lagoon was simulated. The model bathymetry and mesh where the canal and lagoon connect is presented in Figure 3-27. The neap spring tidal boundary was selected as the boundary condition for the canal with a concentration of zero (dimensionless units). The final concentration of a conservative tracer after a neap spring tide cycle is presented in Figure 3-28. The tidal flushing is very limited to the most eastern part of the lagoon. If elevated river flows were allowed to flow into lagoon additional tidal flushing would occur, however there would be a balance with ensuring drainage not significantly effected from surrounding catchments.

In assessing these results, it is worth noting that the channel with a gate structure would allow tidal flushing to take place over a much longer time frame (in principle throughout the year) than what is desired for a normal breach. This could potentially significantly increase the tidal flushing capacity of this option over the long run compared to the breach option which typically would be considered once a year for a limited period of time. For a full comparison to the other options, the tidal flushing as well as a salinity balance for longer term operations would have to be investigated through longer term simulations, which is outside scope and time constraints of this study.

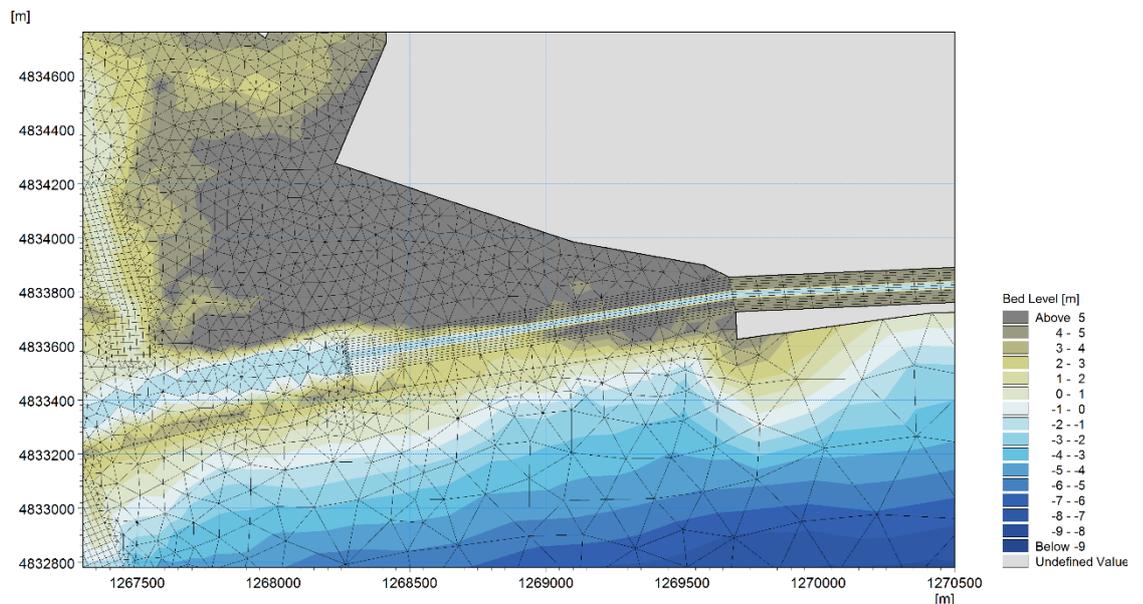


Figure 3-27 Model bathymetry and mesh where the canal and lagoon connect.

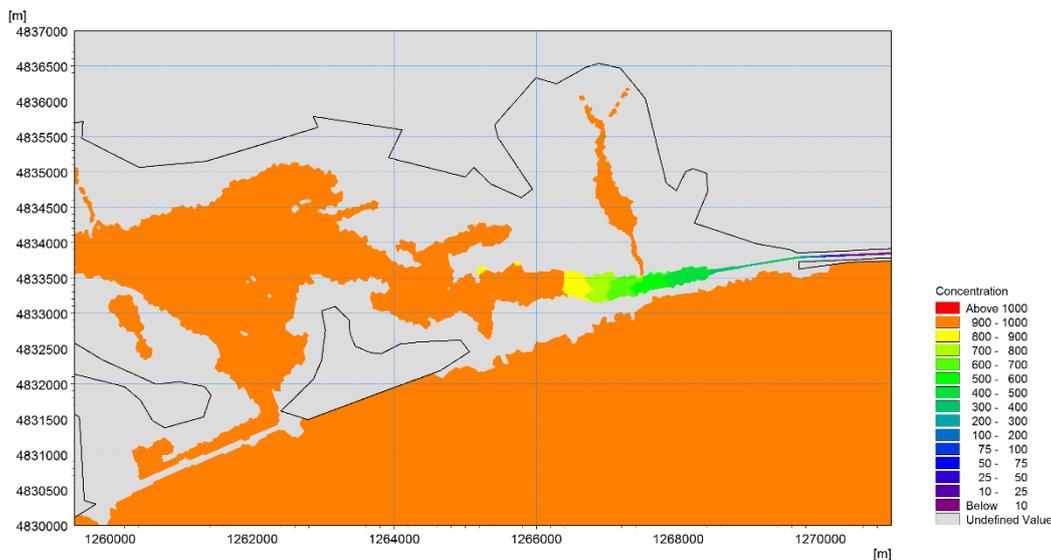


Figure 3-28 Final concentration of a conservative tracer with an initial concentration of 1000 in lagoon and river boundary condition of zero concentration, to predict the tidal flushing that may occur after a neap spring tide cycle.

Conclusion

Although this is an expensive option, we believe that this option could achieve most of the objectives of opening the spit without a lot of the issues associated with spit openings. Unlike spit opening alone, this option allows some level of control over water levels and, perhaps, salinity within the lagoon.

There is uncertainty around whether the salt wedge in the Mataura River extends far enough upstream or whether the additional tidal prism introduced by the lagoon would allow the amount of saline water required to ensure the lagoon does not become predominantly freshwater. This would have to be assessed before this option could be considered further. This option also has the advantage over the Awarua Bay canal outlined below, since nutrient rich discharges to Mataura River are likely to not have an impact on water quality in Toetoes Harbour, as the majority of the water discharged from the lagoon will exit to the sea through the harbour mouth on ebb tides. There is the potential that water quality issues from the river could be introduced to the lagoon. The canal could also be built utilising existing drainage channels through farmland. There is also uncertainty around the amount of fine sediment that could be flushed from the lagoon with this option.

It should be noted that the canal could be used as an option for only the management of flood levels during spring/summer periods with lagoon openings still carried out in winter. With this solution, no water from the river would enter the lagoon and water would only be able to exit the lagoon to the river.

3.5.9 Canal Connection with Awarua Bay

Description

This option consists of creating approximately a 3 km length canal between the western part of lagoon and Awarua Bay as shown in Figure 3-29. The flow through the canal could either be

controlled by some type of structure within the channel or allowed to flow unrestricted between the lagoon and bay.



Figure 3-29 Canal between western lagoon and Awarua Bay.

Advantages and Disadvantages

The following are the perceived advantages for this option:

- The canal could be designed so that a desired water level is maintained within the lagoon.
- The canal could be designed with a structure to allow a desired amount of saline intrusion into the lagoon.
- Will reduce flood levels in the lagoon and improve drainage for the surrounding catchments.
- Will remove the issue of opening and closing spit breaches.
- Will remove the issue of sediment intrusion from the sea to the lagoon during spit breaching.

The following are the perceived disadvantages for this option:

- The canal would have to be constructed through what is ecologically sensitive and important wetland.
- Discharging nutrient rich waters into Awarua Bay may result in water quality issues within the upper part of the bay.

- A much larger investment for the assessment of environmental effects would be required for a resource consent compared with other options.
- Risk that there would be significantly less flushing of fine sediment from lagoon compared with lagoon spit breaching.

Capital Cost and Maintenance Cost

The preliminary capital cost estimate is \$1,600,000 and annual maintenance cost estimate is \$25,000.

Preliminary Assessment using Pilot Model

The tidal flushing potential for this option was not assessed using the pilot model since it can be assumed (based on canal to Toetoes Harbour pilot model predictions) that the tidal flushing will be very localised to the western part of the lagoon in the short term with potential for reasonable tidal flushing of the whole lagoon able to be achieved over a longer time frame.

Conclusion

This option is similar to the Toetoes Harbour canal option in that some of the objectives of the spit opening are achieved without some of the negative impacts. This option has the advantage that you can ensure that water discharged into the lagoon is saline, however it also has the disadvantage that the canal would have to be built through wetland and nutrient rich water would be discharged to Awarua Bay which may impact water quality within the bay. For these reasons we feel this option is probably not worth further consideration.

3.6 Solutions Considered and Not Evaluated in Detail

There were additional options that we considered and have concluded are not viable. We do not believe evaluation of these options, warranted the same detail as the preceding options.

3.6.1 Pump and Pipe Network

A solution that was recommended by Opus (2014) for controlling water levels within the lagoon, was the installation of a pump station and pipe network to discharge from the lagoon to Matura River or the sea. Although we agree in principle that this option could be designed to maintain the desired water levels within the lagoon (could be used in combination with winter lagoon openings), there would be no ability to flush the lagoon and mechanical opening of the spit would still be required on occasion to ensure the lagoon does not become predominantly freshwater.

3.6.2 Rolling Opening Schedule

There has been a recommendation that a rolling opening schedule across all four locations would be a viable solution (Larkin, 2013). We agree with NIWA's concerns that a rolling schedule would potentially increase the risk to the main *Ruppia* beds in the eastern parts of the lagoon (NIWA, 2013). There is the potential that the *Ruppia* beds in the vicinity of all the potential spit opening locations could all be negatively impacted in time. We suggest that focussing on one location (or at the most two) is a better approach for restricting the areas exposed to unfavourable conditions.

3.6.3 External Breakwaters with a Gate through the Spit

Dependent of the net littoral transport in the area (which is still not well understood) another option is to construct a sluice (gate) in the spit protected by some jetties into surf zone at a suitable location where the net littoral transport is close to zero. Such a solution would provide full control over the lagoon tidal flushing through appropriate operation of the sluice. However this option would be very expensive and would only be feasible if there is actually a location with close to zero net littoral transport as the coastal impacts would otherwise be too large.

3.6.4 Two Canals

This option consists of two internal canals, one to Toetoes Harbour and the other to Awarua Bay. The flow through the canals could be controlled with structures in such a way that water would flow through one canal on the flood tide and out the other on the ebb tide. This would provide the ability to decide where to input incoming less nutrient rich waters and where to discharge the nutrient loads from the lagoon. This would also likely allow very good control of the tidal flushing of the lagoon. We see the cost of building such an option as prohibitive.

4 Recommendations

A critical assessment of different solutions for better managing the lagoon has been carried out. The aim of any solution is to obtain desired water levels and salinity within the lagoon while also encouraging the removal of nutrient rich water and sediment from the lagoon. The assessment included determining the perceived advantages and disadvantages for the particular option. An un-calibrated pilot model was set up to better quantify the performance of options with regard to the critical issues which determine the appropriateness of the option. Rough order capital and maintenance costs were also calculated for each option. The solutions for managing the lagoon with perceived advantages and disadvantages and preliminary costs are summarised in Table 4-1.

Environment Southland and DairyNZ requested that DHI recommend a preferred option for better managing the lagoon opening and flushing of the lagoon. With the number of issues that have been identified as critical for assessing the appropriateness of any possible solution, we do not feel that DHI is in a position to be able to determine how these issues should be considered in terms of rank and importance. It is also not clear all the constraints that exist when selecting an option, especially with regard to capital and maintenance costs. We suggest that selecting a final preferred option is a task for the greater project team based on the findings of this report with input from DHI.

However we can make the following recommendations for the different types of management of the lagoon.

Mechanical Opening with Un-aided Closure

Although we agree that Hansen's Bay is currently a suitable location for future spit breaches as it is likely to encourage quicker closure than the other locations, this is very dependent on the sill within Hansen's Bay. If Hansen's Bay is considered a viable location for future spit openings, it will be essential that some further field work is carried out to assess the mudstone sill and whether it will continue to erode with future openings. The pilot model indicated that as this sill erodes away the hydrodynamics of the lagoon will change significantly. A more detailed study would be required to determine whether there are benefits in keeping the sill or potentially lowering it to achieve better tidal flushing in the rest of the lagoon. Also more investigation would be required into the potential negative ecological impacts of a Hansen's Bay opening such as scour or smothering with marine sediment of the main *Ruppia* beds.

With the uncertainty around Hansen's Bay, we recommend that the western opening for Walker's Bay is considered. The reduction in ebb tide flows by 15 - 20% that the pilot model predicts will occur for this opening, compared with the existing opening location, indicates that this may promote earlier closure in favourable conditions. This is, however, assuming a similar magnitude of the processes that promote closure, i.e. the littoral transport, at the two locations.

To better understand the processes that initiate closure of openings along the spit and provide more insight into why one opening is likely to close more quickly than another, an investigation of both the wave climate and littoral transport along the coastline is recommended.

A wave model would be required to provide the near shore wave climate critical for a littoral transport study. Either wave data from a deployed wave buoy in Toetoes bay or the morphological characteristics in the area would be considered for calibration of the wave model.

The near shore wave study would form the basis of a littoral transport study to assess littoral transport rates along different parts of the Waituna Lagoon coastline and inform on any differences in the associated infilling potential for the different sites.

DHI can provide a more detailed scope for the data requirements and modelling methodology of a littoral transport study, if it is required for the lagoon management solution that the project team decide to investigate further.

Mechanical Opening with Aided Closure

Two methods were discussed for aiding closure of the spit. These include mechanical closure of the spit and splitting the majority of the body of the lagoon from the opening with a temporary structure (most likely geotextile tubes). There is too much uncertainty around the practicality of deploying geotextile tubes at this stage to provide a recommendation between that option or mechanical closure.

The proposed wave climate and littoral transport investigations above would help to inform the types of conditions required to determine the likelihood of success of aided closure.

Permanent Control Structure

To obtain more control over water levels and salinity within the lagoon, a solution that incorporates a permanent structure would be required. We propose that the internal dike with gate structure located at Hansen's Bay is the most viable solution of the permanent structure options we investigated. However it should be noted that we believe a canal to Toetoes Harbour still has its merits, especially since you remove some of the issues that are associated with spit breaching.

This option provides the ability to reduce water levels within the lagoon and improve drainage for surrounding catchments and depending on how the gate is designed and operated will still maintain a minimum desired water level within the lagoon at all times. The gate could also be designed to allow a desired amount of tidal flushing to occur within the lagoon when the gate (and spit) is open and provide some control over the salinity within the lagoon.

Similar to a mechanical opening at Hansen's Bay with unaided closure, more investigation would be required into the potential negative ecological impacts of a Hansen's Bay opening such as scour or smothering with marine sediment of the main *Ruppia* beds.

To progress this option to a detailed engineering design stage, the internal dike and internal gate would need to be designed (i.e. dike crest level and dimensions of gate) to ensure the following:

- that the internal dike and open gate would not have an impact on the ability to open the spit at Hansen's Bay when required;
- that the option still provides the same level of drainage from the surrounding catchments as a normal opening;
- that the desired water level can be maintained within the lagoon; and
- that the desired amount of tidal flushing and overall salinity of the lagoon could be obtained.

To assess the matters above, a calibrated hydrodynamic model would be required. The water levels that are currently collected within the lagoon would be used to calibrate this. Current data within the lagoon would also be required for model calibration. The data would need to coincide with an opening period and be from within the vicinity of the opening (and possibly other locations within lagoon). The hydrodynamic model would also form the basis of a morphological

model that would be required for assessing the impacts of the dike and gate on creating a spit opening.

The assessment required for the design of the dike and gate structure could form the basis of any assessment of environmental effects that would be required for gaining a consent.

DHI can provide a more detailed scope for an appropriate study to complete a detailed engineering design (with modelling methodology and field data requirements), if the project team determine a permanent control structure is a feasible option to investigate further.

Table 4-1 Overview of solutions for managing the lagoon.

Type of Solution	Solution Description	Advantages	Disadvantages	Capital and Maintenance Cost Estimates
Mechanical opening of the spit at one or more locations with un-aided closure.	Mechanical opening of the spit with un-aided closure. (Walker's Bay, Hansen's Bay, The Fence and Eastern End)	<ul style="list-style-type: none"> Spit breaching is a relatively straight forward process and can be carried out quickly. Reduces flood levels in the lagoon and improve drainage for the surrounding catchments. <p><i>There are a number of advantages specific to each potential breach location which are discussed in the main body of report.</i></p>	<ul style="list-style-type: none"> All breaches may not maintain a desired water minimum level within the lagoon. Potential for a breach to close too quickly if large storms occur soon after the spit opening before significant tidal flushing of the lagoon has occurred. Significant saline intrusion can occur if the breach remains open for too long. Risk of intrusion of marine sediment into the lagoon from wave action. <p><i>There are a number of disadvantages specific to each potential breach location which are discussed in the main body of report.</i></p>	Cost for each opening ranges from \$1,000 - \$4,000.
	Two mechanical openings at same time with un-aided closure. (Walker's Bay, Hansen's Bay, The Fence and Eastern End)	<ul style="list-style-type: none"> Reduces flood levels in the lagoon and improve drainage for the surrounding catchments. At least one breach location is close to the main <i>Ruppia</i> beds to encourage tidal flushing within these areas. A smaller initial scouring and reduced tidal flow through each opening which may encourage closure of openings. 	<ul style="list-style-type: none"> Spit breaching no longer straight forward. Risk that two simultaneous breaches may close up early before significant tidal flushing of lagoon has occurred. High probability that one opening will close before the other which may then inhibit an earlier closure of the remaining opening. Risk of marine sediment intrusion into the lagoon from wave action. 	Cost for each opening ranges from \$2,000 - \$8,000.
Mechanical opening of the spit with some type of aided closure.	Mechanical opening of the spit with aided mechanical closure. (Walker's Bay, Hansen's Bay, The Fence and Eastern End)	<ul style="list-style-type: none"> Same as mechanical opening of the spit 	<ul style="list-style-type: none"> Same as mechanical opening of the spit, aim of mechanical closure is to minimise the negative impacts of the lagoon open to the sea for a prolonged period. 	Cost for each opening and aided closure is \$12,000.
	Mechanical opening of the spit with aided closure	<ul style="list-style-type: none"> Same as mechanical opening of the spit 	<ul style="list-style-type: none"> Same as mechanical opening of the spit, aim of temporary internal structure is to minimise 	Capital cost = \$60,000. Maintenance cost = \$60,000 / yr.

Type of Solution	Solution Description	Advantages	Disadvantages	Capital and Maintenance Cost Estimates
	from temporary structure (Walker's Bay or Hansen's Bay).		the negative impacts of the lagoon open to the sea for a prolonged period.	
A mechanical opening combined with an internal structure.	Internal dike with gate structure. (Walker's Bay or Hansen's Bay)	<ul style="list-style-type: none"> • Possible to maintain a desired water level within the lagoon. • Will reduce flood levels in lagoon and improve drainage for surrounding catchments • If required the gate structure can be closed to encourage the spit to close with a favourable wave climate. • Not critical that the spit breach closes quickly as the tidal flushing of the inner lagoon and minimum water levels can be controlled by the dike. • Salt intrusion into the lagoon and tidal flushing of the lagoon can be controlled depending on how the gate structure is operated. 	<ul style="list-style-type: none"> • Risk of marine sediment intrusion into the lagoon from wave action. • May require maintenance to keep the gate structure free of sedimentation. • Risk of scour of sand bank or spit adjacent to of dike at Walker's Bay sites. • Risk of erosion to adjacent land in the vicinity of the breach locations, especially at Hansen's Bay. 	Capital cost = \$560,000. Maintenance cost = \$20,000 / yr.
A structure through the spit.	Culvert through spit into littoral zone. (Walker's Bay, Hansen's Bay, The Fence and Eastern End)	<ul style="list-style-type: none"> • Can be designed to reduce flood levels in lagoon and improve drainage for surrounding catchments. • Can be designed so that a desired water level is maintained within the lagoon. • Removes the issue of opening and closing spit breaches. 	<ul style="list-style-type: none"> • As flow only allowed out of lagoon the ability to flush the lagoon is removed. • Culvert may not open as desired if littoral transport of sediment blocks culvert opening. • Lagoon will have minimal saline intrusion and will become predominantly freshwater. • Risk of minimal flushing of fine sediment from lagoon. 	Capital cost = \$2,300,000. Maintenance cost > \$25,000 / yr.
	Culvert through spit beyond littoral zone. (Walker's Bay, Hansen's Bay, The Fence and Eastern End)	<ul style="list-style-type: none"> • Can be designed to reduce flood levels in lagoon and improve drainage for surrounding catchments. • Can be designed so that a desired water level is maintained within the lagoon. • Removes the issue of opening and closing spit breaches. 	<ul style="list-style-type: none"> • Risk of sedimentation in the culvert and subsequent closure of the culvert during large storm events. • Risk of minimal flushing of fine sediment from lagoon. 	Capital cost = \$4,500,000. Maintenance cost > \$10,000 / yr.

Type of Solution	Solution Description	Advantages	Disadvantages	Capital and Maintenance Cost Estimates
A canal to an adjacent body of water.	Canal connection with Toetoes Harbour.	<ul style="list-style-type: none"> • Desired water level is maintained within the lagoon. • Reduces flood levels in the lagoon and improve drainage for the surrounding catchments. • Elevated flow from Maitara River could be allowed back into the lagoon to encourage flushing of lagoon water. However may transfer water quality issues from Maitara River to lagoon. • Discharging nutrient rich waters into Maitara River / Toetoes Harbour is unlikely to result in water quality issues. • Canal located through farmland and could be constructed utilising existing drains. • May encourage flushing of sediment from lake/mouth of Carran Creek at Waghorn's Road bridge. • Removes the issue of opening and closing spit breaches. • Removes the issue of sediment intrusion from the sea to the lagoon during spit breaching. • Potential to short circuit the flow from Curran's Creek away from the lagoon. 	<ul style="list-style-type: none"> • Large flood in Maitara River may reduce drainage to lagoon. • Uncertainty about whether any saline water would enter lagoon through canal. • Uncertainty on impact on navigation through Toetoes Harbour mouth • Large investment for environmental effects assessment. • Risk that there would be significantly less flushing of fine sediment from the lagoon compared with lagoon spit breaching. • May affect salinity intrusion within the lower Maitara River. • Hydrodynamics for the eastern end of the lagoon will be significantly altered. 	Capital cost = \$2,100,000. Maintenance cost = \$25,000 / yr.
	Canal connection with Awarua Bay.	<ul style="list-style-type: none"> • Desired water level is maintained within the lagoon. • Can be designed to allow a desired amount of saline intrusion into the lagoon. • Reduces flood levels in the lagoon and improve drainage for the surrounding catchments. • Removes the issue of opening and closing spit breaches. 	<ul style="list-style-type: none"> • The canal constructed through wetland. • Discharging nutrient rich waters into Awarua Bay may result in water quality issues in the bay. • Large investment for environmental effects assessment. • Risk significantly less flushing of fine sediment from lagoon compared with lagoon spit breaching. 	Capital cost = \$1,600,000. Maintenance cost = \$25,000 / yr.

Type of Solution	Solution Description	Advantages	Disadvantages	Capital and Maintenance Cost Estimates
		<ul style="list-style-type: none"> • Removes the issue of sediment intrusion from the sea to the lagoon during spit breaching. 		

5 References

- AgResearch (2013); *Waituna Sediment Fingerprinting Study*. Report prepared for Environment Southland.
- Bruun, P. (1968); *Tidal inlets and littoral drift*. Univ. Book Co., Oslo, Norway.
- Bruun, P. (1990); *Tidal inlets on alluvial shores*. In: Port Eng., Vol. 2, Chapter 9, Bruun, P., ed., Gulf Pub., 810-929
- Hamilton D.; H.F. E. Jones; D. Özkundacki; C. McBride; M.G. Allan; J. Faber & C.A. Pilditch (2012); *Waituna Lagoon Modelling: Developing quantitative assessments to assist with lagoon management*. Report prepared for Environment Southland.
- Larkin, G (2013); *Waituna Lagoon Mouth Closure, Summary Report*. Report prepared for Environment Southland.
- Larkin, G. (2013); *Waituna Lagoon Mechanical Opening Site Assessment*. Report prepared for Environment Southland.
- NIWA (2013); *Opening and closure of Waituna Lagoon, Review of Recent Investigations*. Report prepared for DairyNZ.
- NIWA (2014); *Macrophyte monitoring in Waituna Lagoon – Summer 2014*. Report prepared for Department of Conservation.
- Opus (2011); *Waituna Lagoon Management Study, Stage One, Urgent Measures Report*. Report prepared for Environment Southland.
- Opus (2014); *Waituna Lagoon Diversion Scheme – Phase 1 Technical Memo*. Prepared for Environment Southland.
- WaterLine (2014); *Waituna Lagoon Hydraulic Management Options Cost Report*. Prepared for Environment Southland.
- Wriggle (2007); *Waituna Lagoon 2007, Macrophyte (Ruppia) Mapping*. Report prepared for Department of Conservation.

APPENDIX A

ENVIRONMENT SOUTHLAND WAITUNA LAGOON HYDRAULIC MANAGEMENT OPTIONS COSTS REPORT

INTRODUCTION

This report has been prepared to provide very rough orders of costs for various physical works options proposed to be constructed for the hydraulic management of Waituna Lagoon. The options under consideration are described in the DHI report of November 2014 (Pre-feasibility Engineering Scoping for Lagoon Closings/Opening) prepared for Environment Southland.

SUMMARY OF OPTIONS AND COSTS

See Table 1 below. This table summarises the various options proposed and gives a brief description of their key construction and maintenance requirements. These costs have been estimated from knowledge of similar types of construction around the country and would benefit from a review using local construction experience

CONCLUSIONS

There is a wide range of initial capital costs, which include design fees and initial consenting, but a narrow range of ongoing maintenance and operating costs except for Option 2 (the use of sand/water filled bags).

Option 1 is of the least cost and has the least risk associated with it in terms of financial, consenting and technical although local doubt has been expressed that the breach channel can be filled. This can be overcome with adequate equipment on the job.

Option 2 is of moderate initial and ongoing cost with major uncertainty associated with fixing the tubes in place and their filling and emptying each year.

Option 3 is of high initial cost and low ongoing maintenance costs and present an option to control water levels in the lagoon with the use of manually adjusted and pre-set standard flapgates. It has a high consenting cost to build a dyke across the channel and is very dependent on the local availability of fill. More sophisticated control gates can be provided but at increased cost.

Options 4 to 7 are at the very high range of costs and will require significantly more effort on investigation and consenting.

Option Number & Name	Option Description	Discussion	Cap Cost	Yr Cost
1. Yearly Mechanical Opening with Aided Mechanical Closure	Establish excavator on site, cut pilot channel, stockpile gravels for later use. Re-establish bulldozers on site and push gravel from stockpiles into channel	Excavated material needs to be stockpiled unlike present operation. When filling channel, work must be fast to close it off	\$10 (consents)	\$12k per opening and aided closure
2. Yearly Mechanical Opening with Temporary Closure Tubes	Establish tubes on site and lay in channel and make secure. Cut pilot channel. Establish filling equipment on site and fill tubes to block flow. Maintain tubes full while spit breach closes naturally	High risk of failure – tubes may wash away; uncertainty of tube emptying operation; need to maintain tubes while breach fills. Each year, bring tubes to site and repeat the process.	\$62k (design, consents, purchase tubes)	\$60k
3. Internal dyke including controllable culverts	Establish equipment on site and push fill across the chosen channel, concurrently protecting with rip-rap. Lay rectangular culverts (ten culverts, 2mx2mx5m long at end of fill then continue to cart and push material across remainder of channel. Culverts have manually controlled simple flapgates at each end (20 flapgates).	Access track has to be formed to dyke location. Fill material has to be available on site. Import rock rip-rap. Operation is manual using cables to open, close and set flapgates. Consenting issues to resolve. Annual work to open spit, keep gates clear and operate gates.	\$560k	\$20k
4. Culvert into Littoral Zone	Permanent short culvert into shoreline with gates on upstream end. Four culverts, 2m x 2m x 150m long.	No annual capital works but annual O&M cost to keep outlet clear and operate gates.	\$2.3M	>\$25k
5. Culvert past Littoral Zone	Permanent long culvert into shoreline with gates on upstream end. Four culverts, 2m x 2m x 300m long.	No annual capital works but annual O&M cost to operate gates. Risk of outlet blocking and then how cleared.	\$4.5M	>\$15k
6. Canal from Mataura River	Excavate 4km x 40m x 1m deep canal from Mataura River. Dispose of fill by spreading on adjacent land. Construct rectangular culverts with flapgates for control	Control gates needed to prevent river floodwaters entering lagoon. Gates could be tidally operated.	\$2.1M	\$25k
7. Canal from Awarua Estuary	Excavate 3km x 40m x 1m deep canal from Awarua Estuary. Dispose of fill by spreading on adjacent land.	Lagoon becomes extension of estuary. May not need control gates unless saline intrusion or water level fluctuations are issues.	\$1.6M	\$25k