Options Report

Assessment of Options for Protecting Harbourside and South City from Direct Impacts of Sea Level Rise

Prepared for Dunedin City Council (Client)

By Beca Ltd (Beca)

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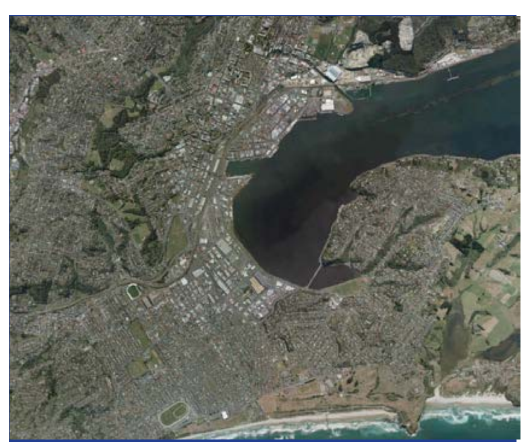

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Glossary and Abbreviations

Aquifer	Below ground body of water held within pores between soil particles.
ARI	Annual Recurrence Interval, often referred to as Return Period
DCC	Dunedin City Council
GWL	Ground Water Level. In this report taken to mean surface of ground water table, eg the equilibrium level of ground water in an open hole.
ICMP	Integrated Catchment Management Plan in the context of this report, for stormwater catchments in the Dunedin area.
LiDAR	Light Detection and Ranging. Method of obtaining ground level information from an aeroplane flying at a given altitude. Not precise but will give ground surface levels within +/- 50 mm of true value depending on nature of ground cover.
MHWS	Mean High Water Springs. Mean level of high tide water level occurring twice per lunar cycle. Actual water levels may be higher or lower. An approximate value of 1 m above MSL has been adopted for this report.
MSL	Mean Sea Level. The mean value of a long series of sea level recordings adopted as a datum.
MSL (1958)	Mean Sea Level established in 1958
MSL (1990)	Mean Sea Level established in 1990. Approximately 50 mm higher than MSL (1958).
MLOS	Mean Level of Sea. A less precise term than MSL and may be influenced by a number of factors other than pure tidal fluctuations.
NIWA	National Institute of Water & Atmospheric research.
OMD	Otago Metric Datum arbitrarily sets a value for MSL (1958) equal to 100.000 m (for surveying purposes).
ORC	Otago Regional Council
Return Period (RP)	Statistical expression of frequency of a particular event, eg return period of 20 years means that a particular event is statistically likely to occur once every 20 years. Note, this does not preclude the possibility of say a 20 year return period event occurring twice (or more) in a much shorter period.
Rough Order of Cost (ROC)	Cost estimate based on limited data but indicative of magnitude of cost of a particular item or scenario.
SLR	Sea Level Rise
Storm Surge	Elevated sea level arising from a combination of low atmospheric conditions and wind run-up.
Tsunami	Rapid changes in sea level generated by sub-sea landslide or sub-sea earthquake.

Executive Summary

The Dunedin City Council (DCC) commissioned this report to assess potential options and costs for protecting the Harbourside and South City area from the direct impacts of sea level rise. This area is the most developed and most densely populated area of Dunedin and is deemed to have the highest sea level rise risk.

The principal threat, at least initially, is rising groundwater level in the South City area, as groundwater is forced up by rising seawater level. As a result, the defence solutions investigated principally involve the management or control of groundwater levels to maintain it at the current level. This report does not aim to address existing drainage issues known to be the result of high groundwater.

The recommended strategy identified is to incrementally install engineered protection solutions as the sea level rises.

By the time the mean sea level has risen 0.3m above 1990 levels, localised pumped drainage systems will be required to protect low-lying areas in Tainui and two other locations in the South City. The rough order capital costs for these works is $10.3m.

By the time the mean sea level has risen 0.8m above 1990 levels, it will be necessary to intercept incoming water at the coastal and harbour perimeter of the South Dunedin aquifer before it reaches the aquifer and forces its level up. The recommended pumped well system would maintain the current drainage flow from the aquifer to the coastal and harbour fringes. Stormwater drainage at the lowest point in the Harbourside area (Lower St Andrew Street) is likely to require a pumped solution at this stage. Areas on the harbour fringe either side of the Harbour Basin will also become susceptible to direct inundation and require ground to be raised in a number of locations including along Portsmouth Drive. The rough order capital costs for these works are $65.1m

In order to have the necessary defences in place in time, the protection works outlined will need to be implemented before the associated sea level is reached. The protection system as a whole will need to be progressively augmented as sea level continues to rise – at a continually increasing cost.

1 Introduction

This report reviews the anticipated impacts of sea level rise (SLR) on the Harbourside and South City area of Dunedin (shown in Diagram 1 below) and identifies potential engineered solutions and rough order costs for protecting the area from the direct impacts of sea level rise. It does not attempt to make any comparisons or draw any conclusions with respect to the relative costs of engineered solutions versus managed retreat.

Diagram 1: Harbourside and South City

The South City has been identified as being the area of Dunedin most at-risk of rising sea levels (Reference 12) and cannot be addressed without considering the connected Harbourside area.

The principal issue, particularly in South City, is that sea level rise will raise the water table (top surface of the South Dunedin aquifer) to the point where it will be above ground level and cause surface ponding. At advanced sea level rise the same affect continues but severe inundation also becomes an issue.

In order to protect South City it is therefore necessary to depress ground water such that it does not rise above ground surface level. Ideally this would involve ground water level suppression sufficient to give a reasonable margin against ground water level rise due to relatively frequent rainfall events and other ground water sources which continually recharge the South Dunedin aquifer. A rainfall event with an ARI (Annual Recurrence Interval) of 10 years would be a reasonable level of service at which ground water level does not rise above ground surface. The actual consequences of such an event will be partially influenced by how deep the ground water surface is before the event, e.g. it may already be elevated before an ARI 10 year event occurs as a result of a prolonged wet period.

In the Harbourside area the initial issue is more likely to be disruption of existing stormwater drainage followed by inundation at higher SLR values. By way of reference, Figure 1 shows the depth existing ground level is below a sea level approximating current Mean High Water Spring (MHWS) tides.

1.1 Sea Level Rise Scenarios

This study looks at four potential sea level rise scenarios (using Mean Sea Level in 1990 as a base level), three taken directly from the DCC's Climate Change Predictions Policy and one outlier scenario. The outlier scenario (Scenario D) is based on Scenario C (+ 1.6 m SLR – the maximum predicted by 2090) and adds an additional 100 mm sea level rise per decade, to reach + 2.0 m by 2130. The scenarios are:

Table 1: Sea Level Rise Scenarios

Scenario	Magnitude of Sea Level Rise above 1990 MSL	Anticipated date at which scenario is reached
A	+0.3 m	2040
B	+0.8 m	Minimum forecast for 2090
C	+1.6 m	Maximum forecast for 2090
D	+2.0 m	Forecast for 2130 based on sea level rise of 100 mm/decade from 2090 maximum forecast

As part of this study, maps have been produced which show approximate Mean High Water spring (MHWS) sea level for each of these scenarios with respect to ground level in the study area, as discussed further in this report.

1.2 Existing Ground Water Level

Ground water level in South Dunedin aquifer is approximately +0.4 m above current MSL or at approximately 100.6 m Otago Metric Datum (OMD). This relationship varies across the aquifer but in the absence of detailed knowledge this relationship has been assumed to be constant for the purpose of this study. It has been suggested that as sea level rise continues this relationship will be non-linear such that every 0.1 m rise in sea level will result in an additional 0.09 m rise in ground water level over and above the rise in sea level itself. For example, while current ground water level is approximately 0.4 m above MSL the effect of +0.1 m sea level rise would elevate Ground Water Level (GWL) to +0.49 m above the new MSL or to +0.59 m above present MSL. This is based on the hypothesis that the present wastewater and stormwater networks are artificially depressing GWL as the aged nature of this infrastructure allows ground water infiltration and that as ground water level rises those networks will become less effective at doing so. However, as ground water level rises, the driving head across the small openings which facilitate infiltration will increase and flow may therefore increase. Consequently the elevation of ground water level above sea level may not increase in such a non-linear fashion. For the purposes of this report it is assumed that the relationship between ground water level and MSL remains constant as follows:

GWL = MSL +0.4 m.

The maps included in this report assume the same relationship between GWL and MSL also applies in the Harbourside area.

1.3 Sea Level Datum

Where Mean Sea Level (MSL) is used in this report it means Mean Sea Level at 1990, consistent with DCC's Climate Change Predictions Policy.

A number of different reference sea levels are used when discussing the impact of sea level rise. The initial analyses for this report were conducted using the value of MSL to the 1958 datum. For survey and level control purposes DCC uses 1958 datum and the LiDAR data supplied by DCC, and upon which the mapping in this report is based, has been adjusted to the 1958 datum for consistency with DCC's level control.

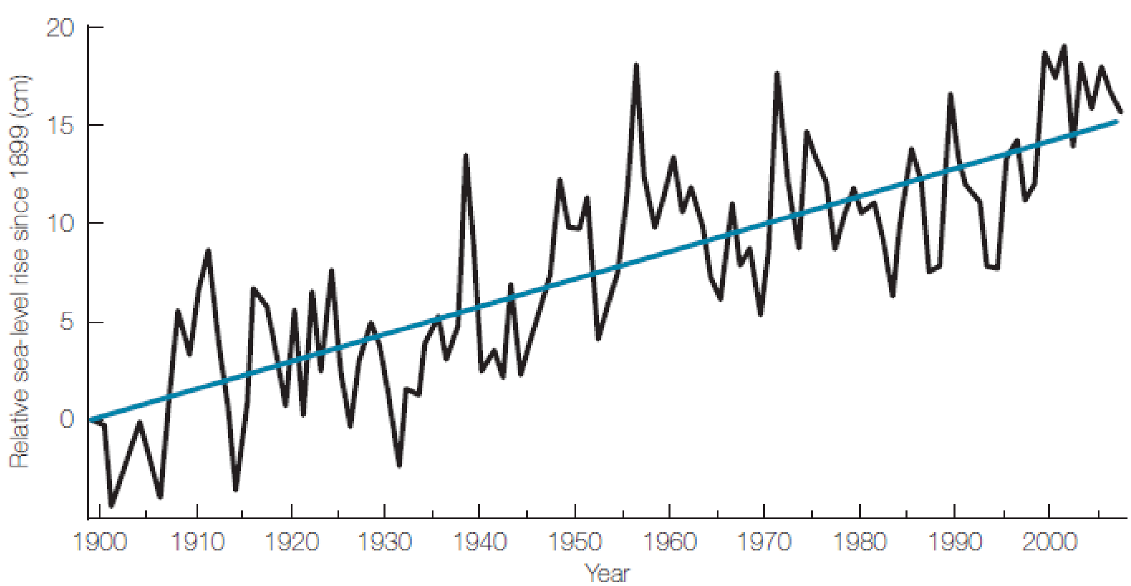
DCC's sea level rise scenarios are relative to 1990 sea levels while the datum for mapping is the 1958 datum. Information available from Ministry for the Environment website (see Diagram 2 below) suggests that the value for MSL in 1990 is approximately 50 mm higher than the datum used by DCC. Therefore a +0.3 m sea level rise relative to 1990 sea level is approximately equivalent to +0.35 m sea level rise relative to DCC's survey control datum.

Further, if sea level rise has continued at the same rate beyond the last plotted date in Diagram 2, sea level in 2013 will have further risen by approximately 35 mm above the 1990 level.

Note that Diagram 2 shows <u>relative</u> sea level rise. Because land in New Zealand is rising approximately 0.5 mm a year, the absolute sea level rise is greater than suggested in Diagram 2.

Diagram 2

(Source MfE Website)



1.4 Modelling Accuracy

It is important to understand that there are inherent inaccuracies in the modelling work contained in this report primarily because of the accuracy of the ground level data used.

Ground level data used in this report has been obtained by DCC using a technique known as Light Detection and Ranging (LiDAR) which gathers ground level data by flying over the chosen area with equipment capable of measuring distance to ground level. Accuracy varies depending on ground surface cover with hard surfaces (pavements) producing the most reliable results and soft surfaces (vegetation) producing less reliable results. The order of accuracy for ground level data used in this report is likely to be approximately +/- 50 mm. This order of accuracy will be significant for the lower SLR scenarios (A and B) but less so for the higher scenarios (C and D). A sensitivity analysis has been carried out for the two lower SLR scenarios. Figures 2 and 3 show these sensitivity analyses by comparing the spatial extent of surface ponding for lower and upper values of +0.25 m and +0.35 m above MSL (1990) and +0.75 m and +0.85 m above MSL (1990). While there are discernible differences in the spatial extent of surface ponding between the lower and upper values used in this sensitivity analysis they are not so great as to justify a more refined analysis. For SLR scenarios A and B this report uses +0.35 m above MSL 1990 for scenario A and +0.85 m above MSL 1990 for scenario B. These values are considered to give a good indication of the spatial upper bound of predicted surface ponding (in the absence of any ground water control) given the uncertainty in ground levels derived from LiDAR data.

1.5 General Explanation of Figures

The figures in Appendix A cover the range of scenarios contained within DCC's Climate Change Predictions Policy statements[(11)]. For the lower SLR scenarios the issue is not direct inundation by overland flow from the sea (with minor exceptions explained elsewhere) but the impact SLR will have by forcing up ground water levels. Assuming that the current relationship between sea level and ground water level continues to apply, ground water will eventually rise above ground surface (in the absence of intervention to control it) resulting in permanent ponding.

Generally there are pairs of figures for each SLR scenario. One figure shows the SLR value +1.0 m which approximates MHWS tide levels for that SLR scenario. Note that some tides are lower than this and some are higher depending on the tidal cycle. These (+1.0 m) figures are intended to demonstrate the potential for overland flow on a frequent basis. The second figure in each pair shows the SLR value plus the assumed impact of SLR on the elevation of ground water level. This figure is intended to demonstrate the spatial extent of surface water in the absence of intervention to control rising groundwater.

The underlying assumption in all scenarios is that intervention to control ground water will eliminate ponding. **Further subsurface investigation work is necessary to confirm that assumption**.

2 Key Modelling Information

2.1 Extreme Sea Level Events

Extreme sea level events include storm surge and Tsunami.

Storm surge is a weather dependent phenomenon brought about by severe low atmospheric pressures causing sea level to rise. This effect is the consequence of the atmosphere applying more pressure on the sea surface outside the low pressure zone than inside the low pressure zone such that sea surface level rises inside the low pressure zone. Wave run up due to strong wind further exacerbates storm surge. These phenomena can be superimposed over normal tidal cycles and when they combine with high tidal cycles (king tides) become what is referred to as an Extreme Sea Level Event.

SLR will make Tsunami impacts worse but coastal defences required to protect against Tsunami are very different to those required to defend against SLR discussed in this report although the raised dykes proposed to protect against the higher level scenarios on the harbour fringe could be modified or augmented to provide Tsunami protection in the upper harbour area. A better understanding of how the most recent Tsunami predictions will translate into sea level changes in the upper harbour area is required before specific Tsunami defences could be conceived for the Dunedin area.

Currently Otago Regional Council (ORC) reports(4) the following scenarios and associated probabilities shown in Table 2. Note that Extreme Sea Levels in this table are **relative to current MSL**.

Table 2: Sea Level Events and their probability of occurrence given current sea level and a 0.5 m sea level rise**

Extreme Sea Level	Current Sea Level	Sea Level Rise 0.5 m
Max water level **above present** MSL (m)	Probability of occurrence in 100 year period (%)	Probability of occurrence in 100 year period (%)
1.5	>99	>99
2.0	15 – 25	>99
2.5	0*	15 - 25

* 1:500 year event generates maximum sea level rise of 2.02 m above current MSL.

** 0.5 m SLR is between DCC's scenario A and B but has not been adopted by DCC as part of its SLR policy. It is included in this report because it has been used by ORC to demonstrate the impact SLR has on the frequency of Extreme Sea Level events.

This table clearly shows that Extreme Sea Level Events become more frequent (i.e. the probability of any particular event increases) as sea level rises and events which currently have zero probability will become more frequent.

Table 3 below shows sea level in metres above MSL (2000) for a range of ARI's and summarises data from various sources.

The figures in Appendix A use a value of +1.0 m to depict the height of MHWS above MSL. This is slightly higher than other figures given for MHWS but is the same value used by ORC in Table 33 of Reference 4.

The five lines of the table show sea level rise events for the baseline (1990) plus each of the sea level rise scenarios.

The baseline sea level events for the Average Reccurance intervals shown are derived from information contained in NIWA's report (Reference 2) and ORC's report (Reference 4).

The assumptions upon which Table 3 is based are:

- Each SLR value in DCC's Climate Change Predictions Policy can be directly superimposed on to the values derived from ORC's reports.

- Atmospheric effects on sea level remain as they are at present i.e. atmospheric and sea warming do not make extreme high and low atmospheric pressure events more frequent or more extreme.

Colour banding is used in Table 3 to provide an illustration of the effect of SLR on the frequency of extreme seal level events.

Banding is as follows:

Extreme Sea Level Event (Above MSL 2000)	Colour Band
1.7 m – 2.0 m	
2.0 m – 2.4 m	
2.4 m – 2.8 m	
2.8 m – 3.2 m	
3.2 m – 3.6 m	

The colour banding is intending to show equivalence in extreme sea level events as we know them now and how they become increasingly more frequent as SLR takes place.

For example, at 0.0 m SLR (current situation) an extreme sea level event at +1.8 m above MSL (2000) has a return period of 10 years (i.e. statistically occurs once every 10 years). Under SLR scenario B the same event (+1.8 m above MSL (2000)) occurs at Mean High Water Spring tides (MHWS) i.e. twice daily for a period of several days twice per month.

Likewise, a one in 100 year event (+2.0 m) at current sea level becomes a one in five year event under scenario A.

Table 3: Summary of Sea Level Events (in metres above MSL 2000 – rounded to nearest 0.1 m)

	Average Recurrence Interval							
	MHWS	2 years	5 years	10 years	20 years	50 years	100 years	500 years
Sea Level Rise Scenarios 0.0 m (Baseline 1990)	1.0	1.6	1.7	1.8	1.9	1.9	2.0	2.0
Scenario A	1.3	1.9	2.0	2.1	2.2	2.2	2.3	2.3
Scenario B	1.8	2.4	2.5	2.6	2.7	2.7	2.8	2.8
Scenario C	2.6	3.2	3.3	3.4	3.5	3.5	3.6	3.6
Scenario D	3.0	3.6	3.7	3.8	3.9	3.9	4.0	4.0

Note this table shows sea level in metres above MSL (2000 datum) as that is what is used in Reference 2. DCC's Climate Change Predictions Policy uses MSL (1990) as a datum. The difference is approximately 0.016 m which is well within the rounding used to obtain the values in Table 3.

The July 2013 event at the intersection of Marne Street and Somerville Street corresponded to a sea level of +1.62 m which by reference to Table 3 is approximately a one in two year event at current sea level but under scenario B it will occur more frequently than spring tides.

2.2 Subsurface Conditions

2.2.1 South City

Two reports have been referred to in order to assess the subsurface conditions which will in turn influence the type of drainage system used to control groundwater. An Otago Regional Council report(3) was prepared following early work in 2009 which entailed construction of three bores to a depth of approximately 6 m. These bores encountered sand layers at that depth. The other report referred to was by E Fordyce(6). This report is based on bores at 10 monitoring sites but at comparatively shallow depth, down to about 3 m below ground level. The value for hydraulic conductivity generally reported by Fordyce is substantially lower than reported by ORC. This value has a significant impact on the design and efficiency of any drainage system which is installed.

ORC have previously carried out ground water modelling in the South City area(3). The approach taken developed a model of the aquifer which was calibrated against known aquifer surface levels, and then run in predictive mode to forecast where inundation is likely to occur as a result of rising sea level. That approach contrasts with the approach taken for this study which compares ground levels with a range of sea levels, and makes provision for the fact that ground water level (free surface of aquifer) is approximately 0.4 m above sea level. An underlying assumption in this report is that this relationship will remain constant as sea level rises. This method identifies the areas most likely to be prone to surface flooding as a result of a rise in aquifer level. The outcome of this study has identified very similar areas to those which are identified as low lying and prone to flooding in DCC's ICMP for the South City Catchment(7).

2.2.2 Ground Water Level – South City

There are no known long term studies of ground water in South City and the most recent study is that conducted by ORC. This study suggests the steady state ground water surface is approximately 0.4 m above MLOS [1]. There is general agreement between ORC's work and the work done by Fordyce although there appears to be a significant difference between ORC and Fordyce in the Bathgate Park area.

For most of the sea level rise scenarios, South City (with specific exceptions referred to later in this report) is not under threat of direct inundation from the sea or harbour. The harbour fringe is sufficiently high to prevent direct inundation as is the dune system on the coastal fringe. The threat in South City is a rising ground water level induced by rising sea level. Even under scenario A there

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[1] Note: MLOS is a much less well defined level than MSL but MLOS (2011) has been cited as 100.1m (OMD) whereas a calculated MSL based on Diagram 2 gives MSL of 100.085 m (OMD) so while MLOS and MSL are different entities the difference between them is sufficiently small that using them as different reference points will not substantially affect the matters discussed in this report.

are isolated low lying areas where the ground water level will be higher than ground water resulting in ponding (refer to Figures 2 and 4).

For the purposes of this report it has been assumed that measures to control rising ground water level consequent to rising sea level will maintain ground water level at its present level.

2.2.3 Harbour Basin Area

It is expected that subsurface conditions in this area will be similar to those for large areas of South City since both areas are reclaimed land using materials from a variety of sources. The boundary of the area affected by the higher SLR scenarios (eg Figure 10) in the Dunedin CBD area closely follows the original shoreline in this area therefore the inundated area in that figure is largely land reclaimed in the mid-1800's. It is expected that ground water levels in the reclaimed area of Central Dunedin will be influenced by tidal fluctuation and that the equilibrium elevation of ground water surface will be above MSL. For the purposes of this report it is assumed that the relationship between GWL and MSL is the same as for the South City area.

3 Defence Options

3.1 Options Considered in Detail

The options for protection of the Harbourside and South City areas fall broadly into two categories:

- Active management of ground water levels by dewatering
- Isolation of the area from sea level influence by cut-off walls or dyke structures

The methods to suppress GWL and to achieve the above two options are covered by four basic concepts as follows:

1. Interception of sea water inflow and removal of natural recharge by deep wells along coastal (including harbour) fringes.
2. Interception of sea water inflows and removal of natural recharge by subsurface drains along coastal fringes.
3. Dewatering wells uniformly distributed over affected areas as required.
4. Installation of an impermeable barrier along coastal fringes. Such a barrier could be a sheet piled continuous wall driven to basement rock. Depth to basement rock has been assumed at 70 m for the purposes of this report.

- Option 1 is depicted in Figure 13 and has the benefit that it can be relatively easily augmented incrementally as required to combat increasing rises in sea level. Augmentation would involve adding further wells between existing wells to decrease the radius of influence of each well and increase the overall well field capacity. Wells would be connected to the necessary pipework to convey discharges to the harbour or the sea. The bulk of this work could be carried out in road reserves and other public spaces.
- Option 2 is less flexible in regard to increasing sea level elevation although it could be supplemented by additional drains. These drains would have to be deep to be effective. Work by Fordyce(6) shows that in the near surface soil layers, hydraulic conductivity is relatively low therefore it will be necessary to construct such drains at depth to take advantage of the higher hydraulic conductivity expected at greater depth. Deep excavation in South City soils is known to be difficult, requiring extensive shoring and dewatering. This option will be much more difficult to

construct than Option 1, which can be constructed from ground level with associated pipe work at comparatively shallow depth, and is less conducive to incremented augmentation.

- Option 3 will achieve a similar outcome to Option 1 except that it does not intercept incoming sea water nearest the location at which it enters groundwater. A consequence of this would be that groundwater would become brackish over time. In addition, more wells are required to achieve the same outcome as Option 1.
- Option 4 involves the installation of cut-off walls to basement rock on an alignment similar to the interception zone as shown in Figure 13. While this would provide isolation, it may not, in the long term, be sufficient to control ground water level as there could be no guarantee that all inward sources of sea water around the perimeter would be controlled. In addition to uncontrolled inflow, recharge of groundwater by rain and pipe losses would require an active dewatering system inside the cut-off walls to discharge recharge water beyond the cut-off wall because such a wall would not only impede ingress of sea water, but also impede the current natural drainage of recharge water to the sea. For this reason it would also be necessary to supplement an isolation system with active control of ground water which would require a substantial network of dewatering wells which would be very similar to the active ground water management options covered by 1 and 3 above. Further, such a system is not capable of incremental augmentation as sea level rises. At the point in time when it becomes necessary to install such a defence system, the entire cut-off wall would have to be built. The basic cost of this wall alone would exceed $200M with a supplementary dewatering system which would also be necessary costing up to a further $100M. The dewatering system to deal with infiltration (rainfall mostly) inside the cut-off wall would also have to be installed to full capacity at the same time as the cut-off wall therefore there is no ability to stage this work. On that basis an active management approach such as Option 1 or 3 from the outset is likely to be more desirable.

For the purposes of providing a basis for estimating a rough order of capital costs, Option 1 has been adopted. The principal reason for doing this is because it is the most flexible option for future expansion and intercepts incoming sea water before it penetrates into groundwater. Of all the options considered, Option 1 is most able to accommodate incremental increases in capacity. SLR is an ongoing process and thus a solution to deal with it needs to be able to respond to it as the demand for defence requires. Ideally the chosen solution will permit spreading capital expenditure to match (as closely as possible) the timing of the need to provide defence. The provision of a perimeter interception well system will require capital to cover initial dewatering wells and connecting pipe work (sized for full capacity) and thereafter the cost of adding further wells can be spread to match ongoing SLR.

For the purposes of this study is has been assumed that the interception zone considered in Option 1 is 100 m wide and approximately 5.3 km long and:

- Follows Victoria Road, Tahuna Road, Cavell Street, Portsmouth Drive, and Strathallan Street
- Wells are bored to basement (depth will vary but assumed 70 m)
- Well water level maintained at 30 to 50 m below ground level at the well
- Ground water level maintained at current elevation between wells.

At higher values of SLR, Option 1 is supplemented with installation of bunds to prevent inundation during high tide events and raising sections of some roads to maintain a viable traffic corridor at all times.

3.2 Other Options Considered

A number of suggestions have been made as to other possible approaches to providing defence, in particular, to South City. These suggestions have come out of the two workshops held with DCC during the course of developing defence options and report preparation.

Broadly, those suggestions are:

Build-up all land

While this is an option and would certainly address the future potential for flooding arising from SLR, it would require a complete reconstruction of all affected areas and therefore is not considered a feasible solution. Raising land only on the coastal and harbour fringe will not stop SLR forcing up ground water level, therefore it will not stop flooding in low lying areas distant from the coastal and harbour fringes.

Build Dykes Now

In the long term, 100 to 200 years from now, dykes may be necessary, particularly along the harbour fringe. Dykes will protect low lying areas from inundation by overland flow but as identified in this report, overland flow is not the immediate threat, particularly in South City. As explained in this report, it is not until SLR reaches 1.6 m or more (predicted maximum for 2090) that overland flow during MHWS becomes a threat. At SLR below this level the threat is from rising ground water which will occur whether or not dykes are built. In this report, dykes (or bunds) along Portsmouth Drive and adjacent the Harbour Basin have been allowed for in the capital cost estimates for SLR scenarios of 1.6 m and 2.0 m. Given that dykes can be built relatively quickly the most effective strategy is to construct them nearer the time it becomes evident they are necessary because that could be well into the next century.

Dykes in some form between the areas around the Harbour Basin and to the north and south of it will provide protection from inundation in that area but this may require extensive modification or removal of harbour side structures.

Surface Drainage System

Surface drainage systems are only effective in diverting water lying on the ground surface and will not act to maintain ground water below ground surface level. Consequently surface drainage systems would not be effective in combating rising ground water levels wherever they occur.

Dig out Forbury Race Course and make a lake

Because of the way water moves through the ground, this option would result in lowering the ground water only in the immediate vicinity of the lake and then only if the lake was continuously pumped out to lower the water surface in the lake significantly below adjacent ground water surface level so as to maintain a ground water gradient falling towards the lake.

Tidal Barrier at Andersons Bay Inlet

This option was mentioned in the context of providing protection to the Marne Street, Somerville Street area and would involve a tidal barrier at the causeway bridge at Andersons Bay Inlet. The intention of the barrier would be to keep water levels in Andersons Bay Inlet at an acceptably low level. While such an approach would suppress tidal fluctuation in the inlet, it is expected that inlet water level would rise to at least match MSL by virtue of infiltration through or under the causeway itself. To prevent this, extensive works would be required on the causeway and harbour bed to prevent infiltration and it is extremely likely this would be an effective long term solution. The cost of doing this work would far outweigh other options to address the impact of SLR on the Somerville Street/Marne Street area.

4 Incremental Defence Strategy

It is not known how SLR will impact the present dune system on the coast south of South City. This report assumes that the dune system remains in place and thus continues to act as a defence to direct inundation from the open sea.

4.1 Baseline Sea Level

Figure 1 is included for comparison purposes only. It shows ground level in the South City area relative to sea level at approximately 1990 MHWS. There are no areas in the Central Dunedin area where ground level is below current MHWS. Because the tidal peak is of short duration, there is insufficient time for the influence of high sea level to penetrate the South Dunedin aquifer and to raise ground water level sufficiently to cause flooding but occasional flooding does occur under very high tides caused by surcharging of stormwater systems. Figure 1 also shows there are no potential inundation issues on the harbour fringe at current MHWS (= MSL +1.0 m).

4.2 Scenario A

Figure 4 shows the relationships between ground level and MHWS at approximately 0.3 m sea level rise (modelled as +0.35 m as discussed in Section 1.4) which is the equivalent of 1.35 m above MSL (1990).

Figure 5 shows the relationship between land surface and ground water level based on approximately a 0.3 m sea level rise plus an additional 0.4 m reflecting the predicted elevation of ground water level under this scenario.

Both figures 4 and 5 show that the harbour fringe is not under threat from MHWS at this SLR except a very small amount of flooding in the Marne Street/Somerville Street area which is consistent with recently observed surface flooding in that area.

What appears to be a significant inundation (1.2 m+) around the wharf areas and in the Leith is in fact an artefact of the LiDAR data in those areas.

Figure 5 does show that lowest areas of South City can expect to have standing water above ground level unless intervention is implemented to deal with this. The worst affected area is between Queens Drive and Cavell Street. This area is considered to be the lowest point in the city which is why the Main Trunk Waste Water Sewer terminates (at the Musselburgh Pump Station) in this area. Figure 5 also shows that there are isolated areas of low lying ground in the vicinity of Hargest Crescent, Kings High School and Macandrew Road between Atkinson Street, Fingall Street and Melbourne Street. It is noted that there is also low lying land within Forbury Race Course which may require remedial works such as locally raising ground level.

The proposed intervention strategy under this scenario is to provide passive subsurface drainage in the above areas as shown on Figure 12 and to install localised pump stations to collect water out of the subsurface drainage system. The pump stations would discharge to the existing stormwater network which would be utilised to discharge ground water via the Portobello Road Pump Station. This may require modifications to the existing stormwater discharge consent and possibly further treatment of the discharge from the Portobello Road Pump Station.

4.3 Scenario B

Figure 6 shows those areas of Dunedin which are below MHWS under scenario B (modelled as +0.85 m as discussed in Section 1.4). This corresponds to a sea level surface of approximately 1.85 m above MSL (1990). Reference to Table 3 shows that a sea surface level approximating this scenario currently has an ARI of 10 – 20 years compared with MSL (2000) and an ARI of two years after sea level rise of +0.3 m. Figure 6 shows that the margin along Portsmouth Drive and Andersons Bay inlet can be expected to experience frequent (i.e. several times a month) inundation corresponding to MHWS under scenario B. By reference to Table 3 it can be seen that inundation to the degree experienced at MWHS under this scenario may be expected at least once every one to two years under scenario A and is equivalent to that which is currently experienced about once every 20 years at present sea levels.

Note that there is no evidence of overland flow from the harbour fringe into either the South City or Central Dunedin areas under this scenario.

Solutions to deal with this impact on the harbour fringe are as follows:

- Raise ground in Kitchener Street area to address inundation south of the Harbour Basin.
- Introduce modifications to stormwater system in lower St Andrew Street area to prevent backflow causing surface flooding.
- Portsmouth Drive
  - Install a protective bund along the harbour edge
  - Raise Portsmouth Drive and adjacent streets
  - Install local pump stations to collect and discharge any accumulated water
- Bayfield Park
  - Raise park ground level by approximately 0.5 m
- Marne Street – Somerville Street
  - Implement a long term strategy to address inundation of low lying properties
  - Raise Somerville and Marne Streets above water level
- South Dunedin – aquifer protection.
  - This requires approximately 50 wells at approximately 100 m centres connected to a system of header pipes, discharging to the harbour in an interception zone generally as shown in Figure 13.

The areas of inundation near Bayfield High School and Musselburgh Rise evident in Figure 6 are unlikely to occur as there is no direct overland connection between them and the harbour and Figure 7 shows that GWL does not rise to the surface at these locations under this scenario.

Figure 7 shows the extent of the predicted ground water surface in the absence of intervention to artificially depress and control ground water under this scenario.

With this rise in sea level it becomes necessary to provide active and on-going intervention to protect virtually the entire area of South City. Under this scenario, a simple model suggests that at somewhere between scenarios A and B, sea water begins to flow into the South Dunedin aquifer on a sustained basis adding to the natural recharge resulting from rainfall and artificial recharge from existing pipe networks.

It should be noted that any dewatering option which severely depresses ground water level in a local area, e.g. around a dewatering well, is most likely to induce consolidation of the ground in the area as ground water is removed and effective soil stress increases. This will result in localised settlement which will affect nearby structures and surface drainage systems such as kerb and channelling which may require repair. The amount of settlement will be very dependent on subsurface conditions and particularly the type of soils under each property. Deep silts and clays will be the most susceptible to dewatering induced settlement. Approximately 200 houses in the South City area would be affected. The cost of remedying such issues has not been addressed in this report.

4.4 Scenario C

The influence of MHWS on the harbour fringe is shown in Figure 8 under this scenario. Inundation along the harbour fringe clearly becomes more extensive and the first signs of a direct connection with harbour water by overland flow become apparent in the absence of a defence mechanism. Under this scenario direct inundation is no longer confined to the harbour fringe. The works proposed above for scenario B will not be sufficient to accommodate this SLR scenario. There is a number of isolated areas of inundation in the Bayfield High School area (adjacent Shore Street and Musselburgh Rise) which are known local depressions. These areas could be dealt with by local filling to raise ground level. By reference to Table 3 it can be seen that sea levels depicted on this map may also be expected to occur approximately once every 10 years under a +0.8 m scenario indicating that irrespective of how long it takes to get to +1.6 m, by the time +0.8 m SLR is reached about once every 10 years widespread flooding can be expected under extreme weather and sea level events.

This is the first scenario where direct and significant overland inflow from the harbour into low lying areas of Dunedin could occur in the absence of any intervention.

Figure 9 shows the expected inundation extent and depth without intervention to depress ground water level.

Defence against this scenario would involve the above mentioned localised filling as well as augmentation of the well network previously installed to defend against scenario B.

This scenario requires the following defence works:

- Increase interception wells to 150 in number in the previously constructed interception zone.
- Raising Bayfield Park by a further 0.5 m.
- Raising Marne Street and Somerville Street by a further 0.5 m.
- Raising Shore Street and Portsmouth Drive by a further 0.5 m.

There may be sufficiently high ground in the Wharf Street area to prevent overland flow reaching the railway yards and Cumberland Street but areas adjacent Fryatt Street could experience flooding by leakage under the adjacent port structures.

The depth of potential inundation in the lower St Andrew Street area suggests this area is a low point and that a pumped stormwater system is likely to be required in this area to combat both stormwater drainage under MHWS and to address ground water level rise.

Figure 8 also indicates that protection along the banks of Leith upstream of Anzac Avenue may be necessary to protect properties adjacent the Leith from intermittent overland flow.

Figure 9 likely over estimates the depth (and extent) of inundation along the harbour fringe under this scenario because it is unlikely that ground water level is sustained at +0.4 m above sea level along this margin. It can reasonably be expected that ground water level will be close to prevailing sea level.

4.5 Scenario D

Figure 10 shows expected extent and depth of inundation under this scenario at MHWS. Reference to Table 3 shows this sea level can be expected to occur more frequently than once every two years under a 1.6 m SLR scenario but is unlikely to occur at all under scenario B.

Figure 10 shows expected inundation levels under this scenario. Without intervention, significant inundation is expected between Portsmouth Drive and Turakina Road, around Bayfield Park right up to Bayfield High School, along Portobello Road and well into Somerville Street and Marne Street.

Figure 10 also shows that under a +2 m SLR + MHWS scenario inundation over large areas of Central Dunedin can be expected in the absence of measures to control overland flow.

Figure 11 shows the expected inundation extent and depth without intervention to depress ground water level.

This scenario requires the following works:

- Additional wells added to the interception zone to increase to a total of 400
- Additional pump station on Portsmouth Drive
- Raise Shore Street
- Localised infilling of low areas on Musselburgh Rise/Bayfield area
- Raising of further land in the Kitchener Street areas
- Further drainage and defence measures in the Fryatt Street area
- Measures to depress groundwater level in the lower St Andrew Street area
- Measures to depress ground water in the Union Street area
- Extension of ground water control measures to the Oval and Crawford Street/Cumberland Street areas.

Interventions in Marne Street/Somerville Street area included in the +1.6 m scenario will be sufficient to accommodate this scenario.

5 Forecast Costs

5.1 Capital Costs

Table 4 shows expected costs to address each of the SLR scenarios. At this stage, these costs are based on the best data presently available however that data is limited and will require further works to refine it as described in Section 7 below.

The following points should be noted with regard to the costs summarised below:

- Assumptions about hydraulic conductivity of the South Dunedin aquifer have a major influence on the number and location of interception wells. Known values for hydraulic conductivity cover a very small area of the entire aquifer and thus further work is required to refine this information.
- The cost of each option (except scenario A) is heavily influenced by the number of wells which in turn is heavily influenced by hydraulic conductivity.
- While the costs reported below are associated with specific SLR scenarios, SLR is an on-going process. The capital costs in Table 4 have to be spent progressively to implement each stage so as to be complete before the relevant SLR scenario is reached.
- Costs below do not include compensation payments for property damage or land acquired.

Table 4: Capital Costs

Sea Level Rise Scenario	Forecast Date	Rough Order Costs (ROC)	Cumulative ROC
Scenario A	2040	$10.3M	$10.3M
Scenario B	2090 (minimum)	$65.1M	$75.4M
Scenario C	2090 (maximum)	$73.5M (additional to above)	$148.9M
Scenario D	2130	$204.1M (additional to above)	$353.0M

5.2 Operating Costs

In addition to capital costs, dewatering systems will incur constant operating costs. These costs are reported below in 2013 dollar terms.

Table 5: Operating Costs

Sea Level Rise Scenario	Operating Costs Per Annum	Maintenance Costs Per Annum	Combined O&M Per Annum
Scenario A	$18,000	$45,000	$63,000
Scenario B	$138,000	$3.8M	$3.94M
Scenario C	$368,000	$7.5M	$7.87M
Scenario D	$530,000	$17.7M	$18.23M

These costs are based on annual pumped volumes which give rising to annual energy charges. Maintenance costs are based on 0.5% of capital cost per annum. This will cover pump replacement, dewatering well and pipeline maintenance inclusive of materials and labour costs.

6 Recommendations

At this stage many assumptions have been made about the behaviour of the South City/Central Dunedin ground water system. In order to refine the work started by this report it is necessary to gain a much better understanding of the behaviour of ground water across the low lying areas of Dunedin City following which the concepts presented in this report can be refined.

Work needs to be carried out to gain a better understanding of the hydraulic conductivity in those areas and how that varies across Dunedin. This work would best be focussed along the South-western and North-eastern fringes of the South Dunedin aquifer in the first instance and then along the harbour fringe either side of, and within, the Harbour Basin area. Such work will necessarily involve extensive subsurface investigation with down hole permeability measurements and may be carried out over a number of years in order to spread expenditure. As that information becomes available the present ground water model can be refined which in turn will enable the proposed defence solutions and their associated costs to be refined.

7 Conclusions

The work conducted in preparing this report has identified that lower lying land within Dunedin can be defended against the SLR scenarios currently included in DCC’s Climate Change Predictions Policy, but the cost of defence is significant.

If current SLR trends continue then in the next thirty years or so, the first significant and persistent effects of SLR will become apparent in the low lying areas of Tainui and isolated areas near Hargest Crescent and Macandrew Road. Localised subsurface drainage systems installed in these areas will provide a solution to this but ultimately as SLR continues more extensive (and expensive) measures will be necessary.

It is considered that the best option to combat on-going effects of SLR in the short to medium term is to prevent the influence of higher sea level penetrating the South Dunedin aquifer by intercepting sea water around the perimeter of South City. Use of interception wells as shown in Figure 13 along the south/south western boundary of the aquifer parallel with the ocean and along Portsmouth Drive/Strathallan Street is considered the best option. This option, unlike others, can be relatively easily augmented as the impact of SLR becomes more severe. An extension of this system would be used to protect low lying ground near the Oval and the Southern End of Crawford and Cumberland Streets.

There is a small area in the Marne Street/Somerville Street area that is already subject to occasional surface flooding under high sea level events and that area will become more difficult to defend as time goes by. Long term defence is unlikely to be an option for the 25 to 30 properties in that area which are directly exposed to elevated water levels.

The area between Kitchener Street and the Leith is much less susceptible to elevated groundwater levels but may experience direct inundation under higher SLR scenarios. Active measures will be required to provide stormwater disposal from the low lying areas at the bottom of St Andrew Street. This area is the low point in a significant city stormwater catchment. Protection works to prevent direct inundation will be required along most of the harbour fringe and on parts of the Leith under higher SLR scenarios.

This study has only looked at the impact of SLR up to +2.0 m MLOS relative to sea level at 1990 MSL. The estimated cumulative capital cost to defend to this level is $353.0M with operating costs of $18.23M per annum (both at 2013 values). While costs are given in this report which relate to the specific SLR values contained in DCC Climate Change Policy (and their corresponding dates), it should be noted that actual expenditure will be required continuously before sea level rises to + 0.3 m above 1990 levels. This is because the estimated expenditure necessary to defend against any particular SLR scenario has to be spent before that level is reached.

It is important to note that even more extensive and expensive measures will be required as SLR continues beyond the notional upper value of +2M SLR above MSL (1990). There may well come a time when the cost of defence outweighs the benefit delivered. This will require major economic and policy decisions by DCC, possibly the largest and most far reaching decisions it has made to date.

References

(1) An updated on Global Sea Level (5th June 2013) Pers.com. B.Fitzharris (appended)

(2) Otago Extreme Sea Level Analysis – NIWA Client Report: CHC2005-114 August 2005 (Sourced from ORC)

(3) The South Dunedin Coastal Aquifer and Effect of Sea Level Fluctuations ORC, Jens Rekker

(4) Community Vulnerability to Elevated Sea Level and Coastal Tsunami Events in Otago, ORC 2012

(5) LiDAR Data supplied by DCC

(6) The Response of the Water Table to Rainfall Events in South Dunedin, NZ. Draft report prepared by Emma Fordyce for DCC

(7) South Dunedin Integrated Catchment Management Plan, Opus and URS. Sourced from DCC

(8) South Dunedin ICMP – Modelling Report, Opus and URS. Sourced from DCC

(9) ORC Memo Report (for workshop on 18th November 2009), by Jens Rekker. Sourced from DCC

(10) Review of Tsunami Hazard in New Zealand (2013 update) GNS Consultancy Report 2013/131 (August 2013)

(11) Climate Change Predictions Policy 2011 – DCC Corporate Policy – Sustainability Advisor, 6th September 2011

(12) Climate Change Impacts on Dunedin – Report Prepared by Blair Fitzharris (2010) for Dunedin City Council

Appendix A

Figures

Introductory Notes:

1. These figures are intended to be read in conjunction with the full report.

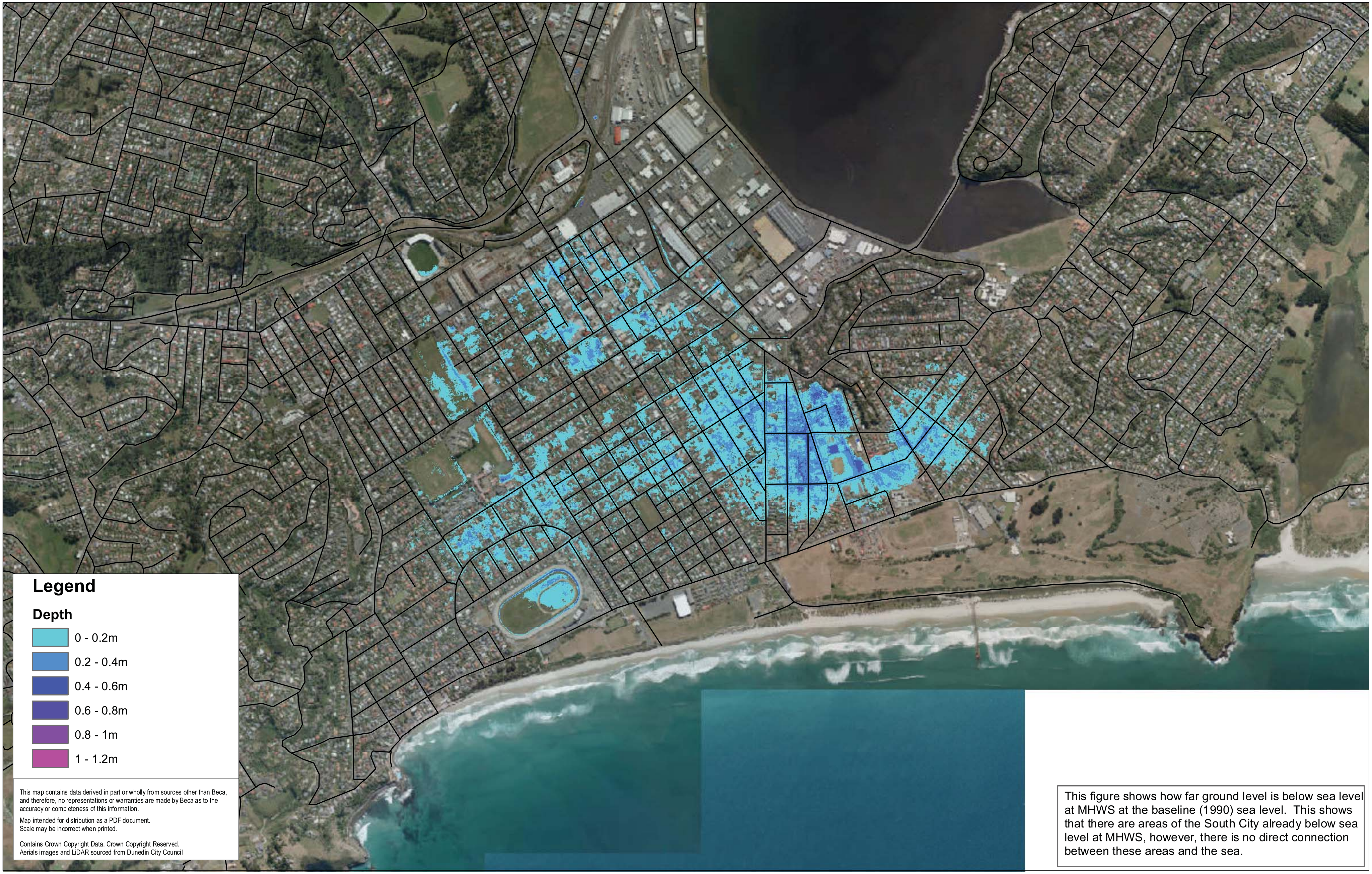
2. The sea level rise scenarios referred to are those explained in section 1.1:

Scenario	Magnitude of sea level rise above 1990 MSL	Anticipated date at which scenario is reached
A	+0.3m	2040
B	+0.8m	Min. expected by 2090
C	+1.6m	Max. expected by 2090
D	+2.0m	Approx. 2130 (Scenario based on sea level rise of 100 mm/decade from 2090 maximum forecast)

3. Generally there are two maps for each scenario; one showing land below MHWS under that scenario; and, one showing the potential extent of groundwater ponding in absence of groundwater control measures. As discussed in section 1.5, while tides vary considerably, the modelling for this report factored in MHWS to demonstrate the sea level expected on a frequent basis.

4. The modelling used to develop these maps is indicative only. It was based on LiDAR data, which, as discussed in section 1.4, has limitations. As yet, no on-ground surveying has been undertaken.

5. As discussed in section 1.3, the modelling adjusted 1958 datum by +0.05m to take into account observed relative sea level rise between 1958 and 1990. The sea level rise scenarios are modelled above this 1990 sea level.



This map contains data derived in part or wholly from sources other than Beca, and therefore, no representations or warranties are made by Beca as to the accuracy or completeness of this information.

Map intended for distribution as a PDF document. Scale may be incorrect when printed.

This figure shows how far ground level is below sea level at MHWS at the baseline (1990) sea level. This shows that there are areas of the South City already below sea level at MHWS, however, there is no direct connection between these areas and the sea.

Map Scale @ A3: 1:15,000

0 125 250 500 750

Metres

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Revision	Author	Verified	Approved	Date
3	AYF	BAP	RLC1	12/11/13
2	RJL	DRAFT	DRAFT	26/07/13
1	AYF	DRAFT	DRAFT	07/06/13

Title:

Figure 1: Land Below Baseline (1990) Sea Level at MHWS

Client: DUNEDIN CITY COUNCIL

Project: Climate Change Adaptation for Dunedin

Beca

Discipline: GIS

Drawing No: GIS-3383598-009

This figure compares the spatial extent of expected ponded ground water if there is no intervention to control groundwater level. The diagram demonstrates the sensitivity of results for a predicted +0.3m rise by comparing the spatial extent for +0.25m and +0.35 rise above 1990 MSL.

Map Scale @ A3: 1:25,000

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Metres

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Revision	Author	Verified	Approved	Date
2	AYF	BEP	RLC1	12/11/13
1	AYF	DRAFT	DRAFT	22/10/13

Title:

Figure 2: Scenario A
Sensitivity Analysis
(MSL +0.4m GWL +0.25m & +0.35m SLR)

Client: DUNEDIN CITY COUNCIL

Project: Climate Change Adaptation for Dunedin

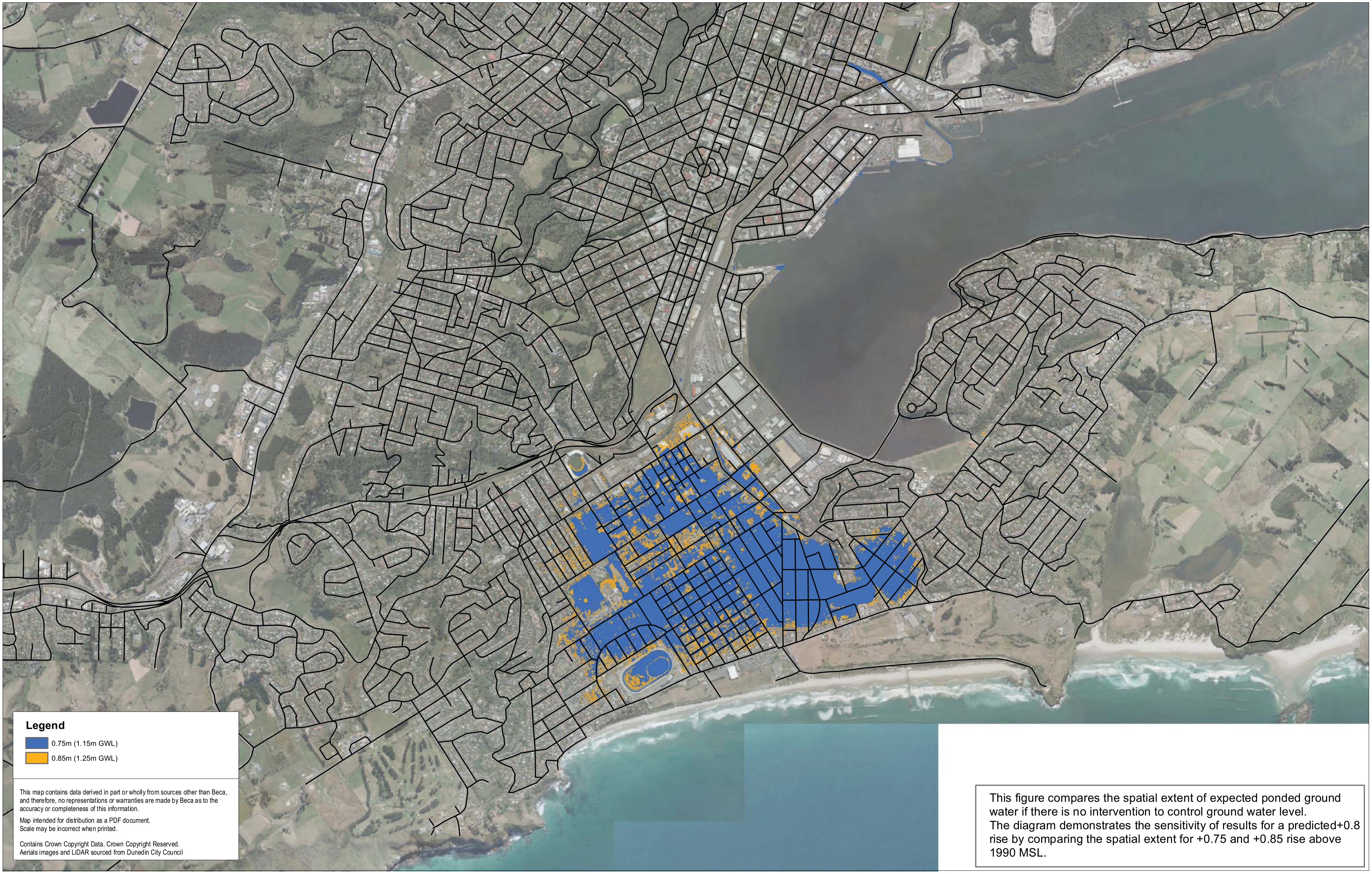
Beca

Discipline: GIS

Drawing No: GIS-3383598-011

File: \\Beca.net\projects\77\777-GIS-AKL\3383598\TGIS5_Workspaces\01_mxd\GIS-3383598-011_Comparison MSL +0.4 (GWL) +0.25 & +0.35 (SLR)_Fig2.mxd Author: Date: 7/07/2014

GIS@beca.com



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Metres

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Revision	Author	Verified	Approved	Date
2	AYF	BEP	RLC1	12/11/13
1	AYF	DRAFT	DRAFT	22/10/13

Title:

Figure 3: Scenario B
Sensitivity Analysis
(MSL +0.4m GWL +0.75m & +0.85m SLR)

Client: DUNEDIN CITY COUNCIL Kaunihera-a-rohe o Ōtepoti

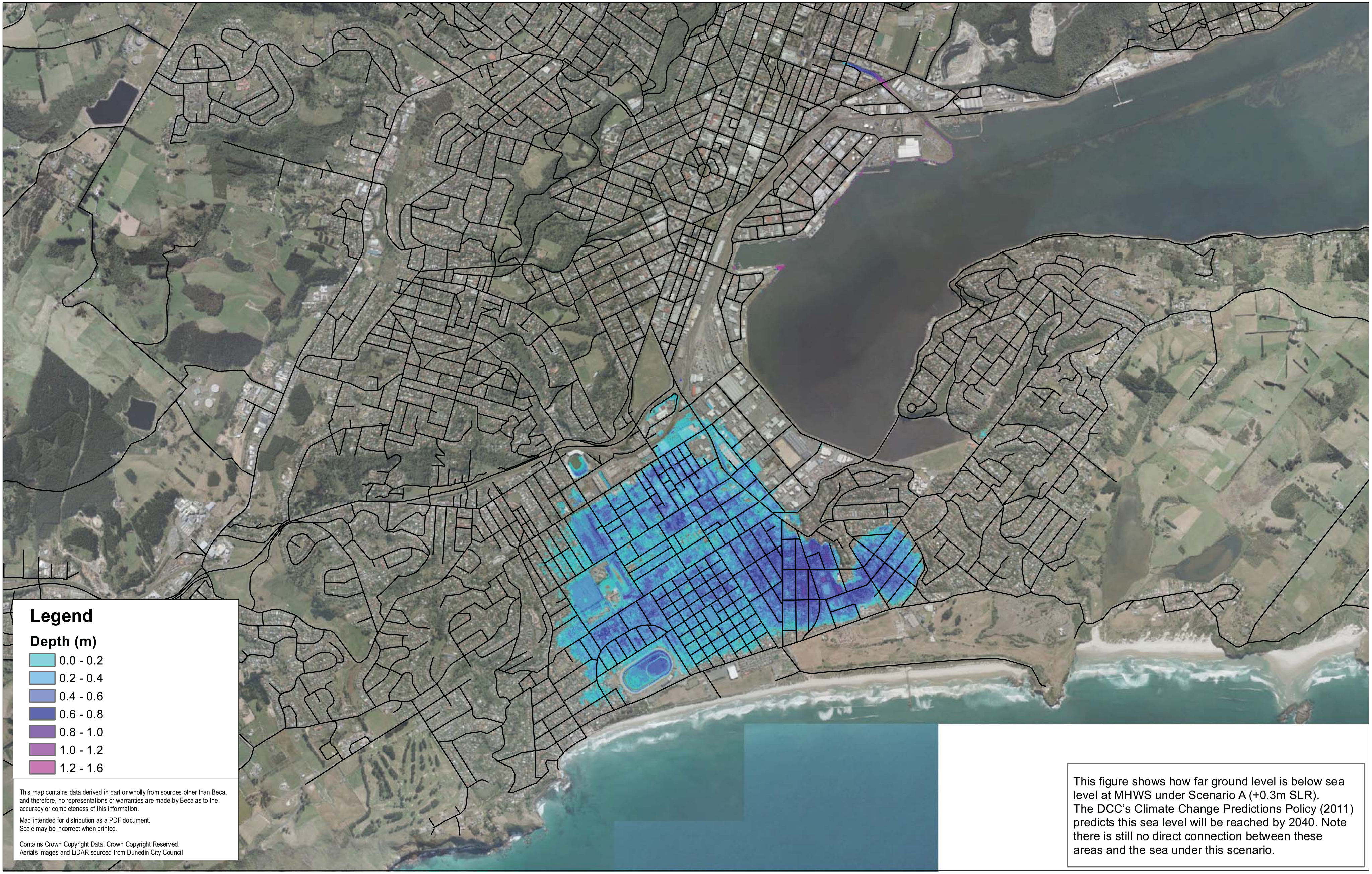
Project: Climate Change Adaptation for Dunedin

Beca

Discipline: GIS

Drawing No: GIS-3383598-012

File: \\Beca.net\projects\77\777-GIS-AKL\3383598\TGIS5_Workspaces\01_mxd\GIS-3383598-012_Comparison MSL +0.4(GWL) +0.75 & +0.85(SLR)_Fig3.mxd Author: Date: 7/07/2014 GIS@beca.com



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Revision	Author	Verified	Approved	Date
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1	AYF	DRAFT	DRAFT	22/10/13

Title:

Figure 4: Land Below Sea Level at MHWS Scenario A (1990 MSL +0.3m SLR + 1.0m MHWS)

Client: DUNEDIN CITY COUNCIL

Project: Climate Change Adaptation for Dunedin

Discipline: GIS

Drawing No: GIS-3383598-013

Map Scale @ A3: 1:25,000

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Revision	Author	Verified	Approved	Date
2	AYF	BEP	RLC1	12/11/13
1	AYF	DRAFT	DRAFT	22/10/13

Title:

Figure 5: Potential Extent of Groundwater Ponding
Scenario A (1990 MSL +0.3m SLR +0.4m GWL)

Client: DUNEDIN CITY COUNCIL

Project: Climate Change Adaptation for Dunedin

Beca

Discipline: GIS

Drawing No: GIS-3383598-014

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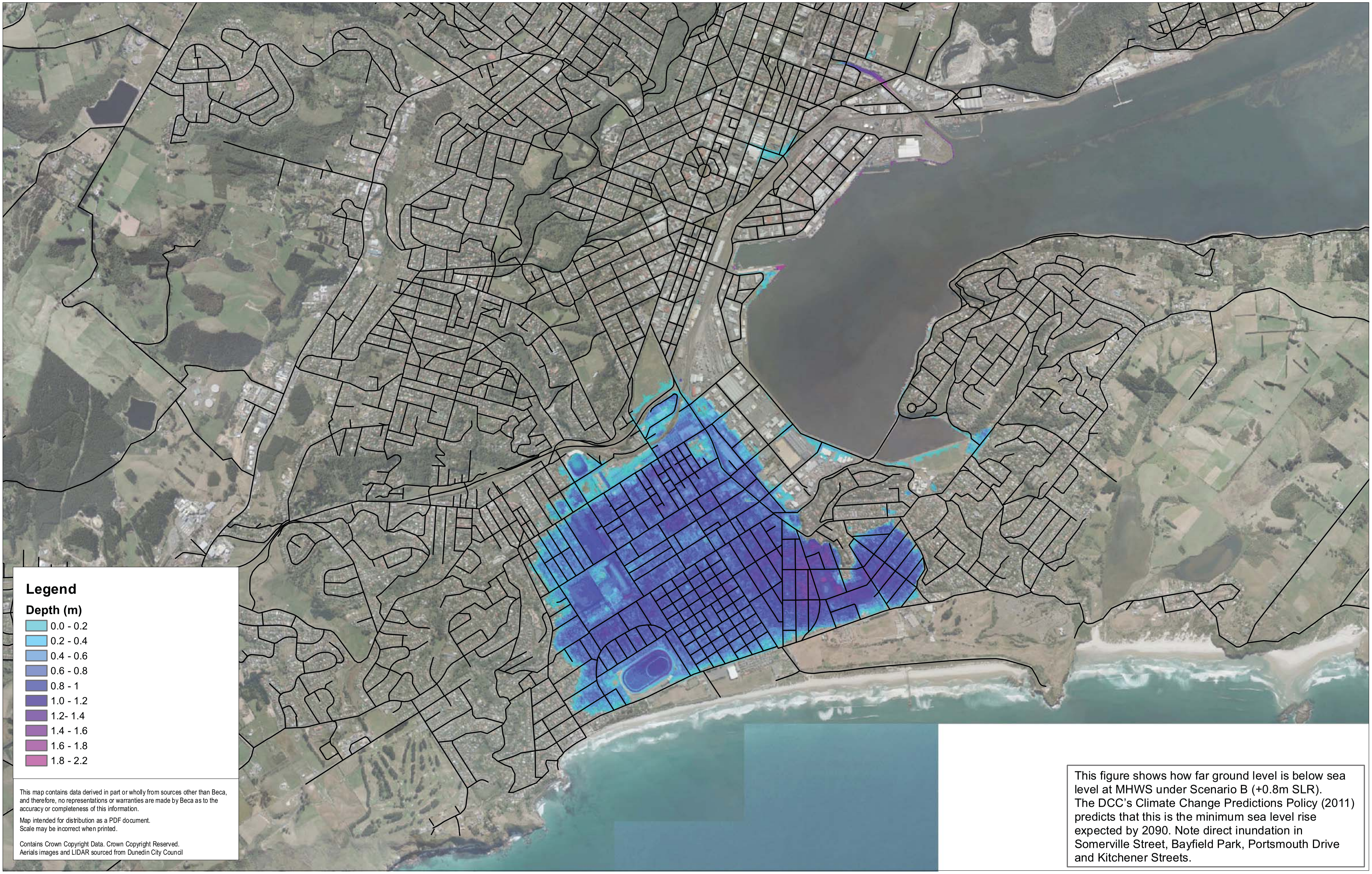
GIS@beca.com



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Revision	Author	Verified	Approved	Date
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1	AYF	DRAFT	DRAFT	22/10/13

Title:

Figure 6: Land Below Sea Level at MHWS Scenario B (1990 MSL +0.8m SLR + 1.0m MHWS)

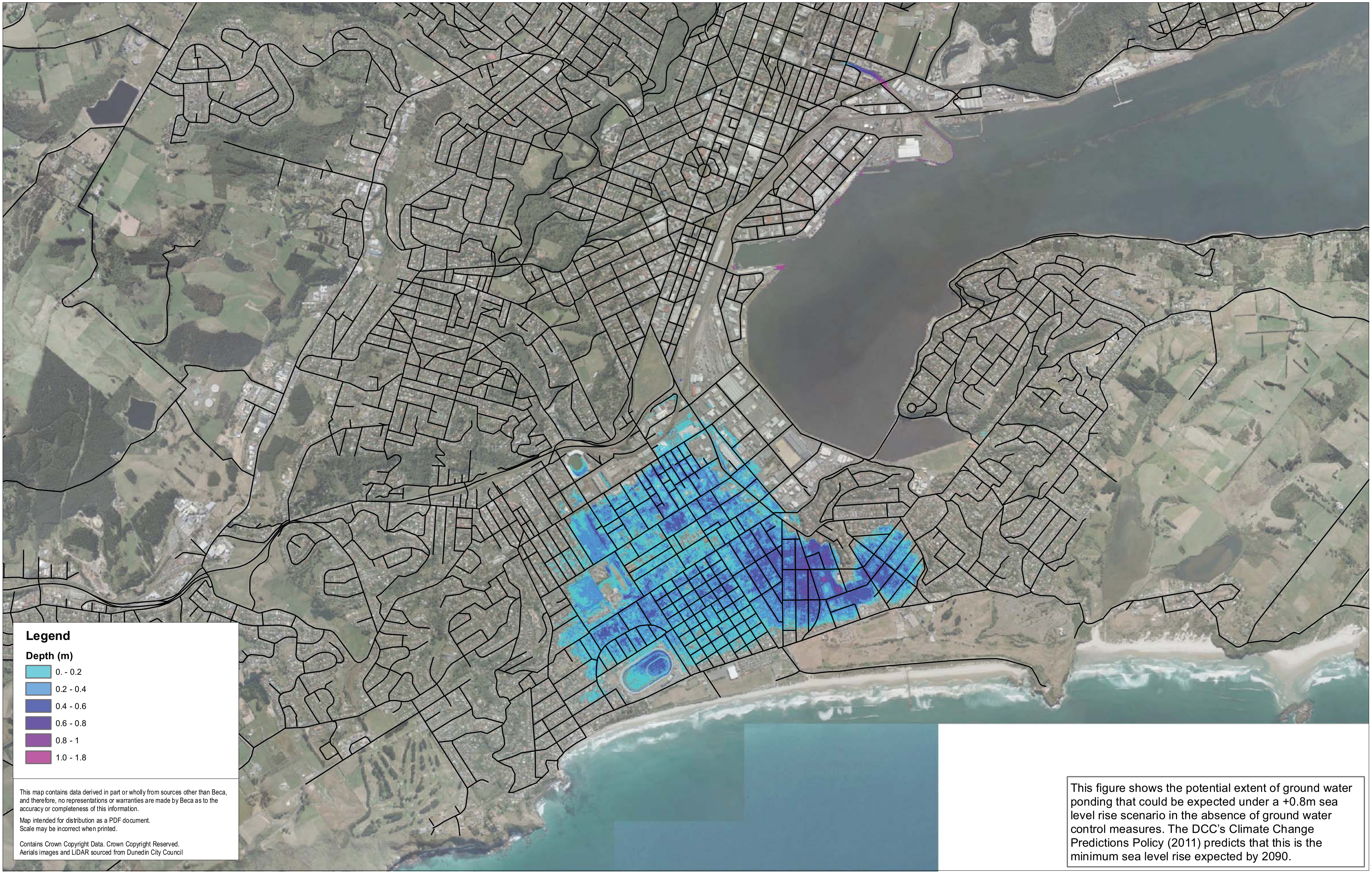
Client: DUNEDIN CITY COUNCIL

Project: Climate Change Adaptation for Dunedin

Beca

Discipline: GIS

Drawing No: GIS-3383598-015



Map Scale @ A3: 1:25,000

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Revision	Author	Verified	Approved	Date
2	AYF	BEP	RLC1	12/11/13
1	AYF	DRAFT	DRAFT	22/10/13

Title:

Figure 7: Potential Extent of Groundwater Ponding Scenario B (1990 MSL +0.8m SLR +0.4m GWL)

Client: DUNEDIN CITY COUNCIL

Project: Climate Change Adaptation for Dunedin

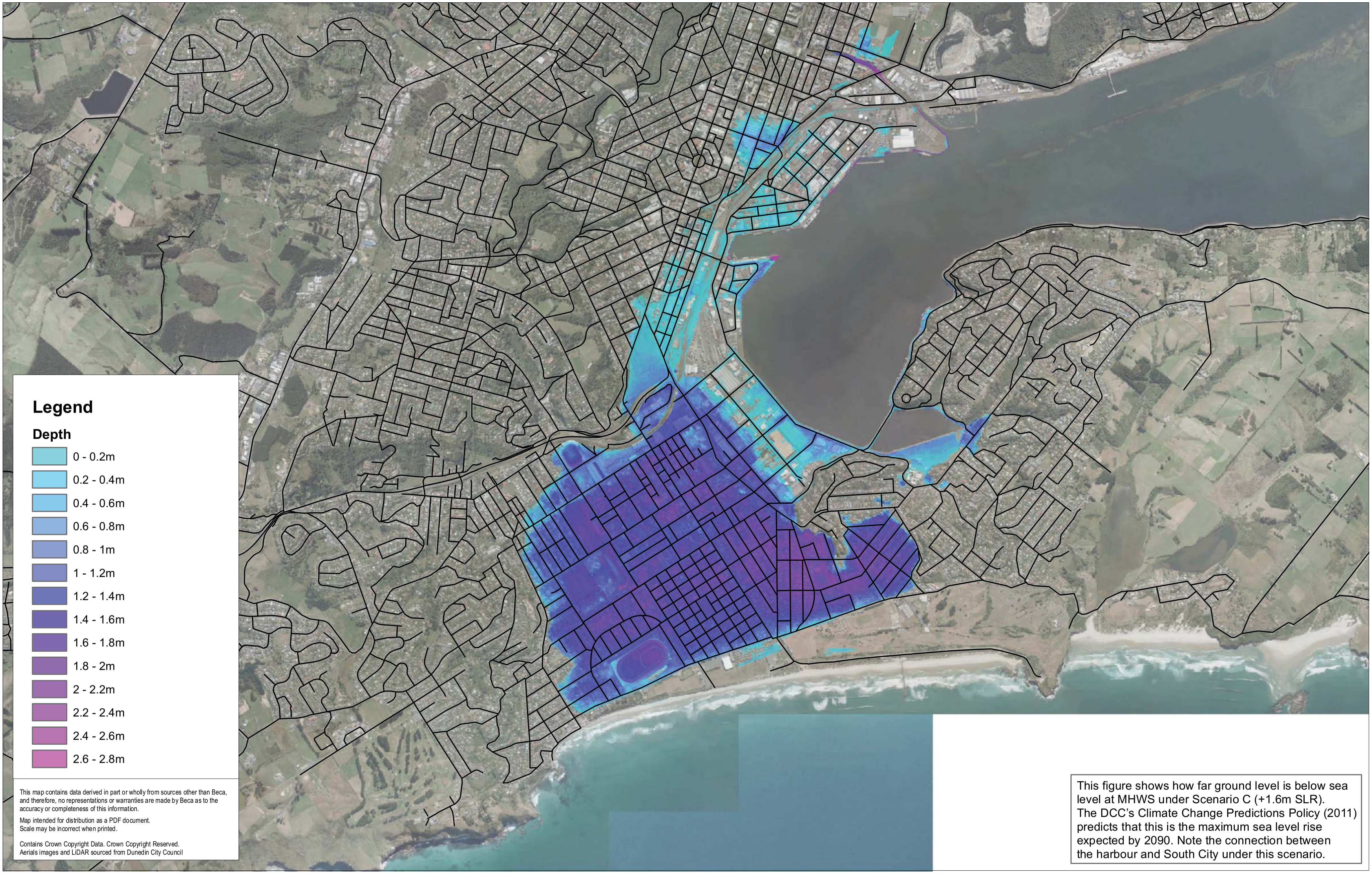
Beca

Discipline: GIS

Drawing No: GIS-3383598-016

File: \\Beca.net\projects\777\777-GIS-AKL\3383598\TGIS5_Workspaces\01_mxd\GIS-3383598-016_MSL +0.94m (GWL) +0.85m (SLR)_Fig7.mxd Author: Date: 7/07/2014

GIS@beca.com



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Revision	Author	Verified	Approved	Date
3	AYF	BAP	RLC1	12/11/13
2	RJL	DRAFT	DRAFT	26/07/13
1	AYF	DRAFT	DRAFT	07/06/13

Title:

Figure 8: Land Below Sea Level at MHWS Scenario C (1990 MSL +1.6m SLR + 1.0m MHWS)

Client: DUNEDIN CITY COUNCIL

Project: Climate Change Adaptation for Dunedin

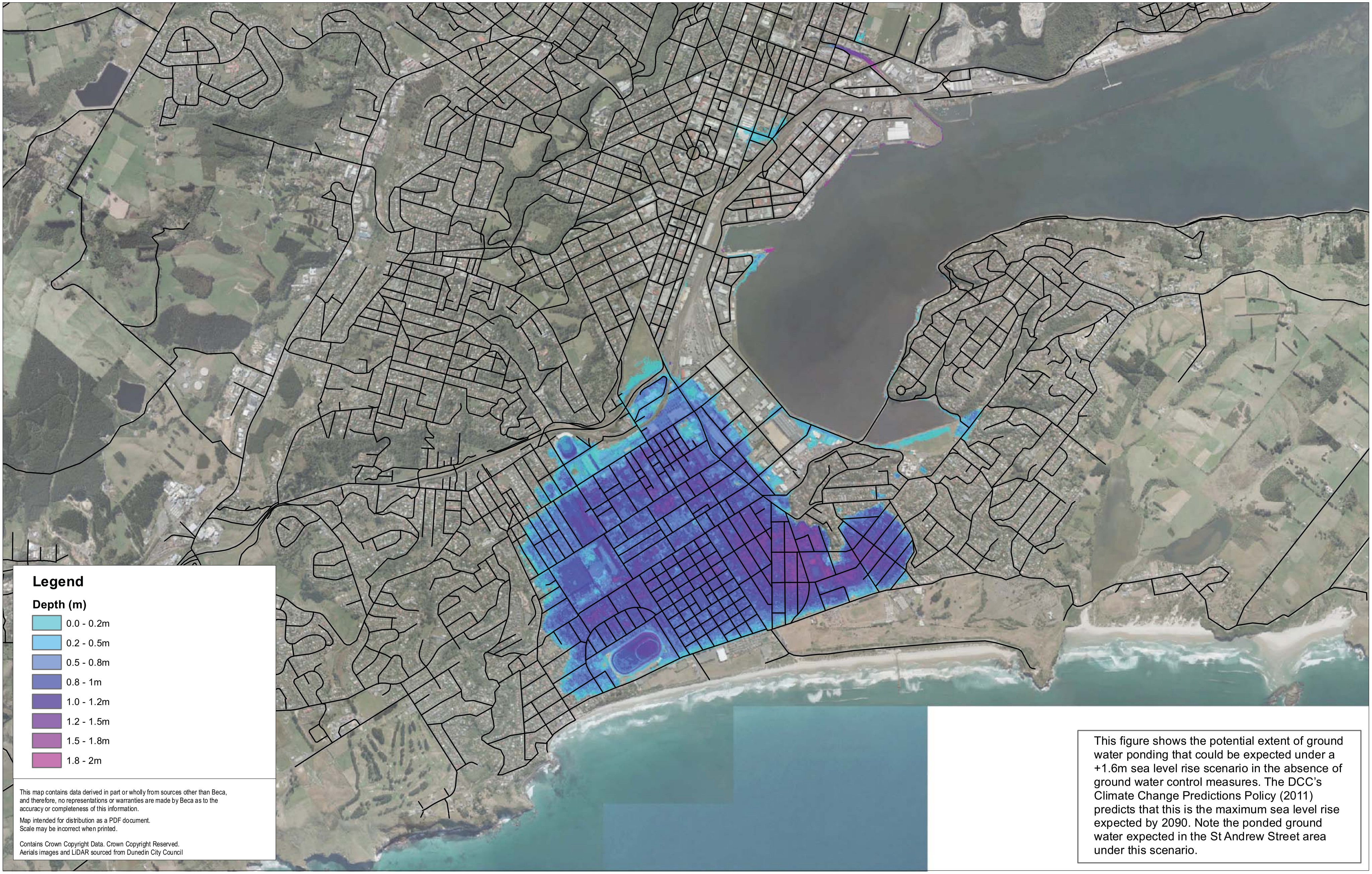
Beca

Discipline: GIS

Drawing No: GIS-3383598-003

File: \\Beca.net\projects\777\777-GIS-AKL\3383598\TGIS5_Workspaces\01_mxd\GIS-3383598-003_Rev_3+2.6m 2090max_Fig8.mxd Author: Date: 7/07/2014

GIS@beca.com



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Revision	Author	Verified	Approved	Date
3	AYF	BEP	RCL1	12/11/13
2	AYF	DRAFT	DRAFT	25/06/13
1	AYF	DRAFT	DRAFT	07/06/13

Title:

Figure 9: Potential Extent of Groundwater Ponding

Scenario C (1990 MSL +1.6m SLR +0.4m GWL)

Client: DUNEDIN CITY COUNCIL

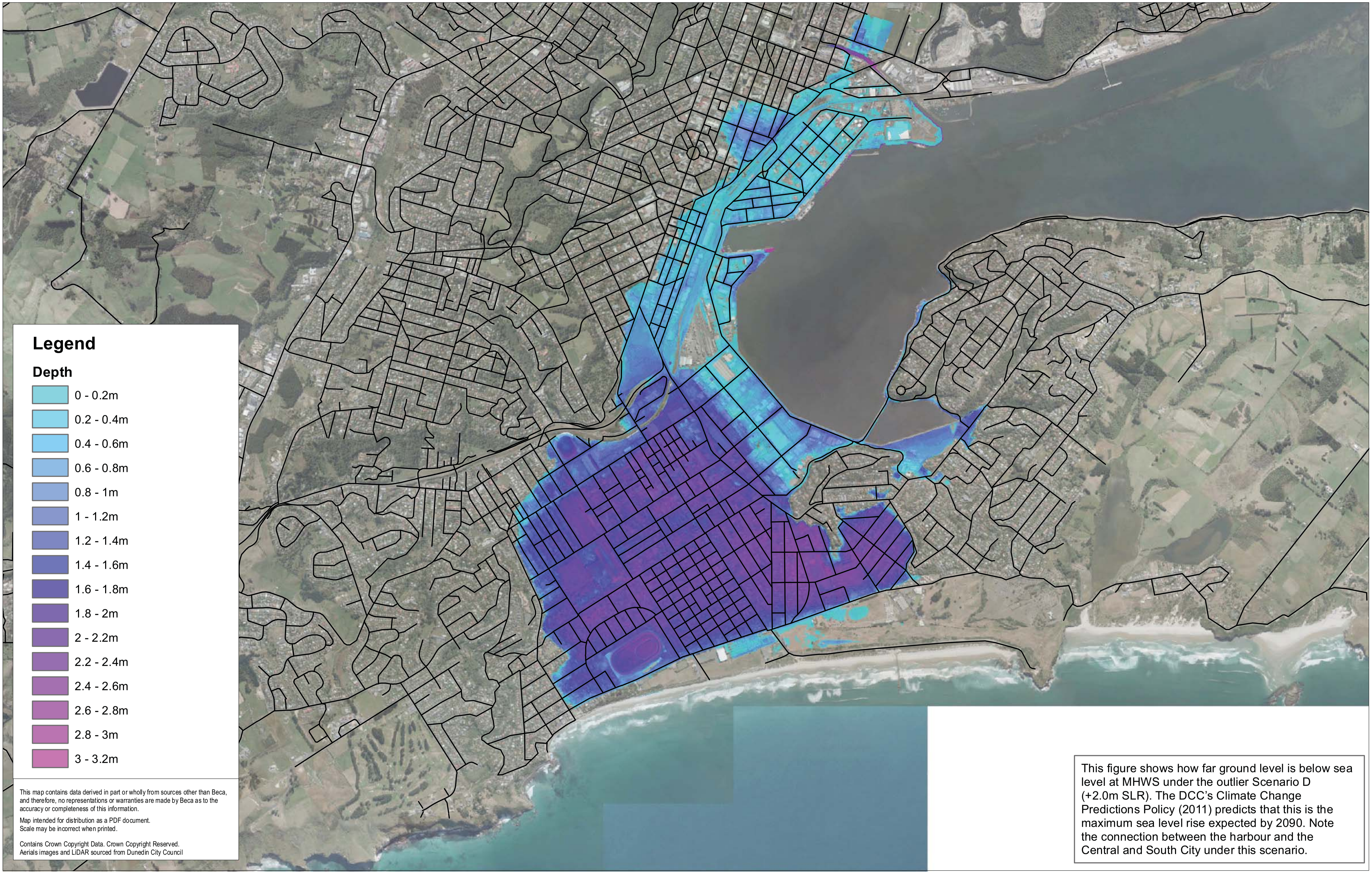
Project: Climate Change Adaptation for Dunedin

Beca

Discipline: GIS

Drawing No: GIS-3383598-007

File: \\Beca.net\projects\77\777-GIS-AKL\3383598\TGIS5_Workspaces\01_mxd\GIS-3383598-007_+1.6m+GWL 2090max_Rev3_Fig9.mxd Author: Date: 7/07/2014 GIS@beca.com



Legend

Depth

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- 0.2 - 0.4m
- 0.4 - 0.6m
- 0.6 - 0.8m
- 0.8 - 1m
- 1 - 1.2m
- 1.2 - 1.4m
- 1.4 - 1.6m
- 1.6 - 1.8m
- 1.8 - 2m
- 2 - 2.2m
- 2.2 - 2.4m
- 2.4 - 2.6m
- 2.6 - 2.8m
- 2.8 - 3m
- 3 - 3.2m

This figure shows how far ground level is below sea level at MHWS under the outlier Scenario D (+2.0m SLR). The DCC's Climate Change Predictions Policy (2011) predicts that this is the maximum sea level rise expected by 2090. Note the connection between the harbour and the Central and South City under this scenario.

Map Scale @ A3: 1:25,000

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Revision	Author	Verified	Approved	Date
3	AYF	BAP	RLC1	12/11/13
2	RJL	DRAFT	DRAFT	26/07/13
1	AYF	DRAFT	DRAFT	07/06/13

Title:
Figure 10: Land Below Sea Level at MHWS Scenario D (1990 MSL +2.0m SLR + 1.0m MHWS)

Client: Dunedin City Council

Project: Climate Change Adaptation for Dunedin

Beca

Discipline: GIS

Drawing No: GIS-3383598-004

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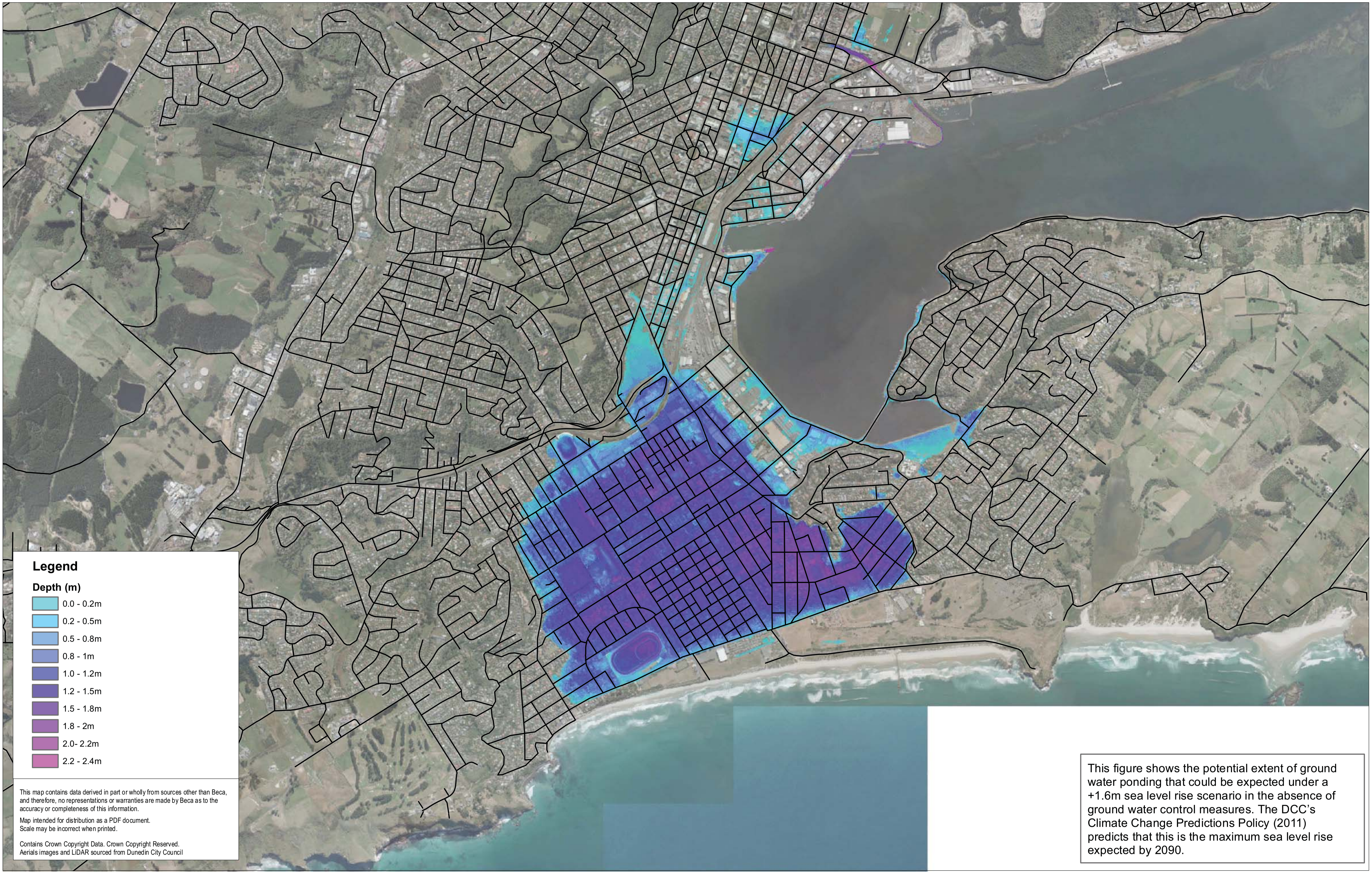
GIS@beca.com



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Revision	Author	Verified	Approved	Date
3	AYF	BAP	RLC1	12/11/13
2	AYF	DRAFT	DRAFT	25/06/13
1	AYF	DRAFT	DRAFT	07/06/13

Title:

Figure 11: Potential Extent of Groundwater Ponding Scenario D (1990 MSL +2.0m SLR +0.4m GWL)

Client: DUNEDIN CITY COUNCIL

Project: Climate Change Adaptation for Dunedin

Beca

Discipline: GIS

Drawing No: GIS-3383598-008

Drawing Plotted: 08 Jul 2014 2:03 p.m.

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No.	Revision	By	Chk	Appd	Date
A	ISSUED FOR INFORMATION	AJS			

Drawing Originator: Beca

Original Scale (A1)	NTS	Design	RLC	06.08.13	Approved For Construction*
Reduced Scale (A3)	NTS	Drawn	AJS	06.08.13	
		Dwg Verifier			
		Dwg Check			Date

* Refer to Revision 1 for Original Signature

Client: Dunedin City Council

Project: SEA LEVEL RISE DEFENCE FOR SOUTH DUNEDIN

Title: FIGURE 12 LOCAL DEWATERING SYSTEM SCENARIO A

Discipline: CIVIL

Drawing No.: FIGURE 12

Rev.: A

Document No. 3383598-CK-002.DWG

DO NOT SCALE

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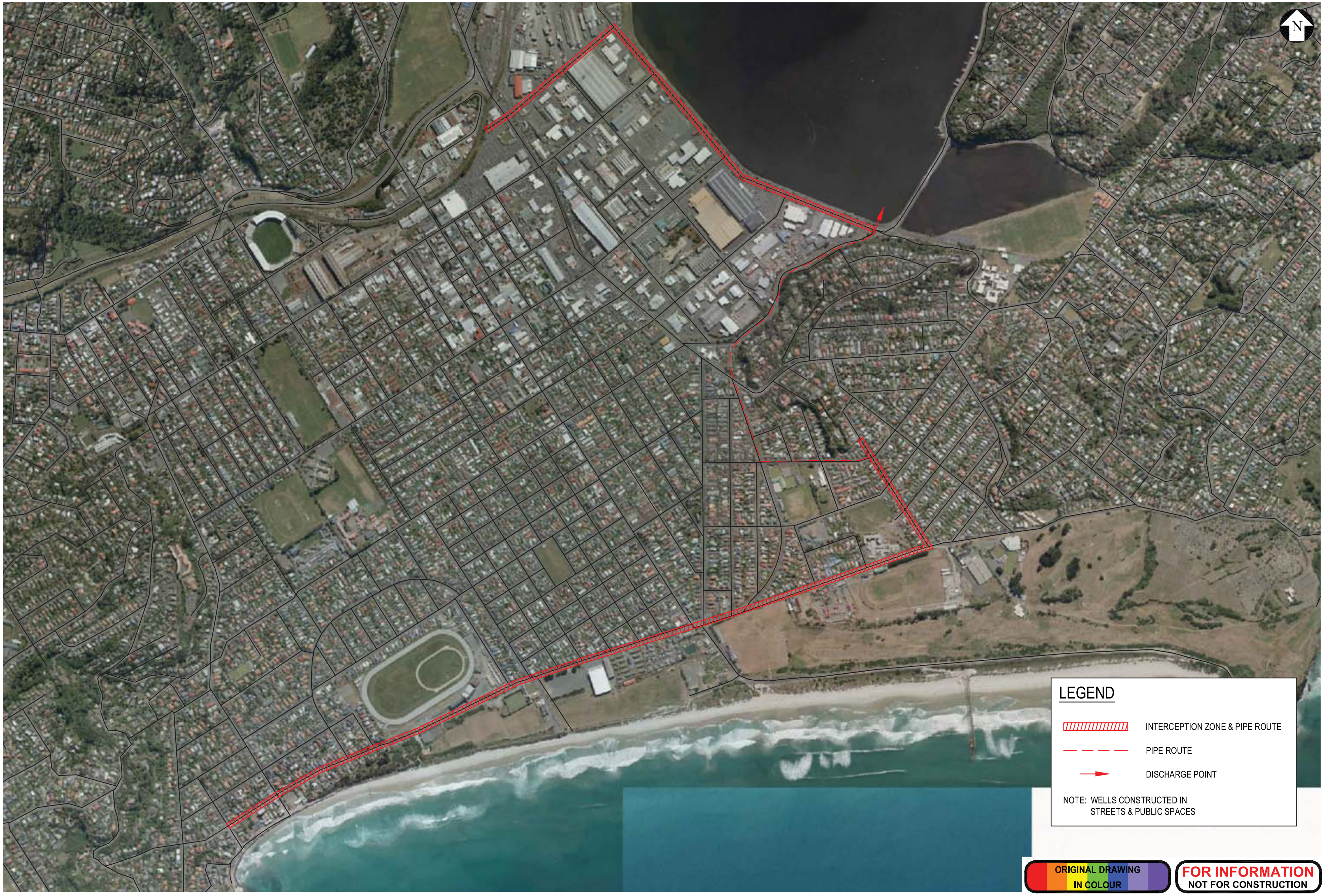
Drawing Plotted: 08 Jul 2014 2:03 p.m.



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Reduced Scale (A3)	NTS	Drawn	AJS	06.08.13	
		Dwg Verifier			
		Dwg Check			Date

* Refer to Revision 1 for Original Signature

Client: DUNEDIN CITY COUNCIL

Project: SEA LEVEL RISE DEFENCE FOR SOUTH DUNEDIN

Title: FIGURE 13 INTERCEPTION ZONE FOR DEWATERING WELLS

Discipline: CIVIL

Drawing No.: FIGURE 13

Rev.: A

Document No. 3383598-CK-003.DWG

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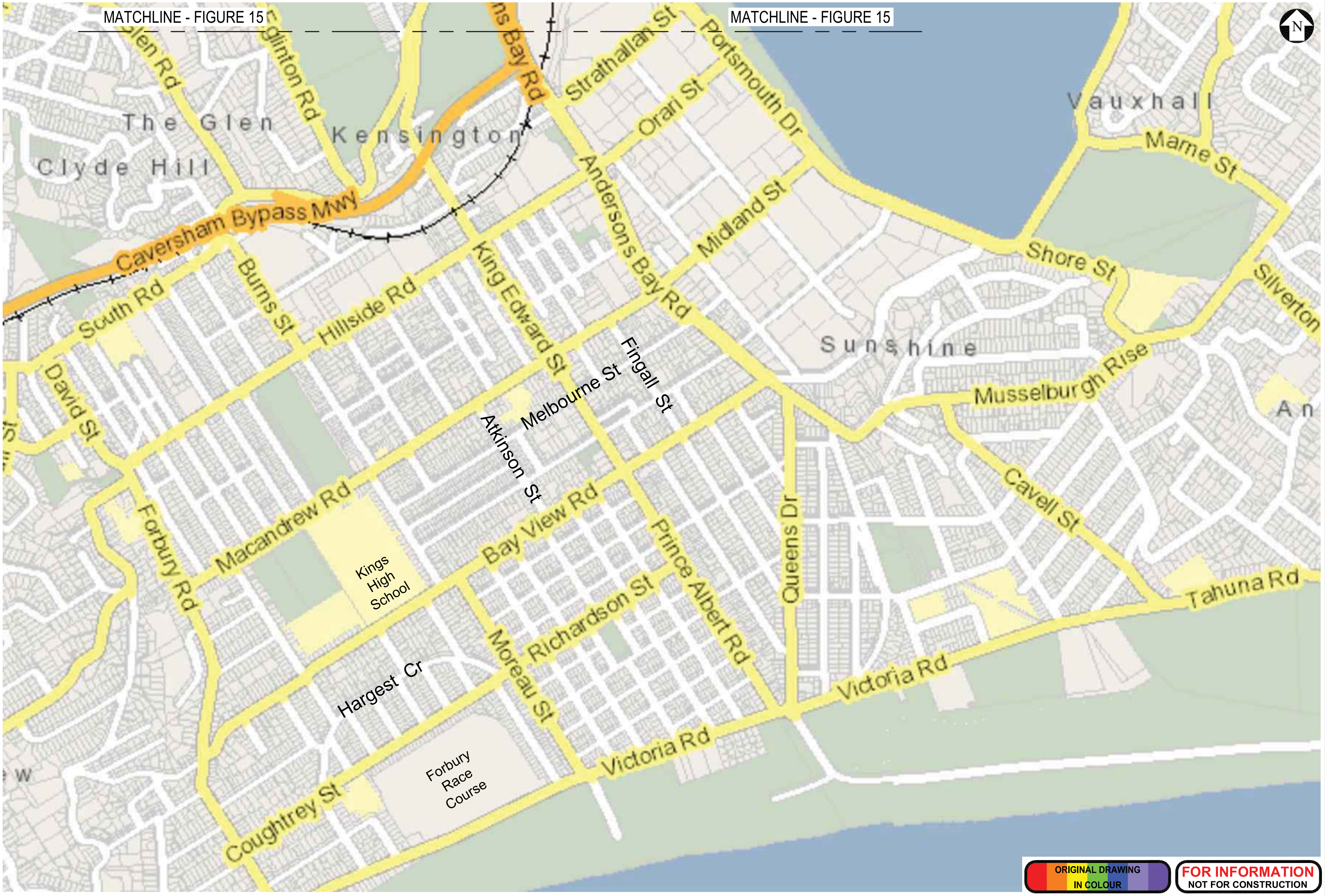

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No.	Revision	By	Chk	Appd	Date
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		Dwg Check			Date

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Client: DUNEDIN CITY COUNCIL

Project: SEA LEVEL RISE DEFENCE FOR SOUTH DUNEDIN

Title: FIGURE 14 STREET MAP 1

Discipline: CIVIL

Drawing No. FIGURE 14 Rev. A

Document No. 3383598-CK-004.DWG

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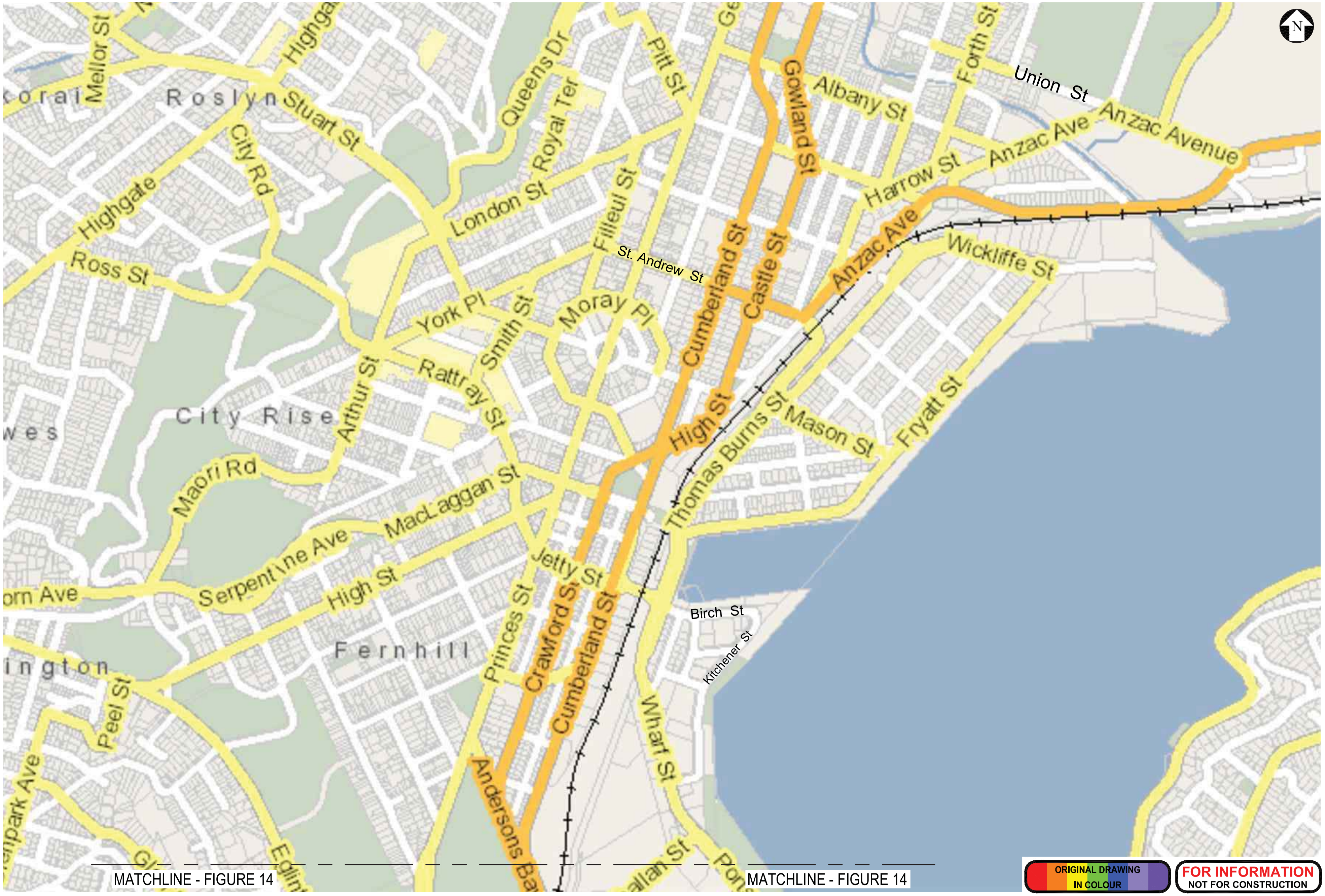

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No.	Revision	By	Chk	Appd	Date
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Drawing Originator: Beca

Original Scale (A1) NTS	Design		Approved For Construction*
	Drawn	AJS 02.12.13	
Reduced Scale (A3) NTS	Dwg Verifier		
	Dwg Check		Date

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Client: DUNEDIN CITY COUNCIL

Project: SEA LEVEL RISE DEFENCE FOR SOUTH DUNEDIN

Title: FIGURE 15 STREET MAP 2

Discipline: CIVIL

Drawing No.: FIGURE 15 Rev.: A

Document No. 3383598-CK-004.DWG

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