Engineering at Hawksbury Lagoon: identifying feasible water management options for ecosystem restoration

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Covering photo

View NW across the lagoon toward Derdan Hill (444m) with Mt Watkin (616m) in the distance from the southern end of the main causeway during water testing. The thick peg represents sampling point HKS7 and the other is the transducer used for the continuous water level recordings. The culvert to the left in the causeway is 600mm in diameter and is the main outlet from the lagoon to the estuary.

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Executive Summary

Background

1. This study investigates the technical feasibility of enhancing the water quality, habitat and recreational value of the Hawksbury Estuary/Lagoon Complex near Waikouaiti town. The study brief from the Hawksbury Lagoon Society was to focus primarily on improving water quality and achieving optimal water levels whilst minimizing the frequency of nuisance insects and odour generally.
2. It is a high level study intended to enable the community to set the direction of environmental restoration for the complex as a whole. In order to do this it brings together what is known about the lagoon that might effect hydrological management, the major issues, and a number of potential restoration approaches.
3. The wider community generally supported the Society's objectives at consultation meetings held during the study, although there was some discussion around the impact of improved water quality on water fowl habitat.
4. The lagoon is formally under the jurisdiction of the Department of Conservation to be managed as a Wildlife Reserve. It appears that changes could be made to the water management regime without contravening the reserve rules in their Management Plan.
5. To give any new water management proposals the best chance of being sustainable in the long-term, local manifestations of changes in the global climate and energy regimes already underway will need to be taken into account. Of pivotal practical significance to future water management is cumulative sea level rise due to climate change.

Lagoon-estuary complex and dynamics

6. Over the past decades, like many other shallow coastal lagoons in New Zealand, the Hawksbury Lagoon has probably been on a trajectory of change toward a wetland, primarily as a result of increased rates of sedimentation from the surrounding land once it had been cleared of forests and put under predominantly agricultural land-use. Moreover, reclamation of estuarine areas, and the partitioning of the lagoon from direct tidal exchange have together greatly reduced the tidal volumes passing over the sandbar on the Waikouaiti Beach. The ability of the lagoon to exchange with the sea would very likely have also been altered by changed sand-dune morphology and higher sand-transport rates caused by the clearance of native sand-dune vegetation through burning and grazing and more recent pine forest establishment.
7. As a result of sea level rise, these trends are expected to reverse over the next decades, with more frequent and increasingly deep tidal incursions into the estuarine part of the lagoon.

Lagoon quality

8. Following earlier studies, the lagoon itself was also found to still be in a highly degraded, nutrient-rich and turbid state, the primary causes being isolation from the natural freshwater and saltwater flushing as well as the removal of peripheral wetland habitat. In combination with elevated water temperatures, the lagoon is thus prone to algal blooms, causing low oxygen events and trophic oscillation which are not conducive to a balanced water column

fauna, including fish life. Such anoxic conditions are also often associated with odour and nuisance insect life.

Setting direction

9. The first step to developing a water plan is therefore for the community to make a considered decision between two future pathways:
   - **Retaining the current relatively isolated state of the lagoon from tidal influence.** In this case, enhancement of the lagoon would be largely limited to freshwater interventions such as, for example, increasing the volume of flushing reaching the lagoon from Post Office Creek, or artificially augmenting it with freshwater from the Waikouaiti River.
   - **Opening up either a part or the entire lagoon to more tidal influence.** In this case, there would be more regular and complete flushing of both the lagoon and the existing estuary with saline water. Rather than a ponded water body, the re-established estuary would again appear as mud flats for much of the time (behaving in a manner more akin to Blueskin Bay).
10. The recommended option is to open the southern compartment of the lagoon to tidal flow, so allowing it to revert to estuary and retain the northern compartment as a lagoon by water level control. Survey data shows that this option does not increase flooding risk to existing homes as floor levels are above peak tide and flood levels. Flooding of lawns could be prevented by the placement of low bunding at the lagoon edge, or spoil placed on the lower areas of some lawns up to about 250mm deep.

Anticipated benefits

11. Enlargement of the estuary this way will increase the tidal exchange volume, increasing the natural scouring of the inlet, and, thereby, keeping the estuary and ocean hydraulically connected more frequently and for longer periods. This would in turn, improve the opportunity for migratory fish to enter the expanded estuary, making it worthwhile to develop habitat areas suitable for fish spawning and nutrient removal in one or more of the creeks entering the complex. Less frequent mechanical breaching of the sandbar would be required so the outlet would look more natural in form.

Other restoration opportunities

12. Additional freshwater can feasibly be directed for flushing the remaining lagoon area. A range of technical options that would enable this have been identified and broadly assessed. Some of these will be simpler, cheaper and less risky than others and the cost-benefit equation varies.
13. Once more information is available on the thickness and nutrient profile of the sediments across the lagoon, the value and feasibility of sediment removal as a means to reset the system to a lower nutrient status can be considered in more depth. The formation of islands and the construction of a hide could be included as part of this process to enhance habitat, minimise excavation haulage and make more of the location as a wildlife attraction.
14. Enhanced flushing of the lagoon with fresh water will be most effective if the incoming water is lower in nutrient and sediment than is currently the case. It is recommended, therefore, that the community engages on how this might best be achieved. Because all who live in the catchment contribute in some way to the nutrient and sediment entering the

system, this process would ideally be genuinely catchment-inclusive. In this way, restoration of the estuary complex may become a catalyst and vehicle for improving local ecosystem services, a stronger community and a more pleasing local environment.

Monitoring

15. An on-going community-based monitoring programme should be undertaken in order to provide a means to measure long-term patterns of the lagoon ecosystem status and populations for birds and fish present, This information would be invaluable for refining restoration interventions and enabling the water management plan to be adaptively managed. Parallel studies into the terrestrial and freshwater fauna diversity and abundances, the sediment's anoxic status and water quality, combined with auto-logging of the weather, flows and levels will improve understanding of the trophic flux and its best management. Many measurements can easily be taken and recorded by the community, ideally with additional assistance from the University of Otago.

Review

16. Once the water management regime and programme is determined, the current planting programme should be reviewed, and potentially expanded in its spatial extent to allow the possibility of establishing more peripheral wetland area. With appropriate design, such wetlands would be multi-functional – providing habitat for birds, fish spawning, as well as filtering of lagoon water.

1 Study purpose & background

1.1 Purpose and report structure

The primary purpose of this study was to identify opportunities that could improve the water quality and restore the Hawksbury Lagoon ecosystem. This would be achieved by altering current water management practice, and, if appropriate, improving flushing of the estuary-lagoon complex. To achieve this, the study has needed to examine matters other than those of a strictly hydrological nature concerning the dynamics of flow and water level. They have included:

- Human activities that span the land/sea interface as well as the catchment
- The degree of connectedness between the estuary-lagoon complex and the sea
- Coastal processes and tides
- The condition of the complex for aquatic plants and fish
- Ecological restoration methods and trajectories
- Nuisance issues of insects and odour
- Climate change and future socio-economic context,
- Integrated catchment management techniques and outcomes
- The water quality status of the complex and the influence of land-management practices on freshwater contaminant loads
- The interests, views, and responsibilities of a range of stakeholder and agencies groups
- The social and cultural values attributed to, and provided by, the complex

Each aspect carries with it opportunities and constraints that must be weighed before identifying feasible water management options for ecosystem restoration.

The report is broadly structured as follows:
Section 1 considers the historical context and regulatory environment
Section 2 sets the bio-physical and socio-ecological context
Section 3 sets out the results of the investigation
Section 4 provides evaluation
Section 5 concludes with findings and recommendations

1.2 The Hawksbury Estuary-Lagoon Complex

Matainaka, the Maori name for the Hawksbury Estuary-Lagoon complex, is a highly modified partly-tidal water body located adjacent to Waikouaiti town and the receptor for drainage from a catchment of approximately 1,600ha. Under normal conditions, the deepest part of the lagoon itself is about 0.5m. In the past it has been a site important to Maori for mahinga kai (e.g. eel/tuna). The lagoon for the most part is highly turbid, owing to wind action keeping sediments suspended Its colour varies from green to various shades of brown. It is an important coastal habitat for birds and recreational activities are controlled through its Wildlife Reserve status.

From an ecological perspective, today the Hawksbury Lagoon complex comprises three distinct hydrological zones –

i. a western zone of former estuary now permanently converted into a **coastal lagoon** with the construction of a causeway;
ii. the remaining area of natural **estuary** and outlet located east of the causeway and mainly consisting of the eastern arm;
iii. **tidal channels** traversing the former wetland area to the north (now racecourse)

The lagoon is brackish (i.e. salinity lying between that of sea water and freshwater) with irregular water input and infrequent openings to the sea. Seawater and freshwater incursion is kept to a minimum by control gates and most surface runoff bypasses the lagoon directly to the sea. The estuary is a beach-bar type, being intermittently open or partially open to the ocean after high runoff or tidal events, or when mechanically breached. The upstream tidal channels are where the saltwater-freshwater interface occurs when the bar is open and at higher tide. This interface zone is an important aquatic habitat in estuaries and these channels represent all that is left of what would once have been an extensive network of channels and marshland.

Table 1.1 contains the areas of the various subzones of the lagoon/estuary complex compared with the pre-European extent. Note that reclamation has reduced the total area of the original estuary-lagoon-wetland by 33% to 51 ha. This area has been further split into 40ha of lagoon and 11.62ha of estuary. The estuary area that remains open to direct tidal influence is therefore only 15% of the original complex.

Table 1.1: Areas measured for different subzones of the lagoon/estuary complex compared with its pre-European extent

Area measured	Area (ha)	Percent of pre-European estuary/wetland (%)
Southern Lagoon compartment	28.3	37%
Northern Lagoon compartment	11.76	15%
Total lagoon area	**40.06**	**52%**
Existing estuary to Inverary St Bridge	11.62	15%
Total lagoon and estuary	**51.68**	67%
Former wetland/estuary (now mainly Racecourse)	25.61	33%
Total original area of estuary/wetland	**77.3**	**100%**

So while the lagoon does still link terrestrial, freshwater and marine ecosystems, it is in a much reduced capacity. On the other hand, the lagoon, with its controlled water level and isolation from the daily tidal cycle, does bring with it some alternative attributes more comparable to a shallow-lake environment, which are valued by the community (e.g. enhanced habitat for some bird populations).

1.3 Historical context

The site was a traditional food gathering location for tangata whenua, but although the Kati Huirapa Runanga retains a fishing easement today, this is rarely exercised, as the water quality and relevant biodiversity has declined. The translation of Matainaka as "the child of the minnow" highlights the former importance to Maori of the indigenous whitebait/īnanga spawning capacity in the former estuarine-wetland complex.

Oral history also records its importance as a food source of tuna (*Anguilla dieffenbachia*), lampreys, and flounder, as well as waterfowl. Sadly, oral history records well the trajectory of ecosystem degradation marked by the extensive loss of poorly-defined water courses and marshes containing "flax, tussocks, reeds of raupo and toi-toi, Maori heads and stagnant water". Interestingly, it is also recorded that it was "much fresher than it is today" - sufficiently so to be occasionally used for domestic purposes[1]. It seems likely that this would have been more to the northern end of the lagoon less influenced by the tidal cycle and at the time, serviced by extensive area of water-cleansing wetlands. Table 1.2 summarises some key management changes and human interventions that have affected the Hawksbury Lagoon.

Table 1.2: Summary of key management interventions affecting the Hawksbury Lagoon

Period	Development and management of the estuary-lagoon complex
Pre- European	Mahinga kai site for Waitaha, Hawea, Rapuwai, Kati Mamoe and Kai Tahu
European	1838 European settlement of the area began
	1860s Extensive drainage of wetlands undertaken to create arable land
	1868 Freehold title of 1.16ha set aside for Maori
	1881 – 1883 The lagoon causeways were built
	1890s Subdivision of larger coastal holdings
1888 - 1912	Under Hawksbury Domain Board
	1899, Gazetted as a Reserve for native and imported game under Animals Act
1912 - 1974	Under Waikouaiti Domain Board
	1929, Becomes a Sanctuary for Native and Imported Game
	1953, Becomes a Wildlife Refuge
	1972, Culverts installed to manage waterlevels
1974-1987	Under Wildlife Service of the Dept. of Internal Affairs
	1977, Becomes Wildlife Management Reserve
	1984, Waikouaiti Sewerage Scheme completed
1987	Under Dept. of Conservation with the Huriapa Runanga based on the draft Management Plan 1982 subject to a Statement of Management Intent
	1991 Hawksbury Lagoon Society Incorporated
1998	The Ngāi Tahu Claims Settlement Act recognized as an iwi customary fishery site and included it in the East Otago Taiāpure established in 1999

[1] J Christie, 1880

1.4 Land tenure and Management today

Currently, a number of agencies have roles and responsibilities in the management and conservation of the Hawksbury Estuary-Lagoon Complex. These include: Dunedin City Council (DCC), the Waikouaiti Coast Community Board, Otago Regional Council (ORC), Department of Conservation (DoC) and the Matainaka Trust (also known as Waikouaiti Maori Reserve Trustees), as well as the Hawksbury Lagoon Society Incorporated who commissioned this report.

There are also a range of land designations on or adjacent to the lagoon including:

- Wildlife Reserve (lagoon)
- Maori freehold land (1.16 ha of promontory jutting into the lagoon from the east)
- Recreational Reserve (golf course, sports fields and much of the racecourse)
- Local Purpose Reserve (foreshore and adjacent erosion protection forestry areas and east end of Stewart St)
- Esplanade (wildlife and esplanade reserves can overlap)
- Roading Reserve (including paper roads leading to or on the margins of the lagoon complex and notably, the inlet mouth)
- Railway Reserve (along the north-east margin of the lagoon and racecourse)
- Coastal protection zone (beach).

While DCC owns and administers land adjacent to the lagoon and the lagoon outlet, DoC has direct statutory responsibility for day-to-day management and conservation. The DCC identifies the complex as an area of "significant conservation value" in the District Plan and DoC lists it as a "regionally significant wetland" in its database of Wetlands of Ecological and Representative Importance (WERI).

The lagoon also falls under the Conservation Management Strategy (CMS) for Otago administered by DoC, although the Department does not see the lagoon as a conservation priority given its highly modified state.

Provisions in the wetland section of the ORC's Water Plan give it indirect functional jurisdiction and they appear to accept that they have responsibility for the quality and quantity of water in the Hawksbury Lagoon (Otago Conservation Board, February 2007). A change to this plan in 2012 altered slightly the boundary on the lagoon between the Coastal Plan and the Significant Wetland category.

The Hawksbury Lagoon Society is a local community initiative formed in 1991 to help protect the ecological and cultural values of the Hawksbury Lagoon now and into the future. Thus far, it has no statutory powers.

To establish administrative demarcation lines, and to secure support in principle for works that might be proposed as a result of this water management investigation, these parties entered into a Memorandum of Understanding (MOU) in March 2012. As the ORC is not a local landowner, they were not included in the agreement. This does not however absolve parties from the normal resource consent process under the ORC when works are proposed.

1.5 Opportunities, constraints and methods

1.5.1 Opportunity

The Hawksbury Lagoon Society is well placed to bring together a wide spectrum of stakeholders behind a common vision to improve the ecological, recreational, aesthetic, conservation and cultural status of the lagoon. However, it appears from the history of lagoon management that finding a satisfactory balance between the values and responsibilities of different stakeholders has been a persistent barrier to optimal outcomes.

This study, whereby ecological and hydrological considerations are brought together, provides an opportunity to align goals and reconsider the best arrangements for optimal ecological outcomes for the complex as a whole. The Society will have the opportunity to put these options before the community for their evaluation and possible adoption.

1.5.2 Constraints and limitations

This study was conceived as a scoping study, so the limited resources available have limited the scope of stakeholder engagement, research and analysis undertaken. Ideally, any ecological management recommendations made by this study would benefit from multi-seasonal and multi-annual data series in order to understand the cycles and magnitudes of natural variation in factors like water flows, flood periodicity, nutrient status fluctuations, bird & fish populations etc.

However, the hydrological, hydro-chemical and ecological status monitoring data that has been included in this study is limited in time-series length and sampling intensity (i.e. number and distribution of samples). Nonetheless, the study scope is considered to be sufficient to make sensible recommendations about the primary ecological engineering and catchment management options for interested parties to pursue.

A study with more resources would ideally undertake specific measurements of the depth, nutrient profile and bottom-dwelling animals in the sediments of both the lagoon and estuary to enable better quantification of the general findings and recommendations. The findings and recommendations of the study have had to be constrained pending the collection of more field data under the natural range of conditions and over a longer period.

A further data constraint was that existing ecological information, such as long-term bird census data, was not available. The value of bird census information would be greatly enhanced in terms of its ability to help decipher ecological cause and effect if it were collected in tandem with hydrological and hydro-chemical data in the future.

1.5.3 Methods

The main methods used for this study were:

- Literature review, including liaison with some other scientists to source material and seek peer review
- Reconnaissance of the catchment and meeting various landowners and locals with knowledge of the lagoon
- In the lagoon, estuary and creeks, water quality sampling at 14 locations on 3 occasions, and with a greater number of analyses at 4 out of the 14 locations – 2 in the lagoon and 2 in the estuary
- Stream-inflow measurements at the time of water-quality sampling
- Level survey-lines from the coast northwards - up the estuary and lagoon, and westwards into the Waikouaiti catchment, to determine relationships between water and ground level
- Continuous logging of water levels in the lagoon for a period of 3 months to compare with tides and rainfall
- Estimating annual runoff and flood flows for the catchment
- Facilitation of two meetings with the community to outline proposals, identify values and report on findings
- Collation of information on local rainfall, groundwater and soils
- Examined model effects of catchment land-use options on freshwater nutrient loading

Summary Box 1
There are a wide range of groups with different interests in, and associations with, the Hawksbury Lagoon both formal and informal. This means some of the issues raised in this report will require a planned process of consultation with a view to establishing a collaborative course of action.

1.6 Regulatory description

1.6.1 Lagoon

Both the Otago Regional Council and the Dunedin City Council formally describe the Hawksbury Lagoon as "regionally significant".

The ORC describe it as a "shallow fresh-brackish lagoon" classed as saltmarsh and 43.3ha in area (Centre E1418600 N 4947400). They record the following values:

- High degree of naturalness
- Scarce in Otago in terms of ecological and physical character
- Highly valued by Kai Tahu for mahinga kai and other waahi taoka (traditional harvesting site for eeling and whitebait and water fowl)
- High diversity of indigenous and exotic fauna. e.g.: White Heron (*Egretta alba modesta*), White-faced Heron (*Ardea novaehollandiae novaehollandiae*), Royal Spoonbill (*Platalea*

regia), Pied Stilt (*Himantopus himantopus*), Black Swan (*Cygnus atratus*), Grey Teal (Anas gracilis), New Zealand Shoveller/Kuruwhengi (*Anas rhynchotis variegata*), Grey Duck (*Anas superciliosa*), Arctic Waders, eels and galaxiids.

- Regionally significant habitat for waterfowl, including nationally threatened and uncommon birds (Wildlands Consultants, 2009).
- 121 plant species have been recorded: 43 local natives and 5 non-local natives, the remainder being exotic. Two species are classified as nationally uncommon. (Wildlands Consultants 2009)
- Freshwater species recorded include eels, inaka (*Galaxias maculates*) and bully (Gobinomorphus sp.)

Figure 1.1 illustrates the wetland boundary in the Regional Plan Water - updated 2012 - to include estuary in the top right corner, most of the central causeway and a wetland area in the top left, but excludes the east arm of the estuary.

Figure 1.1: Hawksbury Lagoon showing the boundary which defines it as a Wetland in the Regional Plan: Water

Source: ORC database on significant wetlands.

Much of the estuary zone is defined in the Regional Plan Coast as a Coastal Protection Area. This is shown on Figure 1.2 below.

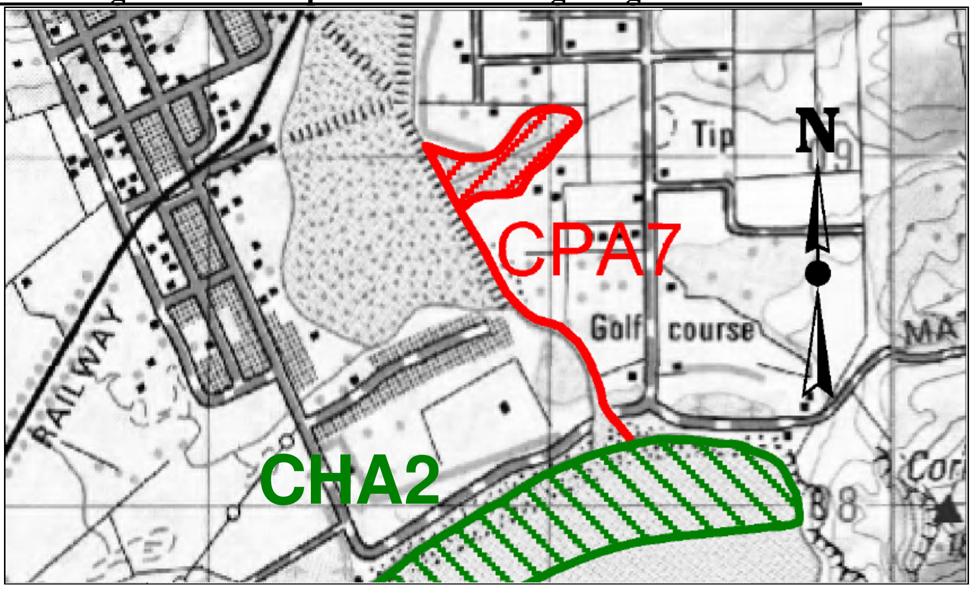
1.6.2 Estuary

For planning purposes, the estuary falls under the Otago Regional Plan: Coast which was updated on 1 January 2012 and is defined as a Coastal Protection Area (CPA). Figure 1.2 shows the extent of that area and its association with the Coastal Hazard Area (CHA). They are described thus

- CPA7– Hawksbury Inlet – Kai Tahu cultural and spiritual values, estuarine values which include a habitat for a large number of wading birds and water fowl. All estuarine areas along Otago's coast have been included in the coastal protection area because they are particularly valuable in terms of biological productivity.
- CHA Coastal Hazard Area – Waikouaiti to Karitane, sandy beach erosion (beach and roads at risk)

Coastal Protection Areas are identified on the basis of their biological, physical or cultural values. In considering applications for activities within or adjacent to any coastal protection area, priority will be given to avoiding adverse effects on the values recognized with the area.

Figure 1.2: Management areas specified in the Otago Regional Plan:Coast



1.6.3 East Otago Taiapure

A Taiapure is a management instrument which can be established in a local area that has been of special significance to iwi or hapu as a source of food or for cultural purposes. It can be set up over any area of estuarine or coastal waters with the objective to "make... better provision for the recognition of rangatiratanga (or soverignty) and for the right secured in relation to fisheries under Article Two of the Treaty"[2].

The East Otago Taiapure was established in 1999 and imposes fishing rules over the area shown in Figure 1.3 below. The area extends as far north as Cornish Head opposite the Hawksbury Lagoon.

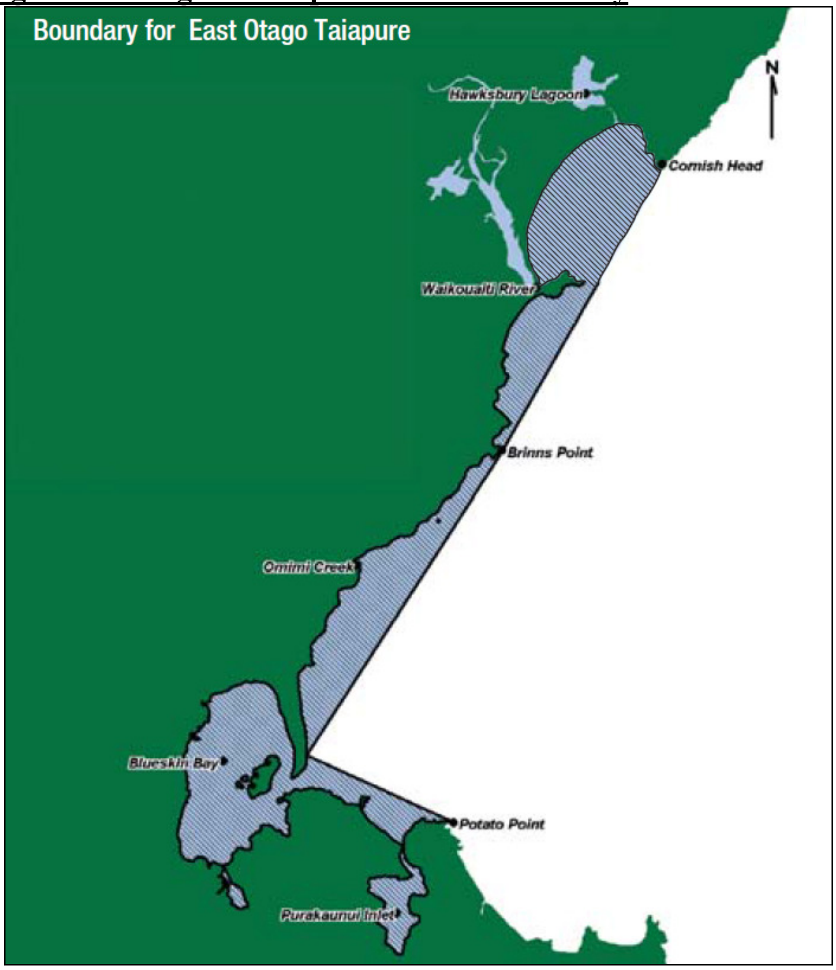
The management committee can provide advice and recommendations to the Minister of Fisheries for regulations concerning the conservation and management of the fish, aquatic life, or seaweed to manage the fisheries in the taiapure area more sustainably[3]. The local committee

[2] Fisheries Act 1996
[3] Ministry of Fisheries, 1 October 2010

comprises representatives from Kati Huirapa Runaka Ki Pueteraki, Karitane Commercial Fishermens Coop, Otago University, River - Estuary Care: Waikouaiti-Karitane and the East Otago Boating Club.

While the Hawksbuy lagoon is not included in the Taiapure, the estuary discharges into it on the Waikouaiti Beach. This means that any management changes in the Hawksbury need to consider their potential to affect the fisher or its suitability for human consumption.

<u>Figure 1.3: East Otago Coastline between Purakanui Inlet on the Otago Peninsular and the Hawksbury Lagoon showing the Taiapure seaward boundary</u>



Source: Ministry of Fisheries, 1 Oct 2010

Summary Box 2
The range of values formally assigned the Hawksbury Lagoon complex, the status of the lagoon as a wildlife reserve and its situation adjacent to the Taiapure supports a primary focus on improving the quality of the location as a healthy wildlife habitat is consistent with the planning provisions.

2 Bio-physical and socio-ecological context

2.1 Catchment, geology and soils

2.1.1 Catchment configuration and drainage

The Hawksbury catchment comprises three broad geomorphological units – steep coastal hills, rolling downlands and coastal floodplains, plus recent terraces, including the estuary complex and adjacent sand-dunes. Two distinctive volcanic cones, rising to 444m and 312m respectively located along the northern boundary, dominate the relief and determine that the drainage system will be south to the coast (Figure 2.1).

Figure 2.1: The Hawksbury Lagoon/Estuary catchment

On the upper slopes of the volcanic cones remains one of the last remaining substantial stands of mature broadleaf trees so close to the East Otago coast and clearly visible from SH1. These cones also form a rather steeply-descending and short catchment, making the estuary complex prone to flash flooding and therefore, also to siltation sourced largely from loessial soils.

There are effectively four creeks draining into the lagoon from the catchment – two are unnamed and the other two are branches of Post Office Creek which join just prior to passing beneath the Inverary St bridge and entering the estuary proper. More details regarding these tributaries are provided in Section 3.1.3.

The present day outflow from the estuary is via a channel approximately 15m in width and 450m in length.

The early settlers described the flood plains of the Waikouaiti River area as being swampy and covered with flax and rushes. Contemporary land-use is predominantly pastoral grazing of sheep, deer or cattle.

2.1.2 Geology

There are two practical reasons for examining the geology of the area:

i. As a basis for assessing groundwater potential
ii. An understanding of the evolutionary processes that have formed the coastal landscape to assist in predicting how changes might be experienced in the future with the likes of rising sea levels

The geology of the area is shown on Figure 2.2, and described with more detail in Appendix E. In summary, there are five broad geomorphic units listed, typically in order of increasing depth:

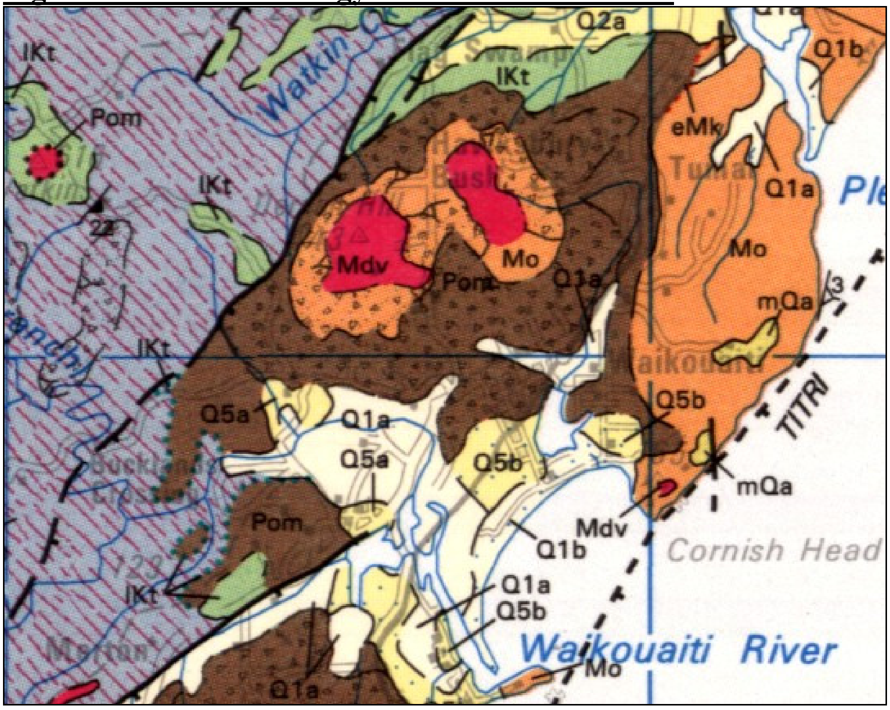
Geomorphic unit	**Map Symbol**
The recent Quaternary sediments on the coast (in which the lagoon lies)	Q1b, Q2a, Q3a, Q5a/b, mQa,
The volcanics which have penetrated the Tertiary marine sediments to form the cones around basalt plugs	Mdv (red)
The Tertiary sediments themselves formed in a marine environment	Mo, (orange) Pom (dark brown)
The Tertiary sediments formed in a freshwater environment	lKt (Green)
The Otago Schist Group basement	Hs (purple)

The Tertiary sediments (pre-Quaternary Cenozoic sedimentary rocks) have down-faulted along the coast with a regional dip to the south-east at about 5 degrees based on exposures at Conish Head. Mantling these units on stable areas of the coastal hills and below about 90 masl. are extensive loessial deposits (i.e. wind-blown dust) which may be up to 7m thick[4].

The groundwater potential of the individual formations and groups is discussed in Section 4.2.5 and the relationship of the geology to the soils is discussed in the following section.

[4] Soil Bureau of the DSIR, (1977)

Figure 2.2: Plan of Geology of the Waikouaiti area



2.1.3 Soils

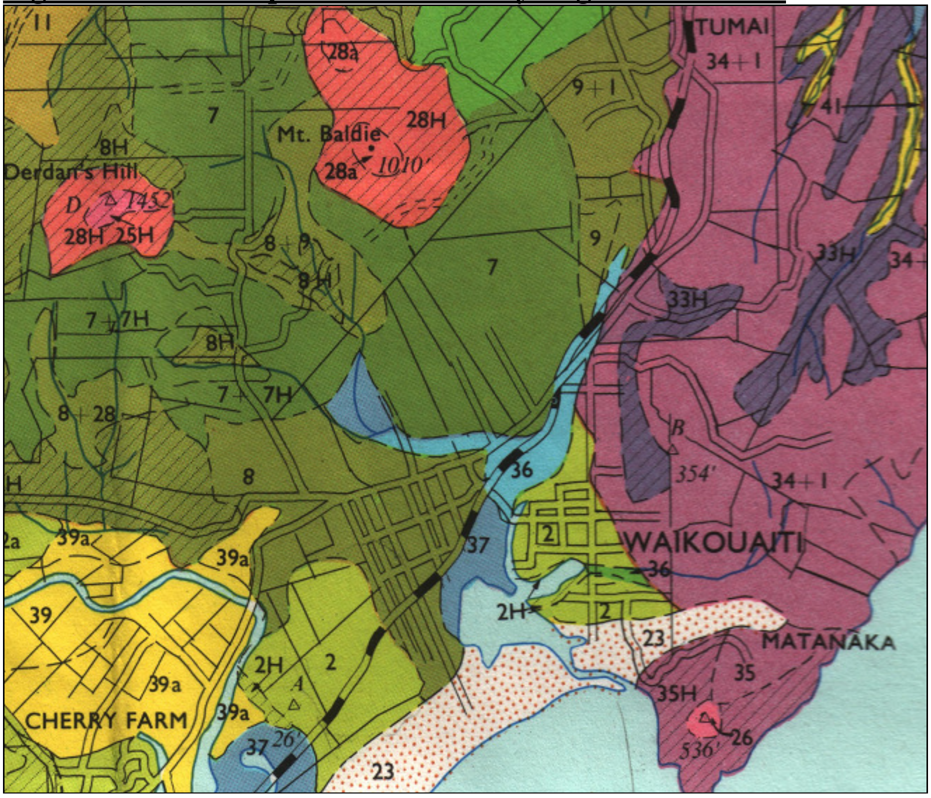
The major soil types found in the Hawksbury Lagoon catchment are shown on Figure 2.3 with a short legend. An expanded legend that summarizes the key properties of these soils relevant to this assessment is shown in Table G1, Appendix G. The close relationship between the geology and the soils that form on the different geological units is also evident from the table and by comparing Figures 2.2 and 2.3.

The pattern of soils provides clues to the hydrological regime and the nature and distribution of different forms of native vegetation cover that prevailed prior to human settlement. This information is an important factor useful in plant selection for any re-vegetation programme. Points to note from the soils map are:

- The splitting of the original lagoon-estuary complex (including the current racecourse area) into 3 distinct areas:
  - the lowland gleyed *Evansdale silt loam* (36) area originally with "rush type" native vegetation cover
  - the lowland gleyed *Kaikorai peaty loam* (37) with a native vegetation of "salt-tolerant swamp vegetation" (e.g. Salicornia) and estuarine alluvium parent material
  - the flooded estuarine area nearest the coast
- The extent to which the poorly drained *Evansdale soils* extend up Post Office Creek to upstream of SH1, suggesting poorly drained/wetland conditions were present here
- The general susceptibility of the soils formed on the marine mudstones (Burnside and Abbotsford Formations) to earth flow and slumping on the rolling land to the north and west of the lagoon and the erodible loessial mantle.
- The distinct and fertile soils formed on the sandstones of the Matanaka farm to the east, part of which drains into the estuary zone via its eastern (Tip) arm.
- The *Brighton sand* (23), formed by wind-blown beach and dune sand, extending as far inland as Stewart St and forming the southern shoreline of the lagoon.

The significance of the soils for catchment management is discussed in Section 3.3.

Figure 2.3: Soils map of the Hawksbury Lagoon catchment



Source: Soils of Waikouaiti County, Otago 1977, Bul 37 DSIR

Soils Legend

2 - Merton silt loam
2H - Merton hill soils
7 - Waerepa silt loam
8 - Abbotsford silt loam
9 - Omimi heavy silt loam
23 - Brighton sand
25H - Saddle hill soils
28a - Cargill loam
28H - Cargill hill soils
34 - Waikakahi clay loam
35 - Karitane heavy silt loam
35H - Karitane hill soils
36 - Evansdale silt loam
37 - Kaikorai peaty loam

Summary Box 3
An understanding of catchment topography, underlying geology and soils provides the physical basis for the hydrological assessment

2.2 Socio-ecological history of a shallow coastal lagoon

2.2.1 Impacts of extensive human land-use and settlement

The hydrology and geomorphology of the lagoon-estuary complex and its feeder catchment have been fundamentally, massively, and irreversibly altered. For example, the reduction in estuary/wetland area by 85% since 1866 and the isolation of the lagoon. These physical properties and processes are the drivers of ecological type and pattern in wetland ecology, and the extent of human-induced changes means that thresholds have been passed that will be a challenge to reverse - politically, socially, financially and logistically. For example, much private property exists where ecological restoration should ideally take place (e.g. lower parts of house gardens bordering the lagoon) – if, that is, ecological restoration were to take precedence over all other values. It is now a question of balancing competing values attached to different land-uses.

Coastal lagoons and estuaries are vulnerable to pollutants as they naturally trap sediment. As freshwater becomes more salty, the sediment tends to flocculate and settle. Plants and animals in estuaries can adapt to rates of sedimentation of up to a few mm/yr but if the rates rise to 25 to 30 mm/yr can, they can substantially reduce the diversity and abundance of sediment-dwelling organisms which are vital to the maintenance of a healthy water-column, and sedimentation rates can be so high as to even fillin an estuary within a short period of time[5]

2.2.2 Current ecological status

2.2.2.1 Regime oscillation

For several decades now, the lagoon has periodically undergone the processes of 'flipping' into a hyper-trophic nutrient status via the following summarised sequence.

Raised turbidity levels (suspended bottom sediments) lead to low light levels, suppressing sediment-rooted plants, and causing higher nutrient concentrations (particularly the limiting nutrient – phosphorous) Excessive algal growth results, leading to amounts which cannot be sustained. Then, the large amounts of dissolved oxygen used to decompose the algal biomass leads to toxically low oxygen conditions for many organisms, and thus a reduced faunal diversity. The cycle eventually returns to a more stable clear-water, lower nutrient status. A good scientific summary of this phenomenon, well known from studies of shallow coastal lagoons throughout NZ, and internationally, can be found in Schallenberg and Sorrell, 2009.

This flipping, or 'regime oscillation is undesirable for both the community members living around the lagoon and biodiversity alike. There is evidence that regime shifts in lakes were unlikely to have been so common in New Zealand shallow lakes before widespread anthropogenic deforestation and introductions of non-native aquatic taxa occurred[6].

2.2.2.2 Residual nutrients held in sediments

The effects of residual nutrients held in sediments can cause on-going release of nutrients from sediments, particularly phosphorous. A review of the literature in Restoration Ecology and Ecological Engineering peer-reviewed journals showed that this problem is repeatedly identified in shallow lake restoration attempts. In one Netherlands case, such issues persisted for 10 years after improvements in input water quality[7]. Another meta-analysis of the restoration of 15 shallow lakes in the Netherlands[8] cites removal of the organic sediment layer as being a successful restoration technique to hasten improvements in water quality.

Further investigations might therefore include surveying the depth of high-nutrient source sediments so as to estimate the cost and potential spoil volumes for the sediment removal restoration mechanism. We suggest that this option be given serious consideration, with the option of spoil being used to establish islands in the lagoon, provided appropriate measures are taken to prevent residual nutrient in those sediments from re-entering the lagoon. Any enhanced nutrient leaching reaching the ocean is likely to be for a limited period and unlikely to have significant adverse effect given the large dilution and dispersal factors.

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[5] Tasman District Council. 2008
[6] Schallenberg et al, 2009
[7] Brouwer and Roelofs, 2001
[8] Bootsma et al, 1999

2.2.2.3 Connectivity to fresh and saltwater

A major factor determining the current water quality and trophic state of the lagoon is its isolation from fresh and salt water.

The Hawksbury Estuary is more often mostly or completely closed to the ocean than it is open. The lagoon is even more hydrologically isolated from the sea than the estuary. This isolation, and the wide fluctuations of physico-chemical factors, influence the estuarine communities in various ways, in particular the species composition and their relative abundances. Freshwater inflow is similarly limited, and the rate of freshwater inflow also has a major influence on community structure and diversity.

Thus, the closure status of estuaries plays an important role in estuarine community structure, tending to increase invertebrate density and decrease fish numbers. Conversely, opening a lagoon has been found to increase plankton diversity, drastically altering the food chain. Species diversity has been found to be highest in some permanently open estuaries[9] A New Zealand study supported the view that altering the open/closed status of an estuary will have significant impacts on estuarine community structure and composition[10].

Summary Box 4

While the hydrology and the geomorphology of the lagoon-estuary complex are highly modified, there is the scope to improve the ecological functioning and diversity by appropriate alteration to the hydrological regime. If there is a feasible method of improving the connectivity between the ocean and the complex, the balance of evidence suggests that there will, in time, be significant changes in the ecology.

2.3 Native and introduced flora and fauna

2.3.1 Waterfowl – resident and transitory

The Hawksbury Lagoon currently provides feeding, breeding and moulting habitat for a wide range of resident and migratory wading birds and breeding waterfowl which varies seasonally and inter-annually. Together with other coastal lagoons in Otago and South Canterbury it forms a network of staging points for migratory and, for some species, over wintering sites.
A full list of the species recorded at the lagoon by various past studies is provided in the Ecological Management Plan for Hawksbury Lagoon (Wildlands 2009). A significant number of the bird species have an at risk or threatened[11] conservation status according to the national threatened species classification system.

The Hawksbury Lagoon is notable for its bird abundances, particularly grey teals, ducks, N.Z. shoveller and pied stilts. It is a significant location for maintenance of N.Z. shoveller populations regionally.

[9] Teske & Wooldridge (2001) quoted in Lill et al, (March 2011)
[10] Lill et al, (March 2011)
[11] Wildlands, 2009

Niches available include for herbivores, piscivores, zooplankton feeders (e.g. Shoveller), benthic dredgers, macrophyte grazers, sievers, open water dwellers and edge swamp dwellers. So, clearly different birds prefer different habitats; for example swallows and some shallow water waders favour areas of exposed mud, yet such low water levels are unfavourable for other species, such as stilts. Further, black swans favour better water quality and have been observed to relocate when their food source diminishes during hyper-trophic episodes, returning again when the water quality improves, whereas other species of wildfowl prefer higher nutrient status.

2.3.2 Fish species – resident and transitory

There is no baseline data on fish species in the Freshwater Database for the Hawksbury Lagoon and tributaries held by NIWA. However, a 1996 gill-net survey of 18 shallow South Island lakes found fish populations in the Hawksbury Lagoon to be among the lowest[12].

Conditions like high water temperatures, high nutrient load and low oxygen levels may be associated with droughts. Most species would find such conditions in the lagoon difficult to tolerate, with the possible exception of bullies where they can withdraw to crevices in the likes of embankment rubble. Low water levels also make fish generally more vulnerable to predation both from above and below the waterline. Seeking refuge in tributaries at such times is probably an important survival strategy.

Diadromous fish like the yellow-eyed mullet will occupy the estuary and tidal reaches of tributaries for periods of the year or even enter and exit with the tide on a given day. Other species such as tuna, giant kokopu and flounder may be resident for years.

Inanga have been observed in the Post Office Creek within the past 5 years. According to DoC the native and introduced species in the left hand column of Table 2.1 are either known to be present in the complex or are potentially resident or transitory. The other two columns list some unwanted or potential pests which are not yet known to be present. Tench are known to be in the Waiareka Creek and Island Stream in North Otago[13].

Table 2.1: Native and introduced fish species that have been observed in the Hawksbury Estuary-lagoon complex or which might survive in this type of habitat

Native and introduced species	Unwanted	Potential pests
• Longfin eel (tuna)	• Perch	• Goldfish
• Shortfin eel (tuna)	• Tench	• Rudd
• Inanga		
• Flounder (black)		
• Common bully		
• Common smelt		
• Yellow-eyed mullet		
• Giant or banded kokopu		
• Brown trout		

[12] Dept of Zoology, Otago University, 1996.
[13] Pete Ravenscroft, DoC (per com)

2.3.3 Midges

The aquatic midge (from the family Chironomidae) do not bite, suck blood, or carry disease. They have four stages in their life cycle. These stages are the egg, larvae, pupae, and adult. The eggs are laid in a mass on the surface of water – often man-made lakes and reservoirs[14]. After hatching, the larvae feed on the gelatinous material that encloses the eggs for about 2 days and then leave the egg mass.

The larvae then migrate to the mud where they live and feed on suspended matter in the water and organic matter in the mud. The larvae then pupate while they undergo metamorphosis. The emerging adults usually hatch and swarm at night to mate. Adults do not feed, and, consequently, normally only live for about 3 to 5 days. The entire life cycle of the aquatic midge is usually completed in 2 weeks. At night they are attracted to lights and during the day, to cool shady places.

Source control of Chironomid midges is impractical for reasons of expense and ecological impact as it requires treatment of the entire water volume with insecticide. Likewise, control of the adult by insecticides is not practical because of the brief adult life span, cost and resistance[15]. It is relevant to remember that midges are also an integral part of the aquatic food chain. Birds prey on adult midges, and both larvae and adults can be important as fish food. Creating bright light spill between the midge source and homes or trees and shrubs as alternate resting sites are practical options for nuisance reduction.

At the root of the problem is that aquatic midges are among the most tolerant freshwater invertebrates to anoxia which is why they tend to dominate the aquatic insect larvae of eutrophic lakes and can breed in large numbers under these conditions. As nutrients increase, the available food increases and aquatic midge populations increase[16] rapidly. Therefore, any intervention that helps avoid the hyper-trophic state should help to reduce midge numbers.

2.3.4 Flora and planting

As sea level rise increasingly impacts the lagoon-estuary complex, attention can be given to adapting the lower lying margins when the hydrologic regime in this zone changes either from pasture to wetland, wetland to estuarine, or, lagoon to estuarine conditions. If the opportunity is provided, there is no reason why plant species should not migrate landward as sea level rise occurs. Land access, land topography and the likely rate of inundation are therefore factors that will need further consideration.

Summary Box 5
Changes in the composition of the estuarine community can be expected to influence the other wildlife it supports above the waterline. Further work would be needed to take maximum advantage of the associated opportunities.

[14] Bay, E.A., (2003)
[15] Bay, E.A., (2003)
[16] Lake County Florida website http://www.lakecountyfl.gov/

2.4 Climate change and sea level rise

2.4.1 Climate change projections

The most recent scientific consensus on climate model projections were summarized in the 2007 Fourth Assessment Report (AR4) by the Intergovernmental Panel on Climate Change (IPCC). They indicated that during the 21st century the global average surface temperature is likely to rise a further 1.1 to 2.9 °C for their lowest emissions scenario and 2.4 to 6.4 °C for their highest[17]. To put this into context, the average global land and sea temperature during the 20th century was 14.0°C.

In New Zealand, mean air temperatures at sea level range from about 11 to 16°C, and have increased by an average of 1.0°C over the period 1855 to 2004, and by 0.4°C since 1950[18].

Among a range of predicted effects of such a temperature rise is an increase in climate variability. Such variability is likely to be manifested as an increased frequency of extreme weather events and a change in the amount and pattern of precipitation (predicted to generally decline on the east coast of the South Island). This climate variability will be accompanied by a rise in mean sea level. Not only is sea level change a key climate indicator, it is also predicted to be one of the more disruptive effects of climate change to human society and nature.

2.4.2 Sea level rise

The IPCC (2007) projected sea level rise by the end of this century to be about 29 cm (midrange 20-43 cm, full range 18-59 cm). These projections did not include contributions from ice sheet dynamics, on the grounds that ice sheet physics (loss of polar ice sheets) is not understood well enough. They also recommended that for planning beyond 2100 a rise of 10mm per annum be assumed.

Based generally on these IPCC recommendations, the Ministry for the Environment currently recommends for planning timeframes to run until 2090–2099

> *"a base value sea-level rise of **0.5m relative to the 1980–1999** average be used **along with** an assessment of potential consequences from a range of possible higher sea-level rise values. At the very least, all assessments should consider the consequences of a mean sea-level rise of **at least 0.8m** relative to the 1980–1999 average"*[19].

Councils are obliged to respond because the New Zealand Building code requires that residential buildings should remain above the flooding level for a minimum of 50 years. In addition, the Resource Management Act 1991 includes responsibilities with respect to natural hazards.

[17] Meehl et al, IPCC, 2007
[18] http://www.mfe.govt.nz/issues/climate/adaptation/sea-level-rise.html
[19] http://www.mfe.govt.nz/issues/climate/adaptation/sea-level-rise.html

2.4.3 Climate Change policy on sea level predications

Guided by the above national policy and subsequent scientific information, in 2011 the DCC adopted a policy to plan for a 0.3m rise by 2040 and 0.5 – 1.6m rise by 2090[20].

In 2012, DCC raised the height required for minimum floor levels in coastal areas. The estimation when planning out to 2060 (50 years) comprises three elements which are accumulated above the mean level of the sea (MLOS being 100.1) to give the minimum floor level at any given location. These are:

1. **A Base Level**, which adds to the mean level of the sea the predicted astronomical tidal range or storm surge event (whichever is the higher -including barometric effects), plus a freeboard height [This is 100.1 MLOS + 2mTidal Range + 0.3m freeboard giving a minimum level allowance of 102.4m, OMD]
2. **A Climate Change Effects (CCE) Factor** relevant to a building project. In the context of this report CC effects are the increases in effects from that currently experienced today eg greater storm surge or rainfall intensity, as well as sea level rise (see MfE 2008) [i.e. 102.4m + 0.5m takes it to 102.9m,OMD)
3. **A Local Adjustment (LA) Factor**, which takes into account additional factors such as tsunami events, greater expected building life, local erosion, backwater, and coastal exposure effects[21] that can together be negative or positive. [i.e. 102.9m OMD + or – for the LA]

For Waikouaiti, a negative LA factor has been applied, bringing the required new level down from 102.9 to 102.65m (OMD) or 2.65m (Dunedin Vertical Datum, 1958). This level will be the minimum floor level required for all new resource consents for houses and communal residential and communal non-residential buildings - but not to commercial or industrial buildings.

The area of residential development where future homes would need to comply with this new regulation is shown on Figure 2.4 . From the survey data obtained by this study, the floor levels of some existing homes are below 2.65m Dunedin Datum (Refer to Longsection A in Appendix H).

For planning beyond 2060, the DCC propose that the CCE factor should be increased by 10 mm per year for every additional year. This is consistent with the Council's Climate Change Policy 2011 and results in a maximum allowance for Climate Change of 0.9m by 2100.

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[20] Montgomery Watson Harza, 2012
[21] Montgomery Watson Harza, 2012

Figure 2.4: Areas at the south end of the Hawksbury Lagoon affected by new local body minimum floor level policy

2.4.4 More recent science around sea level rise

Examples of various estimates of sea level rise that have been made by scientists are shown in Table 2.2 below. They show considerable variation and there is a tendency for more recent studies to adopt higher upper bounds.

Table 2.2: Various examples of estimates of global mean sea level rise by 2100 since the IPCC predictions[22]

Source	Projected sea level rise by 2100 (metres)
Rahmstorf (2007)	0.5 - 1.4
Horton (2008)	0.5 – 1.0
Pfeffer (2008)	0.8 – 2.0
Vermeer (2009)	0.8 – 1.9
Grinstead (2009)	0.3 – 2.2
Jevrejeva (2010)	0.6 – 1.6

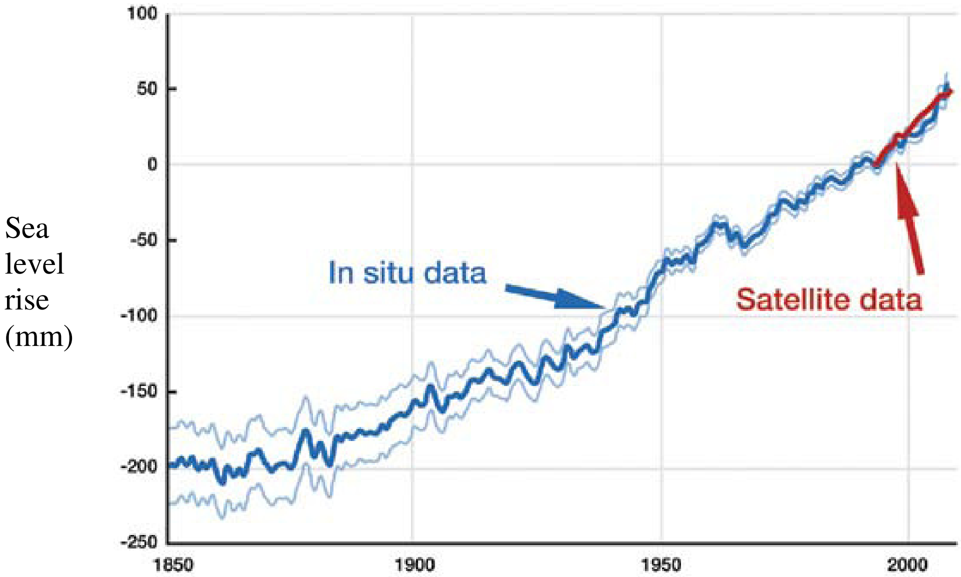
Uncertainty still surrounds the rate of acceleration of mean sea level change attributable to this mass fresh water exchange with the land[23] as melting ice mixes with sea water. Actual

[22] Royal Society of New Zealand. (2010)
[23] Royal Society of New Zealand. (2010)

monitoring results reveal melting rates are following a path close to the highest rates predicted by the IPCC and accelerating. Figure 2.5 shows this trend[24].

Figure 2.5 shows global average sea level since 1850– a total of about 250mm so far - coinciding with the period of fossil fuel combustion at increasing rates. The solid blue line is estimated from coastal and island tide gauges and the red line is sea level measured by satellite altimeters. From 1900 to 2000 the average rate of rise was about 1.7 mm/yr, increasing through this period. Since 1993 the average rate of rise measured by satellite altimeters has been about 3.2 mm/yr and from tide gauges about 3.0 mm/yr.

Figure 2.5: Global average sea level rise (1850-2010)



by According to climatologist James Hansen (NASA), the key issue in sea level rise is whether the response will be linear or non-linear. He argues that amplifying feedbacks make ice sheet disintegration necessarily highly non-linear, and that IPCC's "business-as-usual" climate forcing is so huge that it is likely that ultimately the polar ice shelves will eventually melt entirely. He suggests an acceleration rate with a 10-year doubling time was plausible - equivalent to 7% compound annual rate of increase. He pointed out that such a doubling time would lead to a one meter sea level rise by 2067 and five meters by 2090[25]. Figure 2.6 below illustrates that projection.

Recent work by scientist Stefan Rahmstorf suggests that it is the rate of ice sheet loss that increases with temperature not the total amount[26]. NZ scientist Martin Manning considers this means that if temperature rises linearly, sea level will rise quadratically and therefore linear extrapolations of current annual rates of sea level rise are inappropriate. He has further

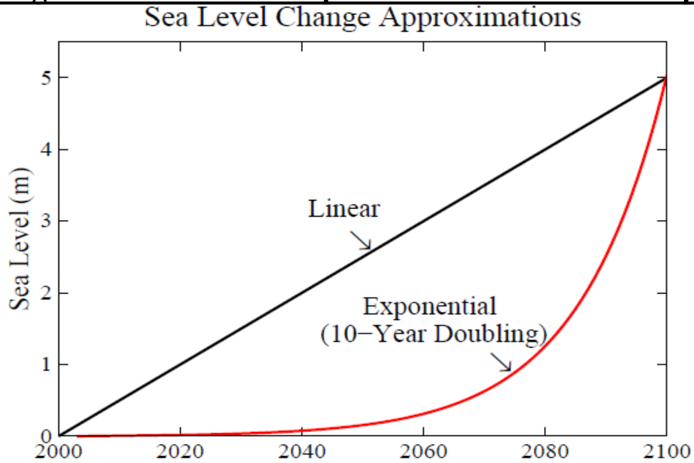
[24] Australian Academy of Sciences (August 2010)
[25] Hansen, J.E., and M. Sato, (2012)
[26] Rahmstorf, S. et al (2007)

suggested rise may occur in "jumps" (e.g. perhaps 0.3m a decade) due to the calving of destabilized chunks of the West Antartic Ice sheets and possibly climate oscillation[27].

The DCC identifying an upper bound of 1.6m rise by 2100 is an allowance for this uncertain acceleration rate but as indicated above, even the most recent DCC policy does not actually plan above a 0.9m rise by that time.

Considering both the estimates made by researchers post the IPCC 2007 report (Table 2.2), as well as the exponential model proposed by Hansen (Figure 2.6), it may be inferred that level rise could be significantly greater than current national and local planning policies envisage, and than even the most recent DCC policy changes accommodate. The limited sea level rise measured in NZ to date[28] appears more consistent with the non-linear response curve than the linear one.

Figure 2.6: Comparing a linear sea level response with a non-linear response curve[29]



2.4.5 Implication for water management of the Hawksbury complex

Based on the above evidence, for the foreseeable future sea level rise will increase the elevation, exchange volume and frequency of tidal events impacting the estuary-lagoon complex.

As a result, the complex will become more vulnerable to flooding and erosion from waves and swell, wind generated storm-surges, king tides and extreme rainfall events - making it increasingly difficult to continue artificial control of the lagoon water levels and to prevent flooding of the lagoon and low-lying property generally. Given this trend, it is inevitable that eventually a decision will be made to allow the lagoon to revert to estuary.

Higher mean sea level will also cause the freshwater/saline groundwater interface to migrate inland, affecting the quality of the lagoon. The reclaimed areas to the north of Inverness St (i.e.

[27] Manning M, 2012 (per com)
[28] Hanah J. (June 2012)
[29] Hansen, J.E., and M. Sato, (2012)

the racecourse) will become increasingly boggy (as a result of the combined effect of a rising groundwater table and capillary rise) well before the area is permanently inundated.

2.4.6 Ranking of coastal vulnerability

A number of variables can be used to assess the vulnerability of a range of coastal environments to sea level rise. Table 2.3 below sets out one example which shows that sand beaches, estuaries and lagoons are among the more vulnerable zones on the index. On this basis, it is perhaps surprising that the Local Area Factor in the DCC minimum floor level calculations (Section 2.4.3) is not positive. The ORC has reported on community vulnerability to elevated sea level from tide, storm surge, wave set-up, run-up and tsunami events, but under current sea level[30].

Table 2.3: Ranking of coastal vulnerability index variables for the U.S. Pacific Coast[31]

	Ranking of coastal vulnerability index				
	Very low	Low	Moderate	High	Very high
VARIABLE	1	2	3	4	5
Geomorphology	Rocky, cliffed coasts Fiords Fiards	Medium cliffs Indented coasts	Low cliffs Glacial drift Alluvial plains	Cobble beaches Estuary Lagoon	Barrier beaches Sand Beaches Salt marsh Mud flats Deltas Mangrove Coral reefs
Coastal Slope (%)	> 1.9	1.3 – 1.9	0.9 – 1.3	0.6 –0.9	< .6
Relative sea-level change (mm/yr)	< -1.21	-1.21 – 0.1	0.1 – 1.24	1.24 –1.36	> 1.36
Shoreline erosion/ accretion (m/yr)	>2.0 Accretion	1.0 –2.0	-1.0 – +1.0 Stable	-1.1– -2.0	< - 2.0 Erosion
Mean tide range (m)	> 6.0	4.1 – 6.0	2.0 – 4.0	1.0 –1.9	< 1.0
Mean wave height (m)	<1.1	1.1 – 2.0	2.0 – 2.25	2.25 –2.60	>2.60

Summary Box 6

The most reliable science available indicates a warming and more unpredictable climate regime for the foreseeable future. Due to thermal expansion, and ice melt and calving, the effect will be to raise the surface sea level which in turn will cause more frequent inundation of the Hawksbury Lagoon complex. This means that any natural trend in the complex toward a wetland over recent centuries as a result of sedimentation will be reversed. The least risk and least cost response would be to adopt a management strategy based on this expectation.

2.5 Community consultation and goal setting

During the study two public meetings have been held by the Hawksbury Lagoon Society Inc to inform the community, to seek feedback on the progress of the project or to report back on key findings.

[30] ORC, 2012
[31] U.S.Geological Survey, National Assessment of Coastal Vulnerability to Sea-Level Rise: Preliminary Results for the U.S. Pacific Coast

2.5.1 April 2011 Workshop

The first, independently facilitated meeting was held on April 1 2011. A leaflet had been mailed out to the wider Waikouaiti community some days beforehand with a flyer outlining the project objectives, the general approach being taken to the study and the constraints to altering the existing lagoon water management regime.

The three primary questions were:

1. *What aspects of the lagoon do you really appreciate?*
2. *What aspects of the lagoon concern you or do you dislike?*
3. *What do you think needs to be done to improve it?*

We also sought feedback on:

- *Whether the attendees considered that the objectives for the study covered all the important needs*
- *Any changes they had noticed in the lagoon (for better or worse)*
- *If they held any information that might assist the investigation*

After brief presentations on the hydrology, ecology and ornithology of the lagoon complex, half a dozen breakout groups were formed to consider the three key questions and report back. The main findings included:

- Improving water-level control and avoiding flooding rates were of greatest concern
- This was followed by a wish for improved breeding habitat for birds and more integrated research and management
- There was a general wish to get to the bottom of the contamination and water quality issue
- The community appeared open to considering islands, wetlands and other ways to improve the overall quality of and access to the lagoon
- Wish to see further plantings including for birds other than water fowl
- Pest control

As the approximately 30 persons who attended the meeting is a small proportion of the total community, more weight has been given to the range of suggestions than the ranking of their relative importance. A fuller summary of the consultation process may be found in Appendix B.

2.5.2 November 2011 Preliminary report back to the Community

A brief outline of the main findings of the study was provided. The following is a list of topics which arose during the subsequent discussion:

- Timing and frequency of the breaching of the sandbar on the beach
- Difference in the water quality between the lagoon and the estuary and between the runoff and the lagoon
- Toxicity risk from the former and existing landfill sites
- Possible reasons for loss of some new plantings at the north end of the lagoon
- Practicality of floating islands

- Nutrient status of the sediments
- Best split between flow for estuary and flow for lagoon from Post Office Creek
- Quantification of climate change and relevance to any work on Hawksbury
- The option of managing the lagoon in two or more zones
- Ways to improve flushing facility in the inlet
- Need to review of planting areas and fencing thereof as a result of this study
- The relationship between the lagoon water quality and that of catchment runoff
- The exchange capacity between the lagoon and estuary of open culverts
- The need to be clear about the aims and what can realistically be achieved
- Managing sediment load during 'freshes' in the Waikouaiti River with any water transfer scheme
- What kind of fish life will be secured? Would there be benefits to more freshwater areas upstream for fish to access?

2.5.3 Approach to goal-setting

From community feedback, shared high-level goals include achieving lower nutrient status and relative ecological stability within the medium term. That is, stability relative to the hyper-trophic flip cycles experienced throughout recent decades, and which are associated with negative lagoon characteristics such as algal blooms. Various habitat mixtures, and ecosystem types could be included to meet these goals, each having different implications on land management practices, lagoon configuration and resources, and the community investment required to effect these changes. Consideration should also be given to whether to revert some previously reclaimed areas back to more natural habitat cover in order to enhance the resilience of the catchment-estuary-lagoon complex. Appropriate restoration goals may be informed by referring to past states for inspiration but can not be wedded to them, since many historic conditions are unlikely to be re-instated, as the environment has and is continuing to change.

There is a functional relationship between ecological-driver status (e.g. soil type, water-regime, nutrient regime) and the ecosystem-habitat type present. This fact combined with the constraint on the natural system's status caused by human settlement and landuse management practices means that when deciding upon the ecological restoration goals, the community should try to remain open-minded about the feasible habitat mixture, and the goals and optimal set of measures necessary to achieve them. Not all goals will be either possible, realistic or desirable; for example attempting to entirely return the ecosystem to its historic, pre-human settlement state is no longer realistic. Certainly an broad perspective should be adopted as the starting point; i.e. one that views the entire hydrological system from hill-top to bay as one inter-connected ecological entity.

Summary Box 7

Given the balance of feedback obtained from the community meetings, the recommended restoration goal is to work towards increasing the health and habitat diversity of a less nutrient - rich lagoon that ceases to flip into hyper-trophic states of collapse, with the accompanying nuisance effects familiar to residents.

3 Results of investigations

3.1 Hydrology

3.1.1 Current water management

Essentially the intent of the current water management of the lagoon complex may be summed up as:

- Maintaining, as far as possible, a constant level in the lagoon to give the appearance of a lake rather than mudflats and ostensibly to minimise smells and midge infestations
- controlling flooding on private property from the tide and inflowing creeks;

While not primarily constructed with this purpose in mind, the north-south orientated causeway effectively causes the majority of the catchment runoff to bypass the lagoon and directly discharge to the ocean. What exchange there is between the estuary and the lagoon is controlled by two manually operated culvert gates – one feeding the northern lagoon compartment from the estuary, the other, the southern.

Flooding can occur as a result of high astronomic tides (possibly compounded by surges) or intense rainfall mainly affecting the lagoon, or some combination of the two.

Whether the estuary is freshwater, brackish or saline depends on whether the estuary inlet is open and on the stream flow rate. And as the relative water level changes, so too does the flow direction in the culverts. Once the lagoon reaches the target water level, these culverts are mainly held close to shut to hold that level.

When a sandbar builds up at the mouth of the inlet on the Waikouaiti Beach, the estuary may become cut off from the ocean for days or even weeks at a stretch. At such times the water level in the estuary (and sometimes the lagoon) may build and the quality of the water, particularly in summer, may deteriorate, causing odour and midges.

If a trigger level of 1.6m amsl (at the Inverary St bridge gauge) is reached, or if water levels or the quality of the lagoon-estuary complex become a concern, then the sandbar is mechanically breached. Mechanical opening during the period of the study occurred four times, on 16/8/11, 3/10/11, 8/5/12 and 8/6/12.

Flooding and water level management are further discussed in Section 4.2 and peak freshwater floods have been calculated in Section 3.1.7.

3.1.2 Rainfall data

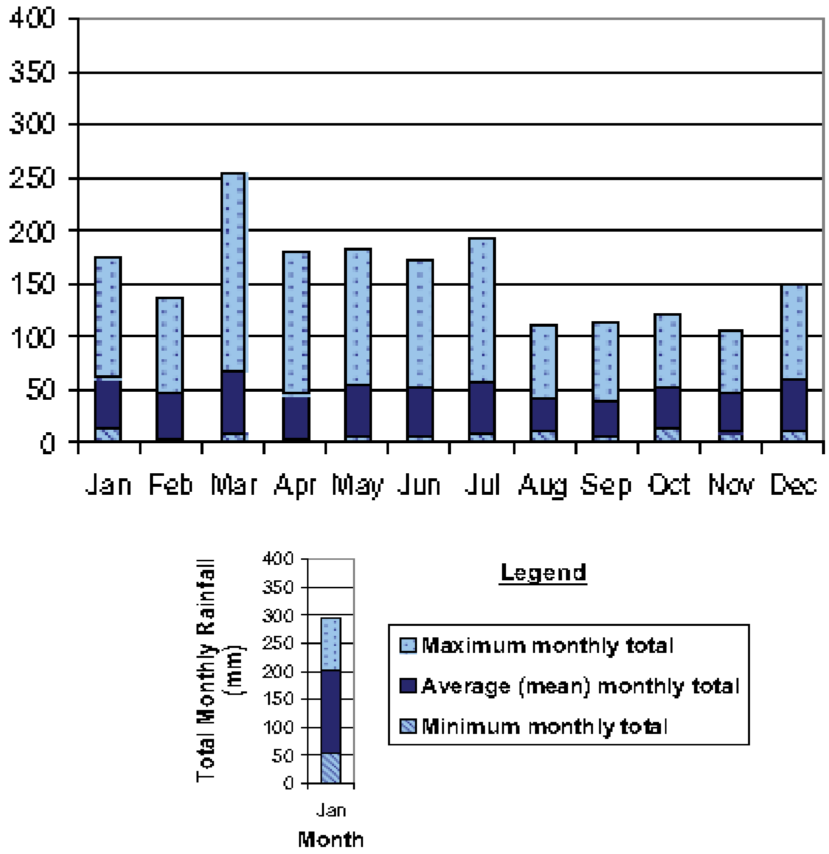
Average rainfall for the Hawksbury catchment as a whole is estimated as 700 -720mm (Appendix C). Median rainfall on the top of Derden Hill (444m) is over 800mm and at the lagoon itself is between 651 and 700mm. The 1 in 5 year annual total rainfall for a dry year (January to December) at the lagoon is between 501 and 600mm[32]. The Silverpeaks to the south

[32] GrowOtago 1970-2001

tend to protect the area from major SW rainfall events. Prolonged rainfall is often associated with easterly winds.

The longest available rainfall record for the local area is that for Cherry Farm, also close to sea level (29 years). While this site is located 3km southwest of the lagoon, the rainfall totals and distribution are likely to be similar to Hawksbury. The maximum monthly total, mean (average) monthly total and minimum monthly total ranges are shown for the period 1960-1989 on Figure 3.1 below.

Figure_3.1: Monthly rainfall means at Cherry Farm (1960 – 1989)[33]



While the mean monthly rainfall is typically around 50mm, the notable feature of the graph is the wide range between the maximum and the minimum for the period of record, and particularly in the January to July period. This implies that there will be considerable variation in the timing and volume of runoff between months and possibly seasons. Rainfall in the August to November period appears to be less variable. A 20 year rainfall record for Apes Rd (1993-2012), located some 6km south of Waikouaiti, shows a similar monthly average and similar monthly variability between years. The annual totals here vary by over 100% from 425mm to 1,000mm. (Table C 2, Appendix C, Hydrology).

[33] The Water Resources of the Waikouaiti River, ORC, 2008

3.1.3 Run-off

3.1.3.1 Hawksbury Lagoon catchment

The catchment boundary for the Hawksbury Lagoon and estuary complex is shown on Figure 2.1.

The catchment includes the southern and eastern flanks of Derden Hill and Mt Baldie in the west, extends east as far as Bush Road near SH1. From there it coincides with the old Tumai Bridge road and then Tumai Station Road and south to Matanaka Station giving a total area of approximately 1,612 ha.

The four drainage lines discharging to the lagoon-estuary complex are also evident in Figure 2.1 and comprise:

1. Waikouaiti town west of Beach St, and the land immediately to its west and south as far as the coastal dunes, drains into the south western corner of the lagoon via a 600mm diameter culvert under Beach St (Figure 3.2). This sub-catchment includes a well preserved area of raupo-flax swamp at the southern end of Henry St.
2. A second sub-catchment (Post Office Creek) drains down from between Derden Hill and Mt Baldie, crossing SHI at the old post office corner before cutting across the SE end of the Waikouaiti Race Course (Figure 3.3).
3. A third watercourse drains the eastern flanks of Mt Baldie southward, adjacent to the new section of SH1, and then across the Waikouaiti racecourse. These two streamlines join just upstream of the Inverary St Bridge before entering the lagoon-estuary complex (Figure 3.3).

<u>Figure 3.2: Drainage line downstream from Beach St Culvert</u>

Figure 3.3: The two branches of Post Office Creek converging at Inverary St Bridge with the Racecourse in the background

4. A fourth stream drains land on Matanaka Station, passing along the northern boundary of the Waikouaiti landfill (Figure 3.4).

Figure 3.4: Tip Creek drainage line looking down stream toward the east arm of the estuary

Flows measured in each of the main drainage lines to the Hawksbury on the days of sampling were as follows.

Table 2.4: Flow rates measured in creeks entering the Hawksbury Lagoon at the time of water sampling

Site ID	Location	Flow rate on that date (L/s)			
		23-Jun-11	2-Aug-11	7-Sep-11	1-Nov-11
HKS9	Creek at Beach St culvert	1.00	0.55	0.29	9.00
HKS13	Post Office Creek (Reid St)	3.35	8.50	2.50	14.40
HKS33	Post Office Creek (Aberdeen St)	3.59	3.70	5.30	4.40
HKS3	Tip Creek	1.62	0.80	2.50	3.75

Source: 23 June, Irricon Consulting; 2 Aug, 7 Sept and 1 Nov, ORC

An estimate of the annual volume of runoff from the Hawksbury catchment is shown in Appendix C.

3.1.3.2 Waikouaiti River catchment

To improve the freshwater turnover in the Hawksbury Lagoon, one possible option is to transfer water from the Waikouaiti catchment.

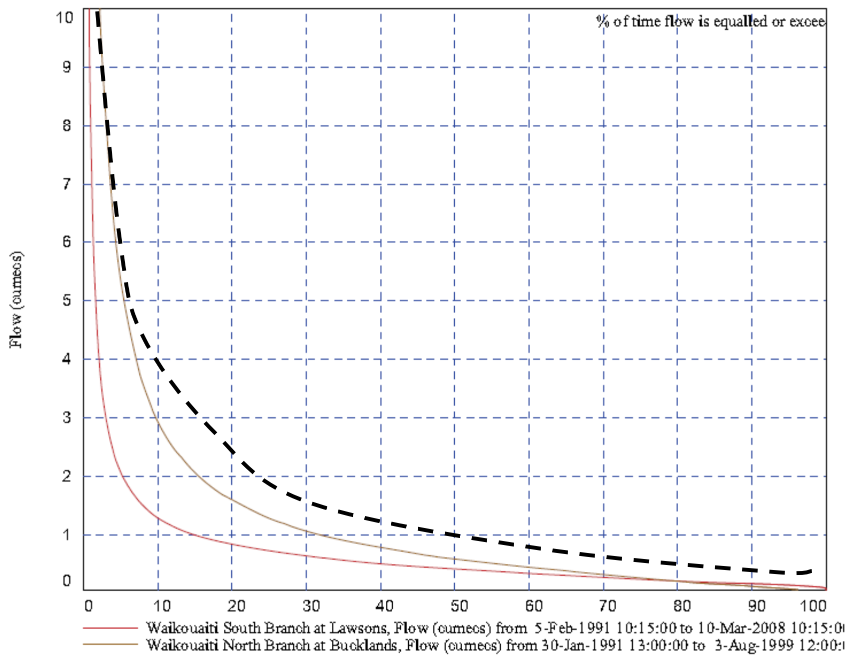
The Waikouaiti River drains to the coast 3 km south of the Hawksbury Lagoon onto a shared river flat - coastal sand dune feature. The river comprises two distinct subcatchments: the north branch (283 km2) extending as far back as Macraes and the more wooded south branch (86 km2) extending as far as the Silverpeaks. Both the branches show a similar pattern of flow variation, with the highest average flows in the winter and the lowest average flows at the end of summer/early autumn[34].

The limit for primary allocation on the Waikouaiti is 129L/s which is what the current consented allocation is and means the primary allocation is fully accounted for. However, as part of the minimum flow setting process, the Council proposes to set a supplementary block of water for allocation at a higher level. If flows within this allocation block occur frequently enough to allow the required volume to be transferred, the scheme would be technically feasible.

In Figure 3.5, the annual volume of water for each branch is represented by the area under their respective curves[35]. As the take from the Waikouaiti River would be downstream of their confluence, an estimate of the combined flow regime in the river is given by adding them together (represented by the dotted curve on the graph). This means the flow in the Waikouaiti is above 1,000L/s (1 cumec) 40 – 45% of the year and above 2,000L/s (2 cumecs) about 25% of the year. Based on the annual distribution patterns of rainfall variation (see previous section) and evapotranspiration it may be inferred that higher flows in the Waikouaiti are less likely January – May.

[34] ORC, 2008
[35] ORC, 2008

Figure 3.5: Flow duration curves for the Waikouaiti River



Nevertheless, without knowing what the details of the supplementary block will be, there would seem little doubt that the hydrological requirements for a transfer scheme are there even when the primary allocation has been accounted for. Scheme concepts that would achieve a transfer are discussed in section 4.2.2.

3.1.4 Water level surveys

Surveys to show relative water levels and depths are illustrated in Figure H1, Appendix H. The Figure H1 shows the survey lines (dotted red), the sites where levels have been taken and records the actual level taken at each site. The surveys are shown as 3 separate long sections, although they all have a common point at level site HKS7 and all heights have a common datum (Dunedin, 1958).

Note that all levels taken are recorded on Figure H1, but only selected sites are shown on the long sections.

3.1.4.1 Coast to the lagoon outlet (Long-Section A)

This long-section is viewed from the SW and incorporates levels from the foreshore up the inlet and across the southern end of the lagoon. Aspects of note include:

- The uniform gradual beach gradient (0.0136) to at least 160m out from the sandbar
- The sandbar height of about 1m amsl at the time of the survey
- The much lower water level of the estuary/inlet compared to the lagoon at the time of that survey
- The deepest location of the inlet is in the vicinity of HKS7 where it is about 0.4m below mean sea level, but this may be a localized souring effect of the culvert

- The lawn and floor levels (in pairs) of approximately every second home on the north side of Stewart St for the purpose of planning for peak water levels. The Street numbers for those surveyed are HKS25, #27; HKS 26, #29; HKS27, #33; HKS28, #47; HKS29, #51: HKS30, #55.

3.1.4.2 Outlet of the lagoon to SH1 at Reid St and Aberdeen St (Long-Section B)

This long-section is viewed from the east and extends the full length of the main causeway from its southern end at Stewart Street (Site HKS7) to the Inverary St Bridge (Site HKS2). From there it bisects with one survey up the Post Office Creek to the intersection of Reid St and State Highway 1 (Site HKS13) and the other up the racecourse creek branch, also as far as State Highway 1 (Site HKS 15). Aspects of note include:

- Both lagoon and estuary water levels are shown either side of the causeway at the time of the survey
- The approximate depth of the lagoon near the causeway in the two compartments (i.e. south and north of the culvert at site HKS12)
- The relatively flat invert (bottom) and very flat surface water level in the estuary and creek as far upstream as Glasgow St (on Post Office Creek East branch) and the bottom end of Reid St (on Post Office Creek West branch)
- The significant increase in invert and water level gradients upstream of these points

The lower reaches of both branches of Post Office Creek are clearly tidal. This will affect freshwater quality and habitat. The limited elevation difference between peak tide and the race course track level limits the scope to raise water levels without causing waterlogging or flooding issues, particularly in the east branch toward Glasgow St. The flat nature of the creek bed as far as Glasgow St is consistent with the extent of the original estuary prior to reclamation.

3.1.4.3 Lagoon to Orbells Crossing (Long-section C)

Long-section C, viewed from the north, also starts from the southern end of the main causeway (Site HKS7) and extends up the Beach St water course toward the Mainland Dairy Factory, heads north to the SH1 bridge over the Waikouaiti River and then on up the river as far as the McGrath Rd bridge at Orbells Crossing. The following can be noted on the section:

- Different horizontal and vertical scale compared to the previous long sections
- The Hawksbury Lagoon water level is shown at the eastern end of the lagoon
- The drainage divide between the Hawksbury Lagoon catchment and the Waikouaiti catchment is shown at chain 1,425m.
- The low floor level of the existing culvert under the main trunk railway line
- Waikouaiti River level at the time of the survey (tidal)

This survey line was to investigate the feasibility of diverting water from the Waikouaiti River to augment inflow to the Hawksbury Lagoon during higher runoff events. The survey shows that it would not be possible to gravity feed water in this manner without the aid of a low lift pump installed near the SH1 Bridge. This pump would discharge into a race graded to pass over the watershed into the Hawksbury via the Beach St culvert.

Engineering matters related to these surveys are further discussed in Section 4.2.

3.1.5 Tidal range

The tidal range on the Otago Coast is recorded at Green Island south of Dunedin. Statistics for that site are shown in Table 3.1 for the period 2008 – 2012, including the maximum and minimum of each year and the overall average for the years. The average range is from -1.2 to +1.7m, a total fluctuation of 2.9m. Note that the true mean is 0.22m above the official mean used for the Otago Datum.

Table 3.1: Tidal extremes for the Green Island Gauge 2008- 2012.

Year	Mean	COV	Median	Minimum			Maximum		
				(masl)	(Date)	(Time)	(masl)	(Date)	(Time)
***2008**	0.226	2.374	0.227	-1.190	30-Aug-08	7:49	1.734	6-Jun-08	17:15
***2009**	0.220	2.483	0.221	-1.150	21-Aug-09	9:20	1.608	11-Mar-09	2:32
2010	0.205	2.711	0.207	-1.246	1-Feb-10	23:07	1.653	2-Mar-10	16:04
2011	0.226	2.477	0.224	-1.164	21-Jan-11	22:16	1.707	17-May-11	14:45
***2012**	0.230	2.446	0.233	-1.113	8-Mar-12	20:39	1.618	5-Jun-12	15:51
Average of complete years				**-1.205**			**1.680**		

Key data:

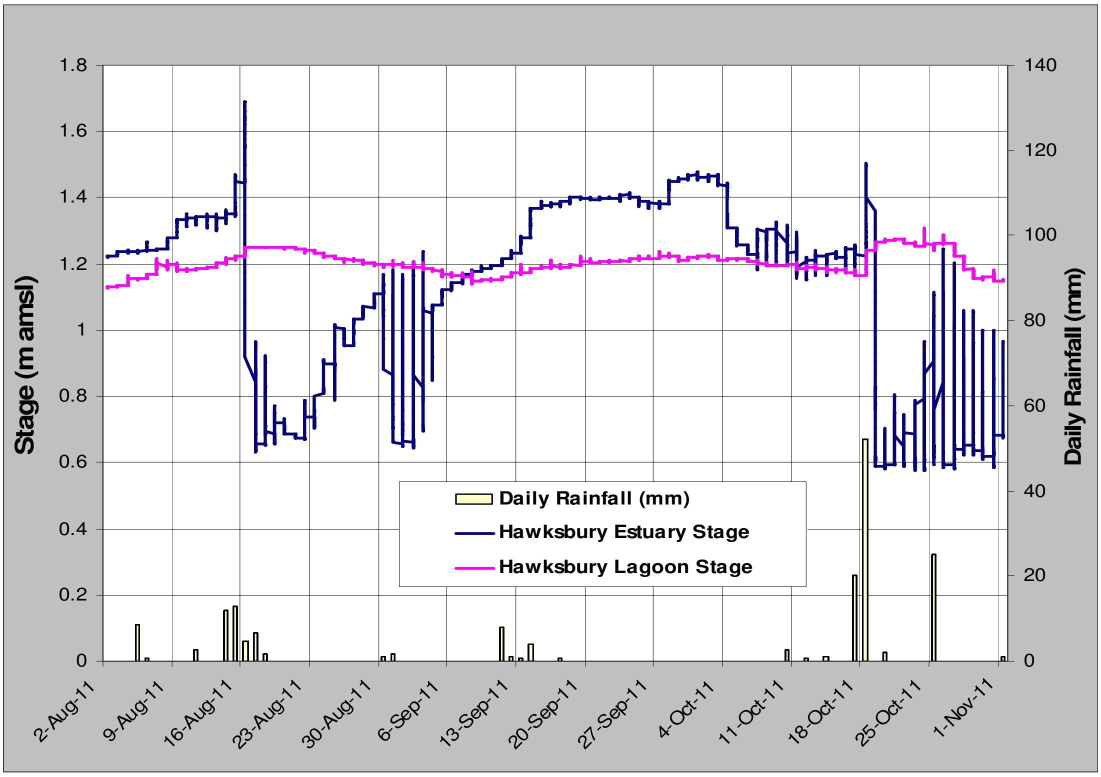
Absolute minimum for period	-1.246	1 Feb-10	23:07h
Absolute maximum for period	1.734	6-Jun-08	17:15h
Mean	0.221		
Median	0.222		
Std Deviation	0.552		
Coef ofVariance (COV)	2.495		

Auto level recorders were set up either side of the causeway at the outlet pipe from the lagoon to the estuary (Site HKS7) for a period of 3 months (August – November 2011). The resulting traces illustrate the dynamic relationship between the water levels in the lagoon and the estuary as influenced by the ocean tides, bar closure and rainfall/runoff events. The data, along with daily rainfall, is plotted on Figure 3.6 below. The mean sea level datum is the same as that for the surveyed levels in the long sections described in the previous section, so can be directly compared.

There are two traces on the graph – the blue (more variable) trace being the water level in the estuary and the red (muted) trace being that of the lagoon. The water level log sequence gives a very good idea of the range of interrelated factors affecting the relative behaviour of the two compartments. The period of the log is interpreted as follows:

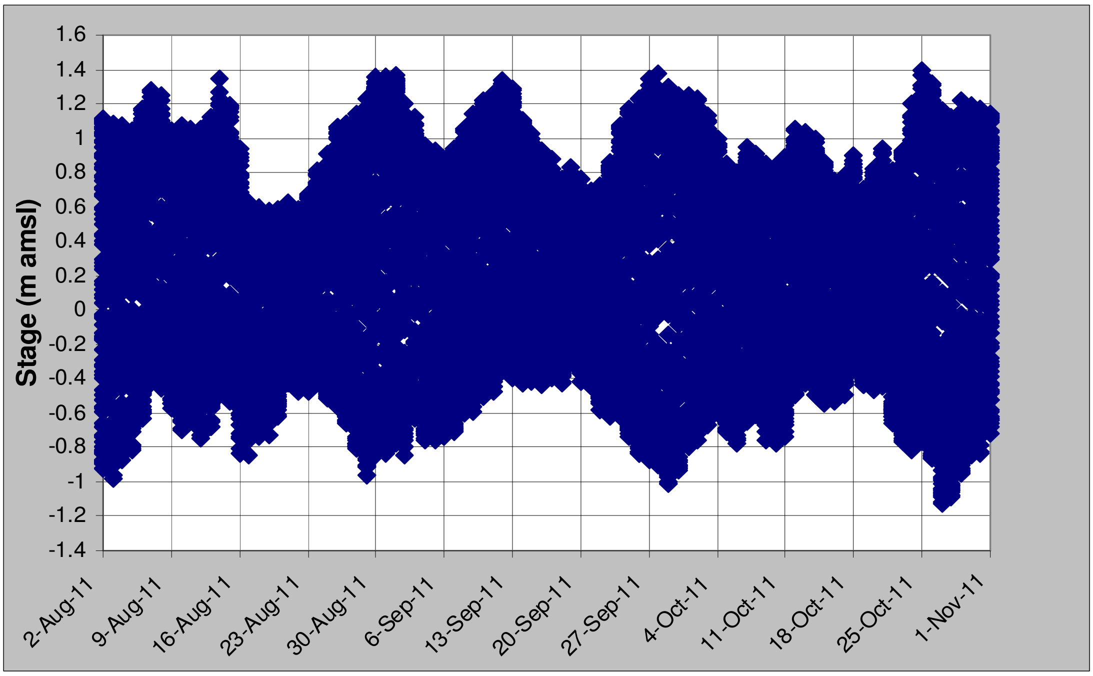
- The lagoon water level was maintained within a range of 150mm between about 1.15 and 1.30m amsl for the 3 months
- In the estuary, there are periods when there is little tidal expression (i.e. a sandbar is acting as a barrier) and other periods when the inlet is open and the daily tidal cycle is changing the estuary water level by up to 0.6m at the recorder (0.6 - 1.2m amsl). At other times, the water level in the estuary builds above 1.2m when the outlet is blocked.

Figure 3.6: Auto-log to show the daily influence of the tidal cycle on water levels in the Hawksbury Estuary and Lagoon in relation to local daily rainfall



Raw rainfall data used in this figure is shown in Table C3, Appendix C, Hydrology

Figure 3.7: Tidal range experienced on the Otago Coastline (August –October 2011)



Green Island Sea Level Station sourced from the ORC

- During the 3 month recorded period, the bar was effectively closed for about 60% of the time and much of the rest of the time only partially open.
- At the start of August, the estuary water level is about 1.22m amsl and rises up due to rainfall, runoff and possibly some wave action over the bar at high tide
- A significant rainfall event between 13-17th of August raises the estuary water level up to1.69m (above the sandbar opening trigger level of 1.6) and the bar is mechanically breached on the 16th of August. This just happens to coincide with a high tide cycle shown on Figure 3.7 after which there is constrained tidal influence again (probably because the opening in the bar is narrow).
- Within a few days, the bar closes over again and the estuary water level builds by natural runoff (while over the same period, the lagoon slowly drains) until the end of August, when the bar is broken and a period of tidal influence of about 0.6m resumes.
- In early September the tidal influence weakens, exemplified by a diminishing tidal range as the bar rebuilds until it is again entirely closed by 5 September.
- In response to further runoff, the water level in the estuary steadily rises above that of the lagoon to plateau at about 1.4m for a period from 14 – 28 September, when a further event (probably the high tide event that coincides on the 28 September – see 3.6) raises it by a further 50mm.
- On the 4 October, the bar is mechanically opened again, permitting a period of some muted tidal or wave influence before a 72mm rainfall event on the 17 and 18 October (coinciding with a 100mm jump in the level of the lagoon) scours out the bar down to 0.6m amsl. The ensuing few days of limited tidal impact suggests the inlet must be narrow until more rain scours a wider channel.
- Between the 23 Oct and month end, the bar again begins to close off, steadily reducing the tidal influence and the marked decline in the lagoon water level suggests the gate openings have been increased
- The slope of the lagoon trace between 20 and 30 August indicates the net rate of loss from the lagoon was 24 L/s (declined 52mm in 10 days over 40ha) and between the 26 and 30 October, 134 L/s (declined 116mm in 4 days).

Figure 3.7 above illustrates the tidal range experienced on the Otago coast over the same 3 month period of the auto-logging in the Hawksbury Lagoon. From this figure, and by comparing it with Figure 3.6 above, it may be inferred that:

- The daily range varies considerably in any given month between a maximum of around 2.4m and a minimum of about 1.2m. This is largely due to astronomic factors.
- When tides are in a high phase, there is the potential to raise the water level in the estuary to about 1.35m amsl, but during a low phase 0.6m amsl would be a maximum
- With a minimum estuary level also recorded of approximately 0.6 (i.e. the outlet level on the sandbar), there are times in the month when it is not possible for tidal inflow to the lagoon even when it is open to the ocean
- Similarly, with this minimum estuary level of 0.6m amsl, the maximum change in depth due to tidal exchange (under the current lagoon configuration) is 0.6m or the upper quarter only of the maximum tidal range.

For calculation of the estuary tidal exchange 0.6 is therefore the maximum and this may be further reduced on accounting for the contour of the estuary.

Further more subtle influences on the estuary water levels caused by the natural monthly tidal fluctuations can be seen by comparing the timings on Figures 3.6 and 3.7. For example, the trends in the monthly maximum tides appear to generally reflect the estuary water levels and, by implication, the elevation of the sandbar. In other words, the rising tidal cycle is building the sandbar. Similarly, it appears that some care over the timing of mechanical opening of the sandbar in relation to the astronomic tidal phases would maximise the period and volume of tidal exchange.

3.1.6 Tidal exchange and estuary opening regime

All tidal inlets are evolving and changing over the long-term. When the inlet to the estuary is open and the daily tidal cycle sufficiently elevated, with each incoming tide the in-flow will continue to "flood" until the tide level in the ocean again falls to an elevation below that of the estuary. Thus the estuary tide always lags that of the ocean.

The amount of water draining from the estuary on the ebb tied is technically referred to as the "tidal prism" and is essentially the volume of water in the estuary between mean high tide and mean low tide. It can also be thought of as the volume of the incoming tide plus the total stream discharge. Figure 3.6 shows that when the inlet mouth is open, the estuary tidal range varies with the elevation (and width) of the inlet and the stage in the monthly tidal cycle. The implication of the relationship is that any significant change in the tidal prism will affect the inlet and vice-versa. For example, when the inlet is constricted, the range of the tide in the estuary will be smaller than that of the ocean and the estuary may not completely fill.

As explained in Section 1.2, about 33 % of the original estuary-wetland complex has been in-filled to the north of Inverary St to create the land for the racecourse. A further 52% has effectively been detached to form the lagoon leaving 15% as estuary. The only remaining hydraulic connection between the lagoon and the estuary is afforded by two 600mm-diameter culverts. However, for the most part, these are kept largely shut to maintain a flooded lagoon, so preventing tidal exchange. We estimate that the net effect of these changes has been to reduce the tidal prism dramatically to perhaps 25 % of what it once was.

Inlets with small tidal prisms have too little power to remove sand deposited by wave action at the shore. Assuming a pre-European settlement tidal prism of 200,000m3, maximum discharge during both flood and ebb tides at times when the mouth was largely unrestricted could have been up to 15cumecs. Now the maximum discharge is likely to be less than 4cumecs under similar conditions. However, the relationship shown on Figure 3.6 between the water level in the estuary and the tide means that now, even when the inlet is open, the tidal influence may be quite muted and the actual tidal exchange very small or non-existent for extended periods.

The key implication of this is that the reduction in estuary size and the tidal prism has also greatly reduced scouring capacity in the inlet and is the main reason the sandbar redevelops so quickly and persists as it does compared to how it would have been in the past. The implications of this on the water quality, the nature of the habitat and the opportunity for restoration are profound and are considered further in Section 4.

3.1.7 Freshwater Flood flows

The flood magnitudes for given return intervals are shown in Table 3.2 below. Flood estimates are provided for both the entire Hawksbury catchment (which is the volume of water that would need to be conveyed to the ocean) and for Post Office Creek where it enters the north of the estuary-lagoon complex. They both include an allowance for climate change of up to 2 degrees which has the effect of increasing the size of the flood for any given return interval or increasing the frequency of a flood of a given size. For the design of any structures, the entire catchment needs to be considered and a minimum of the 100 year flood event.

Table 3.2: Estimates of flood magnitude for given frequency of return

Event frequency	Design rain	Flood magnitude	
		Post Office Creek catchment (1,137ha)	Hawksbury Lagoon catchment (1,612ha)
	(mm/hr)	(cumecs)	(cumecs)
5 year return + 2 deg CC	19.1	17.8	25.2
20 year return + 2 deg CC	27.7	25.8	36.6
50 year return + 2 deg CC	35.0	32.6	46.3
100 year return + 2 deg CC	41.8	39.0	55.2

Rainfall source: NIWA website[36]

Figure 3.8: Estuary inlet discharging to the shore during a fresh of 16 August 2011 showing scouring effect

[36] NIWA Website (HIRDS)

Summary Box 8
Essentially there are two main means of improving water quality in the lagoon through changing the lagoon water management regime and flows. One is to facilitate more freshwater flushing; the other, more salt water flushing. The hydrology analyses show there is scope for enhancing both these sources. Quickest ecological status modification results could be expected if both were implemented, and the community has a range of technical options that could be employed to consider.

3.2 Water chemistry & quality

3.2.1 Sampling locations and analyses

A range of analyses are commonly used to describe the quality of surface water, some being less critical than others (Wright, 2012). For this study, to ensure that the sampling program most effectively addressed all concerns, two sampling intensities were therefore used. At all sampling sites, a suite of less critical parameters were tested in the field. At selected sites both the less critical suite and a more critical set of tests were undertaken.

Less critical indicators used at all sites

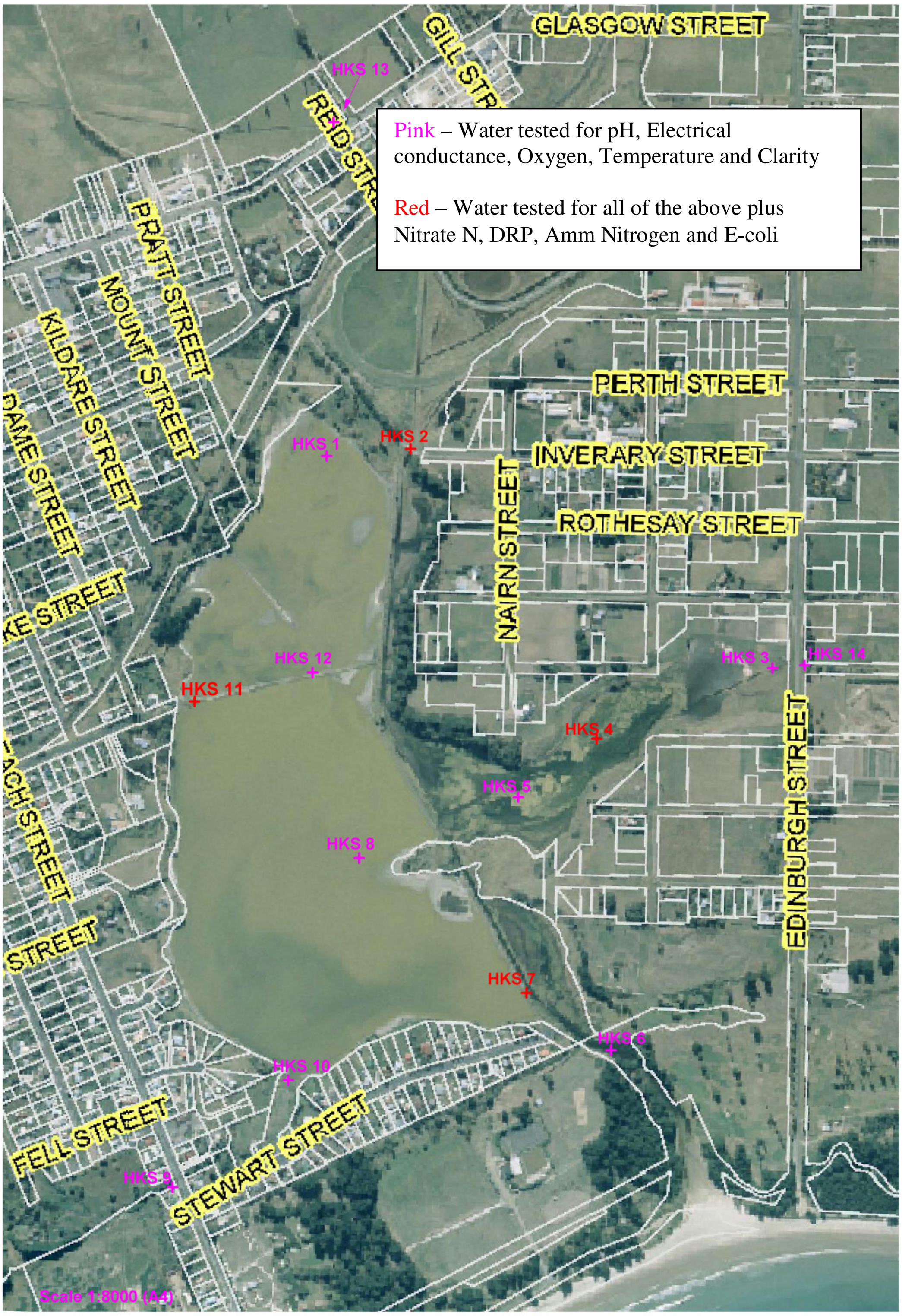
- Ammoniacal nitrogen (NH4) – typically requires substantial pollutant discharge or high rates of nitrogen cycling
- Low dissolved oxygen (02)– does not normally persist, but important as even short periods such as overnight can be fatal for organisms
- Temperature – difficult to control in shallow conditions especially with low flow rates
- Conductivity – not normally a direct threat to aquatic life in rivers but fundamental to determining predominant biota in estuaries
- pH – seldom goes outside ANZEEC critical range of 6.5 – 9.0 but may go above 9 at midday during algal blooms

More critical indicators used at selected sites

- Nitrogen (N) and phosphorus (P) – both absolute concentration and, when sediment resuspension is not occurring, the ratio of the two has been used as a rough indicator (i.e. soluble inorganic nitrogen to dissolved reactive phosphorus). Ratios of >50:1 indicate P limitation for algal growth, and ratios around 3:1 suggest N is limiting
- Suspended solids result in turbidity and a reduction in clarity. This affects photosynthesis, fish feeding and the habitat suitability for invertebrates
- E- coli affects the safety of the water for contact recreation.

All sites where samples were taken are illustrated on Figure 3.9. The four sites where the more extensive set of tests were undertaken are distinguished. Of the four, two are in different parts of the lagoon (HKS7 and HKS11), one in the estuary (HKS4) and one for the Post Office Creek where it enters the estuary (HKS2) However, HKS2 is still tidal so is subject to a level of marine influence that varies with the runoff, tidal and inlet conditions.

Figure 3.9: Water quality sampling sites



3.2.2 Water quality results

Table 3.3 shows the median values only from field measurements taken during the investigation for the three sampling rounds at multiple sites. The tests shown in this table were undertaken at all sites shown on Figure 3.9. The complete suite of results for field tests is shown in Table F1, Appendix F and the site coordinates shown in Table F2, Appendix F.

Table 3.3: Median water quality field measurement results for all sampling sites and for the different hydrological zones (June - Sept 2011)

Zone	Number of samples	pH	Electrical Conductivity	Dissolved Oxygen	Temp	Clarity
Units for results			uS/cm	mg/l	degC	(Tube, cm)
Guideline Ref		1		2	-	3
Guideline value		6.5 - 9.0	None	>80% Saturation	<20	80 (Disc for lowland rivers)
Stream - Median	9 (3 sites)	8.45	589	4.50	6.1	95.0
- Max/Min		9.2/6.1	1,240/380	12.6/2.16	10.4/3.1	>100/11
Lagoon - Median	20 (6 sites)	8.64	19,731	4.16	9.2	9.5
- Max/Min		9.21/8.10	24,592/18,380	9.83/1.70	14.6/5.3	12/4.5
Estuary- Median	16 (5 sites)	8.46	30,200	4.61	8.55	46.3
- Max/Min		8.94/7.30	44,386/1,330	9.17/2.24	12.4/5.5	90/14

1 ANZECC (1992)
2 RMA 1991 Third Schedule
3 ANZECC (2000)
4 All sampling done when under still or light breeze conditions

Table 3.4 below shows all the results of tests taken for nutrients, suspended solids (two rounds only) and indicator bacteria (E Coli)

Table 3.4: Water quality laboratory measurement results for nutrients and bacteria

Location	Date	Time	Total Phosphorus	Dissolved Reactive Phosphorus	Ammoniacal Nitrogen	Dissolved Organic Nitrogen	Nitrate Nitrogen	Suspended Solids (NFR/TSS)	E. coli (Quanti-Tray) 96 MPN/100 mL
			ppm	ppm	ppm	g/m3	ppm	g/m3	MPN/100ml
Guide			<0.033[1]	<0.01[1]	<0.021 [1]		<0.444[1]		<126 Rec[2], <140 Shell fish[3]
Estuary	2/8/11	11:40	0.07	0.02	0.03	0.50	0.188	6	74
(PO Ck	21/8/11	12:10	0.17	0.029	0.35	0.80	0.154	47	74
HKS2)	7/9/11	10:30	0.08	0.025	***0.01***	0.20	0.093		20
Estuary	2/8/11	12:55	0.11	0.008	0.01	0.40	0.008	73	***10***
(HKS4)	21/8/11	12:55	0.25	0.014	0.05	0.80	0.543	150	190
	7/9/11	11:30	0.17	0.034	0.02	0.18	***0.002***		***10***
Estuary average			**0.14**	**0.021**	**0.08**	**0.48**	**0.165**		**70**
Lagoon	2/8/11	14:45	0.3	0.005	***0.01***	0.70	0.008	180	41

HKS7	21/8/11	14:50	0.27	0.005	***0.01***	1.20	***0.002***	300	390
	7/9/11	13:05	0.38	***0.005***	***0.01***	1.10	***0.002***		63
HKS1	2/8/11	9:45	0.29	0.006	***0.01***	0.60	***0.008***	190	96
HKS 11	2/8/11	16:00	0.28	***0.005***	***0.01***	0.60	0.008	190	***10***
	21/8/11	16:25	0.32	***0.005***	***0.05***	1.10	***0.002***	230	10
	7/9/11	14:25	0.27	***0.005***	***0.01***	0.90	***0.002***		20
Lagoon average			**0.30**	**0.005**	**0.02**	**0.89**	**0.005**		**90.00**
HKS13	16/8/11	NA	0.8	0.375	0.26	1.80	0.84		6,900
HKS15	16/8/11	NA	0.51	0.085	0.16	0.97	0.683		10,000

1 ANZECC and ARMCANZ, 2000 (based on median values)
2 Department of Health, 1992
3 Min for Environment/Min of Health (June, 2003)
4 Italicised and bolded results are below the detection limit
5 Insufficient number of samples to derive median values
6 The last two samples on the 16 August (HKS13 and HKS15) were taken during a flood event. HKS13 (West branch) had the higher concentration of nutrient.

Analysis	**Detection limit**	
Total Phosphorus	0.02	ppm
Dissolved Reactive Phosphorus	0.005	ppm
Ammoniacal Nitrogen	0.01	ppm
Dissolved Organic Nitrogen	0.1	g/m3
Nitrate Nitrogen	0.002	ppm
E. coli (Quanti-Tray) 96 MPN/100 mL	1.0	MPN/100 mL

3.2.3 Water quality evaluation

This section first provides a brief description of the characteristics and significance of the various indicator species used in this study or referred to in the standards. Where appropriate a comment is included about the actual results from the study for that parameter. Thereafter is a general assessment of the trophic level of the estuary and the lagoon. Unfortunately, not all the indicator species referred to were measured in this study.

3.2.3.1 Nutrients of Nitrogen and Phosphorus

Total Nitrogen (TN) - Total Nitrogen is the sum of all forms of nitrogen in a water sample; i.e., nitrate (NO_3), nitrite (NO_2), organic nitrogen and ammonia (all expressed as N)[37]. Too much nitrogen in the water can lead to excessive plant growth and nitrogen in certain forms can in itself be harmful or even toxic to aquatic life.

The ANCECC median trigger value for TN in lowland rivers is 0.614mg/l and the average value in Table 3.4 for both the estuary and the lagoon exceeds this even without nitrite having been included.

A preliminary estimate of instream nitrogen load for the Post Office Creek alone is 3.9 t/yr[38].

[37] Note that for laboratory analysis purposes, Total Kjeldahl Nitrogen (TKN) is a test performed that is made up of both organic nitrogen and ammonia.
[38] NIWA Website (WRENZ)

Soluble Inorganic Nitrogen (SIN) - a measure of all inorganic nitrogen compounds (nitrate + nitrite + ammoniacal nitrogen) which are the forms of nitrogen that are capable of being dissolved and do not contain carbon. These forms of nitrogen are readily taken up by aquatic plants. SIN concentration tends to increase down stream due to groundwater and runoff impacted by agriculture. The lack of a measure of nitrite in this study means that SIN can not be calculated.

Total Phosphorus (TP) - a measurement of all forms of phosphorous in a water sample. Excess phosphorus in water can lead to excessive plant growth and potentially toxic conditions for aquatic life. Like nitrogen, phosphorus can take on many forms and is constantly changing. Field trials in small east coast rivers and lagoons in South Canterbury show Chlorophyll-a (see definition below) responds most strongly to treatment of both nitrogen and phosphorus together but also nitrogen alone (ECan 2012).

The ANCECC median trigger value for TP in lowland rivers is 0.033mg/L and average value for both the estuary and the lagoon exceed this.

Dissolved Reactive Phosphorus (DRP) - the form of phosphorus most available to plants in the water (phosphate). DRP is typically not that common in brackish waters such as those found in the lagoon [39].

An important aspect of the available forms of N and P nutrients (SIN and DRP) is that they do not necessarily alone cause problems by exceeding the guideline, as aquatic plant life requires both to thrive. A lack of one or other can limit growth. While algae are part of the food chain they can reach nuisance proportions with excessive concentrations of nutrient. It has been suggested that a ratio of SIN to DRP > 50:1 indicates an unbalanced nutrient supply with P limiting phytoplankton growth while a ratio < 3:1 suggests N limitation of phytoplankton growth[40].

Using the available results as an indication of the most likely limiting factor, it is likely that most of the results are nearer 3:1 SIN to DRP ratio. Note too that nitrate values for the lagoon are largely below detection limit. This would suggest containing nitrogen entry to the complex is the priority for containing the risk of blooms. Howerver, nutrient limitation status varies in time and space and other factors such as temperature and grazing may influence results[41] so further tests would be required to confirm any such general inference.

Tidal flushing removes nutrients from estuaries but as seawater naturally contains moderate amounts of phosphate, in combination with nitrogen, it can result in algal blooms and nuisance seaweed growths.

3.2.3.2 Algae (Chlorophyll-a)

Chlorophyll-a is a pigment that occurs in plant cells and its measurement is used to monitor the amount (sometimes referred to as the biomass) of algae in water samples. The chlorophyll-a test

[39] Schallenberg M pers com
[40] Wilcock et al, 2007
[41] Schallenberg M pers com

measures only living phytoplankton. Water bodies with high nutrient levels (eutrophic, or hypertrophic nutrient statuses) typically have a higher Trophic Level Index (see definition below) and more commonly experience algae/cyanobacteria blooms. Certain kinds of algae can prevent the normal browsing behaviour of invertebrates and can therefore cause flow-on inhibition of the food chain.

We know of no actual occurrences of toxic blue-green algal blooms at Hawksbury Lagoon. Chlorophyll-a was not measured in this study as it was considered that it would require an intensive sampling programme beyond the resources of the study to give useful results. Figure 3.10 provides a good example of how the lagoon may appear when it is experiencing an algal bloom – a vivid green, compared to the deep olive green of the estuary zone to the right of the causeway.

3.2.3.3 Turbidity/clarity (Secchi Index)

The turbidity and clarity measures are the inverse of one another. Clarity was measured using two methods: one was the Secchi disc, and the other a one meter long glass-bottomed tube. Observation distances are affected by algae and suspended sediment at different times of the year. Wind on shallow water bodies can have a significant effect by stirring up the bottom sediments; this effect has a marked influence on turbidity at Hawksbury Lagoon.

Figure 3.10: Aerial view of the Hawksbury Lagoon during an algal bloom

The Secchi disk value is related to the lower depth boundary where photosynthetic production is possible (euphotic depth), and where the growth of aquatic plants (phytoplankton and periphyton) becomes limited by lack of light. The euphotic depth corresponds with the depth to which 1% of the light reaching the lagoon's surface penetrates.

High levels of turbidity increase the total available surface area of suspended solids upon which bacteria can grow. High turbidity reduces light penetration; therefore, it impairs photosynthesis of both submerged rooted vegetation and algae alike. In turn, the reduced plant growth is likely to suppress fish productivity via lower oxygen levels.[42] The Ministry for the Environment guidelines[43] (ANZECC) for visual clarity in lowland rivers is 60cm. The turbidities of both the lagoon and the estuary are far from achieving this guideline (Table 3.3).

3.2.3.4 Trophic Level Index

A trophic level of a lake or river indicates the amount of biological activity (productivity), such as plant growth, that occurs in the water. It can be expressed using the Trophic Level Index (TLI)[44], which combines information from the four variables discussed above – the amount of nitrogen and phosphorus, chlorophyll and clarity. Table 3.5 below shows the ranges of each of the variables reflecting the different trophic states.

Table 3.5: Criteria for determining the trophic state of lakes

Trophic state	Trophic level	Nutrient enrichment category	Chlorophyll a	Secchi depth	Total Phosphorus	Total Nitrogen
			(mg/m3)	(m)	(mg/m3)	(mg/m3)
Ultramictrophic	0.0 to 1.0	Almost Pure	< 0.33	>25	< 1.8	< 34
Microtrophic	1.0 to 2.0	Very Low	0.33 - 0.82	25 - 15	1.8 - 4.1	34 - 73
Oligotrophic	2.0 to 3.0	Low	0.82 - 2.0	15 - 7	4.1 - 9	73 - 157
Mesotrophic	3.0 to 4.0	Medium	2 - 5	7 - 2.8	9 - 20	157 - 337
Eutrophic	4.0 to 5.0	High	5 - 12	2.8 - 1.1	20 - 43	337 - 725
Supertrophic	5.0 to 6.0	Very High	12 - 30	1.1 - 0.4	43 - 96	725 - 1,558
Hypertrophic	> 6.0	Saturated	> 31	< 0.4	> 96	> 1,558

1. Note units in mg/m3 not mg/L as used for the results
2. Chlorophyll a is used as an indicator for algae
3. Descriptive qualities of the trophic levels of lakes
    - **Microtrophic:** clear, very low in nutrients, ever slow- growing plants, few algae - often have snow or glacial sources e.g. Lake Sumner in North Canterbury.
    - **Oligotrophic:** Low in nutrients, usually clear and blue, slow plant growth may support periphyton. e.g. Lake Rotomā
    - **Mesotrophic:** Moderately clear and with moderate nutrient levels, usually blue green, supporting plant growth, typically macrophytes. e.g. Lake Rerewhakaaitu.
    - **Eutrophic:** increasingly green and turbid with high nutrient levels supporting rapid macrophyte or phytoplankton growths that sometimes leads to oxygen depletion. e.g. Lake Rotorua.
    - **Supertrophic**: saturated in phosphorus and nitrogen, usually poor water clarity and severe oxygen depletion, probably no macrophytes and may be dominated by bacteria. During calm sunny periods may have very high algae growth and algal blooms; e.g. Lake Ōkaro.
    - **Hypertropic:** supersaturated in phosphorus and nitrogen. They are rarely suitable for recreation and habitat for desirable aquatic species is limited, e.g. Many lakes in the Waikato

Source: Wright J 2012 and Bay of Plenty Regional Council

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[42] MfE, BC, 1998

[43] ANZECC, 2000 (with correction cited by MfE)

[44] Calculations for Trophic Level Index: TLI = Ó (TLn + TLp + TLs + TLc)/4 Where: TLn = -3.61 + 3.01log (TN), TLp = 0.218 + 2.92log(TP), TLs = 5.10 + 2.27log(1/SD - 1/40), TLc = 2.22 + 2.54log(Chla)

While not all the parameters are available to calculate the Trophic Level Index for the sites, individual results in Tables 3.3 and 3.4 for clarity (tube rather than the Secchi disc) TP , and forms of nitrogen provide a good indication as the general trophic state of each of the water bodies.

- Clarity for the estuary being between 1.1- 0.4m places it in the supertrophic state and the lagoon at <0.4 places it in the hypertrophic state or most degraded.
- TP of 0.14 for the estuary and 0.3 for the lagoon places them both in a hypertrophic state.
- Totalling up the available nitrogen forms places both the estuary and the lagoon in the supertrophic state although if particulate nitrogen data were available to include, it could well be hypertrophic

3.2.3.5 Sediments

This study confirmed a clear and widespread presence of 'reducing' organic sediments (i.e. those where oxygen is severely depleted), as was also observed by the water quality investigation of Hawksbury Lagoon by Dr. Barry Robertson in the 1980s. This indicates that the lagoon sediments are very nutrient-rich. Owing to the shallow depth of the lagoon, the upper layer of organic sediments can become mobile, through the action of wind creating water column turbulence, thereby impacting the aesthetics of the lagoon and introducing high concentrations of nutrients into the water column. Such large stores of nutrients probably stem from the increased rates of sedimentation resulting from the historical change in land-use from forest to agriculture, as well as from on-going intensive pastoral practices over a long period. It is likely that sufficient nutrients to produce an algal bloom can be available when sediment is suspended into the water by wind-generated waves and tidal currents.

Figure 3.11: View up the east arm of the estuary showing extensive mudflats at low tide

An important aspect of estuarine ecosystem dynamics is the amount of soft mud and the rate of sedimentation, both of which indicate whether a change in ecology of an estuary is likely. Any change in the rate of sediment run-off from the land will change the physical nature of the estuary including the percentage of mudflat compared with, for example, the macroalgal cover or saltmarsh habitat. Among the main estuaries in Otago, a correlation has been found between those with a higher percentage of mud (particles of <63µm), and those with the least diverse benthic communities[45]. Excessive sediment in suspension compromises fish vision and capacity to forage and smothers the beds where invertebrates and other food sources may be found when it settles.

Figure 3.11 of the east arm of the estuary rather than the lagoon shows soft mudflats are extensive but we have no real data on any change in the rate of sedimentation. A preliminary estimate of the total volume of suspended sediment reaching the lagoon is 500 - 600 t/yr[46]

3.2.3.6 Dissolved Oxygen

The maximum solubility of oxygen at sea level (fully saturated) ranges from approximately15 mg/L at 0°C to 8 mg/L at 25°C at sea level. Natural sources of dissolved oxygen are derived from the atmosphere or through photosynthetic production by aquatic plants. Lack of dissolved oxygen (DO) can be a major issue in water bodies. Decaying algal material which falls out of the surface water layer uses up dissolved oxygen very rapidly in the bottom water layer. When this happens, nitrogen and phosphorus are released from the lake bed sediments. In deep stratified lakes waters re-mix in winter making these nutrients available for plants and algae in the surface waters. In shallow lagoons like Hawksbury, internal nutrient loads are turned over by winds and currents numerous times a year and, on an ongoing basis, by diffusion[47].

The DO concentration is subject to diurnal and seasonal fluctuations that are due, in part, to variations in temperature, photosynthetic activity and flow. Warm shallow lakes are most vulnerable to these fluctuations and lower concentrations of oxygen are often found in impoundments.

Oxygen balance is critical. Too little, and decomposition processes are altered, producing the 'reducing' conditions that can be associated with unpleasant smells, and nuisance insect abundances. If nuisance midges and odours are to be minimised in the future, oxygen levels resulting from the preferred water management strategy should be one of the parameters considered. Table 3.6 shows guidelines for the lower limits that various forms of aquatic life can withstand over two time frames – instantaneous and over 30 days.

Table 3.6: Oxygen lower limit guidelines for aquatic life in freshwater and recreation

Animal	**Form**	**instantaneous minimum**	**30 day mean**
		(mg/L)	(mg/L)
Fish	buried embryo and alevin stages for water column	9	11
	all life stages other than buried embryo and alevin for water column data	5	8
Aquatic invertebrates	to avoid acute mortality	4	NA
Recreation		2	NA

1. Adapted from Ministry of Environment, BC (1998)

45 ORC, 2010
46 NIWA website
47 Schallenberg M pers com

Care is needed in interpreting oxygen data due to the diurnal and seasonal fluctuations. To check for diurnal phenomena, oxygen concentrations at two sites were measured both morning and afternoon. Table 3.7 shows that the level dropped substantially during the day while temperatures rose. These figures all come from winter/spring. To get a better idea of the environmental conditions affecting aquatic life, summer would be the best time to measure these and just before sunrise would be the best time to measure oxygen depletion. Hence, extremes in this dataset are very likely to be exceeded at many times during summer and at night time[48].

Table 3.7: Examples of diurnal changes in oxygen compared with other parameters in the estuary and lagoon

Location	Site	Date	Sampling Time	pH	EC	DO	Temp
					u/cm	mg/l	degC
Estuary	HKS2	2/8/11	11:40	8.08	28,300	6.00	7.4
(Post Office Ck)		2/8/11	16:45	7.30	15,800	4.30	7.8
Lagoon	HKS1	2/8/11	9:45	8.13	24,592	5.20	5.3
		2/8/11	16:30	8.25	20,870	3.93	9.8
Lagoon	HKS1	7/9/11	10:15	8.52	19,669	7.87	8.7
		7/9/11	15:05	9.00	18,682	1.70	13.9

1. From Figure 3.6 on both the 2 August and 7 September the estuary is isolated from the ocean by the sandbar preventing tidal saline water influence on samples.

Any management practice, such as improving flow or avoiding algal blooms, will also help to minimize the frequency of low DO and improve the habitat for fish.

3.2.3.7 E-coli

Escherichia coli (*E. coli*) is an indicator organism for enteric disease-causing agents in the water. *E. coli* come from human and animal faeces, so if they are present the presumption is that there may also be other pathogens, such as viruses, that make the water unsafe for drinking or swimming as well. Tests for E coli have now been replaced by tests for Enterococci in saline and brackish waters, due to problems of salinity intolerance with *E. coli* affecting its reliability as an indictor.

Drinking water should have no detectable *E. coli* bacteria in it at all. Guideline contact values of *E. coli* colonies for recreation and shellfish are shown in Table 3.8 below. In the last column on Table 3.4, results indicate an average value for E.coli of 70MPN/100ml for the estuary and 90 for the lagoon for the 3 sampling rounds at a total of 8 sites.

On one occasion (21/8/11) one estuary site (HKS4) and one lagoon site (HKS7) exceeded the "alert" categories for marine recreation. Sites HKS13 and HKS15 were taken in branches of Post Office Creek during flooding and show much higher levels of *E. coli*.

[48] Schallenberg M per com

Table 3.8 Guideline Values for Contact Recreation, Shellfish Gathering and Shellfish Flesh

Guideline	Level/type	Allowable Concentration
Marine Recreation	Surveillance Alert Action	No single sample greater than 140 enterococci/100ml Single sample over 140 enterococci/100ml Two consecutive samples over 280 enterococci/100ml
Feshwater Recreation	Surveillance Alert Action	No single sample greater than 260 E.coli/100ml One single sample over 260 E. coli/100ml One single sample over 550 E. coli/100ml
Recreational Shellfish Gathering	Bacteriological Guideline Value	The median faecal coliform content of samples taken over a shellfish gathering season shall not exceed a Most Probable Number (MPN) of 14 per100ml, and not more than 10% of samples should exceed an MPN of 43/100ml.
Food/flesh (Department Of Health 1995)	Microbiological Reference Criteria	A faecal coliform concentration of 230MPN/100 gm represents an acceptable level and values above it are marginally acceptable or unacceptable in terms of the sampling plan. Values above 330 MPN/100gm are unacceptable in terms of the sampling plan and detection of one or more samples exceeding this level would because for rejection of the lot.

1. Guidlines from MfE/MoH, JUne 2003 otherwise indicated
2. Enterococci are members of the Streptococcus group of bacteria characterised as faecal in origin.
3. *Escherichia coli (E. coli)* is a member of the Enterobacteriaceae group of bacteria.
4. *Enterococcus* spp. is used in marine environments and E. coli at fresh water sites as it is believed to provide a higher correlation with human pathogens typical of sewage.

3.2.3.8 Electrical conductivity

Electrical conductivity (EC) may be used to estimate the total ion concentration of the water, and is often used as an alternative measure of dissolved solids. It is therefore useful in a brackish environment to determine the degree of saline influence. In freshwater, high conductivity is used as a generic surrogate indicator of general ionic contamination and can indicate nutrient enrichment or pollution from discharges or runoff and leachate from farms or industrial areas. It gives no other indication of what the contaminant might be.

Table 3.3 shows that the mean EC value of the stream is much lower than both the lagoon and the estuary. A typical EC value for seawater is approximately 48,000 uS/cm. The fact that the lagoon is so shallow and exposed to wind-induced mixing suggests that it is unlikely to develop vertical density stratification.

Table F1, Appendix F shows the salinity levels in the estuary were consistently higher than those in the lagoon. Whether this relationship changes in the summer or fluctuates is unknown. In some shallow lagoons a state of hypersalinity can develop as a result of evaporation during summer concentrating the ions. Creek water flowing into the lagoon has much lower salinity where it is not under direct tidal influence (e.g. PO Creek HKS2). The Tip Creek sidling the landfill (HKS14) consistently returned the highest value of the three creeks monitored.

3.2.3.9 pH

The pH factor is a measure of how acidic or basic a substance is when measured on a scale from 0 to 14, with 7 being neutral. This is a log scale, so a decrease of one full unit represents a tenfold increase in acidity and vice versa. Freshwater generally has a pH between 6.0 and 8.5. If the pH of water becomes high (basic; e.g. > 9) or low (acidic; e.g. < 5), the pH becomes toxic to many aquatic organisms.

pH is probably the single most important factor initiating all chemical reactions in water. High pH values tend to convert ammonium ion to ammonia gas and to solublise heavy metals. The precipitation of bicarbonate into carbonate salts (marl) is encouraged when pH levels are high. Low pH levels tend to occur in conjunction with high concentrations of carbon dioxide and carbonic acid.

Mean pH values measured in the field and shown in Table 3.3 all fall within the guideline value of 6.5 – 9.0 units but are likely to go higher on calm sunny days and fall much lower on summer nights[49]. The median pH of the lagoon was slightly higher than the estuary for the limited tests undertaken.

3.2.3.10 Temperature

Temperature affects the solubility of many chemical compounds and can therefore influence the effect of pollutants (e.g. ammonium) on aquatic life. Increased temperatures elevate the metabolic oxygen demand, which, in conjunction with reduced oxygen solubility, impacts many species.

The spot temperatures taken at the time of each sample suggest the order of increasing median temperature to be: stream, estuary, lagoon. The three sampling rounds were in the winter – early spring. However, an auto-log of the temperature in the lagoon and estuary (Figure 3.12), gathered at the same time as the water level fluctuations (Figure 3.6), shows that the relative temperatures at least between the lagoon and estuary regularly change during late winter/early spring.

Points of note from the recording on 3.12 include:

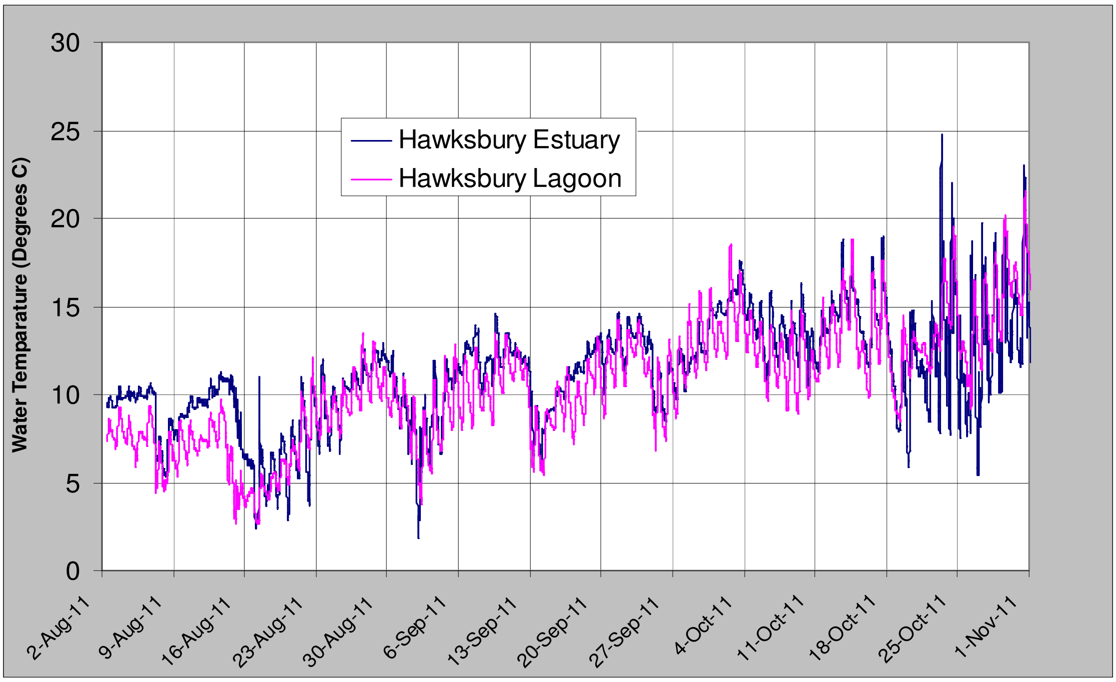
- The lagoon temperature in early August is lower than the estuary and by late October tends to be higher, although the highest temperatures are found in the estuary
- By comparison with Figure 3.6 this generalisation is influenced by the extent to which the estuary is open to the ocean and rainfall/runoff events
- The runoff event around the 16 August drags the temperature of both bodies down by about 5 degrees over a 3 day period
- Isolation of both bodies again enables the temperature to build until it again drops in early September when the mouth is open again
- Both the estuary and the lagoon are on a fluctuating but upward path until another significant rainfall on the 18 October lowers their temperatures and opens the estuary up to

[49] Schallenberg per com

the regular cooling effect of the ocean which keeps its mean temperature lower than that in the estuary

- The highest temperature recorded for the period in the estuary is 24.5 degrees and by the beginning of November the daily maximum temperature in both water bodies is exceeding 20 degrees

Figure 3.12: Auto-log to show temperature fluctuations in the lagoon and estuary (2 August 2011 – 1 November 2011)



Recordings taken at 30min intervals

The preferred temperature of the short fin eel is just above 25ºC, just below 25ºC for long fin, about 20ºC for many bully species and below 20ºC for trout and galaxid species.[50]

This data shows that over the summer period, temperatures could regularly exceed those required to avoid adverse effects on certain fish species, particularly juvenile fish. As both fresh water and ocean influence has a cooling effect, improving connectivity between either or both of these bodies will improve habitat for more temperature sensitive species and stages.

3.2.4 Contaminants

3.2.4.1 Result from this study

One water sample was taken in the lagoon to test for a range of possible metal contaminants. The site (HKS1 on Figure 3.9) is at the north end of the lagoon adjacent to the former County Council Rubbish Tip and Inverary St. Operation of an extension to the rubbish tip was halted in 1968, covered and planted in trees. Debris from the tip has in the past been exposed in the

[50] ORC Website attributed to Richardson et al 1994

lagoon bank[51]. With the exception of boron, Table 3.9 shows all results were below detection limit or below the New Zealand drinking standard. The source of the boron has not been determined.

Table 3.9: Heavy metals results measured in the water column in the lagoon

Site	Date	Boron-Total	Cadmium-Total	Chromium-Total	Lead-Total	Nickel-Total	Zinc-Total
		g/m3	g/m3	g/m3	g/m3	g/m3	g/m3
MAV		1.4	0.004	0.05 (PMAV)	0.01	0.02 (PMAV	1.5 (GV)
HKS1	2-Aug-11	1.65	<0.00021	<0.0011	0.0012	<0.0063	0.0091

1. MAV Maximum acceptable value and PMAV Provisional maximum acceptable value (Provisional because limited information on health effects)
2. GV Guideline value (aesthetic basis only)

3.2.4.2 Results from monitoring for the Waikouaiti landfill

Water quality in the stream flowing along the north perimeter of the Waikouaiti landfill before it discharges to the eastern arm of the estuary is monitored several times each year for selected water quality parameters. Samples are taken both upstream and downstream of the landfill to check for any impact leachate from the landfill may be causing.

The stream has limited flow and is ephemeral. From resource consent monitoring data for the creek, the median qualities at both these sites are compared with guideline values for fresh and marine waters in Table 3.10 below. They show that median values of the parameters measured do not generally exceed the guideline limits but that on occasion the maximums can. The value derived for zinc of 0.03mg/L both upstream and down is the detection limit, not an indication of significant contamination.

Table 3.10: Median and Maximum/Minimum water quality measures in the stream flowing at the base of the Waikouaiti Landfill (7 July 2004 - 26 June 2010)

Parameter	Australian Water Quality Guidelines For Fresh And Marine Waters [1]		Site W1 (Upstream of landfill)	Site W2 (Downstream of landfill at Edinburgh Rd Culvert)
Number of samples	Freshwater trigger	Marine trigger	23	28
pH	5.0 - 9.0[2]	6.0 - 9.0[2]	7.87	7.75
- max/min			8.28/7.19	8.1/7.04
Conductivity (uS/cm)	3,000 - 3,500[2]	3,000 - 54,000[2]	1,100.00	1,400.00
- max/min			3,000/930	9,700/1,100
COD (mg O_2/L)	<40[2]	ND	33.00	**44.50**
- max/min			<270	4,800/<25
BOD_5 (mg O_2/L)	<15[2]	ND	2.00	2.50
- max/min			42/1	52/1

[51] DoC, (?)1982

Total Ammoniacal Nitrogen (mgN/ L)	0.90	0.91	0.02	0.08
- max/min			1.41/0.01	2.05/0.01
Zinc (mg Zn/L)	0.008	0.015	0.03	0.03
- max/min			0.03/0.0012	1.4/0.0074
Iron (mg Fe/L)	ID	ID	0.25	0.83
- max/min			13/0.03	49/<0.03
Lead (mg Pb/L)	0.0034	0.0044	0.00011	0.00020
- max/min			<0.0007	0.28/<0.0001

1. Australian Water Quality Guidelines for Fresh and Marine Waters: for the protection of aquatic ecosystems with a 95% confidence level. Table 3.4.1 (ANZECC: Published 2000).
2. ANZECC Guidelines for aquaculture, Table 4.4.2
3. Where no standard is shown, there are no recommended guideline values. Medians include the minimum detection level were they occur at value
4. Both W1 and W2 are above tidal influence
5. ID = Insufficient data, ND = No data
6. Source of data is Ryder and Associates 2011

3.2.4.3 Results of a study into metals contamination

A research project sponsored by the Pacific Conservation Development Trust was undertaken in 2012 to investigate metal concentrations in the sediments of Hawksbury Lagoon. The study was proposed after the death of many shrubs and trees planted on the margins of the lagoon since 2010. The Hawksbury Lagoon Society wondered if a possible cause might be sediment toxicity. Twenty sediment sampling sites were randomly located thoughout the estuary-lagoon complex.

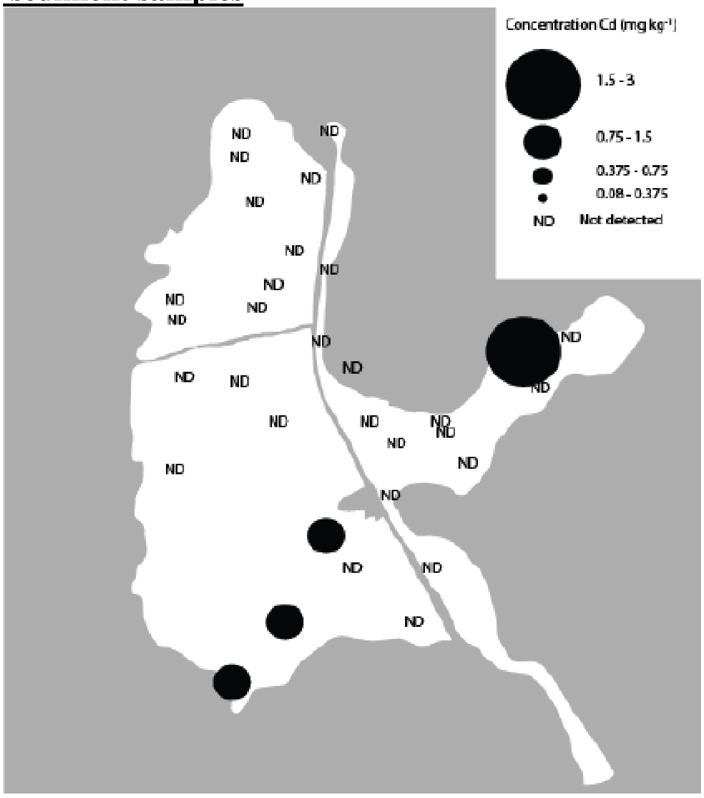
While widely not detected, the study found concentrations of cadmium were elevated at certain locations in the east (Tip arm) and at the southern end of the lagoon in surface sediments (0-5cm depth) and statistical analysis suggested it was human sourced (Figure 3.13). These concentrations fell within the range <0.83 - 2.8 mg/kg in the east arm and <0.83 - 1.14mg/kg in the south arm. Some results were therefore above the threshold effect level for aquatic organisms of 0.6mg/kg[52]. Results from cores sampling at 15-20cm depth did not exceed the guideline.

While present in most samples, other metals tested were below threshold toxicity levels in both surface sediments and cores.

Cadmium has cumulative and highly toxic effects in all chemical forms. It accumulates in plant cells and has been known to have extremely toxic effects on trout and zooplankton. Any presence of other heavy metals such as zinc and copper are known to increase cadmium's toxicity. Some phosphorus fertilizers contain cadmium from guano deposits. However, from these results it seems unlikely that the plant die off observed was due to metals and perhaps salinity levels could be considered as an alternative cause. And toxicity effects on plants differ depending on whether they exceed the limit for sediments or for standing water. Organic pesticide residues could also be tested.

[52] Desmond M et al, 2012 (referencing Burton, A.G. 2002. Sediment quality criteria in use around the world. *Limnology* 3: 65-75).

Figure 3.13: Location of Cadmium results in shallow sediment samples



3.2.5 Water quality monitoring

Establishing the current status of key indicators and any trends in time and space will be an essential part of any significant new initiative for the estuary-lagoon complex. So, components of an appropriate monitoring programme are proposed, but cannot be finalised until such time as the direction and objectives of the water plan are firmed. These recommendations are based on the preliminary water quality results and assume that at least some area of artificially controlled lagoon will be retained.

The results should be designed to enable progress and the effectiveness of different interventions to be gauged and to enable refinement of options. They also need to take into account daily and seasonal changes in salinity, tides, flow, temperature, turbidity, etc.

Should the water quality monitoring show that increased flushing is insufficient to bring water column nutrient levels down to the point where the risk of the hypertrophic state occurring is small, the options of organic sediment removal, and/or catchment transfer can be given serious consideration. If required, this would remove a massive source of nutrient that would, if present, keep introducing high levels of nutrients into the system for years to come.

Summary Box 9

Primary water quality issues with the lagoon are sediment (affecting clarity and habitat), high nutrient loads, temperature and dissolved oxygen. The nutrient has accumulated over decades as a result of waterfowl and runoff. The result is that it is subject to algal bloom and die off affecting oxygen levels and causing the lagoon to be unsuitable (eutrophic – hypertrophic) for many forms of life. Management options are primarily to reduce nutrient and sediment load on the lagoon and improve fresh or saline water flow to lower temperatures and improve oxygen levels. The level of risk for food gathering from metals and organics remains uncertain, particularly where water impoundment is to continue for extended periods.

3.3 Rural and urban catchment land management

3.3.1 Nutrient and sediment buffering

Nutrients, sediments and toxins that originate within a catchment as a result of urbanisation, agricultural activities, vegetation clearing and industry, eventually end up in an estuary affecting the water quality and estuarine ecosystem. In this way, estuaries have been referred to as the 'report cards' of the historical and current catchment management practices. Under many circumstances, measures undertaken in the estuary-lagoon complex itself can only ease the symptoms. For example, gains to removing nutrient-rich sediment from the floor of the lagoon may be short-lived if the nutrient inflow is unchanged.

On agricultural land, different land-use activities and management methods are associated with different levels of nutrient load and leaching. For example pine forest, 2- 4 kg nitrogen per ha/year; sheep and deer, 8 - 15, and dairying 28 to 100kg[53]. And if algal growth in the lagoon is nitrate limited, then containing as much nitrogen as possible is particularly important. Sediment from erosion is the greatest source of phosphate. Clearance and burning of forested hills to create pasture for sheep farming is largely responsible for erosion that carries sediment to our watercourses[54].

Recent farm studies indicate that about one percent of a catchment given over to wetland could trap about 20 percent of the nutrient. For the Hawksbury catchment that is the equivalent of 16ha. Five percent would capture around 50-60% of nutrients[55]. Wetlands throughout the catchment would count towards the nutrient reduction and can also attenuate flood flows, reduce erosion and sediment transport, as well as help maintain plant and animal biodiversity. In the lower catchment, the primary drainage lines are currently largely devoid of riparian vegetation and fencing.

Wetlands can be artificially created in key locations, but preferable, and often simplest is to restore a former wetland. The racecourse was formally an estuary/wetland so restored areas of it could serve both as nutrient traps and fish spawning habitat.

Typically, nutrient, sediment and other pollutant parameters have increased concentrations in flood waters – particularly because the runoff rate increases and any build up of nutrient or sediment is flushed; results for the single sample taken during a flood in both arms of the Post Office Creek (Table 3.3) are consistent with this. Most notable are the higher levels of total phosphorus, nitrate nitrogen and the *E. coli* count during this event.

3.3.2 Integrated response

From the point of view of achieving an improved water quality in the lagoon, this catchment has a number of factors in its favour:

[53] NIWA, March 2012
[54] Parliamentary Commissioner for the Environment, March 2012
[55] NIWA, March 2012

- So far, the most nutrient and sediment intensive land-uses (such as sewerage treatment ponds, industry, dairying, commercial pigeries etc) are absent, and neither has natural runoff been reduced by allocation from the creeks feeding the lagoon. - the poultry farm and town sewage system drain to the lower Waikouaiti catchment
- The hydrodynamics of the estuary complex itself have been so highly modified that there is considerable scope to improve the flushing flows.
- The geology beneath most of the catchment is very low permeability marine sediment, so there is very limited groundwater feeding the estuary area. This means that any steps taken to contain nutrients in surface flow will not be compromised by the lag effects of contaminated slow-moving groundwater.
- A significant proportion of the soils in the catchment are prone to some form of soil erosion (Appendix G). Merton (tunnel gully, sheet erosion) Warepa (slight to severe sheet) and Abbotsford and Omini (earth flow and slumping). Appropriately located plantings can therefore have multiple benefits.
- The catchment retains one of East Otago's few remaining stands of mature coastal native bush and some wetland areas so there is the opportunity to source seed locally and extend these areas to limit sediment loss.

As most of the sediment and nutrient comes in the first-flush of runoff, any modification that slows the flow is of benefit. Options that might be included in any community discussions include:

- Ponds, wetlands and meanders
- Riparian plantings of indigenous vegetation along water courses and around the margins of swamps and estuaries
- Natural barriers to intercept/buffer flows
- Ground cover and management
- Improving soil infiltration
- Corridors linking wetlands to other terrestrial and marine protected areas

Any initiative that attenuates the flow will allow water to infiltrate the soil and thus nutrients will be absorbed. Usually there are "hotspots" that can be targeted. Multiple water quality, environmental and landscape benefits would accrue if primary drains were re-naturalized, protected from stock and planted out. In some cases this can actually simplify farm management.

Similarly, some analysis of the town storm water system that drains to the lagoon might identify opportunities for wetland pre-treatment. For individual families there may be opportunities for small-scale water features based on storm-water collection from larger roof areas or all agreeing not to use phosphate-based washing products, for example.

The lagoon complex is a defining amenity for the Waikouaiti area and any improvements benefit all residents within the catchment. Ideally, therefore, a plan to improve and upgrade the site would be a community-wide initiative.

Summary Box 10

The degraded trophic state of the lagoon complex is largely a result of its isolation from normal freshwater and saltwater flushing cycles, aggravated by the cumulative effect of nutrient-enriched runoff for generations. Enhanced flushing of the lagoon will be most effective if the suspended sediment and dissolved nutrient load in the flushing water is minimized. Because everyone living in the catchment contributes to pollutant loads to some degree, any process to address this would ideally be genuinely catchment-wide.

4 Restoration options

4.1 Bio-physical restoration goals and mechanisms

4.1.1 Primary ecological pathways

From the point of view of what might be feasible within the existing biological and physical constraints on the lagoon ecosystem, there are three broad restoration pathways available for the Society and community as a whole to consider. Each would set a different restoration path.

17. Maintain a brackish lagoon ecosystem but aim to make it more diverse, stable, and with a lower nutrient status (lower-eutrophic/mesotrophic) than present.
18. Convert the entire lagoon to estuary by opening it up to tidal exchange.
19. A combination of the above options by opening up to tidal exchange only one compartment of the current lagoon and improving the quality of the remaining lagoon area.

Within their respective constraints, each option should attempt to restore the more balanced mix of coastal lagoon and terrestrial habitats that would have been present before the era of pastoral expansion (e.g. native plant-bound low profile sand-dune, riparian hill-gallery/flats forest, flax-shrub-reed wetland boundaries, aquatic wetland, and extension of estuarine marsh).

The first option could be achieved by directing greater flushing rates from existing (or augmented) flows derived from the catchment under an Integrated Catchment Management Programme (ICMP). The objective would be to decrease the intensity of the eutrophic state. Ideally the longer term target would be for a mesotrophic state (refer Table 3.5) but a better understanding of the current trophic dynamic drivers and limits will be required to decide if this is realistic.

The second option would be achieved by extending the estuarine area by altering the existing water control structures. When discussing this option in their statement of intent (June 1991), DoC took the view that changing the connectivity to the sea should not be in conflict with its formal status as a Wildlife Sanctuary, and furthermore, maintaining the lagoon is the more costly option.

The various technical options that could achieve these different pathways are discussed in the following sections.

4.1.2 Optimal lagoon water levels

4.1.2.1 Flood risk

As indicated earlier in this report (Figure 3.6), the presence of the causeway enables the lagoon water level to be held fairly constant, independent of the daily tidal cycle.

This means the causeway does help prevent flooding of lower sections of lawns fronting the lagoon. Private lawns fronting the lagoon on the north side of Stewart St are at about 1.5m (while the lowest home floor level is significantly higher at 2.17m). Peak tidal level recorded for the period 2008–12 was 1.7m amsl. This means that with culverts under the causeway closed, it is possible to protect the lower lawn areas from tidal-sourced flooding up to the level of the lowest section of the causeway (also approximately 1.7m). Any higher tidal effect (e.g. due to high runoff or tidal surge) and the causeway would overtop with seawater, flooding into the lagoon. We do not know if this has ever occurred, however.

On the other hand, at times of intense rainfall and high runoff, the causeway can actually aggravate flooding. The primary reason for this is that the outlet culvert is totally inadequate to discharge the inflow to the lagoon at such times. And should such runoff events happen to coincide with a high astronomic tidal phase (such as occurred on August 16 on Figure 3.6) then the situation is made worse.

4.1.2.2 Maintaining a lagoon option

If the lagoon water level is to continue to be isolated from the estuary, there are some key levels to take into account when setting the optimum target range – see Table 4.1 and refer to Longsection A in Appendix H.

Table 4.1: Some key levels to be considered in setting the optimum target water level range

Location	RL m amsl
The upper internal diameter of the southern lagoon culverts at HKS7 (upstream end of a 600mm diameter pipe) and HKS12 (downstream end of a 600mm diameter pipe)	1.28
The main track level of the Racecourse opposite the stadium (HKS17)	1.73
Monthly high tide (which can feed the lagoon when the gates are open)	1.40
Peak high tide (2008 – 2012)	1.70
Current trigger level for mechanical breach of the sandbar	1.60
Lowest house lawn on Stewart St	1.54
Lowest house floor on Stewart St	2.17
DCC Minimum Floor level for Waikouaiti (DCC, 2012)	2.65
Floor of the north end of the lagoon at HKS 18 (to keep flooded)	1.02

During the 3-month period of the auto-logging the lagoon water level fluctuated between 1.15-1.25m amsl. At the time of level survey in 24 August 2010 the level was 1.15m.

It is evident that the lawns bordering the lagoon along Stewart St have evolved assuming that the lagoon water level will remain below about 1.30m amsl for all but short and infrequent events. Equally, to keep some depth of water over the sediments of the north lagoon (HKS18), then the water cannot be much below 1.10m. This suggests that without earthworks, the water level operating range for a lagoon needs to be between 1.10-1.30m amsl.

It might, however, be reassuring for current landowners to note that flooding from high runoff is never likely to exceed about 1.75m amsl. This is because sections of the causeway would start to overtop before this level is reached. This is still 0.4m below the lowest house floor level. And from available data (under current climatic conditions), the most extreme tide level is 1.70m amsl. This margin however, will reduce as the sea level rises with climate change and the surge component linked to extreme events grows.

If the natural limit set by overtopping the causeway is considered too high, then a section of the causeway could be slightly lowered to the required height (and possibly a sill installed), or, the outlet to the lagoon would need to be modified to take significantly more flow.

As the northern compartment of the lagoon does not have the same level constraints, it would be possible to manage this part with a higher water level range.

4.1.2.3 Estuary restoration option

If the community decides to open at least the southern lagoon compartment up to tidal exchange again, then water levels in the current lagoon area are likely to be about 1.40 m amsl more frequently (see Figure 3.7). The simplest solution to this would appear to be raising the level of all the shoreline lawns to a minimum level of 1.75 – 1.8m amsl with suitable spoil. This would accommodate the highest tides and some surge. Some additional protection in the form of a bund or low wall on the edge of lawns could be added as a barrier to wave action during extreme high tides (up to 1.7m).

An additional consideration is that there is currently no bunding protection seaward of Stewart St to protect property from rising water levels or storm surge coming from that direction, even if the lagoon remains isolated.

4.1.2.4 Time scale for sea level rise

While it is clear there is still no scientific consensus on the rate and manner in which sea level will rise (Section 2.4.2), the lower rates of increase so far measured in NZ are consistent with non-linear theory gaining wider acceptance since IPCC 2007. To even meet the lower sea level rise predictions by 2100 the rate will need to accelerate with time as feedback processes activate. If Hansen's prediction that this rate of increase will be exponential is correct, actual rise would be limited up until mid century (Figure 2.6). But with a more unstable climate predicted, surge and high runoff associate with extreme events will increase and may on occasion significantly impact the estuary.

A complicating factor is that anomaly in the global distribution of sea level rise of up to 0.2m or perhaps more is anticipated by models due mainly to shifts in ocean circulation patterns and gravitational field[56]. While last IPCC report had sea level rise in the NZ region somewhat higher than the global average, the net long-term effect of such anomaly here still uncertain.

The current causeway/lagoon arrangement does reduce the frequency of tidal flooding on parts of Stewart St lawns, but at the same time it also aggravates the risk of flooding during heavy rain. But whether the area adjacent to Stewart St is retained as a lagoon or a restored estuary makes no difference to the level of risk that more extreme flood events (be they tide or rainfall

[56] Manning, M, 2012 (per com)

sourced) pose to those homes. Neither does it make any difference to the eventual effects of sea level rise.

4.1.3 Ecological restoration concepts and methods

4.1.3.1 Ecosystem migration and services

The decision on whether to open more of the lagoon up to regular tidal exchange will set the short and medium term direction and scope of restoration effort and biodiversity. In the longer term, restoration planting plans will need to anticipate advancing salinity in surface and groundwater with sea level rise.

In any event, serious consideration should be given to the possibility of creating significantly more trophic status buffering capacity by enlarging the area of freshwater-terrestrial wetland eco-tone (e.g. in addition to that envisaged in the Wildlands 2009 report) either peripherally, or, by creating islands within the lagoon. In addition, more focus should be put on the mid-upper catchment in terms of increasing area of riparian forest and wetland areas in the mid-upper catchment.

Such actions would provide a better diversity and abundance of habitat for fish, zooplankton, birds, and insects, as well as to provide a greater amount of vital water-filtering ecosystem services.

4.1.3.2 Purpose-built de-nitrification wetlands

This approach involves intercepting and diverting inflow into fringing areas set aside specifically for wetland beds that would remove nitrate from water before it entered the lagoon or estuary proper. With this direct throughflow of creek water these cells are likely to be less brackish and able to support a somewhat different ecology[57].

They would be designed to receive base and low flows on a continuous basis, but not with the capacity to receive and store flood flows. Depending on their size and water holding volumes, however, it may be possible to manage these areas so they can receive "first flush" water during higher runoff events. This could still be beneficial as its this first water which typically contains the higher nutrient and sediment load.

These wetland beds can be constructed on land above the high water mark or built into the fringes of the lagoon or estuary rather like padi fields. In the latter case, bunds would need to withstand wave action.

A fringe wetland constructed above the high water line could be similar in function to modifying the lower Post Office Creek to improve spawning grounds (see below). Likewise, introducing more fringe plantings in the existing more northern lagoon compartment.

4.1.3.3 In-lake restoration

Trials are continuing around the world on a range of interventions to reduce nutrients in shallow lakes. Artificially constructed floating rafts moored to the lakebed are one example. They are

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[57] http://earth.waikato.ac.nz/staff/schipper/download/research.pdf

planted with native rushes and reeds to form fibrous mats. In a recent trial it was estimated that the roots could remove, daily, 40-60mg of phosphorus and, through denitrifying bacteria, 500-600mg of nitrogen[58]. Once decisions are made around the fundamental direction of the restoration then this type of intervention may be worth closer examination.

Another in-lake approach under scientific investigation (e.g. Lake Okaro) is that of sediment phosphorus capping and water column adsorption using zeolite[59]. This has been shown to be very effective in the short to medium term (5-15 years) but this is not a long-term solution on its own (as high-wind environments tend to disturb the capping effect and ongoing deposition will reduce adsorption), so would have to be accompanied by a catchment management model.

4.1.3.4 *Restoring fish habitat*

Native fish populations are in general decline nationally. Loss of habitat due to draining, infilling, encroachment, sedimentation and excessive nutrient are all causative factors. Any expansion of the existing wetland areas, and water quality improvements will improve fish habitat, and potentially spawning activity.

The restoration of whitebait/inanga spawning grounds in particular is an appealing proposition, given their general decline in presence and condition at such locations nationally. It seems little consideration has been given to loss of fish spawning habitat in the Hawksbury Estuary and tributaries until now. Planned wetland restoration to enhance freshwater and brackish water fish-spawning habitat is a technical opportunity particularly in the lower Post Office Creek zone - whether the lagoon is retained or not.

Inanga spawning habitat is grassland or rushland on the floodplains of streams around the upper limit of high tides and particularly spring tides. Low velocity hydraulic zones are preferred by inanga[60]. In this upper tidal zone, tidal lift is important to give native fish the opportunity to lay eggs amongst the vegetation.[61] This tidal effect has weakened with more prolonged closure of the estuary sandbar. Battering and shaping banks can expand the surface area for spawning and also provide better access for water fowl.

The level survey (Longsection B, Appendix H) suggests that these water level and flow requirements could be provided in the more inland parts of the tidal zone. Figure 4.1 shows the low-lying area most suited for rehabilitation as fish habitat and spawning grounds in the Race Course Recreational Reserve. The west branch of Post Office Creek can be seen entering the area adjacent to Reid St at the top left and then traversing the reserve between the inner and outer race tracks. The east branch enters at the top right of the photo before passing down the western side of the Race Course. The two branches meet at Inverary St. Starting any enhancement at the downstream end would allow direct access for fish passage. There is also a largely isolated drain up the NW boundary between the reserve and the railway.

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[58] NIWA, March 2012
[59] (http://www.scionresearch.com/general/working-with-scion/commercial-successes/water-quality-improved-by-application-of-modified-zeolite)
[60] Tasman District Council, Estuary Restoration April 2008
[61] Pete Ravenscroft DoC (pers com)

Further investigation is required to determine the most feasible way of enhancing these and how to maximise nutrient removal in runoff concurrently. The present naturally high water table and susceptibility to surface flooding suggests that with some imagination, enhanced wetland fish habitat areas and horse racing could not only coexist but complement each other.

Figure 4.1: Reclaimed Recreation Reserve land immediately upstream of the lagoon most suitable for enhanced Inanga spawning modifications.

Source: http://nz.bing.com/

4.1.3.5 Optimizing waterfowl habitat

Determining the most favourable water levels and nutrient status for birds is complex (D. Onley Pers. Comm. 2011). General requirements for birds include maintaining an appropriate diversity and spatial pattern of habitats for the niches above, good ground cover around the lagoon edge and limited disturbance in general.

In addition to the list provided in Wildlands 2009 and collated from various sources, the local Ornithological Society (OSNZ) hold records of bird observations at the lagoon spanning the last 50 years (Derek Onley, Pers Comm. 2011). This long-term record is an extremely valuable dataset and should be examined for the information it would provide on the local relationships between bird communities and lagoon nutrient status and habitat type-abundance. Certainly, past changes in water levels and quality have led to wide variations in species identity and numbers using the lagoon. Establishing the dynamics of these relationships at Hawksbury specifically will help to detail the implications of different restoration options on bird community species composition and relative abundance.

Bird species typical of coastal lagoons and associated wetlands can be grouped according to their habitat preferences and requirements. The general groupings set out in Table 4.2 were prepared for the Wainono Lagoon in South Canterbury.[62] While it may not be possible to attract all of the species listed, a rich diversity can be encouraged by taking preferences into account when considering the water management options and reviewing the re-vegetation plans.

Table 4.2: General groups of resident and migratory wading birds and breeding waterfowl frequenting the Wainono lagoon and more widely observed in lagoon habitats in coastal Otago and South Canterbury

Guild	Species examples	Habitat requirements/utilization
1. Open water divers	grebes, cormorants, diving waterfowl	Feeding and roosting habitat. Open water, edge water, mud and sandflats, wetland turf or vegetated saltmarsh, and taller swamp vegetation (e.g. sedge, rush raupo). Nearby willow and conifer trees provide cormorant roosts
2. Deep water waders	stilts, herons, oystercatchers, arctic wader	Breeding, feeding and roosting habitat: edge water mud, and sandflats; wetland truf or vegetated saltmarsh; sedge-rush-raupo.
3. Shallow water waders	wrybill, banded dotterel	Breeding, feeding and roosting habitat for banded dotterel: feeding and roosting for other shallow water waders: edge water; mud and sandflats; wetland and vegetated marsh.
4. Dabbling waterfowl	shoveler, paradise shelduck, , grey teal, grey duck, black swan	Breeding, feeding, roosting habit: open water, edge water; mud and sandflats; wetland turf or vegetated saltmarsh; sedge-rush-raupo.
5. Gulls and terns	black fronted tern, black-billed gull	Breeding, feeding, roosting habit: open water, edge water; mud and sandflats; wetland turf or vegetated saltmarsh; sedge-rush-raupo ribbonwood. Gulls and terns may use the beach shore
6. Swamp specialists	pukeko, marsh crake, bittern	Breeding, feeding, roosting habit: primarily utilize the tall, dense sedge-rushs-raupo-marsh ribbonwood habitats of swamp margins; also edge water, mud and sandflats; wetland turf or vegetated saltmarsh.
7. Other species	geese, swallows, pipits, kingfishers	These do not depend exclusively on wetland or aquatic habitats but are associated with them as much as any other. Feeding, roosting habit: open water, edge water; mud and sandflats; wetland turf or vegetated saltmarsh; sedge-rush-raupo; marsh ribbonwood; willow forest

Adapted from Golder and Associates, Oct 2012

4.1.3.6 Restoration planting programme

The 2009 Ecological Management Plan for Hawksbury Lagoon[63] identifies eleven management zones. A number of these zones are on the periphery of the Hawksbury Lagoon and impact upon adjoining land owners and administrators. The aim of most of these zones is to achieve weed control, plantings and amenity improvements. The plan also recommends that a Water

[62] Golder Assoc., Oct 2012
[63] Wildland Consultants, 2009

Management Scheme is required to facilitate ecological restoration of the Hawksbury Lagoon itself and so needs review once the community has decided on the hydrologic regime to be adopted.

Recommendations per zone of the Wildlands report are consistent with our recommended goal of increasing habitat diversity and provide a sound ecological basis from which to build. However, it is important to note that this water management report is recommending more fundamental changes in the hydrology and ecological status of the lagoon, which may also involve the need to shift the location of the 'zones' referred to in the Wildlands report to areas that better match the proposed new physiography and hydrology. Accordingly, the Ecological Management Plan should be formally reviewed once the hydrological direction for the complex is settled.

Moreover, under the objective of improving biodiversity in a highly accessible area, it needs to be clear whether birds or plants are the main priority for each zone. Often both are possible but not always[64]. For additional restoration goal guidance on intervention, the remnant wetland site at the bottom of Henry St in Waikouaiti would be a useful reference and potential seed source.

4.1.4 Implications of changing energy regime on restoration planning

In 2009, the DCC commissioned two reports on the subject of peak oil, energy security and on how it should best prepare for any shortfall in oil access.[65] [66] A summary of the key findings is in Appendix D.

Global "peak oil" is the point beyond which the total rate of oil production declines irrespective of how hard it is pumped because the rate at which new oil is coming on stream is insufficient to fully replace the rate of decline from old wells. Production in existing oil fields around the world is declining at rates of 4.5% to 6.7% per year[67].

Both reports address the changing global circumstances with oil supply and the prediction that we are entering an era when the energy-return on energy invested in oil is declining rapidly. Overlying this was the now general acceptance amongst governments that we can not burn all the fossil fuel reserves identified and stay within the 2 degree C climate change threshold. This means that either way, supply will need to become increasingly limited in the coming years. While there is no local control over this global situation, because of oil's critical role in the economy, its abundance and cost will directly impact on the surplus capacity that all communities have available for projects, and so needs to be taken into account in any planning.

The step change has practical implications for option selection and design criteria for a project like the Hawksbury Lagoon. It implies reconsidering, the relative importance of the following:

- The self-maintaining properties and degree of intervention in natural or dominant processes
- The simplicity, durability and operational convenience of any water control structures
- the level of dependence on external financial support versus self-funding

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[64] Tasman District Council, Estuary Restoration
[65] Lloyd, R, 2010
[66] Krumdieck, 2010
[67] Murray and King, 2012

- Ecosystem productivity and mahinga kai opportunity (i.e. importance of ecological health)
- Local recreational requirements, and appropriateness of current reserve conditions
- Effect of rising commuting costs on future demographic of community
- Local business, education and employment opportunity (eg fish farming, fibre[68], cultural etc)

4.1.5 Change in societal perception and valuation of ecosystem services

There is considerable evidence that society generally is changing its perceptions of value in terms of land-cover and the services provided by managed and natural systems alike. The ecosystem services provided by a particular ecosystem have historically been undervalued, however this is rapidly changing and is likely to have an increasing influence on the community and stakeholder buy-in to ecological restoration initiatives at Hawksbury Lagoon.

Historical records of the estuary generally show a rich relationship with Maori – more than in a purely material sense. Wetlands generally have provided Maori with "food, plants for weaving, medicines, dyes; medicines; canoe landing sites; places to season timber; and to store taonga"[69].

In the context of the less energy-rich future discussed above, it would seem like a good opportunity now to consider how best to facilitate such skills and knowledge when choosing the preferred water management regime for the lagoon complex. There could be both enhanced cultural and economic opportunity for the community.

Summary Box 11
If there is to be a water management intervention at all, a decision about whether to open up the lagoon to more tidal exchange is key. If the project is to be durable, this decision needs to include consideration of "big picture" factors like sea level rise and pending energy limits. Once this decision is made, it will become easier to select from the range of restoration methods available to improve the ecology and ecological services of the overall complex.

4.2 Hydrological engineering options

4.2.1 Sediment removal and island construction

4.2.1.1 Sediments

The Hawksbury Lagoon widely consists of a bed of fine, soft muds, having the appearance and consistency of black ooze although a more sandy consistency reportedly occurs nearer the ocean. Overlying this in some areas there may be a fine grey silt of 30 – 60mm. Particularly when disturbed, a sulphurous aroma may be emitted, characteristic of an anoxic state.

[68] Two flax mills operated in the early days of European settlement but what with wetland destruction the mills closed by early 1870s
[69] http://www.doc.govt.nz/upload/documents/science-and-technical/nzwetlands00.pdf

Nutrients entering the lagoon from adjacent farmland tend to accumulate in the sediments of the lagoon and inhibit the capacity to improve the water quality. These influences were strongest during land clearance and subsequent agricultural activity so that residual nutrient is typically concentrated in the shallow sediment.

A recent study into contamination within the lagoon complex found that the depth of the muds over firmer clay was typically about 20cm. This underlying clay was described as difficult to core. On the other hand, during sampling operations, we experienced difficulty wading in some locations due to the "quicksand-like" nature and depth of some soft sediments (up to knee depth in places) suggesting that the depth of the soft muds that might need removal could be greater in certain parts of the lagoon.

Prior to undertaking such earthworks, the depth of excavation would need to be confirmed by establishing the nutrient regime within the sediment and the depth profile. Ideally this would be preceded by a palaeoecology study to reconstruct the historical environment and the period of anthropogenic impact.

4.2.1.2 Sediment removal

Excavating the floor of the lagoon is a direct way to remove the source of these nutrients and thereby significantly enhance the opportunity to improve the water quality. In fact, only with removal of high nutrient concentrations in the profile would complete rehabilitation in the medium term be possible. Sediments could be moved, for example, to reclaimed areas in the racecourse reserve to create further elevation above sea level. Alternatively, they could be used within the lagoon to form

- constructed islands of appropriate size and height
- widen the existing causeways to improve passage
- create an elevated observation area linked to the causeway for recreation or a hide

Any feature constructed within the lagoon would be susceptible to erosion due to the fine, non-cohesive and sorted nature of the sediments. Containment structures or other means of stabilization would need to be considered. For the original causeway construction, this has been achieved using rows of driven stakes. The ecological report gives some planting recommendations regarding erosion protection[70].

Care would be required not to excavate the lagoon much below sea or estuary level to maintain flushing capacity. The levels on Cross Section B in Appendix H show that the bed of the lagoon adjacent to the central causeway is 0.75 above mean sea level and 0.3 - 0.5m above the adjacent estuary.

4.2.1.3 Feasibility

Factors that would influence the preferred design and feasibility of mechanical removal of sediments include

- The final fate of nutrients within the excavated sediments,

[70] Wildlands Consultants, 2009, pg 28

- The significance of the impact of disturbed and re-suspended sediments (and possibly on the re-liberation of any contaminant) on lagoon, estuary and coastal near-shore ecosystems. following the earthworks
- How long the water quality benefits would persist based on the anticipated nutrient return
- The cost and durability of silt containment and erosion protection of any islands
- The load bearing strength of drained sediments to support heavy earthmoving equipment

Figure 4.2 shows the condition of the lagoon during the drought in April 1999. The lagoon would be drained down as far as possible during favourable tidal conditions then closed off to allow the remaining water to be pumped out.

In addition to the removal of nutrient load, other potential benefits of reclaimed features include reduced wave action and remobilization of sediment in the water column, creating better habitat for bird breeding (e.g. reduced access for predators, disturbance by dogs and humans) and fish life (deepened areas, shelter). Once complete, and with adequate protection against erosion, operation and maintenance for this option will be low.

Figure_4.2: Photo showing the Hawksbury Lagoon during the drought of April 1999

4.2.2 In-catchment lagoon augmentation

4.2.2.1 Enhanced flushing capacity

Two of the three creeks flowing into the estuary-lagoon complex now bypass the lagoon. The Tip Arm Creek could not be readily captured. The Beach St Creek arm already flows through the lagoon. Therefore augmentation potential with natural runoff is effectively limited to the two branches of the Post Office Creek.

Estimates of the potential annual volume of runoff that could be directed through the lagoon with appropriate channel modifications and under two annual rainfall scenarios are shown in Table 4.3. It also shows what that volume of runoff would represent in comparison to the water holding capacity of the lagoon as a ratio. On an average rainfall year, the runoff is equivalent to 6-8 times the lagoon capacity. Directing this water through the lagoon would significantly improve flushing. There will however be considerable variation around this ratio between years, and periods within a given year, when natural runoff is low.

Table 4.3: Potential to enhance the lagoon flushing with natural runoff

Annual catchment rainfall option	Potential runoff to lagoon		Volume stored	Lagoon capacity to runoff Ratio
(mm/yr)	(mm/yr)	(m3/yr)	(m3)	
700	75	906,750	140,000	6.5
720	95	1,148,550	140,000	8.2

Notes:
1. Post Office Creek catchment (excluding Tip arm) = 1,067ha
2. Area of lagoon = 40ha
3. Average lagoon depth assumed = 0.35m
4. Evapotranpiration = 625 mm/yr

4.2.2.2 Diversion options

There is a good location to divert water just downstream of the Inverary Bridge, but there is a lack of fall in the lower end of Post Office Creek where it traverses the racecourse. If the water level in the lagoon is required to be held at no less than 1.15m, then weirs would need to be set both in the creek and in the causeway at this level. The current bed level (termed "invert" on the figures in Appendix H) of the Creek at this locality (HKS2) is 0.70m amsl. So this installation would mean that the base water level for all channels in the racecourse as far up as Glasgow St would also be raised by approximately 0.45m. Such a base water level would raise the watertable beneath the racecourse to within 150mm of the main race track (e.g. see HKS17 on Long section B) and aggravate flooding risk here during high rainfall.

There are several possible ways to address the lack of fall problem and still achieve a diversion:
1. Install a new side-wall weir to the lagoon at a level of 1.15m amsl and simply accept improved through-flow when the creek or tide causes the water level in the estuary to rise above 1.15m
2. Direct the Post Office Creek (Reid St) branch beneath Inverary St (either under the existing bridge or in a new structure) independent of, and with a top water level approximately 0.45m higher than, the Aberdeen St branch, so that it can be discharged directly into the northern compartment of the lagoon at design level.
3. Divert the Aberdeen St branch just below the Glasgow St bridge down the existing (but enlarged) ditch in the railway easement to join with the Reid St branch at the bottom of Reid St and discharge directly into the north end of the lagoon.
4. Install a low-lift flood pump near the Inverary bridge to operate when the water level in the creek reached a certain trigger level and (if desirable according to the restoration goals set) also when the salinity was below a certain level.

The first option should be very straightforward and cheap to implement and operate and may not require resource consent.

With the second option, it might be advantageous to relocate the branch of the creek nearer the railway line to the west. With both the first and second options there would also be opportunity to deliberately expand habitat suitable for spawning by migratory fish

The third option would reduce flooding risk in the racecourse reserve (and therefore may have appeal to managers of the area), but conversely it might reduce fish spawning habitat unless alternative habitat were created.

The choice of option from the above will also dictate which lagoon outlet modifications would be most appropriate to accommodate the changed throughflow regime (but see also the discussion on flooding risk in Section 4.2.4 below).

4.2.2.3 Further work

Other specific issues to address with these options include:

- Local agreements and the necessary consent to modify the lower Post Office Creek
- Improving runoff water quality from the lagoon catchment
- Controlling "first-flush" nutrient load in runoff

4.2.3 Enhanced ocean-estuary connectivity

4.2.3.1 Current connectivity

As explained in Section 3.1.5, the extent to which daily tidal cycles flush all or part of the estuary depends on the state of the sandbar, and on the phase of the monthly tidal cycle. The sandbar can partially or totally prevent interchange for periods of days or weeks until a rainfall event scours out the inlet or exceptionally high tides breach the bar and re-establish connection. Without these processes, wave-driven sand transport would seal off the inlet.

The analysis in Section 3.1.6 showed that a significant reduction in the size of the estuary has similarly reduced the volume of tidal exchange that can occur with each tidal cycle. This in turn has reduced the flow rate and scouring potential in the estuary mouth, and so has prolonged the periods of little or no surface water connection with the ocean, at the same time constricted fish passageway. The current practice of periodically mechanically breaching the sandbar does improve connectivity but, judging by the auto-recording (Figure 3.6), to a limited degree only.

As the estuary opening regime is the primary controller of estuary values and of fish migration, this is the key underlying water management issue of this investigation.

There are two options to enhance and prolong the connectivity between the estuary and the ocean:

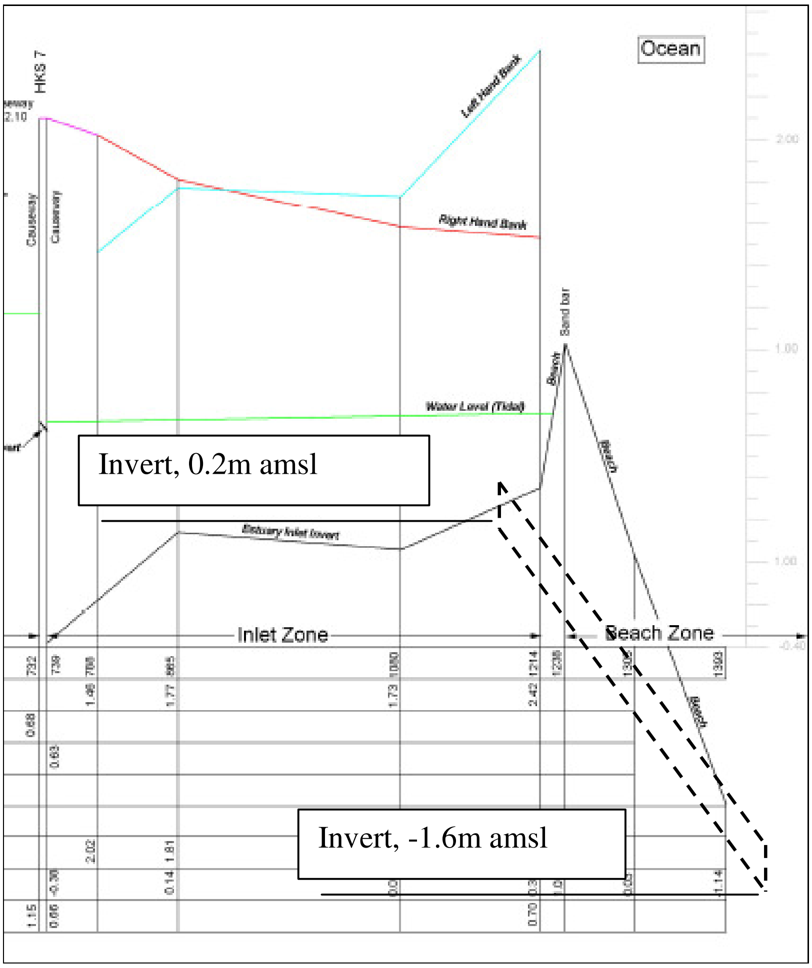
1. Installing a pipe or box culvert from the estuary to the ocean
2. Partially restoring the volume of tidal exchange (tidal prism) to scour the inlet

Each is considered in turn below.

4.2.3.2 Culvert Option

The general concept for a culvert is illustrated in Figure 4.3 with approximate upstream and downstream invert levels shown for a 200mm diameter culvert pipe. In this example both ends of the culvert are set above the current bed levels to minimise the risk of blockage or burial and to keep the ocean outfall below sea level at low tide (i.e. typically about -1.2m amsl) for fish access. Setting the pipe on driven piles would keep the outlet off the beach floor. To meet these criteria, the pipe would need a length of approximately 250m, and the upstream inlet designed to minimise the risk of clogging during high runoff events.

Figure 4.3: Concept for a culvert as a permanent link between the estuary and the ocean



Source: Extract from Long Section A in Appendix H

While technically possible, this is considered a risky option, with uncertain benefits. While a primary purpose would be to facilitate the passage of migratory fish, a 200mm diameter culvert would make little difference to the tidal exchange and estuary water quality. A much larger diameter (and, to contain cost, probably shorter) conduit would need to be installed. The Waihao Box in South Canterbury is an example of a large diameter conduit (Figure 4.4). The cost of such a culvert would be significant not only for the piping but also for protecting it against wave action.

Other factors needing consideration for this approach include:

- The risk of an eroding or accreting beach front affecting the effectiveness of the conduit
- The risk of a perverse effect in prolonging the periods when the sand bar is not breached
- How effective it would be in promoting fish migration

- The operation and maintenance costs and durability of an engineering structure in the littoral zone
- The appearance of the structure at low tide
- Resource consent requirements
- Undertaking a temporary trial and/or modelling before committing to this option

4.2.3.3 Increasing the tidal prism

The tidal prism would be increased by allowing tides to, once again, move unimpeded over a greater proportion of the estuary-lagoon complex. This would require a significantly larger opening for water conveyance across the central causeway in the form of a series of large culverts or a footbridge - perhaps along the lines of the former wooden bridge across the lower estuary to the golf course.

Figure 4.4: Waihao Box on the mouth of the Waihao River in South Canterbury

Source: Environment Canterbury

And if the northern lagoon compartment were also to be opened up to the tide, then much greater hydraulic connection would be required there too.

Other things being equal, the larger the estuary area opened to the tide, the greater the tidal prism and flow exchange in any given tidal cycle.

The areas of the various components of the lagoon/estuary complex are set out in Table 1.1. The southern and northern lagoon compartments are 28.3 and 11.76ha respectively and the estuary, 11.62ha. So if the entire lagoon were opened up to tidal exchange, the tidal prism would increase by a factor of about 3.4 and if only the main southern compartment, by a factor of 2.4.

But the depth of the complex is not constant, causing more peripheral zones of the complex to drain completely at low tide and therefore contributing less to the tidal prism (see drained areas in Figure 3.11, for example). The southern lagoon compartment is deeper and therefore will contribute more volume.

One explanation for this is that since the construction of the causeways, most sediment has been directed to the estuary rather than the lagoon. Greater scour capacity would also probably lower the estuary inlet, drawing on more storage from deeper in the existing lagoon area. So we consider it reasonable to anticipate that opening up the southern lagoon compartment alone will at least treble the current volume of tidal exchange. To more accurately assess this, a contour survey of all flooded areas would be required.

The primary purpose of increasing the tidal prism is to keep the inlet open for longer periods and to improve the flushing in both the new and the existing estuarine areas. While these areas would flush more frequently, it is not possible to say by how much with any confidence.

4.2.4 Inter-catchment transfer

Another technically feasible option to augment flushing in the lagoon is to transfer water from the lower reaches of the Waikouaiti River during times of higher flows there. There are three possible methods to achieve this transfer: open race, buried pipeline or some combination.

All three of the concepts could source water from a pumping station in the vicinity of the SH1 Bridge on the Waikouaiti River (see Longsection C, Appendix C). The option of an entirely gravity-fed race from further up the Waikouaiti was examined as far up river as Orbells Crossing (McGrath Rd Bridge) and found not to be feasible.

4.2.4.1 Open race

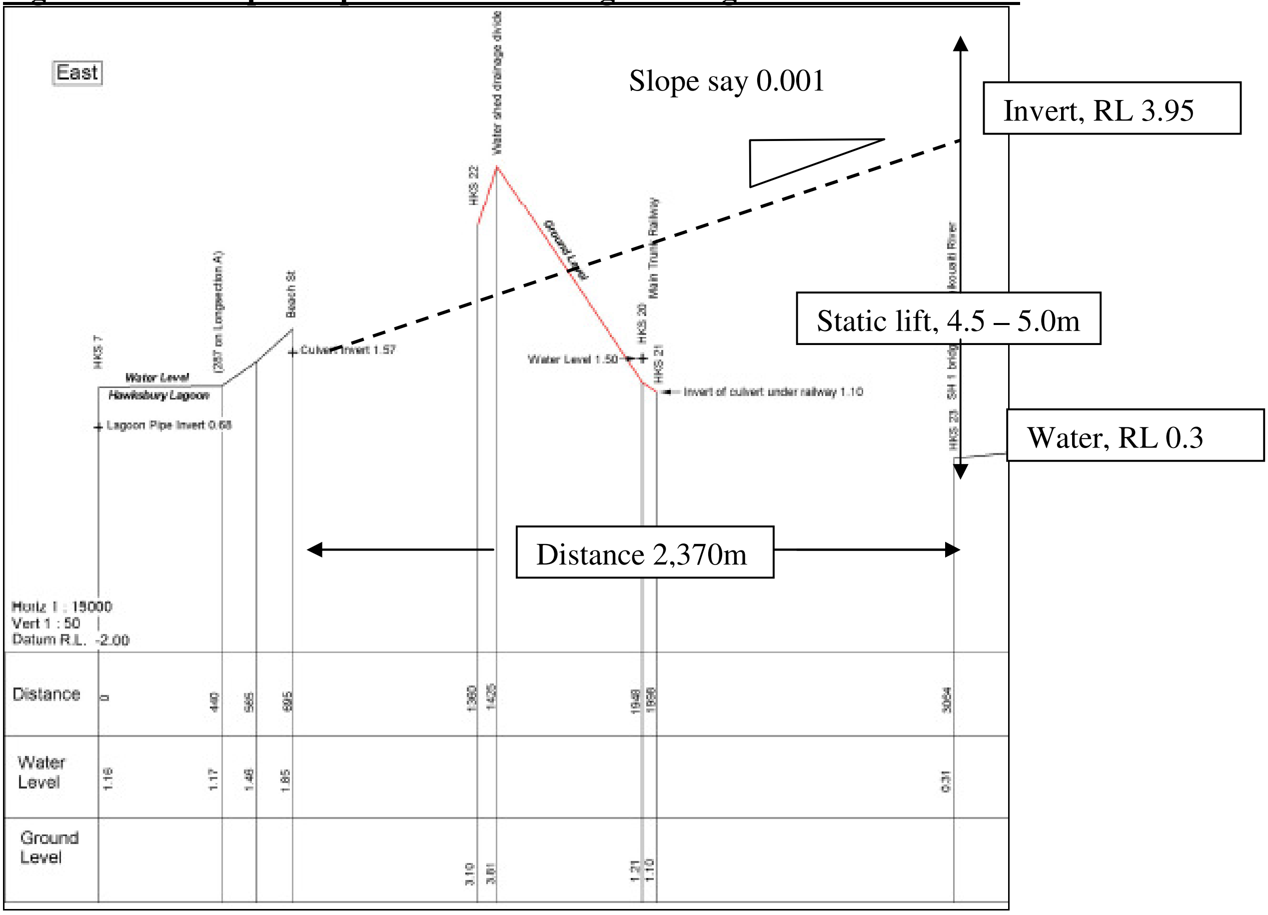
The open race would be aligned to gravity-feed around the base of the terrace scarp that connects SH1 bridge and the Mainland Poultry buildings. The race would then head north-west to discharge into the creek that flows through the Beach St Culvert near the intersection with Stewart St in Waikouaiti.

Long-Section C in Appendix H plots key levels between the Waikouaiti River and the lagoon, including the boundary between the Waikouaiti River and Hawksbury Lagoon catchments which occurs slightly north of the Mainland Poultry office block. The significance of this is that its elevation, along with the required race gradient back to the bridge set the pumping lift requirement at the river. Roughly 5m of lift would be required, depending on the number and types of structures (road culverts etc) located along the length of the race and the rate of water to be supplied.

An attraction with the open race option is that it lends itself to transferring water at a higher rate than a pipeline, unless the latter is large diameter. The rate at which water can be transferred will be important if the resource consent (or salinity levels) restrict the frequency and periods when transfer can occur. For example, 240 L/s race capacity would supply the equivalent of the lagoon volume in 7 days.

The general concept of the open race option is shown in Figure 4.5 below.

Figure 4.5: Conceptual open race invert design feeding the Beach St culvert.



4.2.4.2Buried pipeline

A pipeline could be aligned across country and along Bourke St to discharge in the northern compartment of the lagoon, a distance of approximately 1,600m. An alternative route of similar length is from the SH1 bridge due north to discharge into the Post Office Creek north of Waikouaiti. This might be preferred if more freshwater flushing was required for any enhanced spawning areas in the lower Post Office Creek.

In both cases the actual pumping costs would not be great, as the elevation difference between the Waikouaiti River and the discharge into the creek or lagoon would be small. Another way of imagining that is to consider that once the pipe was flowing, it would be close to siphoning.

4.2.4.3 Pipeline and race combination

The third option is to lift water by pipeline directly up and over the scarp to the east of SH1 Bridge. At this location, it is only a distance of some 250 m from the Waikouaiti River edge to the catchment boundary with the Hawksbury at the top of the scrap, a static life of about 21m . From this latter point water could gravity feed right down to the Beach St culvert and hence to the lagoon. It would be possible to use existing drainage lines but from the landowners' point of view, cutting a special-purpose race to follow, as far as possible, existing fencelines would probably be most practical.

4.2.4.4 Further work

Matters that would need further consideration include:

- Power supply availability and the capital and operating cost of each concept
- Salinity control limits to avoid seawater transfer from tidal effects;
- Securing easements for pump, channel and/or pipeline on private land;
- Resource consent to take water from the Waikouaiti River as part of the supplementary allocation and to discharge to the Post Office Creek or the lagoon;
- Pumping setup design to withstand floods.

Supplementary allocation from the Waikouaiti River should be available and could be allocated for environmental enhancement. Key to securing a resource consent to take and transfer water would be whether it had Runanga support.

4.2.5 Augmentation with Groundwater

4.2.5.1 Groundwater potential

To augment turnover in the lagoon, one potential source of additional water for consideration is that of groundwater. To our knowledge there has been no specific study into the groundwater potential or any deep drilling in the Waikouaiti locality.

If it can be secured in sufficient quantity and quality, the attractions of groundwater are that:

- It takes little time to develop
- The bore may be conveniently located near the site
- Water can be drawn at any time it is required during the year
- If the bore is flowing-artesian, it would have negligible operating cost.

Based on the geology of the location outlined in Appendix E, and on investigations and drilling experience in other localities, the general groundwater potential of the major formations is summarized in Table 4.4 below

Table 4.4: General assessment of groundwater potential

Group	Anticipated limitation	General prospect
Quaternary (Recent alluvium)	Water quality, saline intrusion	Unlikely
Volcanic	Elevation, extent, locality and storage/yield	Unlikely other than for stockwater
Marine deposits (Onekakara)	Low permeability	Very unlikely
Fluvial deposits (Taratu)	Uncertain water quality, recharge, depth/access	Possible
Basement (Haast Schist)	Low permeability and storage/yield, chancy	Unlikely other than for stockwater

There are some springs on the upper flanks of Derden Hill and Mt Baldie. These are probably discharging laterally from the Volcanics when percolating water encounters the underlying impermeable Marine deposit. Springs with hard, limy water are recorded to have existed in the township. These are likely to have been associated with the limestone and carbonaceous mudstone of the Otakou group underlying Matanaka. Others reportedly emanated from the base of the terraces skirting the river flats. In both cases the yields were likely to have been limited due to size of the aquifers and hydraulic parameters.

The Green Island Loose Sand/Green Island Sand which elsewhere is found lying within the marine deposits between the Burnside and the older Abbotsford, has been used as an aquifer around Dunedin (e.g. Burnside Freezing works bore). It is well developed at Blueskin Bay but only around 2m thick on a poor exposure on the Kilmog[71].

An early report by Paterson suggests Green Island Sand is well developed near Palmerston. But nothing shows it, the Tapui Formation or their equivalents are in outcrops in the Waikouaiti area in our present state of knowledge [72] [73].

While Schist may contain some groundwater it is typically limited and uncertain. It is also still deeper than the more promising Taratu.

This would leave the Taratu as the only remaining formation with the potential storativity and permeability to transmit groundwater in any quantity, even though there may be wide variations in texture and permeability. Fluvial deposits such as the Taratu often prove to be good aquifers, because they are formed by braided or meandering rivers, because the river flow sorts the sediments by flushing and transport. The shifting positions of river channels and bars can result in extensive deposits of bedded sand and gravel with minor zones of silty or clayey sediments. While initially unconsolidated and permeable, pressure and chemical reaction (sometimes involving iron reactions from buried organic matter) can, over time, subsequently reduce permeability.

Provided drillers successfully control any artesian pressure, properly install suitable screens, and use corrosion-resistant well casing and fittings, there is a reasonable chance of securing water where the formation is sufficiently thick and has been adequately penetrated.

The Taratu also typically exhibits a fining-up sequence from the base. Cost estimates for drilling should therefore anticipate drilling to the more permeable gravels nearer the Schist basement.

4.2.5.2 Uncertainties

There are no bores known by us to be tapping the Taratu Formation or the Green Island Sand in the area. So, from the point of view of securing water for Hawksbury Lagoon augmentation, the main uncertainties are:

- The drilling depth required to reach the formation (and therefore the cost of the borehole),
- The water quality (which is typically high in iron and dissolved salts due to its age)
- The sustainable yield (as the outcrop area for recharge to the Taratu located to the north of Mt Baldie is limited, and the Green Island Sand is also likely to be quite isolated from recharge)
- Whether the well would be flowing artesian or require pumping.

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[71] Chuck Landis (Geologist) per com, 2013
[72] Forsyth 2013 per com
[73] Linqvist J and Forsyth student mapping

As the formation is dipping to the east, depth of drilling will be minimized if the well was located as far inland as practical. The approximate depth of the Taratu formation near Waikouaiti can be estimated assuming a regional dip of 5 degrees from the outcrop north of Derden Hill at about 90m amsl. This gives a depth to the top of the Taratu below ground level for a bore located at the north end of Park St would be 280m, or located at the Iverary St Bridge, 350m. At least 10m additional length would be anticipated to penetrate the aquifer.

The chances of securing an artesian flow under significant pressure from a bore adjacent to the lagoon are low, as the Taratu formation outcrop north of Mt Baldie is likely to leak into or around the overlying Quaternary sediments in the lower Watkin Creek and Pleasant River estuary, which are of a similar elevation to the lagoon.

Table 4.5 below shows the number of days it would take to discharge into the lagoon an equivalent of the same volume if the lagoon contains 140,000m3 water.

Table 4.5: Number of days required to turnover the lagoon with different bore yields.

Scenario	Bore yield	Lagoon Flushing
	(L/s)	(days)
1	15	108
2	25	65
3	35	46

To make a significant flushing impact on the lagoon, the bore yield would need to be at least 35 L/s. This flow would require a minimum of a 200mm diameter bore to allow for pump insertion if required. But even with this flow it would take 1.5 months to augment the equivalent volume contained in the lagoon. And with imperfect mixing, this would not entirely replace the incumbent water.

Based on experience in the equivalent formation in North Otago, a bore yielding 35 L/s would be at the higher end of the potential range. In any event, it is almost certain that a flow of this rate would not be achieved without the aid of a submersible pump.

Based on this assessment, seeking groundwater of adequate quality and flow to augment flushing of the lagoon is a risky and costly option and not recommended. Unlike groundwater, the yield, quality and reliability are known if supplementary water is required and it is sourced directly from Waikouaiti River.

Summary Box 12

A range of ecological and engineering options enabling more effective flushing of the lagoon and estuary have been identified and broadly assessed. Some of these are simpler, cheaper and more environmentally advantageous than others. But the most suitable method or combination of methods depends heavily on whether the lagoon is to be retained in part or in full.

5 Main findings and recommendations

5.1 Main findings

This study finds that this system has some significant constraints to restoration. These include

- elevation relative to sea level
- projected sea level rise
- major deforestation and drainage within the catchment
- major hydrological alteration through the lagoon-estuary complex
- limited natural hydrological throughput
- major nutrient and sediment legacies in lake bed
- erodible loess soils in the catchment
- former and existing landfill sites and their potential effect on mahinga kai
- encroachment of landowners and building levels

These limit significantly what can be done in terms of easy restoration, for example, to particular historic states.

However, by means of system engineering, its functionality can be further altered to make it more acceptable to current public desires and to re-establishing some of its former ecological function, such as more regular tidal exchange and enhanced fish spawning for example.

Some of these interventions potentially involve capital works, land purchases or access agreements, resource consents and maintenance costs. Others are relatively "soft" techniques and should not require significant ongoing cost or maintenance provided they recognise and seek to complement rather than control natural processes and trends. Certainly it is recommended that this approach is given priority. With due consideration, such interventions may also be made multifunctional.

5.2 Recommended approach

This study has identified a number of hydrological and limnological engineering options for consideration by the community that could either be implemented in parallel or staged. If the community decides to improve the state of the complex, the first step is to seek general consensus amongst the various interest groups whether to either retain the lagoon, or if it, or some part thereof, is to be opened up for at least a trial period of tidal exchange. Once this decision is made then the range of options narrows and it will be easier to see the way forward.

The following recommendations and prioritization of work are based broadly on:

- Maximising the environmental benefit to cost
- Ease of implementation
- Minimising risk

5.3 Recommended programme

Operating framework

1. Adopt a planning framework that assumes that sea level rise will dictate that the current trend toward a wetland will be reversed and plan for an estuarine habitat. Ultimately this reversal of trend will materially impact on the racecourse and residential property on lower-lying areas adjacent to the lagoon complex.
2. Agree the prioritization and staging of the work programme and make fund-raising plan
3. Set environmental quality targets including trophic level.

Monitoring

4. Confirm and initiate the monitoring programme (see below).

Catchment management and plantings

5. Explore with landowners the feasibility of slowing the rate of runoff from the catchment with ponds, wetlands, etc, and fencing off and riparian planting any reaches of the creek most likely to be transmitting sediment or nutrient.
6. Explore the feasibility of establishing a joint nursery for native plants from locally-sourced seed to optimise planting success, This would also preserve the ecological distinctiveness and diversity of the area, and preserve plant varities and forms that are adapted to local conditions.
7. Explore with the City Council the need for, and feasibility of, improving the quality of storm water drainage and deriving more benefit from it for the lagoon.
8. Review lagoon planting programme and macrophyte restoration needs in the light of this water management study and optimize or extend them to improve oxygen levels, nutrient take up, provide faunal habitat and to generally improve the aesthetic values of the area.

Estuary reinstatement (lagoon southern compartment)

9. Open up the southern (main) compartment of the lagoon to the ocean sufficiently to remove any restriction to tidal exchange. This will extend the estuary, increase the tidal prism and thereby also more effectively scour out the inlet to extend periods of exchange to the entire expanded estuary.
10. This new outlet to the lagoon is likely to require a short bridge. To exclude organic detritus that might encourage midge breeding, consideration should be given to including a grill. This facility would be easily converted back for water level control if, after a trial period, the effects of the reversion to an estuary still prove socially unacceptable.

Lagoon enhancement (lagoon northern compartment)

11. In the interim, continue to control the water level in the northern lagoon compartment to provide standing water habitat for the water fowl that prefer such habitat.
12. Improve the freshwater flushing in the northern compartment by splitting the Post Office Creek inflow between the existing estuary and the northern compartment.

13. Upgrade the outlet culvert structure between the northern and southern compartments of the lagoon so that it can convey the increased inflow and turnover.

Fish habitat enhancement and nutrient removal

14. Explore the feasibility of developing whitebait/inānga spawning and wetland areas upstream of the Inverary St bridge in the public reserve or more widely integrated with the racecourse.

Sediment removal and wildlife enhancement

15. If further investigation demonstrates it is feasibility, remove nutrient-laden lagoon bottom material in the northern compartment (after temporary drainage) and build island refuges with the spoil. Consider using the existing abandoned causeway to provide access to an island hide.

Business opportunity

16. Investigate opportunity for local economic activity associated with the expanded estuary, the upgraded lagoon and an enhanced fishery to provide a revenue stream for maintenance that takes into account the longer term implications of sea level rise for the complex and adjacent areas.

Further investigations

17. Establish the current fish status within the complex and tributaries by field survey to provide baseline data from which to gauge improvement
18. Independently assess ornithological data held for the site to determine the likely long term impact on waterfowl of the primary water management options and configurations identified and nutrient loading.
19. Characterize the sediments of the lagoon and estuary (grain size, nutrient profile and biota) with a view to determining the feasibility of sediment removal.
20. Establish a weather station and continuous logging of photosynthetically active radiation (PAR), temperature (at the surface and lagoon bottom for at least a summer), depth and flow (in addition to the general monitoring programme).

5.4 Recommended monitoring

21. Long-term community-based ecological and water quality status as a baseline from which to gauge benefits and refine programmes. Monitoring should be frequent enough to capture seasonal variations, and should operate on repeated schedules inter-annually, as well as be responsive to events that may produce interesting information. This programme assumes the above recommendations are followed and some area of lagoon is retained. In the lagoon, feeder creek and estuarine zone with some guest expert training, monitor the following indicators:
    - Trophic level indicators (nutrients, clarity, and chlorophyll) and confirm limiting nutrient
    - Oxygen levels and temperature
    - Salinity
    - Habitat
        - Bird diversity & abundance

- Fish diversity & abundance
- Nuisance insect abundance

22. Establish flow monitoring facility in the Post Office Creek upstream of the zone of tidal influence to build up a record of actual seasonal flows and volumes

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Appendices

APPENDIX A: Brief and summary of community feedback

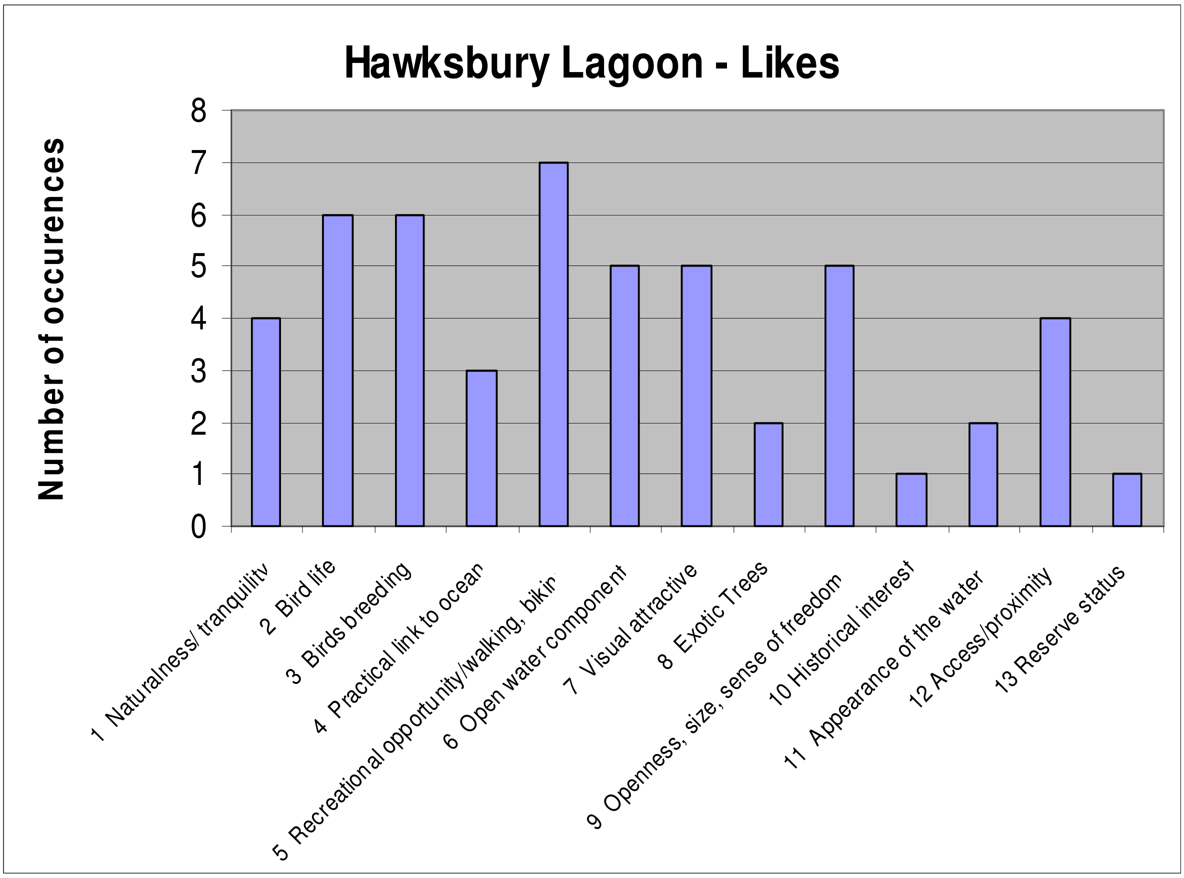
The objectives set by the Hawksbury Lagoon Society Inc for this study were:

1. Overall general improvement in the quality of the water within the lagoon
2. Assessment of the **external nutrient supply**; strategies to manage abundance
3. Assessment of the **severity/type of pollutants** entering the lagoon; strategies to reduce/exclude pollutants
4. Review of the **hydrodynamics of the lagoon**, provision of strategies to better manage hydrodynamics with minimal ongoing human intervention
5. Assessment of the **level of salinity** in different parts of the lagoon; comment on beneficial and detrimental effects
6. Determine **optimal water level** for improving water quality and bird habitats, as well as meeting the requirements of adjacent residents
7. **Provide a range of options** to reduce turbidity, deoxygenation, algal blooms, midge population explosions and sediment exposure (odour)
8. Suggest areas of the lagoon where **aquatic planting** could be beneficial
9. Consideration of strategies which may in the future enable **native fish** (inanga) to access the lagoon during spawning.
10. Anything else which in our opinion may assist in achieving objective 1

Results of public consultation

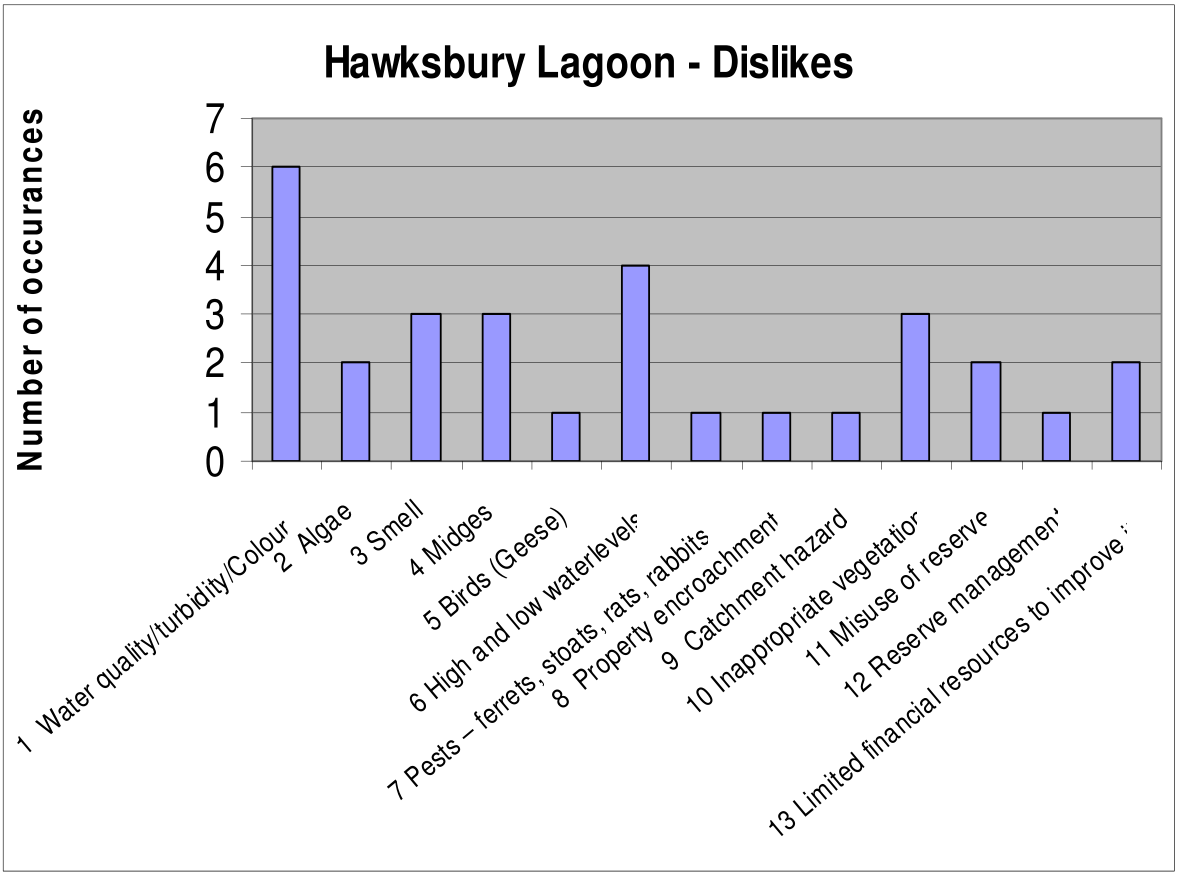
1 Likes

- Recreational opportunity /walking biking etc followed by birds and breeding thereof recorded as most liked.
- Water quality concerns some but not others
- The open water appearance, naturalness and openness is important to many
- The ready access and the fact that its always there adds value



2 Dislikes

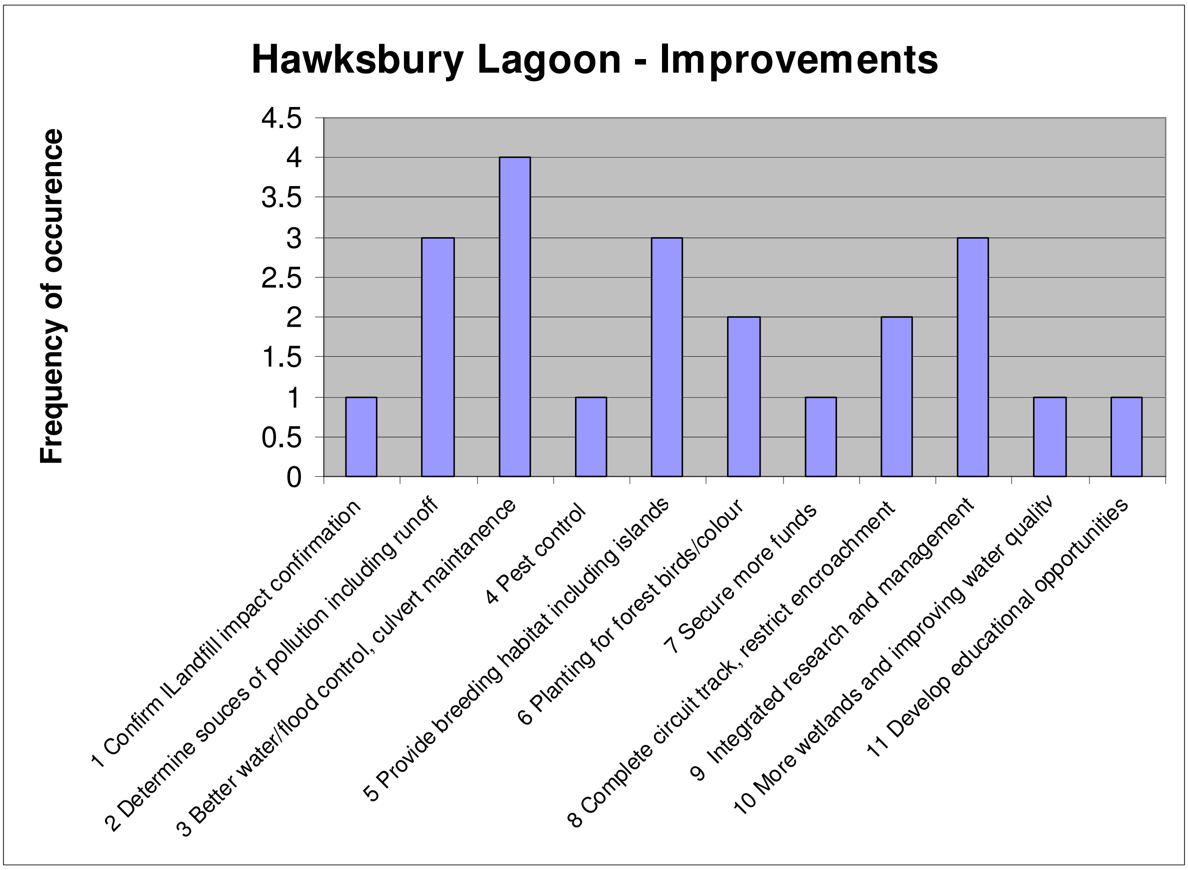
- Water quality, turbidity colour followed by the lack of good water control rated most highly as dislikes
- Not all birds appreciated (eg geese)
- Appears to be concern about pests. Could this impact bird nesting?
- Perhaps two camps on access to the margins of the lagoon – those with property interests and those how would like to see access and perhaps more natural look around the edges
- Perhaps two camps over exotic trees. Recent suggestions in press about removal of some exotics perhaps affecting people on this issue
- Some concerned that general enforcement of rules of reserve not adhered to and want stronger more coordinated management



3 Improvements porposed

Improved waterlevel control and avoiding flooding rates most highly

- This is followed by a wish for improved breeding habitat for birds and more integrated research and management
- General wish to get to the bottom of the contamination and water quality issue
- Community appears open to considering islands, wetlands and other ways to improve the overall quality of and access to the lagoon
- Further plantings including for birds other than water fowl
- Is pest control in need of enhancement?
- Numbers are low, so range of suggestions is more important than relativity.



APPENDIX B: Design principles for transformation toward sustainable catchment management

Scientific peer reviewed socio-ecological literature (e.g. Chapin et al. 2012[74], involving entirely New Zealand case studies) suggests a set of guiding principles that identify conditions facilitating local community-based transformation to more sustainable ecosystem management trajectories. Hawksbury Lagoon has many shared characteristics with these case studies and may benefit from working through the principles:

- Sense of place owned by wide spectrum of stakeholders
- Recognition and acceptance by all stakeholders of multiple cultural, social, and environmental contexts and values
- Understanding of, and communication with, all relevant stakeholders
- Willingness to engage policy makers
- Ability to listen, communicate (patience; skilled facilitation), and, if necessary, compromise for the common good ("gifts and gains")
- Information-gathering and knowledge-seeking at relevant scales (monitoring and education)
- Planning with flexible guidelines for operation and adaptation
- Respect for both traditional and scientific ways of evaluating ecosystems
- Identifying funding that is tied to achieving a desired and durable outcome rather than the goals of a subset of stakeholders

All of the successful transformations identified in Chapin et al 2012 as moving toward a stewardship trajectory were said to have involved a skilled facilitator.

Desired facilitator attributes cited were: ability to earn the confidence of all stakeholders through demonstration of an understanding of the spectrum of viewpoints and concerns; investing passion, energy, and persistence in the outcome; viewed by all parties as someone who was trustworthy and impartial; prioritized equitable compromise through consensus above their own personal or group agenda; and recognized when consensus could be destructive in practice and hard decisions had to be made.

When all conditions facilitating local transformation to more sustainable ecosystem management trajectories are present (as in the bullets above), an accordant stewardship is then plausible, yet the *process* by which such a stewardship arrangement is negotiated strongly influences the outcome.

Other factors influencing success for consideration may be: formal and informal monitoring of progress toward social and environmental restoration or stewardship goals, maintaining the opportunity to renegotiate the goals or adapt to changing conditions, receptive political structures, and reasons for investment of economic resources into the stewardship.

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[74] Chapin et al (2012).

Of potential importance may be a complex relationship between community income and stewardship incentives. For example, some householders around the lagoon may find their assets raised by lagoon enhancement, whereas a farmer requested to bear the costs of stock reduction and riparian habitat restoration measures may stand to lose income, at least in the short term. Many residents will measure the value of the lagoon in non-financial terms. In the long term it would seem feasible that any investment in more sustainable catchment management would pay dividends to all residents.

APPENDIX C: Hydrology

Hawkesbury Lagoon Catchment Estimated Surface Water Resources

There is no continuous record of actual runoff in the Hawksbury catchment so the following estimate has been provided by Dave Stewart of Raineffects Ltd, Dunedin.

The Hawksbury Lagoon catchment is a small catchment on the East Coast of the South Island just north of Dunedin. The catchment has an area of 1,612 ha and its outline is defined in Figure 2.1.

There are no flow or rainfall data for this area, so the estimate needs to be based on estimates of average annual rainfall and evapotranspiration. The Otago Regional Council has a series of unpublished plans showing average annual rainfall isohyets for Otago and this is used to estimate the rainfall. From the plan showing the Hawkesbury Lagoon, the average annual catchment rainfall is approximately 700-720mm/year.

The evaporation estimates are not so simple. Average annual actual evapotranspiration estimates have been mapped for the Taieri, Waikouaiti and Kakanui catchments and these were extended into the adjoining coastal catchments for this analysis. Using this information from an earlier study undertaken for Ryder Consulting Limited titled "Blueskin Bay Inflow Analysis" prepared by Raineffects Ltd (2007), an assumption was made that average annual evapotranspiration rates were 650mm/year for areas with average annual rainfalls in excess of 1000mm/year and between 600mm/year and 650mm/year in areas with average annual rainfalls less than 1000mm/year.

The reasoning was that catchments with rainfalls in excess of 1000mm/year are usually at higher elevations but are more likely to have evapotranspiration rates closer to actual because of less dryness due to more rainfall. Those areas with lower rainfalls are also more likely to be drier during dry spells and so would be unable to have evapotranspiration rates close to actual rates due to lack of moisture. Subtracting the average annual evapotranspiration from the average annual rainfall provides an average annual runoff (in millimetres). This depth of runoff was converted into a volume using catchment area and from this an average or mean annual flow derived.

In this Blueskin Bay study, an average annual evapotranspiration rate was calculated for the Waikouaiti South Branch measured at Lawsons flow gauging site of 625mm. The same rate is adopted for the Hawksbury Lagoon catchment.

Using the rainfall and evapotranspiration estimates, the equation is
Rainfall (700 or 720mm) minus evapotranspiration (625mm) yields runoff of between 75mm and 95mm.

With a catchment area of 1,612 ha, the mean annual runoff is estimated to be between 1,209,000m^3 and 1,531,400m^3, which equates to mean annual flows of 40 l/s and 50 l/s.

Comparison with runoff model

By way of comparison, the NIWA Water Resources Explorer model yields the following data for the 3 sub-catchments feeding the lagoon

Table C1: Mean annual flow estimates for the 3 sub-catchments draining to the Hawksbury Estuary-Lagoon complex.

Item	Units	Post Office Creek	Tip Creek	Beach St	Total
Area	(ha)	12,300	2,300	100	14,700
Mean annual flow	(L/s)	29	5.87	1.88	36.75

Note that the gross catchment area used in the calculator is 14,700ha compared with the 1,612ha used in the above analysis which may go some way to explaining the slightly lower mean annual flow.

It is important to remember that this is not the median flow (most common) to the lagoon which is likely to be significantly lower from all three catchments.

Rainfall records for Waikouaiti and Apes Rd

Table C2: Average and median rainfall for Apes Rd Station (1993-2012)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
1993	92	40	35.75	38.5	71.5	13.25	17.25	23.75	60.5	37.5	74	123.25	628
1994	123	108.3	182.3	20.25	35	105.3	100.3	5.5	51.5	17.5	75.5	40	864
1995	9.5	30.5	58.5	20.5	32.25	153.8	20.75	25	122.3	76.25	52.75	42.5	645
1996	44	58.25	26.5	83	38.25	63.25	45	33.25	13	107	77.75	61	650
1997	97	147	51.5	105.3	37.5	8.5	45	63.75	22	45	79	69.25	770
1998	12.5	44	36.5	30.25	49.25	19	20	25	31.75	74.5	20.25	61.5	425
1999	34.5	15.75	36.75	44.5	28.5	58.25	134	32.25	55.75	38.5	42	72.75	593
2000	116.8	35.75	105	76.25	29.75	49.75	23.75	190.5	118.8	64.75	107	81.75	1,000
2001	40.25	24.5	4	23	58.75	55	99.75	25.75	18.5	86.25	53.5	39.5	529
2002	198.8	50.75	45.25	123	45	79.25	27.25	49.75	35.75	46.75	46.75	23.25	772
2003	62.5	37.5	29.25	25.25	40.25	40.5	18.5	43	64.25	69.25	41.5	14.5	487
2004	55.5	96	26.5	20	155	34.75	11.5	143.8	36	58	79.25	116.5	733
2005	46.5	110.5	73	40	23.25	34.5	30.5	8.75	55.25	38.75	14	77.5	552
2006	47.75	39.25	39.75	186	26.75	47.75	25.25	46.5	11.5	38.75	67	124.5	703
2007	44.75	16.5	38	44.25	19.5	70.75	112.8	27.25	48	117.3	28	83.75	651
2008	43.25	38.25	43.25	31.75	72	28.25	157	54.5	42	37.25	24.25	83.25	655
2009	69	241.3	42.5	30.75	185	4.75	51.5	21.5	47.25	60.75	19.5	61.25	835
2010	53.25	21.75	18.75	52.5	293.8	65	35.5	94	43	32.25	29.25	103.3*	843
2011	81.5	123.3	61.75	75.25	65.5	12.5	27.25	63.5	17.75	97	61.5	9.5	696
2012	79.5	110.8	57	20.5	21	41.25	74.75	157.3	35.25	73.25	70.75	66.5	808
Count	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**19**	
Median	**54.4**	**42.0**	**41.1**	**39.3**	**39.3**	**44.5**	**33.0**	**38.1**	**42.5**	**59.4**	**53.1**	**66.5**	
Ave	**67.6**	**69.5**	**50.6**	**54.5**	**66.4**	**49.3**	**53.9**	**56.7**	**46.5**	**60.8**	**53.2**	**65.9**	**692**

Data collected by Greg and Vivian Kerr, Apes Rd

Table C3: Daily rainfall recorded for Waikouaiti (April - Nov 2011) for comparison with the water level recorders located in the lagoon and estuary for the period (2 August - 1 Nov 2011).

Day of month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1	1							1
2								1.5
3	1	7						1
4	16	16	4					3
5		1			8.5			
6	1.5	4.5			0.5			
7		27		1	t		t	3
8				t				
9		2.5		0.5				6.5
10							2.5	10
11					2.5	8	t	
12				1.5		1	0.5	
13	2	3		1	t	0.5		
14	1	1.5			12	4	1	
15	11	2.5			13			1
16	2	1			4.5	t		
17	1				6.5	0.5	20	4.5
18					1.5	t	52	
19		0.5						4
20		t					2	25
21								
22								
23			1					3
24	1			11		t		
25				0.5			25	
26		3.5						
27								
28			1.5					
29				1			t	
30					1			1.5
31					1.5			
Monthly total	37.5	70	6.5	16.5	51.5	14	103	65

Data provided from a private site located in Waikouaiti township.[75] t = trace

[75] A wedge catcher located on a lawn at the property of Mr D Martin (retired hydrologist) 34 Greenlaw St. The gauge has a minimum of five meters clearance to any potential interference and is read at approximately 9.00am daily

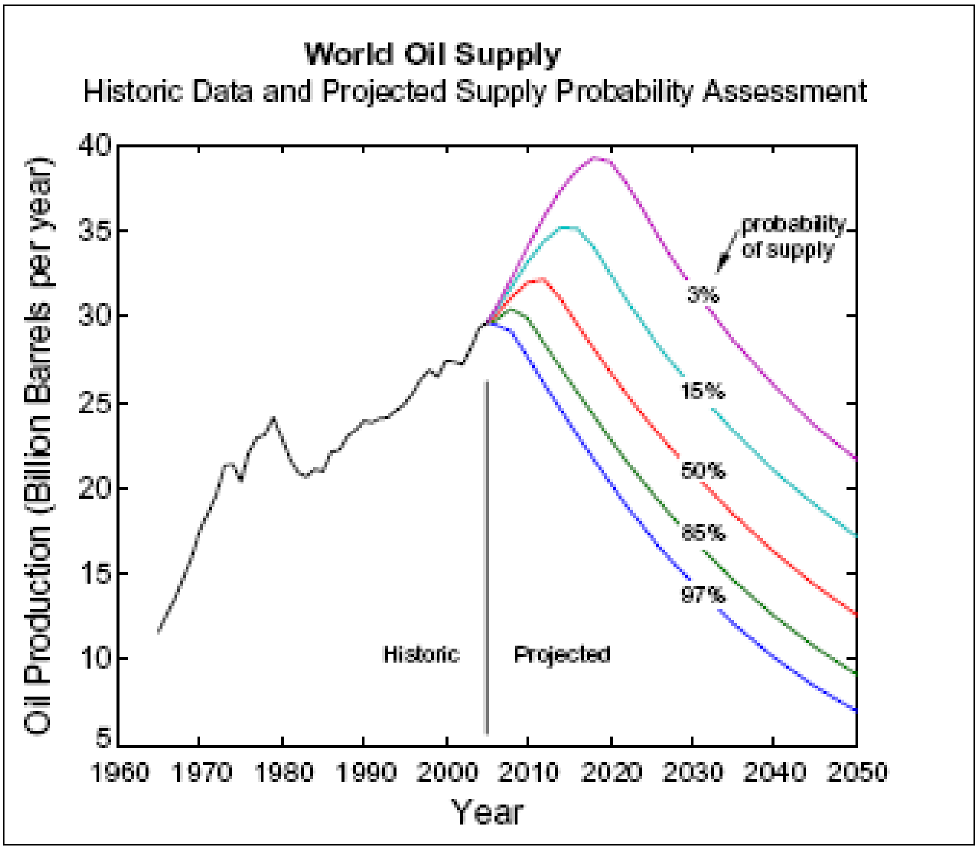
APPENDIX D: Energy regime

In 2009, the DCC commissioned two reports on the subject of peak oil, energy security and on how it should best prepare for any shortfall in oil access.

Key messages from the reports include:

- Not only does oil provide the vast majority of our transport fuel, it is also a key feedstock of almost all products and services (including modern agriculture) which communities have come to take for granted. In other words, the world basically runs on oil and without it food shortage looms.
- The plateau of global oil production and the onset of 'inelasticity' (when supply can no longer respond to match demand – experienced since 2005) is causing price swings and is further evidence that the peak oil scenario is already upon us.
- There are no equivalent substitutes for oil to make up the decline and those partial substitutes like oil sands, shale and coal further aggravate climate change because of the energy intensity of their extraction methods.
- That there is a general lack of appreciation of the link between cheap and freely available oil and a stable economy. The relationship is such that if oil production cannot grow, the economy cannot grow either. This will affect employment, taxable income and revenue generally.
- There is a ceiling to what the global economy can afford for energy and that is considered to be 5.6% of global GDP which equates to US$120/barrel. This implies that any future shortfall will need to be accommodated by economic contraction rather than increasing price.
- Universally, politicians and economists have shown an unwillingness to confront this issue apparently for fear of undermining local economic activity and employment.
- Political and social factors make predicting how the economy will respond to oil depletion difficult – whether the impact can be managed gradually (0.6% per annum oil decline) or if it will be a more abrupt (4%/annum). A non-linear and erratic response, rather than a steady and linear, one is considered more probable.
- In any event, with more expensive travel and less average discretionary income, economies will necessarily need to become more locally focused.
- Figure D1 illustrates the probability of different future global oil supply rates excluding gas, coal and non-conventional energy sources.

Figure D1: Senarios of future oil supply in terms of probability[76].



[76] Krumdieck, 2010

APPENDIX E: Geology

No detailed geological mapping has been done in recent times of the wider Waikouaiti area. The detailed studies are for locations elsewhere[77] [78]and the local map is old[79] (Benson). The geology in this study is limited to the generalized regional-scale map[80] (Forsyth). Other information includes studies at Cornish Head[81]

The generalized geology of the immediate area around the Hawksbury Lagoon is detailed in Figures 2.2 and E1 below. Figure 2.2 shows the main formations and the cross section in Figure E1 below (which passes from the coast, through the lower Pleasant River and hence to Mt Pleasant and Middle Mount) and shows how these formations are set in relation to each other. From the similar outcrop arrangement in the vicinity of Waikouaiti on Figure 2.2 it may be inferred that a similar general stratigraphic cross section exists here.

The basement is Haast Schist (lKt shown in purple) and the younger Tertiary and Quaternary sequences sit on top, except for the volcanic extrusions and deposits (which form the two cones Derden Hill and Mt Baldie to the NW of Waikouaiti and Cornish Head to the East on the coast) that have subsequently penetrated the Onekakara marine group (Pom). The key to the two figures is summarized in Table E1.

Geology of the Waitaki Area (GNS Forsyth, P.J. 2001) describes the main formations in the tertiary sequence as follows

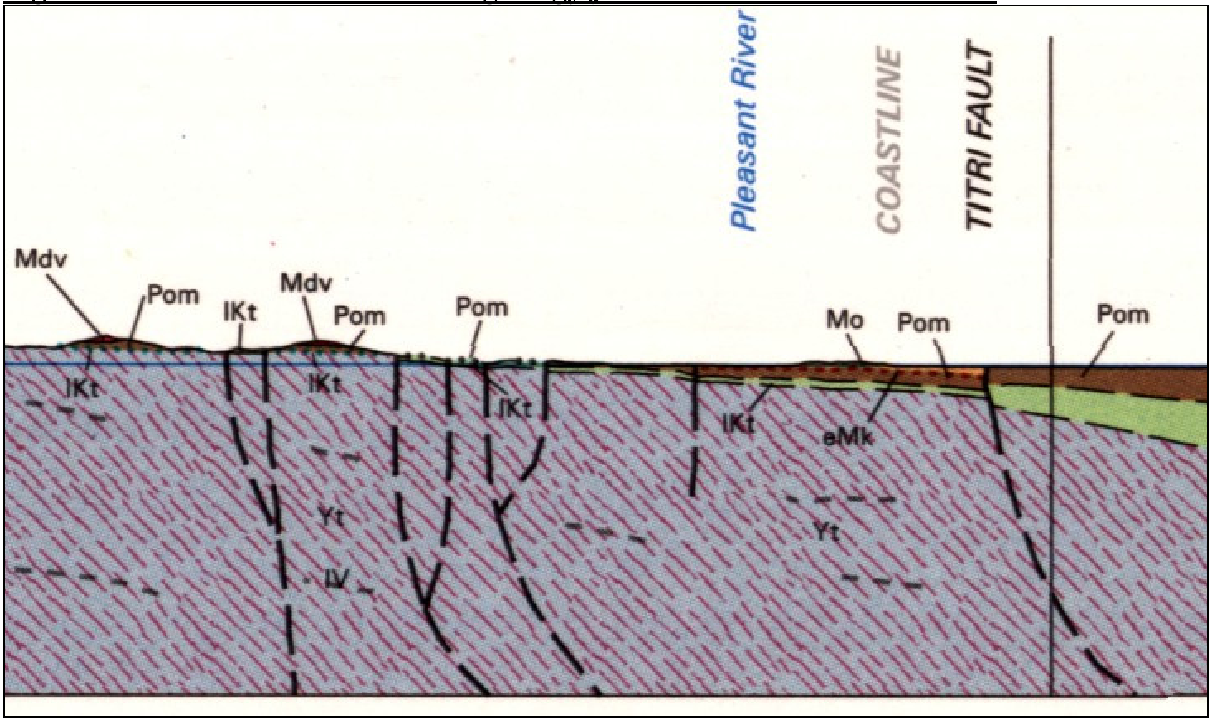
> *The Taratu Formation is up to 120m thick, but typically less than 50m…accumulated in valleys, fluvial plains, swamps and estuaries as the sea transgressed north westwards. Variations in thickness result from irregularities in the underlying ancient land surface and marine erosion before deposition of the overlying units. …Sedimentary structures typical of steam systems, such as tough cross bedding, are common in the lower part, but towards the top of the units the better sorting, very low-angle cross-beds, hummocky cross stratification, increased bioturbation and presence of marine dinoflagellates indicate marine influence. Silica and limonite-cemented layers are common, especially near the base. Coal seams of up to 8m at Ngapara but elsewhere are typically 3m or less.*
>
> *The stratigraphically higher, marine formations mapped as undifferentiated Onekakara Group marine units: Eo, Pom are present in a coastal strip up to about 15km wide…These rocks were deposited in a wide range of shallow marine environments, ranging from shoreface to outer shelf and offshore bars.*

Units such as the Raki Siltstone and other formations related to the Waiareka Volcanics that are found in North Otago absent locally due to the Marshall Paraconformity

[77] McKellar, I.C. 1990
[78] McMillan S.G. 1999
[79] Benson S.G. 1969
[80] Forsyth, P.G. 2001
[81] Lindqvist J (Unpublished)

Marshall Paraconformity was probably related to a glacio-eustatic sea level fall which occurred during the period of almost maximum submergence of the NZ subcontinent when terrigenous sediment supply was greatly reduced.

Figure E1: Inferred cross section of geology just to the north of Waikouaiti



The estuary-lagoon zone itself comprises alluvium, modern swamps giving way to modified and coast-parallel dune fields south of Stewart St. At one time the dunes were covered by grasses but are now dominated by pine plantations.

All these rocks are overlain by widespread but relatively thin unconsolidated surficial deposits, including river sediments, coastal sediments, slope debris and wind blown loess (Barrel et al, 1998).

More elevated land to west (undulating 4-8m amsl) and to the east of the estuary complex respectively form the lowest and second lowest (older) coastal terraces. Terrace are probably of marine origin and surfaces are usually underlain by deposits (e.g. fluvial or beach gravel or beach sand) (Barrel et al, 1998). The implications of the geology for groundwater and the estuary-lagoon setting are discussed in Section 4.2.5.

Table E1: Generalized stratigraphy of the Waikouaiti area

Formation	Age (MaBP)	Lithology	Group	Maximum measured thickness to date in North Otago
Q5b	0.5	floodplains and coastal terraces of river valleys, including modern swamps, estuaries and dune fields (Barrel et al)	Quaternary	
		Unconformity		
Mdv	15	Alkaline volcanic rocks, mainly alkali basalt and basanite occurring as lava flows, agglomerate, tuff and shallow intrusions	Dunedin volcanic (Non-marine)	
Mo		Siltstone, sandstone, limestone and carbonaceous mudstone with local lignite	Otakou	
	23-34	*Marshall Paraconformity (Period of 2-4Ma)*	*Oligocene*	
Pom (e.g, Burnside, Abbotsford, Kauru, Tapui Formations)	?80-50	Quartzose and glauconitic sandstone and siltstone with shellbeds south of Waihemo fault system	Onekakara (Marine)	350m
Taratu (lKt)	80-50	Non-marine quartzose conglomerate, sandstone, mudstone, mudstone and lignite; variable limonite and silica cemented; south of Waitaki River	Onekakara (Non Marine)	120m (but locally probably very things to absent)
		Regional Unconformity		
Haast Schist IV (Yt)	295 – 170 (Barrel et al)	Grey schist with bands of pyllite, state and some greenschist, Quartz veins present. Strongly foliated (IV). Upper zone often weathered to creamy brown clay	Otago Schist (Metamorphic Rock)	NA

Sources:

1. Forsyth, P.J. 2001: Geology of the Waitaki area. Institute of Geological & Nuclear Sciences 1:250,000 geological map 19
2. Barrell DJA et al 1998: Quaternary fans and terraces of coastal Otago, New Zealand
3. Otago Regional Council, 1993: North Otago Groundwater Investigation
4. Chuck Landis, pers com, 2013

APPENDIX F: Water quality results

Table F1: Water quality field measurement results and medians for the different zones

Zone	Site	Date	Sample Time	pH	EC	DO	Temp	Disc	Tube	Wind	Remark
					uS/cm	mg/l	degC				
Estuary	HKS3	21-Jun-11	12:30	8.86	1,330	5.50	6.4			Still	3m d/s of tree in tip creek
		2-Aug-11	12:20	8.20	20,000	4.90	5.5	25	55	Still	EC still dropping
		7-Sep-11	11:10	8.37	39,930	4.35	8.6	28	83	NE	
Estuary	HKS4	21-Jun-11	12:55	8.36	23,960	7.82	11.2	>13		Still	
		2-Aug-11	12:55	8.55	28,150	4.60	7.2	>36	45	Light NW	
		7-Sep-11	11:30	8.70	42,774	2.72	11.3	>30	21	NE, sunny	5% cloud
Estuary	HKS5	21-Jun-11	13:05	8.80	32,010	9.17	10.5	7		Light NE	Mid east arm
		2-Aug-11	13:20	8.75	29,750	4.00	7.6	>36	47.5	Light NW	
		7-Sep-11	11:50	8.70	38,717	2.24	11.1	>31	32	NE, sunny	15% Cloud
Estuary	HKS6	21-Jun-11	14:30	8.94	30,800	6.92	8.7	22			100m d/s from Stewart St car park in esturay
		2-Aug-11	14:30	8.40	30,650	3.60	7.6	54	25	Light NW	Estuary, no flow out
		7-Sep-11	12:45	8.51	37,940	2.69	11.6	33	14	NE, sunny	No outflow (beach blocked)
Median				**8.63**	**30,725**	**4.48**	**8.65**		**38.5**		
Lagoon	HKS1	21-Jun-11	11:55	8.66	19,650	6.79	7.1			Still	North end of lagoon
		2-Aug-11	9:45	8.13	24,592	5.20	5.3	16	11	Still	Contaminant sample taken
		2-Aug-11	16:30	8.25	20,870	3.93	9.8	NA	NA		
		7-Sep-11	10:15	8.52	19,669	7.87	8.7	>19	9	Still, sunny	
		7-Sep-11	15:05	9.00	18,682	1.70	13.9	17		Still,	Overcast
Lagoon	HKS7	21-Jun-11	14:50	9.07	19,000	9.83	8.4	15			Opposite outlet
		2-Aug-11	14:45	8.56	22,630	4.27	7.9	16	12	Light NW	
		7-Sep-11	13:05	8.93	19,825	2.52	11.8	14	7	NE, sunny	
Lagoon	HKS8	21-Jun-11	15:15	9.05	18,940	8.56	8.7	14			Mid lagoon off point
		2-Aug-11	15:05	8.46	20,885	4.40	7.8	11	11	Light NW	
		7-Sep-11	13:25	8.90	19,792	2.23	11.9	15	4.5	NE breeze, fine	Overcast
Lagoon	HKS10	21-Jun-11	16:00	8.62	18,380	8.00	9.1	15			Beach St inlet
		2-Aug-11	15:40	8.10	20,400	4.00	9.8	15	11	Sheltered	
		7-Sep-11	13:55	8.60	18,547	2.15	13.9	12	5	Slight breeze,	Overcast

Zone	Site	Date	Sample Time	pH	EC	DO	Temp	Disc	Tube	Wind	Remark
					uS/cm	**mg/l**	**degC**				
Lagoon	HKS11	21-Jun-11	16:25	8.88	18,846	6.78	8.7	14			Outlet to upper lagoon
		2-Aug-11	16:00	8.40	23,550	3.93	9.3	11	11	Light NW	
		7-Sep-11	14:25	9.21	19,592	2.13	14.6	15	8	V slight breeze	
Lagoon	HKS12	21-Jun-11	16:35	8.90	18,764	6.72	8.7	14			Top end of main lagoon
		2-Aug-11	16:15	8.39	20,130	4.05	9.8	12	10	Still	Bubbles from mud on disturbance
		7-Sep-11	14:10	8.80	19,865	1.87	14	13	5	V slight breeze	
Median				**8.64**	**19,731**	**4.16**	**9.20**		**9.5**		
PO Ck SHI	HKS13	21-Jun-01	17:00	9.00	660	6.33	6.7	>45			u/s SH1 bridge PO Ck
		2-Aug-11	15:00	6.72	582	5.04	6.1	>25	95		
		7-Sep-11	14:45	9.09	589	2.16	10.4	>38	100*		
PO Ck	HKS2	21-Jun-11	12:10	8.40	24,400	5.10	8.5	21	NA	Still	PO Creek,
		2-Aug-11	11:40	8.08	28,300	6.00	7.4	52	90	Still	
		2-Aug-11	16:45	7.30	15,800	4.30	7.8				
		7-Sep-11	10:30	8.38	44,386	4.61	12.4	>45	65	Slight breeze,	Sunny
Tip Ck	HKS14	21-Jun-01	17:15	8.45	1,280	2.40	7				u/s Tip Creek culvert
		2-Aug-11	12:05	7.05	1,240	4.50	4.1	>23	100*	Still	Flow is d/s and no tidal influence
		7-Sep-11	10:50	8.21	1,175	4.97	4.9	>23	11	Breeze	
Beach St Ck	HKS9	21-Jun-11	15:40	9.00	380	12.60	5.8	>18			u/s Beach St culvert
		2-Aug-11	15:30	6.10	387	3.40	3.1	>12	100*		
		7-Sep-11	13:45	9.20	430	2.72	8.1	>10	74	NE breeze	Overcast
Median				**8.38**	**1,175**	**4.61**	**7.00**		**92.5**		

1. Greater then 100 cm but 125 used to derive median
2. The much lower Electrical conductivity at HKS3 on 21 August was do to low tide and stong outflow of freshwater from the Tip creek.

Table F2: Grid coordinates for water quality and leveling sampling sites shown on Figures 3.9 and H1

Site	East	North	Site	East	North	Site	East	North
HKS 1	403613	824123	HKS 12	403589	823758	HKS 25	403575	823004
HKS 2	403755	824135	HKS 14	404424	823768	HKS 26	403654	823105
HKS 3	404369	823762	HKS 15	403628	824688	HKS 27	403697	823116
HKS 4	404071	823643	HKS 16	404159	824841	HKS 28	403842	823130
HKS 5	403938	823544	HKS 17	404112	824481	HKS 29	403887	823138
HKS 6	404095	823115	HKS 18	403734	824109	HKS 30	403937	823150
HKS 7	403955	823214	HKS 19	403730	824541	HKS 31	403706	823799
HKS 8	403668	823441	HKS 20	402293	822503	HKS 32	403797	823495
HKS 9	403351	822883	HKS 21	402234	822499	HKS 33	404191	825153
HKS 10	403548	823065	HKS 22	402819	822511	HKS 34	399584	823094
HKS 11	403389	823707	HKS 23	401817	823487			

Coordinates are in terms of Geodetic Datum 2000, observation point circuit

APPENDIX G: Soils

Table G1: Summary of the main soil types and properties found in the Hawksbury Lagoon catchment linked to the geological group on which they commonly form

Geological Formation	Geological Lithology	Geological Group	Map ID	Soil Name	Native vegetation	Parent Material	Drainage, soil erosion and flooding	Soil erosion and flooding	Natural Nutrient status
Q5b	floodplains and coastal terraces of river valleys, including modern swamps, estuaries and dune fields (Barrel et al)	Quaternary	2	Merton silt loam	Fescue tussock, flax, and scrub	Loess	Imperfectly drained, nil, nil	Nil	Medium to low
			2H	Merton hill soils	Dicotylous coastal forest and fescue tussock, some scrub	Loess, mudstone, gravel, etc	Well drained	Tunnel gully, sheet some slips	Medium to low
			23	Brighton sand	Marram grass and lupins	Wind-blown beach and dune sand	Excessively drained	Wind	Low
			36	Evansdale silt loam	Rushes , etc on swampy areas, some tussock or forest on well-drained sites	Alluvium from Teritiary and basult rocks, loess	Poorly drained	Periodic flooding	Medium to high
			37	Kaikorai peaty loam	Salt-tolerant swamp vegetation	Estuarine alluvium	Very poorly drained, high water tables governed by sea levels	Nil (?)	Very low
Unconformity									

Geological Formation	Geological Lithology	Geological Group	Map ID	Soil Name	Native vegetation	Parent Material	Drainage, soil erosion and flooding	Soil erosion and flooding	Natural Nutrient status
Mdv	Alkaline volcanic rocks, mainly alkali basalt and basanite occurring as lava flows, agglomerate, tuff and shallow intrusions	Dunedin volcanic (Non-marine)	28a	Cargill loam	Podocarp-dicotylous forest	Basult and some loess	Moderately well drained	Nil	High to medium
			28H	Cargill hill soils	Podocarp-dicotylous forest	Slope deposits of basult and some loess	Well drained	Slips where drained	Medium
			25H	Saddle hill soils	Dicotylous coastal forest	Weakly to moderately weathered basult	Well drained	Nil	High
Mo	Siltstone, sandstone, limestone and carbonaceous mudstone with local lignite	Otakou	34	Waikakahi clay loam	Tussock, some coastal forest	Calcarious sandstone (Caversham Formation), some loess	Moderately well drained	Nil	Very high
			35	Karitane heavy silt loam	Dicotylous coastal forest, some tussock, scrub	Calcarious sandstone (Caversham Formation), some loess	Well drained	Nil	High
			35H	Karitane hill soils	Dicotylous coastal forest, some tussock	Calcarious sandstone (Caversham Formation), some loess	Well drained	Slight sheet	High
Marshall Paraconformity (Period of 2-4Ma)		*Oligocene*							

Geological Formation	Geological Lithology	Geological Group	Map ID	Soil Name	Native vegetation	Parent Material	Drainage, soil erosion and flooding	Soil erosion and flooding	Natural Nutrient status
Pom (includes Kauru and Tapui Formations)	Quartzose and glauconitic sandstone and siltstone with shellbeds south of Waihemo fault system	Onekakara (Marine)	7	Waerepa silt loam	Dicotylous forest with tussock on ridges	Loess on igneous or Tertiary sedimentary rock	Moderately well drained	Slight to severe sheet; some slips	Medium
			8	Abbotsford silt loam	Dicotylous coastal forest, some tussock	Glauconitic mudstone (Abbotsford Formation), loess, and basalt	Moderately well drained	Earth flow, slumping	Medium
			9	Omimi heavy silt loam	Dicotylous coastal forest, some tussock	Mudstone (Burnside formation), with some loess	Imperfectly drained	Earth flow, slumping	Medium
Taratu (lKt)	Non-marine quartzose conglomerate, sandstone, mudstone, mudstone and lignite; variable limonite and silica cemented; south of Waitaki River	Onekakara (Non-marine)							
Regional Unconformit y									
Haast Schist IV (Yt)	Grey schist with bands of pyllite, state and some greenschist, Quartz veins present. Strongly foliated (IV). Upper zone often weathered to creamy brown clay	Otago Schist (Metamorp hic Rock)							

Source: Soils of Waikouaiti County, Otago, 1977, Campbell I B, DSIR

APPENDIX H: Engineering

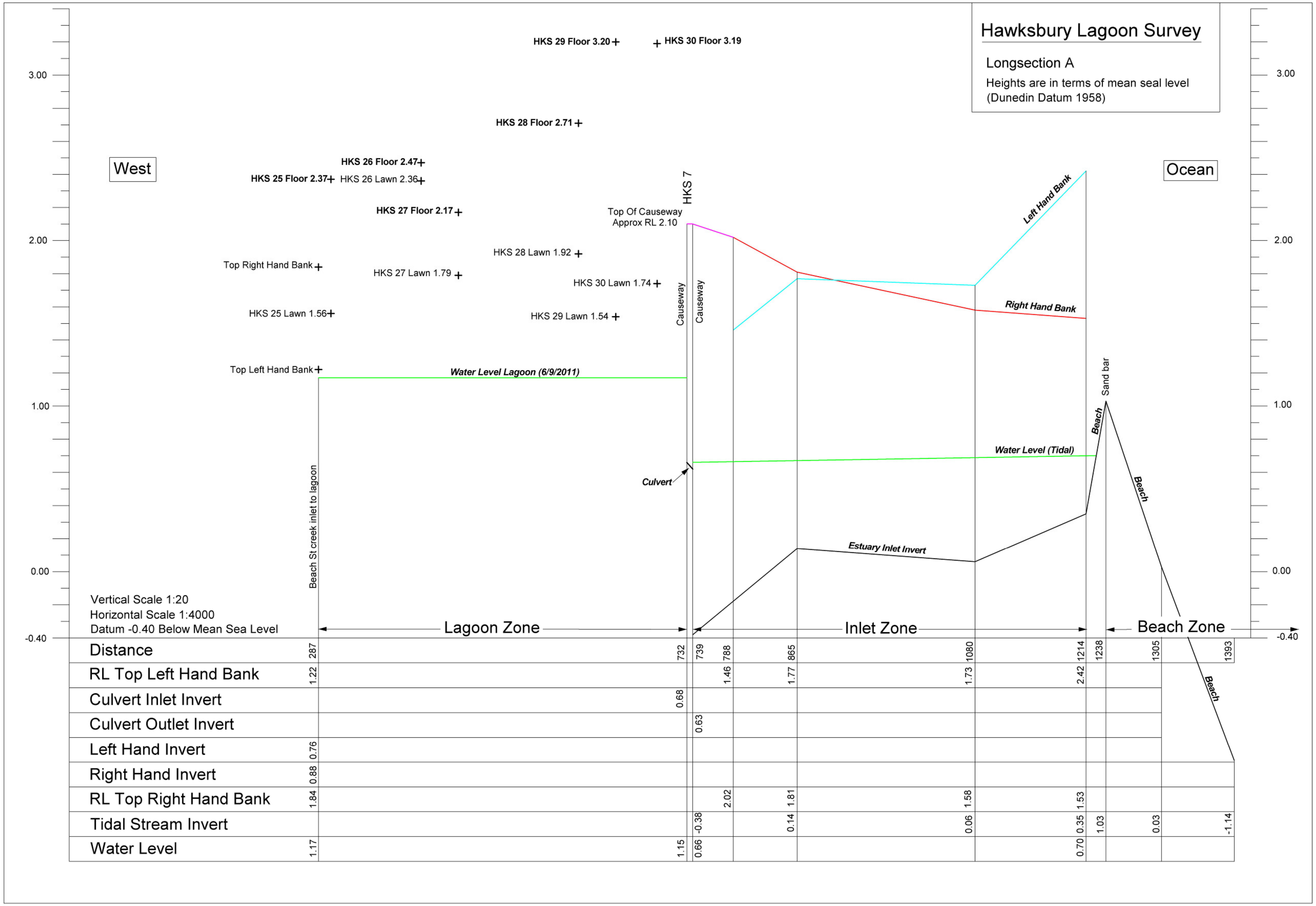
Figure H1: Location of survey levelling sites and levels recorded

Long-Section A: Coast to the lagoon outlet

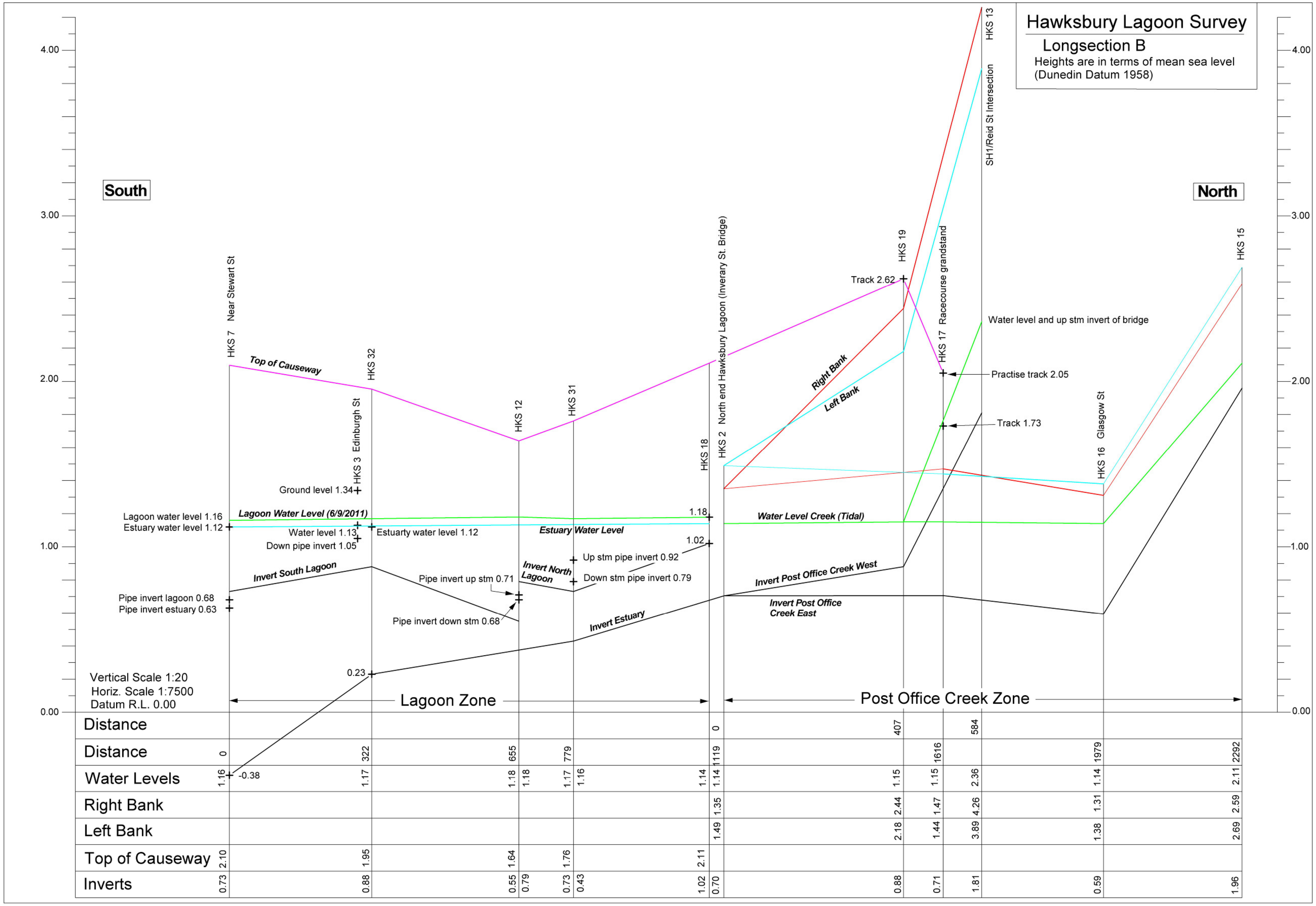
Long-Section B: Outlet of the lagoon to SH1 at Reid St and Aberdeen St

Long-section C: Lagoon to Orbells Crossing

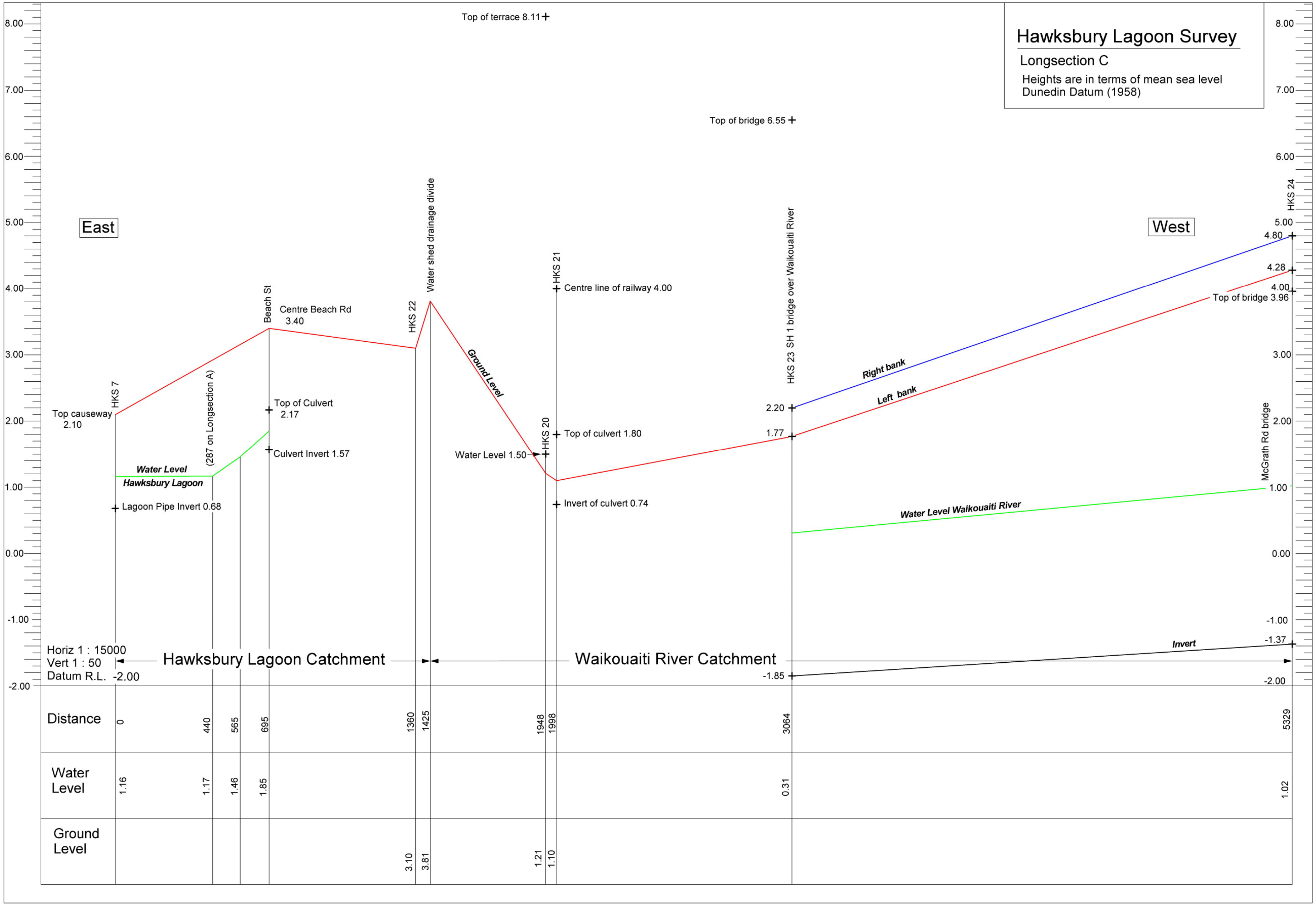
Figure H1: Location of levelling sites and levels recorded



Hawksbury Lagoon Survey
Longsection A
Heights are in terms of mean seal level
(Dunedin Datum 1958)
West
Ocean
HKS 29 Floor 3.20
HKS 30 Floor 3.19
HKS 28 Floor 2.71
HKS 26 Floor 2.47
HKS 25 Floor 2.37
HKS 26 Lawn 2.36
HKS 27 Floor 2.17
HKS 7
Top Of Causeway
Approx RL 2.10
HKS 28 Lawn 1.92
Top Right Hand Bank
HKS 27 Lawn 1.79
HKS 30 Lawn 1.74
HKS 25 Lawn 1.56
HKS 29 Lawn 1.54
Causeway
Causeway
Left Hand Bank
Right Hand Bank
Top Left Hand Bank
Water Level Lagoon (6/9/2011)
Sand bar
Beach
Water Level (Tidal)
Culvert
Beach
Estuary Inlet Invert
Beach St creek inlet to lagoon
Vertical Scale 1:20
Horizontal Scale 1:4000
Datum -0.40 Below Mean Sea Level
Lagoon Zone
Inlet Zone
Beach Zone
Beach
3.00
2.00
1.00
0.00
-0.40
Distance 287 732 739 788 865 1080 1214 1238 1305 1393
RL Top Left Hand Bank 1.22 1.46 1.77 1.73 2.42
Culvert Inlet Invert 0.68
Culvert Outlet Invert 0.63
Left Hand Invert 0.76
Right Hand Invert 0.88
RL Top Right Hand Bank 1.84 2.02 1.81 1.58 1.53
Tidal Stream Invert -0.38 0.14 0.06 0.35 1.03 0.03 -1.14
Water Level 1.17 1.15 0.66 0.70



Hawksbury Lagoon Survey
Longsection B
Heights are in terms of mean sea level (Dunedin Datum 1958)
South
North
Vertical Scale 1:20
Horiz. Scale 1:7500
Datum R.L. 0.00
Lagoon Zone
Post Office Creek Zone
HKS 7 Near Stewart St
HKS 32
HKS 3 Edinburgh St
HKS 12
HKS 31
HKS 18
HKS 2 North end Hawksbury Lagoon (Inverary St. Bridge)
HKS 19
HKS 17 Racecourse grandstand
HKS 13
SH1/Reid St Intersection
HKS 16 Glasgow St
HKS 15
Top of Causeway
Lagoon Water Level (6/9/2011)
Estuary Water Level
Invert South Lagoon
Invert North Lagoon
Invert Estuary
Water Level Creek (Tidal)
Invert Post Office Creek West
Invert Post Office Creek East
Right Bank
Left Bank
Track 2.62
Practise track 2.05
Track 1.73
Water level and up stm invert of bridge
Ground level 1.34
Lagoon water level 1.16
Estuary water level 1.12
Water level 1.13
Down pipe invert 1.05
Estuarty water level 1.12
Pipe invert lagoon 0.68
Pipe invert estuary 0.63
Pipe invert up stm 0.71
Pipe invert down stm 0.68
Up stm pipe invert 0.92
Down stm pipe invert 0.79
1.18
1.02
0.23
-0.38
Distance
Water Levels
Right Bank
Left Bank
Top of Causeway
Inverts


Hawksbury Lagoon Survey
Longsection C
Heights are in terms of mean sea level
Dunedin Datum (1958)
East
West
Top of terrace 8.11
Top of bridge 6.55
Water shed drainage divide
HKS 21
Centre line of railway 4.00
HKS 23 SH 1 bridge over Waikouaiti River
HKS 24
Beach St
Centre Beach Rd
3.40
HKS 22
Ground Level
HKS 7
Top causeway
2.10
(287 on Longsection A)
Top of Culvert
2.17
Culvert Invert 1.57
Water Level
Hawksbury Lagoon
Lagoon Pipe Invert 0.68
Water Level 1.50
HKS 20
Top of culvert 1.80
Invert of culvert 0.74
Right bank
Left bank
2.20
1.77
4.80
4.28
4.00
Top of bridge 3.96
McGrath Rd bridge
Water Level Waikouaiti River
Invert
-1.37
-1.85
Horiz 1 : 15000
Vert 1 : 50
Datum R.L. -2.00
Hawksbury Lagoon Catchment
Waikouaiti River Catchment
Distance
0
440
565
695
1360
1425
1948
1998
3064
5329
Water Level
1.16
1.17
1.46
1.85
0.31
1.02
Ground Level
3.10
3.81
1.21
1.10