

Before the Board of Inquiry  
Waterview Connection Project

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in the matter of: **the Resource Management Act 1991**

and

in the matter of: **a Board of Inquiry appointed under s 149J of the Resource Management Act 1991 to decide notices of requirement and resource consent applications by the NZ Transport Agency for the Waterview Connection Project**

Statement of evidence of Jonathan Hind (Causeway Geometrics and Options) on behalf of the NZ Transport Agency

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## STATEMENT OF EVIDENCE OF JONATHAN HIND ON BEHALF OF THE NZ TRANSPORT AGENCY

### INTRODUCTION

- 1 My full name is Jonathan Michael Hind. I am a Principal Highway Engineer at Aurecon (previously Connell Wagner). I am a professionally qualified engineer and have worked in this field for 29 years. My particular area of expertise is highway engineering, with particular emphasis on geometric design.
- 2 I have a BTEC Higher National Certificate in Civil Engineering Studies from Southampton Institute of Higher Education (UK), achieved in 1986. I am also an Incorporated Engineer (IEng) registered with the Engineering Council in the United Kingdom and a Fellow of the Institute of Highway Engineers (FIHE).
- 3 I have extensive experience in the planning, design and management of a broad range of road projects ranging from local improvements to major highways and motorways in New Zealand, the UK and Asia. I have specialised in the highway geometry and scheme assessment of major road projects throughout my career. I am experienced in the use of international design standards and geometric design tools.

Throughout my career, I have been involved in the investigation and design of a number of projects similar to the Waterview Connection Project (Project). Some examples of these follow below:

- 3.1 SH18 Hobsonville Deviation (Design and Construct) - I was the Highway Team Leader responsible for producing the road design elements. I led the design of innovative and cost saving geometric solutions, and provided technical advice to the design team throughout the detailed design stage.
- 3.2 Additional Waitamata Harbour Crossing Study – Two stage investigation. I was the Highway Design Team Leader for this study into options for an additional crossing of the Harbour. Our work focused on a range of options and the recommendation of a preferred solution to be refined for NOR lodgement. I was responsible for the geometric design elements of this project.
- 3.3 A38 Dobwalls Bypass, UK – I was the Deputy Project Manager for this £25 million Highways Agency scheme to provide a 4.6 km bypass of Dobwalls in Cornwall, England. Our brief was to review the 1997 preferred route in light of the DMRB (Design Manual for Roads and Bridges) and GOMMMS (Guidance on the Methodology for Multi-Modal Solutions) assessment procedures and propose improvements where

necessary. Environmental issues in connection with the tributaries of the East and West Looe Rivers were significant.

- 3.4 I was the A249 Iwade Bypass to Queenborough Improvement (UK) Design Team Leader undertaking preliminary design and document preparation leading to publication of draft orders. Work on this project included modification and refinement of the scheme design, preparation for an orders exhibition and Public Inquiry. The £62 million scheme, which included a major 1.3 km high level structure, consisted of some 6 km of dual carriageway with at-grade junctions. A major objective of the design was to minimise the scheme impact on the environmentally sensitive area through which it passes.
- 4 My evidence is given in support of Notices of Requirement and applications for resource consents lodged with the Environmental Protection Authority (EPA) by the NZ Transport Agency (NZTA) on 20 August 2010 in relation to the Project. The Project comprises works previously investigated and developed as two separate projects, being:
- 4.1 The State Highway 16 (SH16) Causeway Project; and
- 4.2 The State Highway 20 (SH20) Waterview Connection Project.
- 5 I am familiar with the area that the Project covers, and the State Highway and road network in the vicinity of the Project. I am the Aurecon Project Leader for the SH16 elements of the Waterview Connection Project and have been involved in the scheme since 2006.
- 6 I have read the Code of Conduct for Expert Witnesses as contained in the Environment Court Consolidated Practice Note (2006), and agree to comply with it. In preparing my evidence, I have not omitted to consider material facts known to me that might alter or detract from my opinions expressed.

#### SCOPE OF EVIDENCE

- 7 My evidence will deal with the following:
- 7.1 An executive summary;
- 7.2 A summary of my background and role;
- 7.3 The structure of the coastal evidence;
- 7.4 Causeway geometrics;
- 7.5 Summary of the Causeway Options report; and

## 7.6 Comments on submissions.

### EXECUTIVE SUMMARY

- 8 Aurecon was engaged by the NZTA to develop the scheme design for the SH16 Causeway. Three categories of reports support the Causeway works: Causeway design (geometrics and future-proofing), Causeway construction and assessment of environmental effects. These categories have a number of components, all of which are interlinked. My evidence explains how these pieces fit together.
- 9 When designing the Causeway, the Project team<sup>1</sup> needed to consider the elements that would make up the width of the Causeway. Broadly, these elements can be split into road, berm (stormwater), coastal protection, geotechnical construction and future-proofing. Ultimately, having considered all of these elements, it was determined that the overall width of the Causeway needed to be approximately 66 metres between the two top edges of the embankment.
- 10 My evidence also outlines the historic development of the Causeway design leading to the proposed option. This is detailed further in the Causeway Options Report that is attached to my evidence. I briefly discuss the history of the existing Causeway (including its issues relating to settlement and inundation) and the need for the improvement works, I summarise the method used in the Causeway options analysis and describe the key points of the Causeway Options Report that documents this process. Ultimately, Aurecon and the Project team recommended Option D(W) ("widening the existing Causeway revetments and raising its elevation while accounting for future settlement and sea level rise") for the Causeway works.

### BACKGROUND AND ROLE

- 11 The NZTA retained Aurecon as part of a consortia team to assist with engineering for the Projects scheme design. Aurecon's role related to the development of the SH16 section of the Project, including the SH16 Causeway between the Great North Road and Rosebank Road Interchanges (Causeway). Aurecon has been involved with this part of the Project since 2006.

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<sup>1</sup> As Team Leader for the SH16 Improvements project, I am a member of the Project team.

12 As part of Aurecon's role, Mr Lawrence Rutt, a civil engineer from Aurecon, prepared the Causeway Options Report,<sup>2</sup> which was peer-reviewed and verified by:

12.1 Andrew Hale: Senior Civil Engineer (Aurecon);

12.2 Aly Gleeson: Senior Civil Engineer (Aurecon); and

12.3 Owen Burn: Director (Green Group Limited).

13 I approved the Report for issue. The Report is a component of a suite of documents that support the technical reports lodged with the EPA on 20 August 2010 as part of the Notices of Requirement and resource consent applications for the Project. A copy of the Report is attached to my evidence as Annexure B. I will provide a summary of the report later in my evidence.

#### STRUCTURE OF THE COASTAL EVIDENCE

14 Three categories of reports support the Causeway works for the Project (Causeway Works):

14.1 Causeway design;

14.2 Causeway construction; and

14.3 assessment of environmental effects.

Below I describe each of those categories, the relevant reports and the expert witnesses who will give evidence in relation to each of those reports.

#### Causeway design

15 The Causeway design has been determined through consideration of geometrics and future-proofing as follows:

15.1 Geometrics. The Causeway must accommodate (amongst other things) traffic lanes, stormwater treatment systems, service berms, shoulders and the pedestrian/cycle way. A number of experts have considered the Causeway elements and carried out assessments of them. Later in my evidence, I will discuss the specific elements of the Causeway.

15.2 Future-proofing of the Causeway. Currently, the Causeway is subject to long-term settlement and periodic coastal inundation by the sea. Climate change and the associated

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<sup>2</sup> Doc Ref No. 20.1.11-3-R-J-304 (September 2010) – Not lodged as part of AEE, but appended to this document.

sea level rise will exacerbate these problems. The Coastal and Estuarine Processes Group of the National Institute of Water and Atmospheric Research (NIWA), advised Aurecon on the design of the Causeway in order to mitigate the effects of climate change and provide safe vehicle operation with respect to wave overtopping hazards. NIWA's hydrodynamic design advice focussed on the height of the Causeway crest and various options for the revetment slope and crest width. NIWA also considered options for the realignment of three sections of channels that will be in-filled by the widened Causeway.

Dr Rob Bell from NIWA will discuss the future-proofing and hydrodynamic design of the causeway in his evidence.

#### Causeway construction

- 16 Construction of the Causeway presents unique engineering challenges, particularly related to the soft marine mud upon which it is founded and the Marine Reserve through which it passes. Technical Report G.23 Coastal Works of the application documents lodged with the EPA, describes the Causeway Works and how they relate to the proposed occupation of the adjacent CMA. The Coastal Works Report also describes the likely construction activities, construction methodology and timing of the Causeway Works. Dr Jeff Hsi, the Global Manager/Chief Technical Principal from Snowy Mountain Engineering Corporation (SMEC), specialises in soft ground engineering and will give evidence focussing on the ground improvements, construction process and reclamation requirements for the Causeway Works.

#### Assessment of environmental effects

- 17 Two of the reports lodged with the EPA specifically assess the environmental effects of the Causeway Works, namely:
- 17.1 Technical Report G.4 Assessment of Coastal Processes.<sup>3</sup> This report describes the effects of the Causeway Works and the completed Causeway on coastal processes, including hydrodynamic processes, sediment transport and deposition processes, and geomorphologic changes. Dr Rob Bell will give evidence on these effects and describe the proposed mitigation of potential impacts. He will also discuss some of the proposed coastal consent conditions.<sup>4</sup>
- 17.2 Technical Report G.11 Assessment of Marine Ecology Effects.<sup>5</sup> This report assesses the effects of the Causeway Works on the marine ecology of the adjacent CMA. In response to the

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<sup>3</sup> See AEE, Part G.

<sup>4</sup> Attached to Dr Bell's evidence.

<sup>5</sup> See AEE, Part G.

permanent loss of marine habitat resulting from reclamation, the Marine Ecology Report identifies opportunities to off-set that loss by remediating the mudflat adjacent to the Causeway, achieving better contaminant removal through efficiency of stormwater treatment and restoring the coastal fringe habitat. Dr Sharon De Luca, a Principal Ecologist at Boffa Miskell Limited, will give evidence relating to the marine ecological effects of the Causeway Works and completed Causeway, and will discuss the proposed marine ecological consent conditions.<sup>6</sup>

#### CAUSEWAY GEOMETRICS

- 18 The Causeway width comprises a number of elements and these are illustrated in Figure 1 below. Figure 1 also details the expert witness related to each Causeway element. Broadly, these elements can be split into Road, Berm, Coastal Protection, Geotechnical Construction and Future-Proofing. The experts who will discuss these elements are:-

##### 18.1 Road:

- (a) lane requirements – Andrew Murray (of Beca); and
- (b) geometrics and pedestrian/cycle way – me;

##### 18.2 Berm (stormwater) – Dr Tim Fisher (of Tonkin & Taylor Limited);

##### 18.3 Coastal protection - Dr Rob Bell (of NIWA);

##### 18.4 Geotechnical construction (including ground improvements, Causeway construction, temporary works, settlement) – Dr Jeff Hsi (of SMEC); and

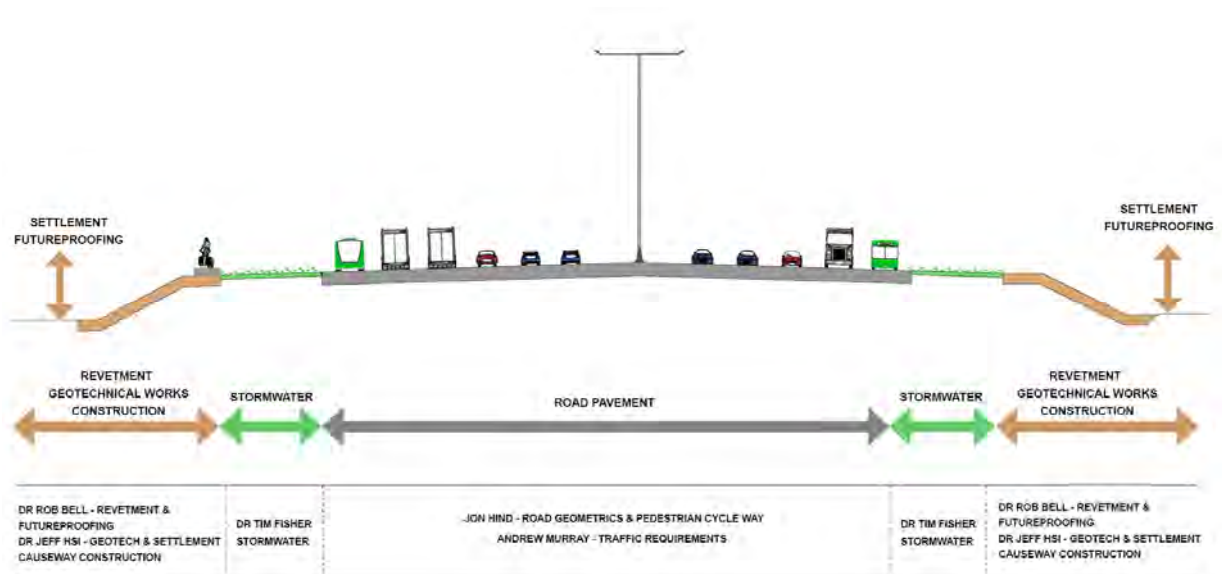
##### 18.5 Future-proofing the crest height – Dr Rob Bell (of NIWA).

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<sup>6</sup> Attached to Dr De Luca's evidence.



Figure 1 – Causeway Components and Related Expert Witnesses



#### Road Requirements and Geometrics

- 19 The SH16 carriageway across the Causeway will consist of five general traffic lanes in the westbound direction and four in the eastbound direction. The number of lanes required is governed by outputs from the traffic modelling process, on which Mr Andrew Murray will give expert evidence.
- 20 The lane widths on the Causeway will be 3.5m, which is an established New Zealand and international standard.
- 21 Any reduction in lane width would generally result in reduced safety, lower vehicle speeds and less lane capacity due to the reduced clearance from other vehicles and safety barriers. Reductions in lane widths are only considered appropriate for low speed urban roads. The Austroads guide recommends that a width of 3.5m is the minimum that should be used for State highways.<sup>7</sup>
- 22 The SH16 carriageway across the Causeway also includes bus shoulders in both directions. Buses will use the hard shoulders proposed for the SH16 motorway, offering improved public transport connections through the corridor. The bus shoulders will be 3.5m wide. If the bus shoulders were omitted from the Causeway design, the Austroad guide would recommend a minimum nearside

<sup>7</sup> Austroads Guide to Road Design, Part 3: Geometric Design, Section 4.2.4 and Table 4.4

motorway shoulder width of 3m.<sup>8</sup> The inclusion of the bus shoulders in the Causeway design therefore adds 1m to the overall width.

- 23 A 3m median or offside shoulder has been provided in the design, in both east and westbound directions. The 3m median is the minimum width recommended in current New Zealand standards,<sup>9</sup> although previous design standards<sup>10</sup> allowed an absolute minimum of 2m to be provided. The central median width, particularly on multi-lane highways, is related to user safety. A 2m provision does not allow sufficient space for a vehicle to stop without encroaching into live traffic lanes. Use of a general 3m shoulder also allows the median shoulder to be reduced to 2m at pinch points such as bridge piers and gantry signs, thereby allowing a smooth running line in the adjacent traffic lane.
- 24 A shared use pedestrian/cycle way is located on the southern side of the Causeway. A 3m wide pedestrian/cycle way will provide a consistent facility for pedestrians and cyclists using the SH16 corridor, and complies with accepted design standards (both current and those relevant at the time of scheme development).<sup>11 12</sup> The 3m width is based around provision of 1m for a cyclist, 1m for a pedestrian, and 1m separation between the two.
- 25 The pedestrian/cycle way will need to be reduced to 2m in places between Rosebank Road and Patiki Road. This reduction is due to neighbouring industrial properties which abut the Motorway. Given the tight land constraints within this section of the Causeway, the proposed pedestrian/cycle way has had to reduce to 2m. This 2m width complies with the Austroads guide relevant at the time of design<sup>13</sup> given that it allows 1m for a cyclist and 1m for a pedestrian should they meet at any point within the constrained section. Although this section of the pedestrian/cycle way will not have the desirable 3m width, I do not believe the reduction in width when combined with suitable warning signage will present any significant safety issues nor compromise the overall effectiveness of the pedestrian/cycle way.

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<sup>8</sup> Austroads Guide to Road Design, Part 3: Geometric Design, Section 4.3 and Table 4.4.

<sup>9</sup> Austroads Guide to Road Design, Part 3: Geometric Design, Section 4.3 and Table 4.4.

<sup>10</sup> State Highway Geometric Design Manual, Section 6.3.3 (b) (ii).

<sup>11</sup> Austroads Guide to Traffic Engineering Practice, Part 14: Bicycles, Section 6.6.1 and Table 6.3.

<sup>12</sup> Austroads Guide to Road Design, Part 6A: Pedestrian and Cyclist Paths Table 7.4

<sup>13</sup> Austroads Guide to Traffic Engineering Practice, Part 14: Bicycles, Section 6.6.1 and Table 6.3. The current Austroads Guide (Austroads Guide to Road Design, Part 6A: Pedestrian and Cyclist Paths Table 7.4) however suggests a minimum of 2.5m.

#### Berm – Stormwater

- 26 The berm width on the Causeway is directly related to the requirements for stormwater treatment, which are discussed in greater detail in Dr Tim Fisher’s evidence. The width has been selected to accommodate an engineered Bio Filter, which is required to provide contaminate removal before the stormwater run-off enters the adjacent coastal environment.<sup>14</sup>
- 27 The provision of a Bio Filter within the berm adds to the overall width of the Causeway. However, the width required for the berm also provides other benefits related to vehicle safety and visual improvement. With the Bio Filters incorporated into the Causeway design, we are able to provide the desirable minimum “clearzone” width of 9m, which allows for the removal of the safety barriers on the outer edges of the Causeway. The clearzone is the area required for vehicles that inadvertently run off the road to regain control with minimum damage to the vehicle and the occupants. The provision of safety barriers adjacent to the road can have a detrimental safety effect as errant vehicles can bounce off them back into live traffic, creating larger accidents involving multiple vehicles. Removing the need for the safety barriers also improves the visual aspects of the Causeway, providing wider views for vehicle occupants.

#### Coastal protection

- 28 The coastal protection requirements for the Causeway are related to preventing periodic inundation by the sea caused by combinations of wind, low atmospheric pressure and tidal surges. Coastal rock armour is also required to prevent erosion of the Causeway edge. Various types of coastal protection were assessed by the Project team, with consideration of elements such as the height and angle of the Causeway embankment, the construction material, and the toe and crest widths. The Coastal protection requirements of the Causeway are discussed further in Dr Rob Bell’s evidence.

#### Geotechnical construction

- 29 Geotechnical construction relates to the extent of ground improvements to be undertaken before the Causeway embankment can be increased to the finished design level, and the construction methodology used to complete the Causeway. Geotechnical construction includes the channel realignment required to widen the Causeway, bridge construction at the Causeway and Whau Bridges, as well as the different forms of ground improvement within the CMA. Dr Jeff Hsi will discuss the details of how the Causeway will be constructed in his evidence.

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<sup>14</sup> Refer to Section 6.6.3, pages 74-76 of Technical Report No. G.15 Assessment of Stormwater and Streamworks Effects.

### Causeway Geometrics Conclusion

- 30 The overall width of the Causeway (approximately 66 metres between the two top edges of the embankment) is therefore governed by the provision of:
- 30.1 5 x 3.5m westbound traffic lanes;
  - 30.2 4 x 3.5m eastbound traffic lanes;
  - 30.3 2 x 3.5m bus shoulders;
  - 30.4 2 x 3m median shoulders;
  - 30.5 1 x 0.6m TL4 median barrier;
  - 30.6 2 x 7m grassed stormwater Bio Filters;
  - 30.7 1 x 3m shared pedestrian / cycle way; and
  - 30.8 2 x rock armour crests/revetments of 3m width (northern seaward side) and 0.75m width (southern landward side).
- 31 A cross-section of the Causeway is shown in Annexure A to my evidence.

### SUMMARY OF THE CAUSEWAY OPTIONS REPORT

- 32 The Causeway Options Report (Report)<sup>15</sup> addresses:
- The history of the existing Causeway;
  - Causeway options assessment, including assessments of symmetrical versus asymmetrical widening and stormwater treatment options;
  - An option assessment update; and
  - Conclusions and recommendations.
- 33 In this section of my evidence, I will briefly outline the need for the Causeway Works, summarise the method used in the Causeway options analysis and describe the key points of the Report.

### The Causeway history and the need for the Works<sup>16</sup>

- 34 The Causeway was constructed by the Ministry of Works in the 1950s (construction started in 1952). The construction fill was a

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<sup>15</sup> Doc Ref No. 20.1.11-3-R-J-304 - L Rutt, Aurecon (September 2010), not lodged as part of the AEE, but attached to my evidence as Annexure B.

<sup>16</sup> Refer to section 2, pages 7 - 9 of the Report.

mixture of scoria and cohesive material, which was end-dumped within the intertidal area and then tracked, compacted and in-filled until a trafficable route was established. The Causeway embankment was subsequently widened in 1959. The SH16 motorway was widened again in 1991 and 2005, though this related only to the sealed width of the motorway and not the Causeway itself.

#### Settlement

- 35 The Causeway between the Great North Road and Rosebank Road Interchanges has been suffering from on-going long-term settlement. A comprehensive topographical survey of the Causeway shows that the existing (centre line) elevations vary from approximately 4.6m RL at the western abutment of the Causeway Bridges to a low point (centre line) of approximately 2.6m RL (recorded at a point approx 400m to the west of the Causeway Bridges), compared with 1.63m RL for Mean High Water Spring tide.<sup>17</sup> Periodic infilling, patching, shape corrections and asphalt overlays are thought to have occurred (although few records exist and the extent of these improvements are unknown) since initial construction in the 1950s.

#### Inundation

- 36 The Causeway is also subject to storm-tide and wave inundation during the highest tides of the year. The existing bus shoulders, cycle way and coastal rock armour are being inundated approximately 4 to 6 times per year. Sea water has been observed<sup>18</sup> at the edge of the sealed motorway surface on average once a year during storm surges. Anticipated sea level rise projections, in combination with storm-tides and waves, are expected to increase the frequency of inundation, and thus the possibility of increasing Motorway closures.<sup>19</sup> Further on-going settlement of the Causeway will increase the incidence and duration of these effects.

#### Need for the Works

- 37 The NZTA has determined that the Causeway needs to be widened to improve its transport capacity and to provide opportunities for improved public transport, cycling and walking. The elevation of the Causeway between Great North Road and Rosebank Road, and between Patiki Road and the Whau River, also needs to be increased to prevent increasing potential for Motorway closure due to storm-tide and wave inundation.

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<sup>17</sup> Refer to page 28 of Coastal Process Report (Technical Report G.4).

<sup>18</sup> Refer to section 2, pages 7 and 9 of the Report.

<sup>19</sup> Refer to section 2, pages 7 and 9 of the Report.

Causeway options assessment: 2007<sup>20</sup>

- 38 Figure 1.4 of the Report contains a Causeway options flow chart showing the progression of the options analysis during the Project's design phase.<sup>21</sup> The following paragraphs summarise that process.

Causeway options

- 39 In June 2007, in order to establish the optimum Causeway improvement solution, a series of potential high level options were considered and assessed at a workshop by a Project Team consisting of Highway, Geotechnical, Traffic and Structural Engineers, Geologists, Resource Planners and Coastal Experts (NIWA). These high level options were then broadly assessed in order to produce a shortlist of six options that were taken forward for more detailed assessment.
- 40 Those six Causeway options were:
- 40.1 Option A: Widening of the existing Causeway with wall structures to form a 'trough';
  - 40.2 Option B: Widening of the existing Causeway with rock revetments to form a 'trough';
  - 40.3 Option C: Widening and raising of the existing Causeway with wall structures;
  - 40.4 Option D: Widening and raising of the existing Causeway with rock revetments;
  - 40.5 Option E: Placing a viaduct structure over the existing Causeway; or
  - 40.6 Option F: Raising of the existing Causeway and widening with viaduct structures.
- 41 The six options were assessed by the Project Team against the following five key criteria:
- 41.1 Environmental constraints, including scour, erosion, permanent intertidal habitat removal, removal of flora and fauna and effects on geomorphology;
  - 41.2 Coastal hazard and climate change considerations, such as dissipation of wave energy, risk of wave overtopping, exposure to wave attack and protection from inundation and accommodating sea-level rise;

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<sup>20</sup> Refer to section 3, pages 10-15 of the Report.

<sup>21</sup> Page 6 of the Report.

- 41.3 Geotechnical considerations and the impact of the marine mud's compressibility and low shear strength on the future settlement of the Causeway;
  - 41.4 Constructability arising from issues such as traffic management, working in intertidal areas, ground improvement, piling and safety; and
  - 41.5 Maintenance and future flexibility, the latter related to the ability to accommodate future on-going settlement, unpredicted sea level rise and increasing traffic requirements.
- 42 The Project team recommended Option D – “widening the existing Causeway with revetments and raising its elevation while accounting for future settlement and sea level rise”. The following points highlight some<sup>22</sup> of the reasons for selecting Option D:
- 42.1 Option D requires less maintenance when compared to the other options.
  - 42.2 Some economic benefits associated with recycling the existing rock armour for the proposed coastal protection.
  - 42.3 Rock armour is a proven coastal protection solution that will adjust to changes such as localised settlement.
  - 42.4 Causeway widening with rock revetments does not require any complex or large scale structures as were present with each of the five other options.
  - 42.5 Rock armour dissipates wave energy, as opposed to reflecting wave energy back into the sea, minimising impacts on the existing hydrodynamic conditions.
- Symmetrical or asymmetrical widening assessment<sup>23</sup>
- 43 Having recommended Option D, the Project team then focused its design consideration on the relative position of the widened Causeway to the existing Causeway. The team considered either a symmetrical or asymmetrical widening. Three options were considered:
- 43.1 Option D - Symmetrical widening of the Causeway about the existing centreline;
  - 43.2 Option D(1) - Asymmetrical widening of the Causeway to the north; or

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<sup>22</sup> Refer to section 3.4, pages 13 -15 of the Report for discussion of option analysis and see Appendix B of the same report for an Evaluation Matrix.

<sup>23</sup> Refer to section 4, pages 16-21 of the Report.

- 43.3 Option D(2) - Asymmetrical widening of the Causeway to the south.
- 44 Reclamation requirements for each of the three Causeway widening options were assessed<sup>24</sup> against the following criteria:
- 44.1 Ecology;
  - 44.2 Coastal hydrodynamics;
  - 44.3 Geotechnical;
  - 44.4 Ease of construction; and
  - 44.5 Structures, use of existing infrastructure and cost effectiveness.
- 45 The Project team considered asymmetrical widening of the Causeway to either side was not favourable given the high construction costs (replacement of the existing Causeway Bridges would be required as well as an increase in ground improvements and fill) and environmental effects. Additionally, there were environmental benefits associated with the symmetrical widening, such as reducing the impacts on both Pollen Island to the north, and the two channels (Oakley Inlet and Waterview Estuary) to the south, either of which would be significantly impacted should an asymmetrical design be advanced.
- 46 Following its assessment of the comparative reclamation impacts, the Project team considered that Option D (symmetrical widening) was the most preferable option. The Report therefore recommended that the Causeway be widened about the existing carriageway centreline between the Great North Road and Rosebank Road Interchanges.

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<sup>24</sup> The method of assessment was discussed and agreed with the Department of Conservation, Auckland Regional Council and the Project team during a series of consultation workshops, as the best approach to assess the relative environmental impacts of each option.



- Causeway option assessment: 2009 (Stormwater)<sup>25</sup>
- 47 The Stormwater treatment measures for the Project have the potential to significantly influence the width of the Causeway. Accordingly treatment options were assessed as part of the design.
- 48 Two stormwater options for the Causeway were considered (and are discussed in the Report):
- 48.1 A cartridge filter system (Option D(N)) (the “narrow” option) - A cartridge filter system is a more traditional stormwater treatment approach, whereby a reticulated or piped network conveys runoff from the road surface to large vaults that remove suspended solids and contaminants before being released into the environment. This approach relies on pipe gradients that were not considered sustainable without significant maintenance issues given the expected ground settlement on the Causeway.
- 48.2 Bio Filters (Option D(W)) (the “wide” option) - Bio filters are shallow treatment devices that essentially remove contaminants as the stormwater runoff flows across the media (i.e. grass) and/or infiltrates through a top layer of prepared ground. This approach requires more horizontal space (hence the wider Causeway) but is low maintenance and is significantly more flexible to ground settlement when compared to the reticulated approach.
- 49 Bio Filters (Option D(W)), although requiring a wider Causeway footprint, were the preferred option selected by the Project team based on a comparison of operational capability, constructability, maintenance requirements, future-proofing, capital cost and ecological considerations.
- 50 The benefits of the Bio Filters and/or the wider Causeway footprint (Option D(W)) can be summarised as follows:<sup>26</sup>
- 50.1 Design tolerances for the Bio Filters provide greater flexibility in combating the effects of differential settlement across and along the Causeway;
- 50.2 The wider footprint provides a clear zone, removing the need for shoulder barriers and thus improving safety and reducing ongoing maintenance costs;
- 50.3 Maintenance of the Bio Filters is less complex and intensive than that of the filter cartridges and open grated channels;

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<sup>25</sup> Section 5, pages 22-29 of the Report.

<sup>26</sup> Page 27 of the Report

- 50.4 A greater width provides increased flexibility during the construction staging process and allows existing bus shoulder operation through all but one of the six construction phases;
- 50.5 Providing a wider Causeway cross-section will allow more space for future proposals such as an adjacent, dedicated Busway facility, with less likelihood of additional reclamation of the marine environment being required; and
- 50.6 Providing a wider Causeway cross-section will allow the Causeway to be raised more easily than the narrower option in the future should predicted sea level rise be greater than currently projected.
- 51 Technical Report G.15 Assessment of Stormwater and Streamworks Effects<sup>27</sup> discusses the stormwater treatment devices considered for the Project and Dr Tim Fisher will address the Causeway stormwater treatment in his evidence.
- Options assessment update<sup>28</sup>**
- 52 As the Causeway embankment for the preferred option (Option D (W)) was wider than originally envisaged during the initial options assessment, the Project team considered it prudent to reassess this option against the viaduct structure option<sup>29</sup> with both options being developed to a similar level of design.
- 53 The causeway option requires more reclamation than the viaduct option and the effects of reclamation on marine ecology will be greater for Option D (W). However, other than permanent habitat loss, all other ecological effects of Option D (W) were considered either minor or negligible.<sup>30</sup> Mitigation of the adverse effects of permanent marine habitat loss can be off-set through remediation of intertidal mudflat habitat, a higher level of stormwater treatment<sup>31</sup> and restoration/cleaning of the coastal fringe habitat.
- 54 While the majority of the geotechnical risks (such as settlement and stability) can be reduced using a viaduct founded on bored piles, the cost of the viaduct is substantially more than raising and widening the Causeway. In addition, future modification to the Causeway (if required) is likely to be easier to implement and cheaper than modifications to a viaduct. Furthermore, there are a number of

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<sup>27</sup> AEE, Part G.

<sup>28</sup> Section 7, pages 30-34 of the Report.

<sup>29</sup> This option scored highly in the assessment contained within Appendix D of the Report.

<sup>30</sup> Statement of evidence of Dr Sharon De Luca.

<sup>31</sup> Refer to Section 9, pages 93-94 of Technical Report No. G.11 Assessment of Marine Ecological Effects.

engineering challenges associated with a viaduct structure, including (but not limited to):

- 54.1 Deep marine mud will require large earthquake loading design criteria;
  - 54.2 Bed rock is very deep, resulting in exceptionally long piles;
  - 54.3 Traffic management will be difficult whilst constructing a viaduct over the existing Causeway;
  - 54.4 Given the number of expansion joints and bridge bearings with a long and wide viaduct structure, there would be significant ongoing maintenance costs; and
  - 54.5 Treatment of stormwater and generation of suitable longitudinal falls would increase the complexity and visual impact of the structure.
- 55 Following the assessment update, the recommended preferred option was still Option D(W).

#### Conclusions in the Report<sup>32</sup>

- 56 The Project team assessed six main options for the development of the Causeway in order to recommend a preferred solution for the Project. Option D(W) was preferred, defined as:
- 56.1 Raising (by use of engineered fill material) across the full width of the proposed Causeway taking into consideration coastal hazards and sea level rise caused by climate change;
  - 56.2 Symmetrical widening about the existing Causeway centre line;
  - 56.3 Coastal protection against wave overtopping and wave action using rock revetment slopes (similar to the existing Causeway design); and
  - 56.4 A wider Causeway footprint that incorporates Bio Filters as treatment for stormwater runoff.

#### COMMENTS ON SUBMISSIONS

- 57 I have read submissions lodged on the Project that raise geometric design or related issues relevant to my area of expertise.
- 58 A number of submitters have raised issues regarding the extent of reclamation proposed for the Causeway.<sup>33</sup> In my evidence I have

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<sup>32</sup> Refer to Section 8, page 35 of the Report.

addressed the various geometric widths within the cross-section of the Causeway and the components that make up the Causeway (see Annexure A).

- 59 **Improve pedestrian movement within Te Atatu Interchange**  
Two submissions<sup>34</sup> seek improvements to pedestrian movement at the Te Atatu Interchange. As part of the up-grade to the Te Atatu Interchange, additional at-grade pedestrian crossings have been proposed across the eastbound off- and on-ramps. Additionally, the existing underpass will be significantly enhanced to provide increased personal security and better links through the Interchange. It is my opinion, that with these measures in place, the Project will offer significant improvements for pedestrians and cyclists through the Te Atatu Interchange.
- 60 **Auckland City Council**  
Auckland City Council requested<sup>35</sup> that both the Te Atatu and Lincoln Road Interchanges be designated to accommodate future Busway provision. The Lincoln Road Interchange is not within the scope of the Project, and although a future Rapid Transit Network (RTN) Busway facility and/or a bus-to-bus passenger connection at the Te Atatu Interchange is not part of the current Project, the Project does not preclude such an improvement being pursued in the future.
- 61 Auckland City Council questioned<sup>36</sup> the tapering (where it is avoiding obstacles, such as industrial buildings and communications infrastructure) of the proposed pedestrian/cycle way from 3 to 2m, suggesting that no tapering is required. The Council also wanted assurance that the pedestrian/cycle way met the Austroads recommendations.
- 62 A taper was incorporated into the design of the pedestrian/cycle way to heighten awareness of the downstream narrowing, therefore reducing risk of injury to cyclists and pedestrians. Exactly how the change in width will be effected can be resolved at detailed design stage along with suitable warning signing, and the layout will be reviewed as part of the Project's next Safety Audit. The proposed designation/consents provide scope for altering or removing the tapers should it be necessary. The current proposals comply with the current Austroads Guide recommendations with the exception

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<sup>33</sup> These include Submitter Nos. 065, 069, 104, 113, 121, 130, 136, 179, 210, 213, 237 and 239. Justification for the various traffic lane widths, median/hard shoulder widths and the pedestrian/cycle way width are described in section 30-35 of my evidence.

<sup>34</sup> Submitter No. 187, item 2 (Mr Martin B Roberts) and No. 247, section 3.1.6 (Waitakere City Council).

<sup>35</sup> Submitter No. 111, point 213.

<sup>36</sup> Submitter No. 111, point 211.

of the 2m minimum width which complies with the Austroads guide relevant at the time of design<sup>37</sup>.

#### Geometric design of Te Atatu Interchange

- 63 One submission<sup>38</sup> seeks improvements to the ramp metering and HOV lane facilities at the Te Atatu Interchange in the eastbound direction. The submitter supports the use of these facilities, but is concerned about the provision of two eastbound on-ramps rather than one, and particularly safety issues regarding the interaction of these two ramps. The need for these two ramps is traffic-related and will be covered in Mr Andrew Murray's evidence.
- 64 However, I can comment on the geometric issues related to the submitter's suggested solution that a bus/HOV lane be included on the loop on-ramp. A bus/HOV lane has not been included in the Interchange design because of a lack of space, specifically the space for the bus/HOVs to continue on the shoulder of the Motorway to merge safely downstream of the general lane ramp meter merge. The shoulder width is significantly constrained under the existing Te Atatu bridges (which are to remain) such that vehicles could not run on the shoulder. If a third lane were added to this ramp, three lanes of traffic would have to merge within approximately 40m of the ramp meter line, which would create an unsafe situation, potentially forcing traffic to make unexpected evasive manoeuvres into lane 1 of the Motorway.




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Jonathan Hind

November 2010

Annexure A: Causeway Cross Section (Option D(W))

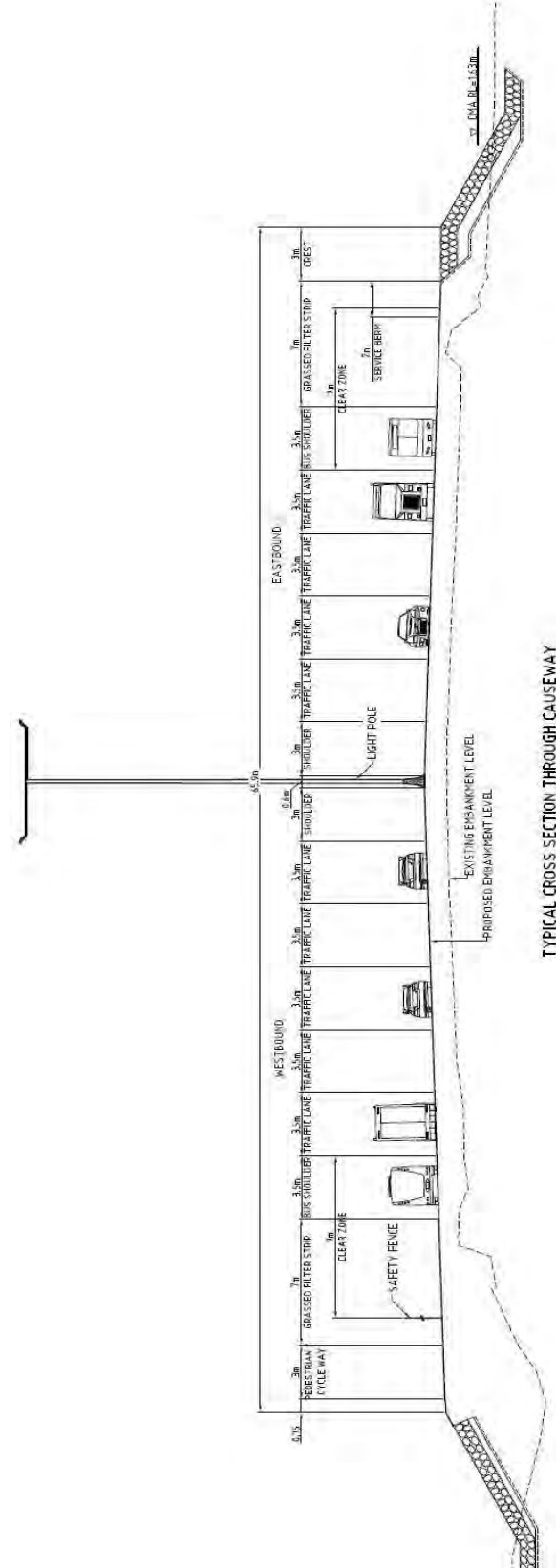
Annexure B: Causeway Options Report (Document No. 20.1.11-3-R-J-304)  
(September 2010)

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<sup>37</sup> Austroads Guide to Traffic Engineering Practice, Part 14: Bicycles, Section 6.6.1 and Table 6.3.

<sup>38</sup> Submitter No. 191, (Mr Michael Galbraith and Christine Coste).

ANNEXURE A: CAUSEWAY CROSS SECTION (OPTION D(W))



TYPICAL CROSS SECTION THROUGH CAUSEWAY

ANNEXURE B: CAUSEWAY OPTIONS REPORT<sup>39</sup>

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<sup>39</sup> Doc Ref No. 20.1.11-3-R-J-304 (September 2010)



# Western Ring Route – Waterview Connection



## Causeway Options Report







This report has been prepared for the benefit of the NZ Transport Agency (NZTA). No liability is accepted by this company or any employee or sub-consultant of this company with respect to its use by any other person.

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**Quality Assurance Statement**

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# Causeway Options Report

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APPENDIX F: Option E – Cross Section, Plans and Long Sections (2010)

# 1. Introduction

The 'Waterview Connection Project' is the final key project to complete the Western Ring Route (WRR). In 2009 the NZ Transport Agency (NZTA) confirmed that the Waterview Connection Project (Project) would be lodged with the Environmental Protection Authority as a Proposal of National Significance. The Project will be the largest roading Project undertaken in New Zealand, and due to its size and complexity has been divided into nine Project Sectors. These Sectors broadly define the different planning and construction requirements of the Project. A diagram of these Sectors is presented in Figure 1.1.

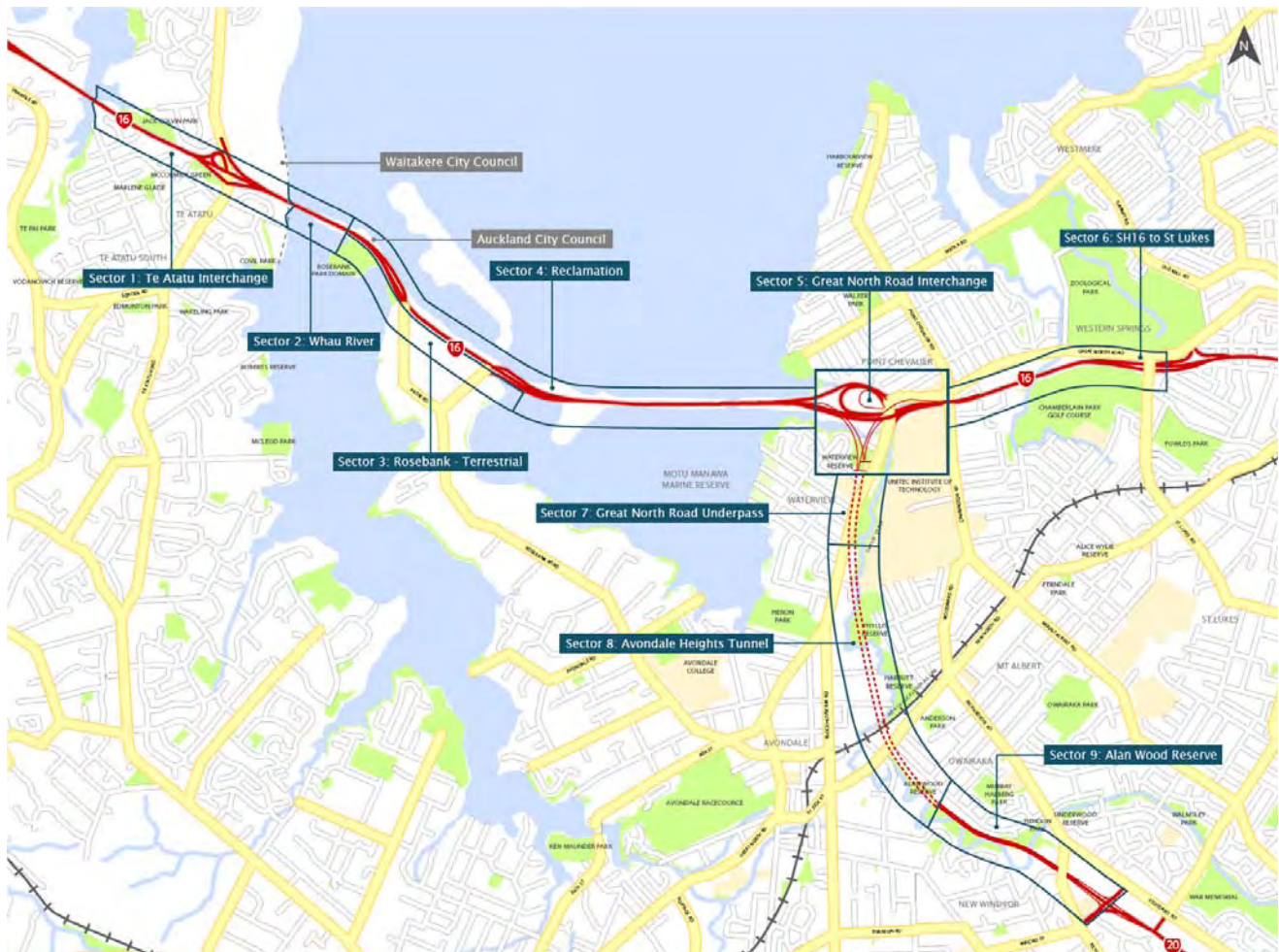


Figure 1.1 – Waterview Connection Project Sector Diagram

The improvements to SH16 provided as part of the Waterview Connection Project are approximately 8km in length, extending from the St Lukes Road Interchange to Henderson Creek, and will primarily consist of widening the existing motorway with additional lanes to accommodate the increased traffic demand from SH20.

The SH16 alignment between the Great North Road and Te Atatu Road Interchanges passes through an estuarine area, crossing parts of the central Waitemata Harbour. From the Great North Road Interchange to the

Rosebank Road Interchange, and between the Patiki Road Interchange and Whau River, sections of the carriageway are formed on low man-made embankments and the improvement works will require reclamation of the Coastal Marine Area (CMA).

The section of SH16 between Great North Road and Rosebank Road is commonly referred to as the 'Causeway' (see Figure 1.2). The majority of the reclamation required for the improvements will be along the northern and southern edges of the Causeway. The ground conditions found adjacent to the Causeway are poor due to the underlying very soft Recent Alluvium (marine mud).



Figure 1.2 – Photograph of the Causeway

## 1.1 Report Purpose and Scope

The NZTA has confirmed the following Project Objectives for the Project:

1. To contribute to the region's critical transport infrastructure and its land use and transport strategies:
  - by connecting SH16 and SH20 and completing the Western Ring Route; and
  - by improving the capacity and resilience of SH16.
2. To improve accessibility for individuals and businesses and support regional economic growth and productivity:
  - by improving access to and between centres of future economic development.
3. To improve resilience and reliability of the State Highway network:
  - by providing an alternative to the existing SH1 corridor through Auckland that links the northern, western and southern parts of Auckland; and
  - by securing the SH16 Causeway against inundation.
4. To support mobility and modal choices within the wider Auckland Region:
  - by providing opportunities for improved public transport, cycling and walking; and
  - by protecting opportunities for future passenger transport development (e.g. rail).
5. To improve the connectivity and efficiency of the transport network:
  - by separating through traffic from local traffic within the wider SH20 corridor.

For the Project to comply with the Project Objectives, SH16 must be widened to improve capacity and provide opportunities for improved public transport, cycling and walking. The elevation of the motorway Causeway between Great North Road and Rosebank Road, and between Patiki Road and Whau River, will also need to be increased to prevent inundation and therefore improve resilience.

Where reclamation is required, the philosophy has been to carefully define the extent needed to accommodate the reclamation, permanent occupation and any necessary temporary works. Therefore all design elements that might affect the overall footprint of the enlarged reclamation have to be fully assessed.

This report (the Causeway Options Report) investigates and assesses the potential engineering solutions to provide an improved connection between the Great North Road and Rosebank Road Interchanges (the Causeway) and recommends a preferred option.



## 1.2 Report Structure

This report evaluates the potential options to provide a motorway link across the central Waitemata Harbour between the Great North Road and Rosebank Road Interchanges. The report is structured as follows:

- **Causeway History** – provides an overview of the Causeway’s history since construction and includes background information on settlement and inundation issues;
- **Causeway Options Assessment** – provides a high level assessment of six broad options and concludes with the recommendation of widening the existing Causeway;
- **Symmetrical or Asymmetrical Widening Assessment** – takes the preferred option and evaluates widening to the north, south or both sides of the existing Causeway;
- **Causeway Stormwater Treatment Option Assessment** – evaluates two options for Causeway stormwater reticulation and treatment. This assessment is required as each stormwater option can affect the proposed Causeway footprint;
- **Option Assessment Update** – following the broad level assessment undertaken in previous sections, this section selects two of the most favoured options and develops a greater level of assessment before recommending a preferred option;
- **Conclusions and Recommendations.**

To establish the optimum Causeway improvement solution, a series of potential ‘high level’ options were tabled, and these options were then assessed in order to produce a shortlist of six Causeway and/or viaduct options that were assessed further:

The design then focused on the Causeway alignment, assessing symmetrical or asymmetrical (to the north or south) widening. The assessment then considered stormwater treatment for the proposed Causeway and what influence this would have on the proposed Causeway width.

Figure 1.3 charts the assessment development during the design period.

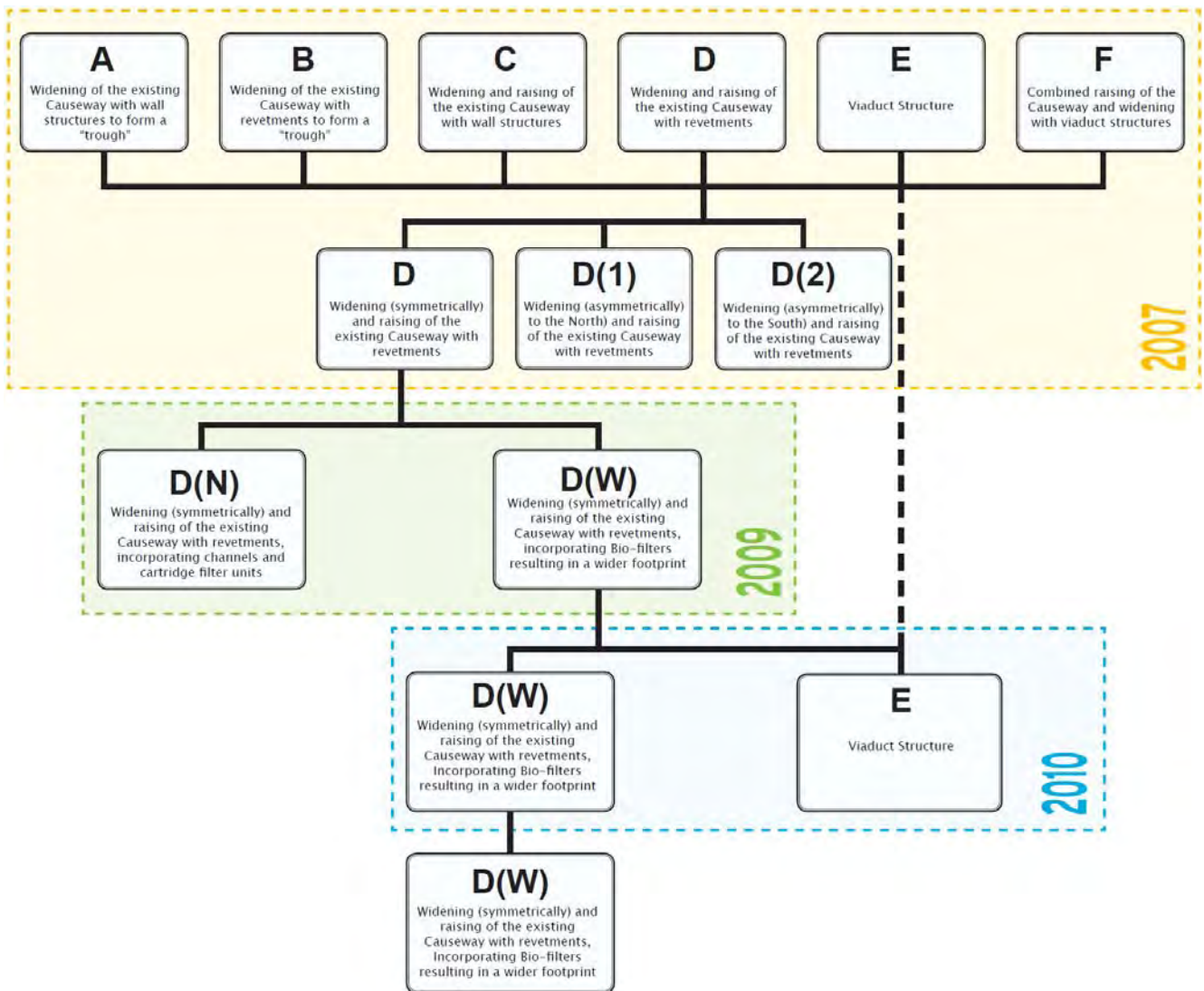


Figure 1.3 Causeway Option Flowchart

## 2. Causeway History

The Causeway was constructed by the Ministry of Works, with construction commencing in 1952 and taking approximately 2 years to complete (see Figure 2.1). The construction fill used a mixture of scoria and cohesive material, which was end-dumped within the intertidal area and then tracked, compacted and infilled until a trafficable route was established.

To provide a four lane highway (two lanes in both directions) the Causeway was widened on the south side, with the second Causeway Bridge opening in 1959.

In 1991 both Causeway Bridges were widened by approximately 6.5m each and the sealed width of each carriageway was widened to accommodate a six lane highway (three lanes in both directions).

In 2005 the sealed carriageway shoulders along the Causeway were widened by approximately 1m providing bus shoulders during peak times only.



Figure 2.1 – Historical Photograph of the Causeway (1950s)

Core sampling (exploratory holes) undertaken through the Causeway found a mixture of scoria and cohesive materials. Irrespective of the fill material, the difficult depositional environment means that the fill below the Causeway is unlikely to have been placed in the controlled manner expected under current construction techniques and hence variation can be expected in both material type and compaction characteristics.

## 2.1 Causeway Settlement

The section of motorway between the Great North Road and Rosebank Road Interchanges has been suffering from on-going long-term settlement. The Causeway's settlement can be characterised by a combination of:

- primary consolidation of the intertidal mud and/or organic and peat layers within the underlying Tauranga Group Alluvium;
- shear failure within the intertidal mud; and
- ongoing secondary compression within the intertidal mud and/or organic and especially the peat layers within the underlying Tauranga Group Alluvium.

The marine mud is highly compressible with very low shear strength. Given the age of this construction, primary consolidation is likely to be complete and any ongoing settlement is likely due to creep (secondary compression) effects.

This section of SH16 has settled notably since construction. A comprehensive topographical survey of the Causeway now shows that the existing (centre line) elevations vary from approximately 4.60m RL at the western abutment of the Rosebank Bridges to a low point (centre line) of approximately 2.6m RL.

Initially it was believed the entire Causeway was constructed to the same elevations of the original Causeway Bridge i.e. 4.60m RL, thus parts of the Causeway were believed to have settled by as much as 2–2.5m since construction. However, an original typical cross section drawing obtained from archives (reference: NZ Works Ministry as-built A.D.O.22109) indicates that only the approach sections either side of the original Causeway Bridge were constructed to a centre line elevation of 4.60m RL, but the majority of the Causeway was generally constructed to a centre line elevation of only 3.50m RL. This implies settlement of the Causeway since construction is more likely to be in the order of 0.5–1.0m rather than the speculated 2–2.5m.

However, periodic infilling, patching, shape corrections and asphalt overlays have been reported (although the extent of these is unknown); combined with the indicative variations in fill thickness this suggests that settlement of the Causeway since construction could be greater than 0.5–1.0m.

Refer to **Coastal Works Engineering Report (20.1.11-3-R-J-306)** for further geotechnical information.

## 2.2 Causeway Inundation

The existing bus shoulders, pedestrian/cycle way and coastal rock armour are being inundated by high tides approximately 4–6 times per year (see Figure 2.2). Sea water has been observed to come to the edge of the sealed surface on average once a year during storm surges. It is believed the last time the motorway was completely

closed was in August 1987. Water has been present on the carriageway since, but complete motorway closure has not occurred as road users have been allowed to pass at low speeds.



**Figure 2.2 – Photographs Showing Inundation (Top: Northern revetment, Bottom: Southern revetment and pedestrian/cycle way)**

It is accepted that sea level rise will continue over the coming century and beyond. The anticipated sea level rise projections and increased storm intensity are expected to increase the frequency of inundation and severity of wave overtopping, and thus the possibility of motorway closures. Any further settlement of the Causeway will only exacerbate the situation.

## 3. Causeway Options Assessment

### 3.1 Causeway Options

Notwithstanding the requirement to improve transport capacity of the motorway, the improvements to SH16 are also required to secure its reliability as a lifeline corridor within Auckland. Maintaining reliability of this route is of strategic network importance.

In order to establish the optimum Causeway upgrade solution, a series of potential 'high level' engineering solutions were tabled by the project team, and a variety of Causeway upgrade options were then assessed by the project team in order to shortlist potential solutions. In 2007 the Causeway upgrade accommodated the following design elements:

- 4 x westbound traffic lanes;
- 4 x eastbound traffic lanes;
- 2 x bus shoulders;
- 2 x median shoulders;
- 3 x TL4 barriers;
- 1 x services berm; and
- 1 x pedestrian/cycle way.

The 'high level' options that were considered are summarised below:

#### **Alternatives to a Causeway:**

- Replace the existing Causeway with a viaduct structure;
- Replace the existing Causeway with a tunnel; or
- Replace the existing Causeway with a combined viaduct/raised Causeway cross section.

#### **Widening and raising the existing Causeway:**

- Widening and raising the existing Causeway to an elevation and width to enable a full design life of approximately 100 years;
- Staged raising of the existing Causeway. Construct the width and base to a design life of 100 years but raise the elevation to only a 30 or 50 year design, i.e. a 'trough' structure; or
- Split carriageway. Raise the seaward side of the existing Causeway higher than landward side to protect against wave attack more efficiently.

#### **Side protection options:**

- Wave deflection/re-curve walls;
- Vertical walls; or

- New revetments with rock armour (similar to existing).

In any case, SH16 must be widened to facilitate new traffic lanes, so all of the options are likely to require reclamation and ground improvements to the adjacent founding marine mud. The following list (but not exhaustive list) of ground improvement measures could be used to combat settlement:

- Preload or surcharge the existing Causeway;
- Deep soil mixing/controlled modulus columns;
- Concrete piles or stone columns;
- Vibrocompaction/flotation;
- Vertical soils drains (wick drains);
- Raft foundation or shallow improvements (Geogrid reinforced); or
- Lightweight fill (such as polystyrene).

### 3.2 Initial Option Appraisal

Not all of the above options are independent of each other. For example, if it is chosen to raise and widen the existing Causeway, then at least one option for side protection would be required. Also, ground improvement measures are dependent upon the extent of Causeway widening and raising, the chosen coastal protection and the findings from geotechnical ground investigations. Therefore, it was not considered necessary to discuss and select a preferred ground improvement technique at this stage. For the same reason, stormwater treatment options were also not considered at this early stage of design.

The tunnel option alternative was discounted as the tunnel diameter would have to be of an unprecedented scale to accommodate the number of proposed traffic lanes. To overcome this, two tunnel bores would need to be provided in both directions. It was determined that the resulting cost of four tunnels would be prohibitive. In addition, the poor ground conditions are not suitable for tunnelling. Consequently, the options were refined into a shortlist of six broad Causeway and/or viaduct options that were put forward for assessment:

- A. Widening of the existing Causeway with wall structures to form a 'trough';
- B. Widening of the existing Causeway with revetments to form a 'trough';
- C. Widening and raising of the existing Causeway with wall structures;
- D. Widening and raising of the existing Causeway with revetments;
- E. Placing a viaduct structure over the existing Causeway;
- F. Raising of the existing Causeway, and widening with viaduct structures.

Appendix A contains indicative typical cross sections of Options A to F.

### 3.3 Option Evaluation

Options A to F were assessed against the following five key criteria. A table describing the option evaluation is presented in Appendix B.

#### 1. Environmental Constraints

The Causeway passes through the Pollen Island (Motu Manawa) Marine Reserve. The Causeway options are likely to require varying amounts of reclamation in the Marine Reserve and the following environmental considerations are of importance:

- Scour and erosion;
- Permanent intertidal habitat removal;
- Removal of flora and fauna; and
- Effects on watercourses and tidal channels.

#### 2. Coastal

The following coastal criteria is relevant when assessing the Causeway options:

- Dissipation of wave energy – how effective is the structure in dissipating wave energy and what could potentially be the effects of specific structures?
- Risk of wave overtopping – what is the likelihood and severity of waves overtopping onto the proposed traffic lanes;
- Exposure to wave attack – is the structure sensitive (erosion and scour) to the level of wave attack and what are the consequences and structural implications?
- Protection against pavement inundation – what level of protection against pavement layer inundation is provided? Are there complications expected regarding inundation and drainage?

#### 3. Geotechnical

The marine mud is highly compressible with very low shear strength. It is this layer that has consolidated extensively to cause the majority of the historic Causeway settlement. The geological and geotechnical conditions will have a significant influence on the selected Causeway option.

#### 4. Constructability and Construction Cost

Different Causeway options are likely to be more difficult to construct than others. Significant constructability issues and cost increases may arise from the following:

- Temporary traffic management – the existing number of traffic lanes must be open to traffic throughout the construction period;
- Working in intertidal areas;
- Ground improvements and piling; and



- Working at height.

## 5. Maintenance and Future Flexibility

This focuses on elements of each option, which are expected to contribute significantly to the motorway operational maintenance. Maintenance aspects, mainly associated with the coastal protection and structures, have been considered. Future flexibility refers to the ability of the design option to meet future needs such as settlement, sea level rise and traffic increases.

### 3.4 Option Discussion

Referring to the information presented in Appendix B the option evaluation is discussed below:

#### 3.4.1 Viaduct Options assessed against Causeway Options

The key **disadvantages** of a viaduct structure (Options E & F) compared to raising and/or widening the Causeway with earth fill (Options A to D) would be as follows:

- deep marine mud would force piling to be taken down to significant depths, which would be costly;
- high ongoing maintenance cost – replacement work would be required to bridge bearings and expansion joints every 30 years;
- intensive maintenance of proprietary stormwater treatment devices would be required;
- shadow cast over the existing Causeway would result in a wasted ‘dead area’ which would be difficult to convert into an amenity, and would still require regular maintenance (e.g. removal of litter);
- for Option F there would be a significant longitudinal differential risk between the viaduct structures and the raised Causeway section – surcharging of the existing Causeway would exacerbate on-going settlement, whereas the viaduct structures founded on bed rock would undergo minimal settlement. This differential settlement would be difficult to accommodate;
- the viaduct structure would alter the appearance of the Marine Reserve.

The key **advantages** associated with a viaduct structure (Option E & F) compared to raising and/or widening of the existing Causeway with earth fill (Options A to D) would be as follows:

- very little or no reclamation would be required;
- unpredictability in wave overtopping and sea level rise projections not as critical as any viaduct could be ‘well above’ sea level;
- for Option E, there is minimal settlement and differential settlement risk if piles were driven into bedrock or stronger alluvial layers – maintenance of a raised/widened Causeway would require ongoing shape correction due to differential settlement;
- sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment; and
- elevated views of the Marine Reserve for vehicle occupants.

The general advantages and disadvantages of a viaduct structure when assessed against raising and/or widening the existing Causeway with earth fill are for the most part neutral. The viaduct would require very little, or no, permanent occupation of the CMA, and this is its main environmental advantage. However, the environmental quality of the marine reserve immediately adjacent to the existing Causeway (where reclamation would occur) is considered to be of relatively low to moderate value (refer to the **Assessment of Marine Ecological Effects (20.1.11-3-R-N-1006)**). A widened and raised Causeway with rock revetments will resemble the existing Causeway. The construction and maintenance costs associated with a viaduct are expected to be significantly greater than widening and raising of the existing Causeway with rock revetments.

Significant differential settlements are likely between the viaduct structures and the raised Causeway section – raising of the existing Causeway will exacerbate on-going settlement, whereas the viaduct structures founded on piles will undergo minimal settlement. The differential settlement will be difficult to mitigate within the design. Option F consisting of combined raising of the Causeway and widening with viaduct structures has been discounted.

### 3.4.2 Trough Causeway Options assessed against Raised Causeway Options

The **disadvantages** of widening the Causeway to form a trough (Options A & B) compared to widening and raising of the Causeway (Options C & D) would be as follows:

- carriageway stormwater runoff would need to be mechanically pumped out as there is insufficient head between road elevation and high tide levels to provide gravity reticulated water quality treatment. This situation would only be exacerbated by sea-level rise caused by climate change;
- existing or proposed pavement layers could be frequently inundated by static storm tide levels. This would reduce the life span of the pavement, and the situation would only be exacerbated by sea-level rise caused by climate change;
- seepage could occur through the walls or revetments causing carriageway flooding;
- carriageway flooding would occur if the revetment was breached or overtopped by the sea; and
- limited views to the marine reserve for vehicle occupants.

The **advantages** of widening the Causeway to form a trough (Options A & B) compared to widening and raising of the Causeway (Options C & D) would be as follows:

- traffic management during construction would be relatively simple as raising the existing carriageways would not be required. Work would proceed as basic parallel motorway widening;
- induced settlement of the existing Causeway would be less than that of Options C & D; and
- minimal volume of bulk fill would be required and the existing pavement could be retained in places.

Options A and B can not address sea level rise, pavement flooding nor stormwater runoff effectively. These factors are significant given the Project objectives to secure a reliable motorway and future-proofing for predicted sea-level rise. Both Options C and D involve raising the Causeway across its full width to a sufficient level to combat sea level rise, pavement flooding and extreme static-storm tide events satisfactorily. Options C and D are therefore preferred over Option A and B.

### 3.4.3 Wall Options assessed against Revetment Options

The **disadvantages** of using wall structures (Options A & C) compared to using rock revetments (Options B & D) would be as follows:

- rock revetments absorb and dissipate wave energy via wave run up. Wall structures reflect wave energy upwards, and would therefore likely need to be notably higher than the crest of a rock revetment of exhibiting similar overtopping characteristics;
- wall structures would reflect wave energy back into the Marine Reserve, potentially causing scour and erosion of the sea bed – wave reflection from vertical wall structures can be substantial and random causing erosion of the sea bed up to a significant distance from the wall;
- the deep soft marine mud would require very deep piled foundations for walls. Therefore the construction cost of retaining walls would likely to be high;
- wall structures could be extended vertically if sea level rise is greater than expected. However, the wall foundations would need to be future proofed to accommodate any future increase in height; and
- wall structures are “hard” coastal protection solutions, that could cause problems when differential settlement and/or localised erosion of the Causeway occurs.

The **advantages** of using wall structures (Options A & C) compared to using rock revetments (Options B & D) would be as follows:

- narrower footprint reduces the need for reclamation; and
- narrower footprint minimises effects on the southern tidal channels (Waterview Inlet and Oakley Creek).

Although wall structures may reduce the footprint, wave energy reflection and the requirement for extensive piled foundations limit the use of wall structures. Wave reflection from vertical wall structures can be substantial causing erosion of the sea bed up to a significant distance from the wall. Creating a more extreme wave climate is considered a disadvantage from an environmental and ecological point of view. Rock revetments (Options B and D) are therefore preferred over wall structures (Option A and C).

Option D is recommended – summarised as ‘widening the existing Causeway with revetments and raising its elevation while accounting for future settlement and sea level rise’.

Based upon this recommendation, a typical cross section of Option D is provided in Appendix C.

## 4. Symmetrical or Asymmetrical Widening Assessment

With early assessment indicating the preference for a Causeway with revetments, the design then focused on the form or type of Causeway alignment. The design looked at either a symmetrical or asymmetrical widening assessment. This section outlines this analysis.

### 4.1 Symmetrical or Asymmetrical Options

Given the location of the Causeway within the Motu Manawa (Pollen Island) Marine Reserve, an assessment of the effects of the reclamation was undertaken in terms of the relative impact upon the environment to either the seaward side to the north of the Causeway, the landward side to the south (i.e. asymmetrical widening) or reclamation on each side of the Causeway through symmetrical widening. Note: This assessment applied to the section of motorway between Great North Road Interchange and Rosebank Road.

Symmetrical widening of the Causeway about the existing centreline impacts on both the seaward and landward sides of the Causeway. Ecological investigations (refer to the **Assessment of Marine Ecological Effects (20.1.11-3-R-N-1006)** and the **Assessment of Coastal Processes (20.1.11-3-R-N-1012)**), noted some environmental constraints on either side of the Causeway. As environmental issues are of special importance throughout this section of the Project, three options were assessed:

- Option D – Symmetrical widening of the Causeway about the existing centreline;
- Option D(1) – Asymmetrical widening of the Causeway to the North; or
- Option D(2) – Asymmetrical widening of the Causeway to the South.

Reclamation requirements for each of the three Causeway widening options above were assessed. The method of assessment was discussed and agreed with DOC, ARC and the Project Team during a series of consultation workshops, as the best approach to assess the relative environmental impacts of each option. Each of the options was assessed against the following criteria:

- Ecology;
- Coastal Hydrodynamics;
- Geotechnical;
- Construction; and
- Structures, Existing Infrastructure & Cost Effectiveness.

### 4.2 Symmetrical Widening

The results of the symmetrical widening assessment are reported below:

#### 4.2.1 Ecology

Ecological effects of symmetrical widening on the ecology of the surrounding marine environment are considered to be relatively neutral compared to asymmetrical widening. The coastal margins adjacent the

Causeway are protected by rock armour, accumulating litter and flotsam. The areas of rock armour are of low ecological values, but below the armour within the marine sediments the values on the northern side are moderate to high and the southern side low to moderate (refer to the **Assessment of Marine Ecological Effects (20.1.11-3-R-N-1006)**). Mangroves are also sporadically present on either side of the Causeway. There is a patch of *Mimulus repens* (Creeping Musk) on either side of the Causeway that would be affected by the works. This plant is ‘endangered’ regionally but only ‘at risk but not threatened’ nationally. Symmetrical widening would likely require the removal of this plant, but it can be translocated to an alternative site to be agreed with the Auckland Motorway Alliance, Auckland Council and the ecologists. The effect on bird life is also expected to be relatively neutral compared to asymmetrical widening as the habitats immediately adjacent to either side of the Causeway are similar. However, it is also noted that intertidal bird feeding grounds are marginally closer to the Causeway on the southern side (refer to the **Avian Ecological Assessment (20.1.11-3-R-N-1008-A)** for further information). Conversely it is also noted, that the north side has a slightly higher ecology value as there is a greater diversity of invertebrates present in the marine mud.

#### 4.2.2 Coastal Hydrodynamics

Symmetrical widening of the Causeway would encroach, and therefore impede, the flow in channel locations within the Marine Reserve. Two potential locations where this impedence may occur exist to the south of the motorway in Oakley Creek Inlet. The other location, Waterview Estuary Inlet, is also south of the motorway. This channel is exposed at low tide and conveys the main flow from the upper inner lagoon area to the Causeway Bridges. It is suggested that these channels are not encroached. However, if it is unavoidable, then mitigation through excavating a new bypass channel is recommended. For the symmetrical widening option, there is potential encroachment on 3 channels (refer to the **Assessment of Coastal Processes (20.1.11-3-R-N-1012)**).

The reclamation required for the improvements under the symmetrical option is approximately half that required when compared with asymmetrical widening, either to the north or south of the Causeway.

#### 4.2.3 Geotechnical

Symmetrical widening would have to accommodate differential settlement and slope instability on both sides of the Causeway. However, preliminary findings predicted that less fill would be required to compensate for settlement for the symmetrical option when compared to either asymmetrical options. Another important advantage of symmetrical widening (and raising) is that all the proposed traffic lanes would be directly above parts of the existing Causeway. This would reduce the risk of uneven traffic lane settlement and instability as the existing Causeway has already undergone significant settlement and stabilisation (approximately 60 years worth). Asymmetrical widening would increase the risk of the traffic lanes (those lanes constructed over the new reclaimed ground) settling unevenly.

#### 4.2.4 Construction

The symmetrical widening option would require significant amounts of work in close proximity to, and on top of, the existing traffic lanes. This would require temporary management arrangements and phased construction. It is anticipated that at least five temporary traffic phases would be required.

#### 4.2.5 Structures, Existing Infrastructure & Cost Effectiveness

It is typically easier to widen existing highways symmetrically, reducing complexities associated with widening structures off centre. For this section of the motorway, in particular the Causeway Bridges, widening would be constructed with greater ease. Each bridge would be widened on the nearside edge with the existing cross-fall of each bridge deck maintained. Both the Rosebank Road on- and off-ramp bridges would also be retained.

### 4.3 Asymmetrical Widening to the South

The results of the assessment of the widening to the south option is reported below:

#### 4.3.1 Ecology

Ecological effects of widening the Causeway to the south (as opposed to the north) are expected to be relatively neutral as the habitats immediately adjacent to either side of the Causeway are similar. Although, below the rock armour within the marine sediments the values on the northern side are moderate to high and on the southern side low to moderate (with respect to benthic invertebrates and sediment quality) (refer to the **Assessment of Marine Ecological Effects (20.1.11-3-R-N-1006)**). Intertidal bird feeding grounds are marginally closer to the Causeway on the southern side; therefore from this aspect, widening solely to the South is not desirable. The stand of *Mimulus repens* (Creeping Musk) would require removal but it can be translocated to an alternative site to be agreed with the Auckland Motorway Alliance, Auckland Council and the ecologists. However, the reclamation required for the improvements under the asymmetrical options is approximately double that required when compared with the symmetrical widening option.

#### 4.3.2 Coastal Hydrodynamics

Asymmetrical widening of the Causeway to the south would also encroach, and therefore potentially impede, the flow in the three tidal channels highlighted in Section 4.2.2. For the asymmetrical widening option to the south, encroachment of these 3 channel locations would be to a greater extent than that of symmetrical widening, requiring approximately double the amount of reclamation on the southern side of the Causeway when compared with symmetrical widening. However, asymmetrical widening has the benefit of only disturbing the marine environment on the south side of the Causeway (assuming no upgrade or improvements to the north side are required).

#### 4.3.3 Geotechnical

Asymmetrical widening would have to accommodate differential settlement and slope instability issues on the south side of the Causeway only (assuming no upgrade or improvements to the north side are required). However, preliminary findings predicted that more fill would be required to compensate for settlement for an asymmetrical option. Also, asymmetrical widening would increase the risk of the traffic lanes (those lanes constructed over the new reclaimed ground) settling unevenly. This is a significant risk given the very soft and weak nature of the underlying marine mud.

#### 4.3.4 Construction

This option would have a greater extent of off-line construction (away from the existing traffic lanes), therefore the roading construction works and traffic management are anticipated to be less complex than the

symmetrical option. It is anticipated that only three temporary traffic phases would be required. However, re-construction of the Causeway Bridges would be required.

#### 4.3.5 Structures, Existing Infrastructure & Cost Effectiveness

Asymmetrical widening would require additional work to the Causeway Bridges. Linking of the Causeway Bridges was investigated in some detail and found to be technically feasible. However, the adverse camber would have to be accommodated on the Causeway Bridge carrying the eastbound carriageway, and this is not recommended particularly for a RoNS. In addition, widening asymmetrically would result in the freeboard of the wider bridge being reduced further. Both Causeway Bridges would require demolition at a significant increase in cost.

As there is approximately double the area of reclamation required for asymmetrical widening when compared to symmetrical widening it is likely that twice the area of ground improvements would be required for the asymmetrical widening. A small cost saving would be achieved by widening on one side of the Causeway only, as construction mobilisation would be reduced. However this saving would be minor compared to the cost of the anticipated asymmetrical ground improvements.

### 4.4 Asymmetrical Widening to the North

The results of the assessment of the widening to the north option is reported below:

#### 4.4.1 Ecology

As discussed earlier, the ecological effects of widening the Causeway to the north (as opposed to the south) are expected to be relatively neutral as the habitats immediately adjacent to the Causeway are similar. Although, below the armour within the marine sediments the values on the northern side are moderate to high and on the southern side low to moderate (with respect to benthic invertebrates and sediment quality). The north side has slightly higher ecology values as there is a greater diversity of invertebrates present in the marine mud; therefore from this aspect, widening solely to the north is not desirable. Asymmetrical widening to the north would also affect bird feeding habitats more so than symmetrical widening. The stand of *Mimulus repens* (Creeping Musk) would require removal and translocation. However, the reclamation required for additional road reserve under the symmetrical option is approximately half that required when compared with either asymmetrical widening options.

#### 4.4.2 Coastal Hydrodynamics

Asymmetrical widening of the Causeway solely to the north would not encroach upon the southern tidal channels discussed earlier. Widening to the north however may potentially encroach upon the Pollen Island drainage channel, depending upon the tie-in to the existing road geometry. This channel is considered environmentally sensitive given its proximity to the ecologically sensitive Pollen Island. However, asymmetrical widening to the north has the benefit of only disturbing the general marine environment on one side of the Causeway (assuming no upgrade or improvements to the south are required).

The reclamation required for additional road reserve under asymmetrical widening is approximately double the amount of reclamation on the northern side of the Causeway when compared with symmetrical widening.

#### 4.4.3 Geotechnical

The constraints to asymmetrical widening to the north are as described for asymmetrical widening to the south.

#### 4.4.4 Construction

The constraints to asymmetrical widening to the north are as described for asymmetrical widening to the south.

#### 4.4.5 Structures, Existing Infrastructure & Cost Effectiveness

The constraints to asymmetrical widening to the north are as described for asymmetrical widening to the south i.e. demolition of the Causeway Bridges is required. In addition the horizontal geometry of the eastbound carriageway over Traherne Island is noted. At present the curve to the left on the eastbound carriageway is substandard and significant widening to the north will only exacerbate this departure thus reducing safety standards. Widening solely to the north would potentially require the reconstruction of the Rosebank Road on-ramp viaduct structure at a considerable cost.

### 4.5 Symmetrical or Asymmetrical Widening Discussion

The **disadvantages** of widening solely to the north compared to solely to the south are:

- the Rosebank Road on-ramp bridge structure would require demolition and re-construction at significant additional cost;
- the horizontal curve to the left (on the eastbound carriageway over Traherne Island) would be further reduced in geometric standard;
- the north side has a slightly higher ecological value as there is a greater diversity of invertebrates present in the marine mud.

The **advantages** of widening solely to the north compared to solely to the south are:

- encroachment into three tidal channel locations within the Marine Reserve is not required. However the environmental effects (coastal processes) of realigning the existing channels are expected to be less than minor; and
- the intertidal bird feeding areas are marginally further away from the Causeway on the northern side (refer to the **Avian Ecological Assessment (20.1.11-3-R-N-1008-A)**).

The general **disadvantages** of asymmetrical widening (to the north or to the south) compared to symmetrical widening, is that either asymmetrical option;

- requires approximately double the area of reclamation;
- requires approximately double the area of ground improvements;
- increases settlement of the new traffic lanes (those constructed over the new reclaimed ground), and would require significant remedial work (i.e. carriageway reshaping) to manage differential settlements. This is due to the very soft and weak nature of the underlying virgin marine mud;
- requires replacement of the Causeway Bridges; and



- requires more fill material.

The general **advantages** of asymmetrical widening over symmetrical widening are;

- works to only one side of the existing Causeway are required (assuming no upgrade or improvements to the non-widened side are needed; and
- simplified temporary traffic management.

#### 4.6 Symmetrical or Asymmetrical Widening Recommendation

The reclamation required under both asymmetrical widening options (Options D(1) & D(2)) was approximately double that required when compared with symmetrical widening (Option D). This quantitative assessment was based upon the proposed geometric design in 2007 (refer to Appendix C for the Option D typical cross section). Basing the assessment solely on reducing reclamation it is apparent that Option D – symmetrical widening is preferred.

Asymmetrical widening to either side is not preferred due to the high construction costs (replacement of the existing Causeway Bridges would be required as well as an increase in ground improvement and fill). In addition, there are environmental benefits associated with the symmetrical widening, such as reducing the impacts on both Pollen Island to the North, and the two channels (Oakley Inlet and Waterview Estuary) to the South. Both of which could be significantly impacted should an asymmetrical design be preferred.

Considering the above-mentioned general disadvantages of asymmetrical widening, symmetrical widening is preferred. Therefore, it is recommended to widen the Causeway about the existing carriageway centreline between Great North Road and Rosebank Road Interchanges.

## 5. Causeway Stormwater Treatment Option Assessment

As mentioned in Section 3.2 of this report stormwater treatment options were not considered in detail when assessing the previous Causeway options. However, various stormwater treatment options have the potential to significantly influence the proposed Causeway width, so treatment options were assessed as part of the overall design. A summary of this assessment is included in the following sections.

### 5.1 Background

The Causeway has zero longitudinal gradient making it difficult to not only collect stormwater but also to convey it to an outfall point. A “traditional” gravity reticulated network would need to be deep or of large diameter in order to provide an effective gradient to the outfall. This would result in pipe outfalls being placed below sea level.

As it is considered costly and impracticable to build the road level to a height where the outlet pipes would not be submerged, a ‘shallow system’ must be proposed. The ‘shallow system’ options considered are:

- open channel & cartridge filters based upon minimising the Causeway width – Option D(N);
- grassed Bio Filters requiring a wider Causeway – Option D(W).

#### 5.1.1 Cartridge Filter System - Option D(N)

The cartridge filter option proposes a sloping invert, open grated channel at the edge of the shoulders to capture the run-off during the Water Quality (WQ) event. The channel is limited in capacity and therefore the outlets from this system, discharging to the intertidal areas, could be as close as 165m.

At each outfall a system of water quality treatment is required. It is therefore proposed to use vaults containing propriety cartridge filters. The total headloss through this system is approximately 1.5m, equating to an outlet reduced level of 1.5m RL (refer to **Interpretation of Hydrodynamic Design Conditions Report** for the recommended construction elevation of the proposed Causeway), this is 130mm below existing MHS (defined as 1.63m RL).

#### 5.1.2 Bio Filter - Option D(W)

Bio Filters can be used as an alternative ‘shallow system’. Bio Filters are a uniformly graded and densely vegetated strip of grass designed to treat stormwater runoff by filtration, infiltration, adsorption and biological uptake.

At this stage of the project, and to determine marine reclamation requirements and cost, it is prudent to use a conservative width calculation for the Bio Filters. Therefore, 7m wide Bio Filters have been allocated, refer to

the **Stormwater and Streamworks Report** for further details. The Causeway crest-to-crest width is therefore approximately 9m wider for the Bio Filter option compared to the narrower cartridge filter option.

## 5.2 Option Evaluation Criteria

The two options were assessed against the following seven key criteria:

- System Capability;
- Maintenance;
- Barriers;
- Constructability;
- Future Proofing
- Capital Cost;
- Ecological.

## 5.3 Option Discussion

### 5.3.1 System Capability

#### **Cartridge Filter System**

With an outlet reduced level of 1.5m RL the outlet pipes would be submerged for a period of time during high tide. It is therefore recommended to incorporate a flap valve on the outlet pipe to avoid inundation of the system by seawater. There is no risk of flooding to the carriageway when the flap valves are closed as the treatment vaults contain a high level overflow.

**Coastal Works Engineering Report** outlines the difficulty and uncertainty of predicting the amount and uniformity of settlement that the raised and widened Causeway will undergo throughout both its construction period and operational life. The sloping invert open grated channel relies on a shallow gradient of 0.25% to convey the stormwater to the treatment vaults. Expected longitudinal differential settlement therefore has the potential to alter the channel gradients to such an extent that they no longer convey the stormwater effectively to the treatment vaults.

#### **Bio Filter**

A Bio Filter option adopts a 'shallow system' resulting in headloss across a Bio Filter, of 7m wide and 1% cross fall, of 70mm. This is significantly less than the 1.5m headloss required for the cartridge filter and open channel system. Therefore the risks of sea level rise, high tides and large storm events would be minimal (in terms of outlet inundation) if Bio Filters are adopted.

It is expected that the Bio Filters would be less susceptible to both lateral and longitudinal differential settlement given that flexibility to accommodate less than standard gradients.

### 5.3.2 Maintenance Considerations

All stormwater treatment systems, whether natural or manufactured, require regular maintenance. Water quality targets will not be achieved if the treatment devices, berms, swales or structures are not properly cleaned and maintained.

#### **Cartridge Filter System**

The sloping invert open grated channels would accumulate, over time, debris such as sediments and litter. These channels would need to be cleaned by hand digging or water blasting. A full shoulder closure would be required. The vault inlet chamber and litter screens would require visual inspection and cleaning as required. The outlet flap valves would require regular maintenance. They would need to be inspected, cleaned and maintained on a regular basis and replaced if damaged or ineffective.

The cartridge treatment devices would require a stringent maintenance regime. Based on results of the first annual inspection, maintenance actions can be modified. The typical maintenance interval for the cartridge type devices is 12 to 24 months. Ultimately, the maintenance frequency would depend on site conditions, regulatory requirements and site-specific pollutant loading.

Manufacturers have indicated that maintenance would take approximately 2–3 hours per vault. Full cleaning and replacement of the cartridges require a tripod, winch and a vehicle mounted gully sucker. Therefore a shoulder closure would be required, protected by vehicle mounted attenuators in accordance with the Code of Practice for Temporary Traffic Management (COPTTM). All waste material captured during the maintenance visit would need to be taken off site and disposed of appropriately.

#### **Bio Filter**

Bio Filters should be visually inspected for the following:

- Correct vegetation height;
- Evidence of concentrated flows paths;
- Signs of vegetation becoming sparse or overgrown;
- Excessive sediment or debris accumulation.

The vegetation would be kept to its design height typically by mowing. A mobile shoulder closure would need to be implemented under COPTTM for this activity. Concentrated flows must be prevented by use of level spreaders. Where concentrated flows are found to occur these would have to be locally remediated by either re-levelling the level spreader or re-profiling the top soil.

### 5.3.3 Barriers

To maintain the motorists existing view across the Waitemata Harbour it was suggested to investigate removal of the proposed nearside shoulder barriers.

Removing the proposed TL-4 concrete barriers would require a Clear Zone to be maintained from the near edge of the nearside live lane. When adopting the standards set out in Fig 6.2 of the SHGDM, a minimum Clear Zone of 9m (for a straight level section of road) is required before removal of the nearside shoulder barriers can be considered.

#### **Option D(N) (Cartridge Filter System)**

There can be no provision for nearside shoulder barrier removal with the narrow Causeway option (Option D(N)) utilising the stormwater cartridge filter system.

#### **Option D(W) (Bio Filter)**

The 9m Clear Zone could be incorporated within the stormwater Bio Filters. The application of a 7m wide Bio Filter would result in an effective Clear Zone width of 10.5m, exceeding the required minimum 9m width in accordance with the SHGDM.

Therefore the Bio Filter option suggests an opportunity to remove the safety barriers on the nearside shoulder.

### 5.3.4 Constructability

#### **Option D(N) (Cartridge Filter System)**

The Causeway phasing arrangements (refer to **Coastal Works Engineering Report**) are very constrained with minimum lane widths and clear zones provided throughout most of the construction period. The existing bus shoulders would have to be closed from the start of construction until at least Phase 5 when the westbound bus shoulder could be opened. The eastbound bus shoulder could be opened at the completion of works in Phase 6.

#### **Option D(W) (Bio Filter)**

The additional width provides more flexibility for construction, traffic management, temporary stormwater systems and construction related erosion and sediment control measures. The existing Causeway bus shoulders only have to be closed during Phase 2. Provision has been made for temporary bus shoulders during the remaining construction phases right through to completion of works.

### 5.3.5 Future Proofing

Currently there are uncertainties that carry a risk as part of this project, namely:

- future sea-level rise and storm intensity;
- requirements for future road improvements.

#### **Option D(N) (Cartridge Filter System)**

The minimum width Causeway (Option D(N)) would not preclude future proofing for additional raising and rearrangement of traffic lanes (reduced standards maybe required) but construction of such future improvements would create significant problems.

If the minimum width Causeway is required to be widened for future capacity improvements, and raised further due to under-estimation of sea-level rise, additional reclamation and construction of new coastal protection

measures will be required. These works may require additional construction time, owing to the confined Causeway width. In addition it will be difficult to maintain the number of general traffic lanes (totalling nine) during construction, therefore possibly reducing in general traffic capacity over the period of construction in the future.

#### **Option D(W) (Bio Filter)**

The wider Causeway option (Option D(W)) offers more flexibility and future cost efficiency for:

- further raising of the Causeway at some point in the future in the event that sea-level rise or storm intensity is greater than currently predicted;
- carriageways to be widened to allow for future growth, i.e. additional traffic lanes for general capacity improvements, or change in policy regarding travel demand management.

As such part of the stormwater treatment could be used to accommodate these future improvements but a change to the Bio Filters width would require a change to the type of drainage system.

#### **5.3.6 Capital Cost**

The differences between the major capital costs for the two Causeway profile options ((N) and (W)) can be described briefly as:

- Option D(W) would require greater ground improvement measures;
- Option D(W) would require greater earthwork volumes;
- Option D(W) would allow for the removal of the nearside concrete barriers.

A comparison of the cost to construct the minimum and wider Causeway was undertaken.

#### **Cartridge Filter System Option**

The estimated capital cost to construct the minimum Causeway profile was estimated as \$114,530 per linear metre.

### **Bio Filter Option**

The estimated capital cost to construct the wider Causeway profile was estimated as \$119,470 per linear metre. This equates to a cost increase of \$4,930 per linear metre to construct the wider Causeway option. This costing does not include the likely long-term savings obtained through reduced maintenance and design flexibility over its design life.

#### **5.3.7 Ecological**

The Causeway crest-to-crest width is 9.3m wider for the Bio Filter Option D(W) compared to the narrower cartridge filter Option D(N). Therefore from a marine ecological aspect the narrower Causeway, utilising cartridge filters, would have less of an ecological effect compared to Option D(W).

## **5.4 Causeway Stormwater Treatment Recommendation**

The wider Causeway footprint Option D(W) that incorporates the Bio Filters as treatment for stormwater runoff is recommended. Table 5.1 summarises the assessment between Option D(W) and D(N).

The benefits of the wider footprint can be summarised as:

- design tolerances for the Bio Filters provide greater flexibility in combating the effects and uncertainty of differential settlement across and along the Causeway;
- it provides the minimum clear zone removing the need for shoulder barriers and thus improving safety and reducing ongoing maintenance costs;
- removing the need for shoulder barriers also provides uninterrupted views to the Waitemata Harbour and marine reserve, thereby enhancing the vehicle occupants' experience;
- maintenance of the Bio Filters is less stringent and intensive than that of the filter cartridges and open grated channels;
- a greater width provides increased flexibility during the construction staging process and allowing existing bus shoulder operation through all but parts of Phase 1 and 2 of construction;
- providing a wider Causeway cross-section will allow future long-term proposals with less likelihood of additional reclamation of the marine environment;
- providing a wider Causeway cross-section will allow it to be raised more easily than the narrow cross-section in the future in case sea level rise is greater than currently projected;

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	Cartridge System / Minimum Causeway Section / Option D(N)	Bio Filter / Wider Causeway Section / Option D( W)
<b>System Capability</b>	<ul style="list-style-type: none"> <li>✗ The design tolerance for a cartridge system is relatively stringent and finite, resulting in reduced flexibility to counteract the effects of differential settlement across the Causeway.</li> <li>✗ Higher level of risk associated with a more complex and design heavy system compared to the Bio Filter option associated with a wider Causeway footprint.</li> </ul>	<ul style="list-style-type: none"> <li>✓ Design tolerances for the installation of Bio Filters provide greater flexibility in combating the effects of differential settlement across and along the Causeway.</li> <li>✗ The Bio Filters are designed to accept transverse runoff. The current design width of 7m is considered conservative.</li> </ul>
<b>Maintenance</b>	<ul style="list-style-type: none"> <li>✗ Unlike Bio Filters, the cartridge system will require regular invasive cleaning and cartridge replacement.</li> <li>✗ Safety Barriers will require maintenance.</li> </ul>	<ul style="list-style-type: none"> <li>✓ Non-intensive maintenance required. However grass length must be controlled frequently by mowing and/or weeding.</li> </ul>
<b>Barriers</b>	<ul style="list-style-type: none"> <li>✗ A minimum Causeway cross-section will not have the necessary width to provide an adequate Clear Zone, thereby requiring safety barriers adjacent to the bus shoulders.</li> <li>✗ Safety barriers are expected to impede vehicle occupants' views to the Waitemata Harbour, thereby reducing the aesthetics when driving over the Causeway.</li> </ul>	<ul style="list-style-type: none"> <li>✓ A wider Causeway cross-section will provide a satisfactory Clear Zone, negating the need for safety barriers. Omitting safety barriers will maintain uninterrupted views to the Waitemata Harbour.</li> <li>✓ Providing clear zones instead of safety barriers is best practice and safer for vehicle occupants.</li> </ul>
<b>Constructability</b>	<ul style="list-style-type: none"> <li>✗ Existing bus shoulder operation would need to be suspended during construction (approximately 3 years).</li> <li>✓ Shorter construction time (relative to wider Causeway section) reduces the negative impacts on travel times for the Public.</li> </ul>	<ul style="list-style-type: none"> <li>✓ A wider Causeway cross-section will allow greater width and flexibility during the construction staging process, and will allow bus shoulder operation through all but one phase of construction.</li> <li>✗ A wider Causeway cross-section may possibly demand a longer construction period, resulting in longer inconvenience to the travelling Public.</li> </ul>
<b>Future Proofing</b>	<ul style="list-style-type: none"> <li>✗ A minimum cross-section will not allow long term future proofing of the Causeway. Possible further reclamation would be required in the long term.</li> <li>✗ Long term proposals may require additional construction time, due to a confined Causeway width and associated difficulties with traffic management and further disturbance within the ecologically sensitive Marine Reserve.</li> </ul>	<ul style="list-style-type: none"> <li>✓ Providing a wider Causeway cross-section will allow it to be raised more easily than minimum cross-section in the future in case sea level rise is greater than currently predicted.</li> <li>✓ Providing a wider Causeway cross-section will allow future long term proposals.</li> <li>✓ Future proposals may be undertaken without the need of additional reclamation of the marine environment, thereby limiting further disturbance within the Marine Reserve.</li> </ul>
<b>Cost</b>	<ul style="list-style-type: none"> <li>✓ A reduced Causeway footprint will have a lower overall capital cost compared to a wider Causeway cross-section.</li> <li>✗ Though the initial capital cost of constructing a minimum Causeway cross-section will be less than a wider cross-section, the long term or whole life cost may be higher due to cost of maintenance requirements.</li> </ul>	<ul style="list-style-type: none"> <li>✗ The capital cost associated with a wider Causeway cross-section will be greater than that of a minimum Causeway section.</li> <li>✓ Though the initial capital cost of constructing a wider Causeway section will be greater than a reduced section, the long term or whole life cost may be less due to the nature of the maintenance requirements.</li> </ul>
<b>Ecological</b>	<ul style="list-style-type: none"> <li>✓ A reduced Causeway footprint will require minimum land take from the Marine Reserve.</li> </ul>	<ul style="list-style-type: none"> <li>✗ A wider Causeway footprint will require more reclamation of the Marine Reserve.</li> </ul>

**Table 5.1 - Assessment between Option D(N) and Option D(W).**



## 6. Options and Sub-options Assessment Summary

In addition to the original options assessed (Options A to F) various sub-options have also been assessed i.e. Options D(1) and D(2) (taking into consideration symmetrical or asymmetrical widening) and Option D(W) (considering stormwater treatment and the influence this will have on the Causeway width). Therefore to provide a clear and holistic assessment summary an options assessment table has been developed and is included as Appendix D.

As the Causeway embankment for the preferred option (Option D(W)) is wider than originally envisaged it was considered prudent to reassess this option against the viaduct structure option (this option scored highly in the assessment contained within Appendix D) with both options being developed to a similar level of design detail, refer to Section 7 of this report.

## 7. Option Assessment Update

### 7.1 Embankment Widening Design Development

The design of the proposed Causeway cross section (Option D(W)) has developed since 2007. Appendix E contains simplified plans, long section and cross section of the proposed Causeway design. The Causeway width now consists of:

- 5 x westbound traffic lanes;
- 4 x eastbound traffic lanes;
- 2 x bus shoulders;
- 2 x median shoulders;
- 1 x TL4 median barrier;
- 2 x grassed stormwater Bio Filters;
- 1 x services berm included within the eastbound grassed Bio Filters;
- 1 x cycle way;
- 2 x rock armour crests/revetments.

The proposed Causeway design is wider (crest to crest) than that of the design based in 2007 (Appendix C). The increased width arises from the following main design changes:

- an additional westbound general traffic lane is required, resulting in five proposed westbound traffic lanes (refer to the **Assessment of Transport Effects**;
- engineered Bio Filters to treat and convey motorway stormwater runoff are required (refer to the **Stormwater and Streamworks Assessment** and Section 5 of this report); and
- allowance of a 3m rock armour crest as a coastal protection measure to seaward revetment (refer to **Interpretation of Hydrodynamic Design Conditions Report**);

As a result of the width increase it was considered prudent to re-assess Option D(W) (widened and raised embankment) and Option E (viaduct structure).

### 7.2 Viaduct Option E - Design Development

#### 7.2.1 Viaduct Superstructure

In order to assess both Option D and E in greater detail, the viaduct design has been developed to encompass the relevant changes in design. Appendix F contains plans, long sections and cross sections of the viaduct Option E. The viaduct concept design for this assessment consists of 43 spans of 1500mm deep double tee

beams 33m long. Each of the 42 piers and 2 abutments will be founded on eleven 1200mm diameter piles cast insitu, penetrating the bed rock by 5m. A 3% carriageway cross fall and 1% longitudinal fall has been included. Option E viaduct width consists of:

- 5 x westbound traffic lanes (3.5m)
- 4 x eastbound traffic lanes (3.5m)
- 2 x bus shoulders (3.5m)
- 2 x shy lines (0.5m)
- 2 x median shoulders (3m)
- 1 x TL4 median barrier (0.6m)
- 2 x TL5 shoulder barriers (0.6m)
- 1 x cycleway and barrier (3m + 0.6m)

Provision for services would be accommodated between the beams on the northern side of the viaduct. The total proposed viaduct width is 51.0m.

### 7.2.2 Viaduct Foundation Selection

Two foundation options were considered for the viaduct. The main advantages and disadvantages of either foundation option are presented below:

#### Bored Piles Foundations

##### **Advantages**

- Removes (both differential and total settlement issues) which may result from driven pile foundations; and
- Ability to pass through volcanoclastic layer approximately 20m below ground level.

##### **Disadvantages/Risks**

- Longer construction time compared to driven piles; and
- Deep pile depth (50m+) restricting construction equipment to the largest currently available in New Zealand.

#### Driven Pile Foundations

##### **Advantages**

- Possible reduction in construction costs compared to bored piles; and
- Possible reduction in construction time compared to bored piles.

##### **Disadvantages/Risks**

- Long slender pile elements would be difficult to handle, and may require splicing to reach the required depth;
- Piles may buckle under driving loads due to very little support from weak upper ground layers;
- A volcanoclastic layer exists at approximately 20m below ground, which is difficult to drive precast piles through; and
- Negative skin friction may be present due to the continued settlement of the existing Causeway.

As a result of the greater number of risks outlined above for driven pile foundations, the bored pile foundations were taken forward for comparison with Option D(W).

## 7.3 Option Evaluation Discussion

Referring to the information presented in Appendix A and the plans, long sections and cross sections contained within Appendices E and F, the option evaluation is discussed as follows:

### 1) Environmental & Ecology Constraints

The coastal margins beside the Causeway are protected by rock armour rubble that accumulates litter and flotsam. These areas are generally of relatively low ecological value. Although, below the armour within the marine sediments the ecology values on the northern side are moderate to high and on the southern side low to moderate (with respect to benthic invertebrates and sediment quality). (refer to the **Assessment of Marine Ecological Effects (20.1.11-3-R-N-1008)**). Option D(W) resembles the existing Causeway, whereas Option E does not.

### 2) Coastal

Unpredictability in wave overtopping and sea level rise projections is not as critical for Option E as it is for Option D, since the viaduct can be well above sea level. Most of the piles would be founded through the existing Causeway, with only part of the southern row of piles located within the CMA. Further consideration would be required to determine the minimum required elevation of the viaduct to future proof against climate change. Retrofitting the viaduct structure would be more costly and difficult in the future whereas the widened embankment could be readily modified at a lower cost.

### 3) Geotechnical

The geotechnical advantage of Option E is that the viaduct would minimise settlement risk if piles were driven into bed rock or stronger founding layers. Ground improvements to the marine mud would only be required on the approach embankments to the viaduct abutments.

The geotechnical advantage of Option D(W) is that earthworks and revetments can naturally adjust to differential settlements. Raising the existing Causeway would induce additional settlement of the existing Causeway. There is a risk of differential settlement being unacceptable between these two elements, but this can be mitigated through the detailed design process. It is noted that all proposed traffic lanes are directly above the existing portion of the Causeway (symmetrical widening) and therefore any differential settlement between the two elements should not cause significant detriment to the paved surfaces.

It is anticipated that raising (but not widening) the Causeway again in the future would not require any further ground improvements, as the founding marine muds below the embankment extensions would have gained strength over time, and would allow a greater load to be imposed upon them without creating new instabilities.

### 4) Constructability

Staging of the construction works and traffic management is expected to be similar for Option D(W) and Option E. Both options require the existing traffic lanes to be managed during construction.

Option D(W) would require the widest footprint to enable the contractor additional space for construction activities related to ground improvements and earthworks.

For Option E, the viaduct could be constructed off-line from the existing Causeway centreline to ease traffic management constraints, although the room allowed for construction activities would be limited and would require additional working at height related safety measures to be implemented.

## 5) Construction Cost & Maintenance

In order to robustly compare the construction cost difference between Option D(W) and Option E, an indicative construction cost estimate exercise was undertaken. The cost estimate was undertaken along the same section of motorway for both options (from Ch850 to Ch2775 inclusive). For Option D(W) the preferred ground improvement technique (in-situ Mudcrete) was also taken into consideration. For Option E, this included the viaduct (Ch1000 to Ch2420) and a raised and widened section of Causeway either end of the viaduct required to tie into to the existing road alignment.

The expected estimate for Option D(W) is \$210M and for Option E is \$404M, a difference of \$194M.

The viaduct stormwater treatment devices would be likely to consist of numerous maintenance intensive filter cartridges i.e. similar to Option D. The Bio Filters proposed in Option D(W) would require less intensive maintenance (such as mowing and levelling when required). Significant maintenance work would be required to replace bridge bearings and expansion joints every 30 years, whereas maintenance of the Causeway would be likely to include shape correction of the carriageway over its lifetime. Therefore, maintenance costs for the bridge viaduct is likely to be more than the widened Causeway. In addition, any future modifications to the Causeway (if required) are likely to be relatively straightforward to implement as well as less expensive, when compared to Option E.

## 7.4 Option D(W) against Option E Recommendation

Following further assessment, Option D(W) is recommended (widening and raising of the existing Causeway with revetments).

The Causeway option requires more reclamation than the viaduct option and the effect of reclamation to marine ecology will be greater for Option D(W). However, the ecological effects for Option D(W) are considered to be less than minor as ecological off-set mitigation is proposed; namely, increasing the level of treatment to stormwater motorway run-off, refer to the **Assessment of Marine Ecological Effects (20.1.11-3-R-N-1006)** for further information.

While the majority of the geotechnical risk such as settlement and stability can be eliminated using a viaduct founded on bored piles, the cost of the viaduct is substantially more than raising and widening the Causeway. In addition, future modification to the Causeway (if required) are likely to be easier to implement, as well as less expensive than modifications to a viaduct.

## 8. Conclusions

Six main options for the development of the Causeway as part of the Project were assessed in order to recommend a preferred solution for the existing Causeway replacement. These options are:

- A. Widening of the existing Causeway with wall structures to form a ‘trough’;
- B. Widening of the existing Causeway with rock revetments to form a ‘trough’;
- C. Widening and raising of the existing Causeway with wall structures;
- D. Widening and raising of the existing Causeway with rock revetments;
- E. Placing a viaduct structure over the existing Causeway; or
- F. Raising of the existing Causeway and widening with viaduct structures.

Options A and B can not address sea level rise, pavement flooding or stormwater runoff. These factors are significant given the importance of the Project objectives such as securing a reliable motorway and future proofing for sea-level rise caused by climate change.

Option D was preferred over replacing the existing Causeway with a viaduct structure (Option E) due to whole life costs (construction and maintenance), as well as the flexibility to accept additional lanes that may be deemed necessary in the future.

Option F was discounted due to the significant longitudinal differential settlement risk between the viaduct structures and the central raised Causeway section.

An assessment was carried out to understand whether the Causeway should be widened symmetrically or asymmetrically (north or south). This report recommends symmetrical widening.

An assessment was carried out to understand what stormwater reticulation and treatment should be used on the Causeway. The two options considered were:

- open channel & cartridge filters based upon minimising the Causeway width – Option D(N);
- grassed Bio Filters requiring a wider Causeway – Option D(W).

## 9. Recommendations

The recommended option for the Causeway replacement is Option D(W). This is defined as:

1. Raising (by use of engineered fill material) across the full width of the proposed Causeway taking into consideration future sea level rise caused by climate change; and
2. Symmetrical widening about the existing Causeway centre line;
3. Coastal protection using revetment slopes (similar to existing);
4. A wider Causeway footprint that incorporates Bio Filters as treatment for stormwater runoff.

## 10. References

Aurecon (2010) “Western Ring Route – Waterview Connection - **Interpretation of Hydrodynamic Design Conditions Report 20.1.11-3-R-J-305**”, August 2010

Aurecon (2010) “Western Ring Route – Waterview Connection - **Coastal Works Engineering Report 20.1.11-3-R-J-306**”, August 2010

Aurecon and Tonkin & Taylor (2010) “Western Ring Route – Waterview Connection - **Assessment of Stormwater & Streamworks Effects 20.1.11-3-R-N-1013**”, August 2010

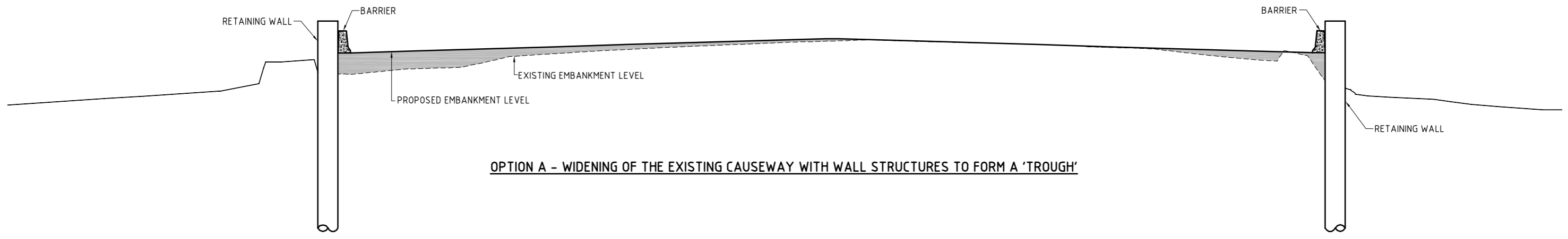
Boffa Miskell (2010) “Western Ring Route – Waterview Connection – **Assessment of Marine Ecological Effects 20.1.11-3-R-N-1006**”, August 2010

NIWA and Tonkin & Taylor (2010) “Western Ring Route – Waterview Connection - **Assessment of Coastal Processes 20.1.11-3-R-N-1012**”, August 2010

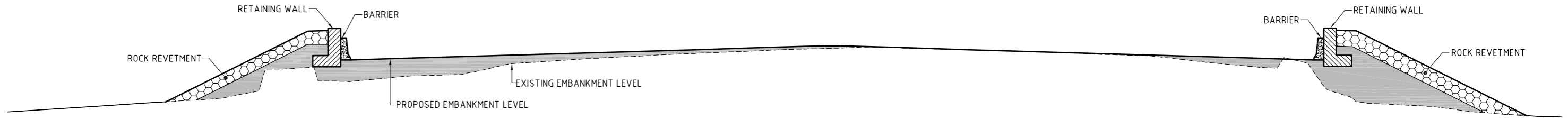
Bioresearches (2010) “Western Ring Route – Waterview Connection - **Avian Ecological Assessment 20.1.11-3-R-N-1008-A**”, August 2010



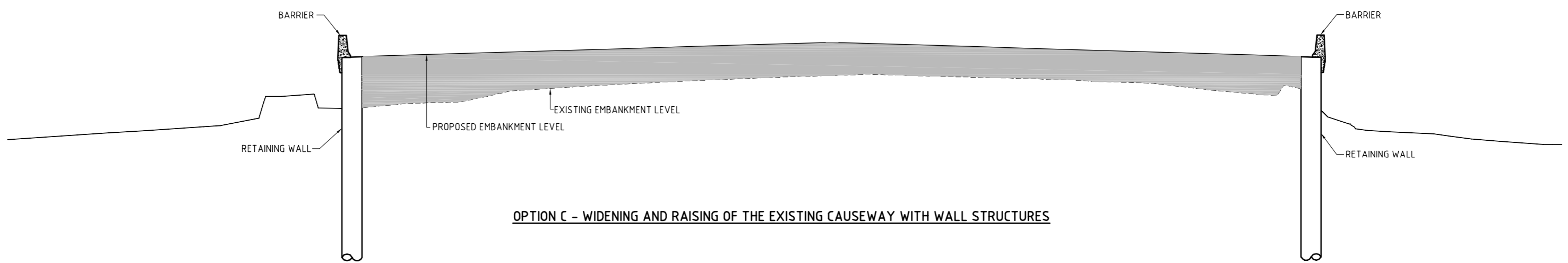
## APPENDIX A: Indicative Cross Sections of Options A to F



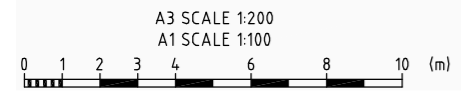
**OPTION A - WIDENING OF THE EXISTING CAUSEWAY WITH WALL STRUCTURES TO FORM A 'TROUGH'**



**OPTION B - WIDENING OF THE EXISTING CAUSEWAY WITH ROCK REVETMENTS TO FORM A 'TROUGH'**



**OPTION C - WIDENING AND RAISING OF THE EXISTING CAUSEWAY WITH WALL STRUCTURES**



**DRAFT FOR REVIEW**

No.	Revision	By	Chk	Appd	Date
A	FOR REVIEW				

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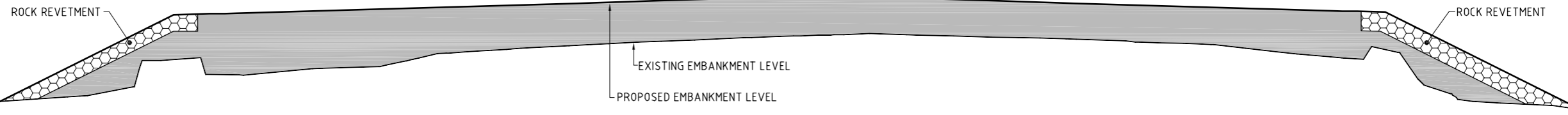
Original Scale (A1) 1:100	Design Engineer
Reduced Scale (A3) 1:200	Review Engineer
	Drafting Checked
	Consultant Approval
	Received by Becca

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 WAKA KOTAHI

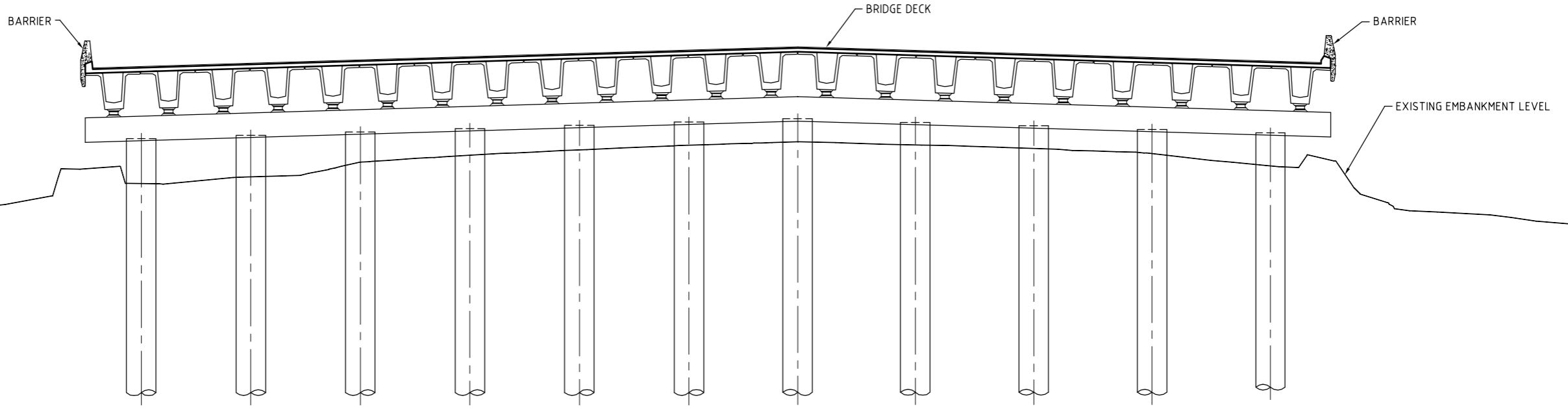
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 SH16 / SH20

Title: **INDICATIVE CROSS SECTIONS CAUSEWAY OPTIONS SHEET 1**

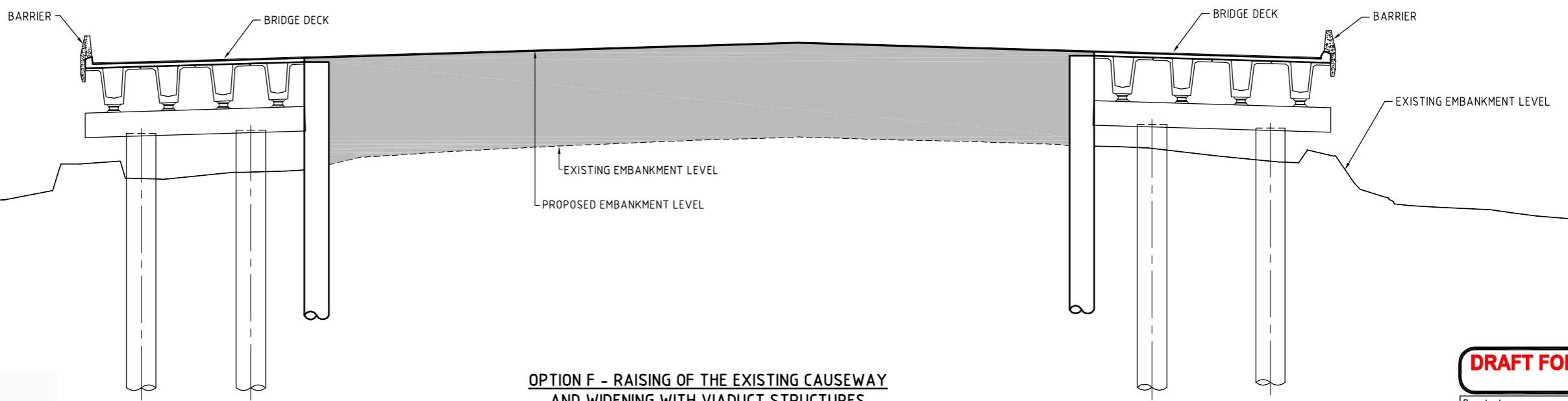
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Originator No.
Project No. <b>20.1.11-3-D-C-109-201</b>
Rev. <b>A</b>



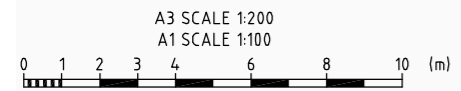
**OPTION D - WIDENING AND RAISING OF THE EXISTING CAUSEWAY WITH ROCK REVETMENTS**



**OPTION E - VIADUCT STRUCTURE**



**OPTION F - RAISING OF THE EXISTING CAUSEWAY AND WIDENING WITH VIADUCT STRUCTURES**



**DRAFT FOR REVIEW**

Base Level: <b>MSL AUCK. VERT. DATUM 1946</b>	
Grid Reference: <b>Mt Eden 2000</b>	
Originator No.	
Project No.	Rev.
<b>20.111-3-D-C-109-202</b>	<b>A</b>

No.	Revision	By	Chk	Appd	Date
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Reduced Scale (A3) 1:200	Review Engineer
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WAKA KOTAHĪ

Project: **WATERVIEW CONNECTION PROJECT SH16 / SH20**

Title: **INDICATIVE CROSS SECTIONS CAUSEWAY OPTIONS SHEET 2**


## APPENDIX B: Options A to F Evaluation

Option	Environmental	Coastal	Geotechnical	Constructability and Construction Cost	Maintenance
<p style="text-align: center;"><b>A</b></p> <p style="text-align: center;">Widening of the existing Causeway with wall structures to form a "trough"</p> 	<ul style="list-style-type: none"> <li>✓ narrower foot print minimises reclamation</li> <li>✓ narrower foot print minimises effects on tidal channels</li> <li>✗ walls will reflect wave energy back into the Marine Estuary potentially causing scour/erosion of the sea bed</li> <li>✗ limited views to the Waitemata Harbour for vehicle occupants</li> <li>✗ walls structures can be unnatural in appearance</li> </ul>	<ul style="list-style-type: none"> <li>✗ walls could be extended vertically if sea level rise is greater than expected, however the wall foundations must be future proofed to allow extension</li> <li>✗ design for wave over topping and sea level rise projections critical</li> <li>✗ significant flooding would occur if wall structures were breached or inundated by the sea</li> <li>✗ pavement layers will be frequently inundated by static storm tide levels. This would reduce the life span of the existing pavement</li> </ul>	<ul style="list-style-type: none"> <li>✓ no induced settlement of existing Causeway</li> <li>✗ foundation Issues – the walls would require deep piled foundations. These may have to be very deep (uneconomic) to obtain adequate capacity</li> <li>✗ wall structures would require water cut-off to prevent seepage</li> <li>✗ wall structures are "hard" coastal protection solutions, that could cause problems when differential settlement and/or localised erosion occurs</li> </ul>	<ul style="list-style-type: none"> <li>✓ traffic management would be relatively simple as existing carriageways are not required to be raised. Work would proceed as parallel widening</li> <li>✓ minimal volume of bulk fill required and existing pavement may be retained</li> <li>✗ deep soft marine mud would result in extensive and heavy engineered wall structures, cost of retaining walls expected to be high</li> </ul>	<ul style="list-style-type: none"> <li>✗ stormwater would require to be mechanically pumped out as there is insufficient head between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✗ maintenance and monitoring of retaining walls required</li> <li>✗ additional works in the future would be costly</li> </ul>

Options A to F evaluation:

✓ Positive Effect


✗ Negative Effect

Option	Environmental	Coastal	Geotechnical	Constructability and Construction Cost	Maintenance
<p style="text-align: center;"><b>B</b></p> <p>Widening of the existing Causeway with revetments to form a “trough”</p> 	<ul style="list-style-type: none"> <li>✓ resembles the existing Causeway</li> <li>✓ appearance of the Waitemata Harbour similar to existing</li> <li>✗ wide footprint increases reclamation</li> <li>✗ wider footprint increases throttling effects on tidal channels</li> <li>✗ limited views to the Waitemata Harbour for vehicle occupants</li> </ul>	<ul style="list-style-type: none"> <li>✓ rock armour dissipates wave energy, as opposed to reflecting wave energy back into the sea, minimising impacts to the existing hydrodynamic conditions</li> <li>✗ design for wave over topping and sea level rise projections critical</li> <li>✗ significant flooding would occur if wall structures were breached or inundated by the sea</li> <li>✗ pavement layers will be frequently inundated by static storm tide levels. This would reduce the life span of the existing pavement</li> </ul>	<ul style="list-style-type: none"> <li>✓ rock armour is a proven coastal protection solution that will adjust to changes like local settlements</li> <li>✓ no induced settlement of existing Causeway</li> <li>✗ differential settlement (new/old) to be accommodated for</li> </ul>	<ul style="list-style-type: none"> <li>✓ traffic management would be relatively simple as existing carriageways would not require to be raised. Work would proceed as parallel widening</li> <li>✓ minimal volume of bulk fill required and existing pavement may be retained</li> <li>✓ cost of rock armour revetments expected to only be moderate as some of the existing rock can be reused</li> <li>✗ engineered retaining wall structures also required</li> </ul>	<ul style="list-style-type: none"> <li>✗ stormwater would require to be mechanically pumped out as there is insufficient head between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✓ maintenance of revetment coastal protection relatively straight forward (i.e. add more rock when required)</li> </ul>

Options A to F evaluation:

✓ Positive Effect


✗ Negative Effect

Option	Environmental	Coastal	Geotechnical	Constructability and Construction Cost	Maintenance
<p style="text-align: center;"><b>C</b></p> <p>Widening and raising of the existing Causeway with wall structures</p> 	<ul style="list-style-type: none"> <li>✓ narrower foot print minimises reclamation</li> <li>✓ narrower foot print minimises effects on tidal channels</li> <li>✓ views to the Waitemata Harbour for vehicle occupants are maintained</li> <li>✗ walls will reflect wave energy back into the Marine Estuary potentially causing scour/erosion of the sea bed</li> <li>✗ walls structures can be unnatural in appearance</li> </ul>	<ul style="list-style-type: none"> <li>✗ walls could be extended vertically if sea level rise is greater than expected, however the wall foundations must be future proofed to allow extension</li> <li>✓ elevation of Causeway can be sufficient to prevent inundation</li> <li>✓ pavement layers infrequently inundated by static storm tide levels. Life span of proposed pavement increased</li> </ul>	<ul style="list-style-type: none"> <li>✗ induced settlement of existing Causeway</li> <li>✗ foundation Issues – the walls would require deep piled foundations. These may have to be very deep (uneconomic) to obtain adequate capacity</li> <li>✗ wall structures would require water cut-off to prevent seepage</li> <li>✗ wall structures are “hard” coastal protection solutions, that could cause problems when differential settlement and/or localised erosion occurs</li> </ul>	<ul style="list-style-type: none"> <li>✗ phased construction required to allow temporary traffic management</li> <li>✗ deep soft marine mud would result in extensive and heavy engineered wall structures and foundations</li> <li>✗ significant volume of bulk fill required</li> <li>✗ cost of retaining walls expected to be high</li> </ul>	<ul style="list-style-type: none"> <li>✓ sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✗ maintenance and monitoring of retaining walls required</li> </ul>

Options A to F evaluation:

✓ Positive Effect

✗ Negative Effect

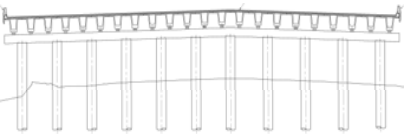
Option	Environmental	Coastal	Geotechnical	Constructability and Construction Cost	Maintenance
<p style="text-align: center;"><b>D</b></p> <p style="text-align: center;">Widening and raising of the existing Causeway with revetments</p> 	<ul style="list-style-type: none"> <li>✓ resembles the existing Causeway</li> <li>✓ views to the Waitemata Harbour for vehicle occupants are maintained</li> <li>✓ appearance of Waitemata Harbour similar to existing</li> <li>✗ wide footprint increases reclamation</li> <li>✗ wider footprint increases throttling effects on tidal channels</li> </ul>	<ul style="list-style-type: none"> <li>✓ rock armour dissipates wave energy, as opposed to reflecting wave energy back into the sea, minimising impacts to the existing hydrodynamic conditions</li> <li>✓ elevation of Causeway can be sufficient to prevent inundation</li> <li>✓ pavement layers infrequently inundated by static storm tide levels. Life span of proposed pavement increased</li> </ul>	<ul style="list-style-type: none"> <li>✓ rock armour is a proven coastal protection solution that will adjust to changes like local settlements</li> <li>✗ significant risk of differential settlement being unacceptable between elements</li> <li>✗ ground improvements required</li> <li>✗ induced settlement of existing Causeway</li> </ul>	<ul style="list-style-type: none"> <li>✓ widest footprint enables greater space and flexibility</li> <li>✓ no extensive and heavy engineered retaining wall structures and foundations required</li> <li>✓ cost of rock armour revetments expected to only be moderate as some of the existing rock can be reused</li> <li>✗ phased construction required to allow temporary traffic management</li> <li>✗ significant volume of bulk fill required</li> </ul>	<ul style="list-style-type: none"> <li>✓ sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✓ maintenance of revetment coastal protection relatively straight forward (i.e. add more rock when required)</li> </ul>

Options A to F evaluation:

✓ Positive Effect

✗ Negative Effect




Option	Environmental	Coastal	Geotechnical	Constructability and Construction Cost	Maintenance
<p style="text-align: center;"><b>E</b> Viaduct structure</p> 	<ul style="list-style-type: none"> <li>✓ very little or no reclamation required</li> <li>✓ views to the Waitemata Harbour for vehicle occupants are maintained</li> <li>✗ shadow cast over the existing Causeway will result in a 'dead area' which would be difficult to convert into an amenity</li> <li>✗ viaduct structure will alter the appearance of the Waitemata Harbour</li> </ul>	<ul style="list-style-type: none"> <li>✓ unpredictability in wave over topping and sea level rise projections not as critical since viaduct can be 'well above' sea level</li> <li>✗ piles penetrating the Marine Reserve along either side of the Causeway, in places, may cause scour issues</li> </ul>	<ul style="list-style-type: none"> <li>✓ minimal settlement risk if piles are driven into bed rock or stronger alluvial layers</li> <li>✓ very little or no ground improvements required</li> <li>✗ deep marine mud will require large earthquake loading design to structure</li> <li>✗ bed rock is deep resulting in exceptionally long piles</li> </ul>	<ul style="list-style-type: none"> <li>✓ bulk fill minimised</li> <li>✗ deep marine mud will force piling to be taken to significant depths and therefore costly. Construction equipment restricted to the largest currently available in New Zealand</li> <li>✗ phased construction required to allow temporary traffic management</li> <li>✗ temporary work platforms likely to be required to construct outer rows of piles</li> <li>✗ foundation costs are expected to be very high</li> <li>✗ working at height</li> </ul>	<ul style="list-style-type: none"> <li>✓ sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✗ stormwater quality treatment is likely to consist of intensive proprietary devices</li> <li>✗ significant replacement work required to bridge bearings and expansion joints every 30 years</li> </ul>

Options A to F evaluation:

✓ Positive Effect

✗ Negative Effect

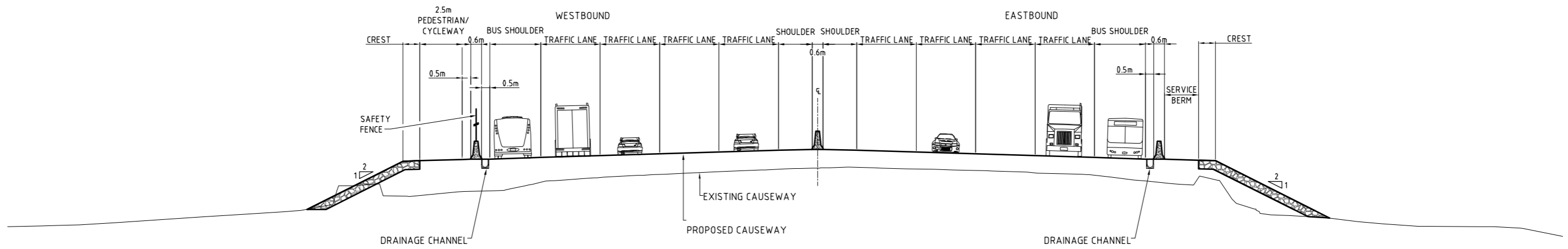
Option	Environmental	Coastal	Geotechnical	Constructability and Construction Cost	Maintenance
<p style="text-align: center;"><b>F</b></p> <p style="text-align: center;">Combined raising of the Causeway and widening with viaduct structures</p> 	<ul style="list-style-type: none"> <li>✓ very little or no reclamation required</li> <li>✓ narrower foot print minimises effects on tidal channels</li> <li>✓ views to the Waitemata Harbour for vehicle occupants are maintained</li> <li>✗ viaduct structures on either side will alter the appearance of the Waitemata Harbour</li> </ul>	<ul style="list-style-type: none"> <li>✓ unpredictability in wave over topping and sea level rise projections not as critical since viaducts and road pavement can be 'well above' sea level</li> <li>✗ piles penetrating the Marine Reserve along either side of the Causeway, in places, may cause scour issues</li> </ul>	<ul style="list-style-type: none"> <li>✗ surcharge on existing Causeway will exacerbate on-going settlement</li> <li>✗ longitudinal differential risk between viaducts and raised central part will be difficult to mitigate</li> <li>✗ deep marine mud will require large earthquake loading design to retaining walls and viaduct structures</li> <li>✗ bed rock is deep resulting in exceptionally long piles</li> </ul>	<ul style="list-style-type: none"> <li>✗ deep marine mud will force piling to be taken to significant depths. Construction equipment restricted to the largest currently available in New Zealand</li> <li>✗ phased construction required to allow temporary traffic management</li> <li>✗ structural connection details between viaducts and retaining walls will be complex in order to accommodate differential settlement</li> <li>✗ considerable volume of fill required to raise central section of Causeway</li> <li>✗ foundation costs are expected to be very high</li> </ul>	<ul style="list-style-type: none"> <li>✓ sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✗ stormwater quality treatment is likely to consist of maintenance intensive proprietary devices</li> <li>✗ significant replacement work required to bridge bearings and expansion joints every 30 years</li> </ul>

Options A to F evaluation:

✓ Positive Effect

✗ Negative Effect

## APPENDIX C: Option D – Typical Cross Section (2007)



**TYPICAL CROSS SECTION OPTION D**  
**WIDENING & RAISING OF THE EXISTING CAUSEWAY WITH REVETMENTS (2007)**



**PRELIMINARY**  
**NOT FOR CONSTRUCTION**

Base level: <b>MSL AUCK. VERT. DATUM 1946</b>	
Grid Reference: <b>Mt Eden 2000</b>	
Originator No.	
Project No. <b>20.111-3-D-C-109-211</b>	Rev. <b>A</b>

No.	Revision	By	Chk	Appd	Date
A	FOR REVIEW				

Drawing Originator:  
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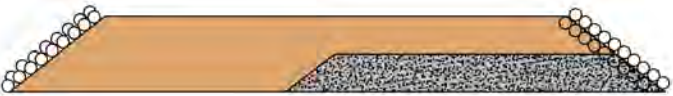



Original Scale (A1) 1:125	Design Engineer
Reduced Scale (A3) 1:250	Review Engineer
	Drafting Checked
	Consultant Approval
	Reviewed by <i>Beca</i>

**NZ TRANSPORT AGENCY**  
 WAKA KOTAHĪ

Project: **WATERVIEW CONNECTION PROJECT**  
**SH16 / SH20**

Title: **TYPICAL CROSS SECTION OPTION D**

## APPENDIX D: Options and Sub-options Scoring Table

	Option/Sub-option Description	Option/Sub-option Sketch	Overall Score
A	Widening of the existing Causeway with wall structures to form a “trough”		10
B	Widening of the existing Causeway with revetments to form a “trough”		15
C	Widening and raising of the existing Causeway with wall structures		11
D(N)	Widening (symmetrically) and raising of the existing Causeway with revetments		16
D(1)	Widening (asymmetrically to the North) and raising of the existing Causeway with revetments		15
D(2)	Widening (asymmetrically to the South) and raising of the existing Causeway with revetments		19
D(W)	Widening (symmetrically) and raising of the existing Causeway with revetments – incorporating Bio-filters resulting in a wider footprint		21
E	Viaduct structure		16
F	Combined raising of the Causeway and widening with viaduct structures		13

Option/Sub-option		Comments and Scores (1 = Worst, 5 = Best, ✓ = Positive Effect, ✗ = Negative Effect)									Overall Score	
		Environmental	Score	Coastal	Score	Geotechnical	Score	Constructability and Construction Cost	Score	Maintenance and Future Flexibility		Score
<b>A</b>	Widening of the existing Causeway with wall structures to form a "trough"	<ul style="list-style-type: none"> <li>✓ narrow footprint reduces reclamation</li> <li>✗ walls will reflect wave energy back into the Marine Estuary potentially causing scour/erosion of the sea bed</li> <li>✗ walls structures do not resemble the existing Causeway</li> </ul>	2	<ul style="list-style-type: none"> <li>✗ pavement layers will be frequently inundated by static storm tide levels. This would reduce the life span of the existing pavement</li> <li>✗ significant flooding would occur if wall structures were breached or inundated by the sea</li> </ul>	1	<ul style="list-style-type: none"> <li>✓ no induced settlement of existing Causeway</li> <li>✗ foundation issues – the wall structures would require deep piled foundations. These would have to be very deep (uneconomical) to achieve adequate capacity</li> <li>✗ differential settlement will cause structural issues for the retaining walls</li> </ul>	2	<ul style="list-style-type: none"> <li>✓ traffic management would be relatively simple as existing carriageways are not required to be raised. Work would proceed as parallel widening</li> <li>✓ minimal bulk fill volume required and existing pavement may be retained</li> <li>✗ deep soft marine mud would result in extensive and heavy engineered wall structures, cost of retaining walls expected to be high</li> </ul>	3	<ul style="list-style-type: none"> <li>✗ stormwater would need to be mechanically pumped as there is insufficient head between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✗ additional works in the future would be costly</li> <li>✗ maintenance of retaining walls required</li> </ul>	2	10
<b>B</b>	Widening of the existing Causeway with revetments to form a "trough"	<ul style="list-style-type: none"> <li>✓ rock armour dissipates wave energy, as opposed to reflecting wave energy back into the sea, minimising impacts to the existing hydrodynamic conditions</li> <li>✗ wide footprint increases reclamation</li> </ul>	3	<ul style="list-style-type: none"> <li>✓ resembles the existing Causeway thus unlikely to have adverse hydrodynamic effects</li> <li>✗ significant flooding would occur if revetment and wall structures were breached or inundated by the sea</li> <li>✗ pavement layers will be frequently inundated by static storm tide levels. This would reduce the life span of the existing pavement</li> </ul>	2	<ul style="list-style-type: none"> <li>✓ no induced settlement of existing Causeway</li> <li>✓ rock armour is a proven coastal protection solution that will adjust to changes like local settlements</li> <li>✗ differential settlement will cause structural issues for the retaining walls</li> </ul>	3	<ul style="list-style-type: none"> <li>✓ traffic management would be relatively simple as existing carriageways would not need to be raised. Work would proceed as parallel widening</li> <li>✓ minimal bulk fill volume required and existing pavement may be retained</li> <li>✗ retaining walls required</li> </ul>	3	<ul style="list-style-type: none"> <li>✓ maintenance of revetment coastal protection relatively straight forward (i.e. add more rock armour when required)</li> <li>✗ stormwater would need to be mechanically pumped as there is insufficient head between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✗ maintenance of retaining walls required</li> </ul>	4	15

Option/Sub-option		Comments and Scores (1 = Worst, 5 = Best, ✓ = Positive Effect, ✗ = Negative Effect)								Overall Score		
		Environmental	Score	Coastal	Score	Geotechnical	Score	Constructability and Construction Cost	Score		Maintenance and Future Flexibility	Score
C	Widening and raising of the existing Causeway with wall structures	<ul style="list-style-type: none"> <li>✓ narrow footprint reduces reclamation</li> <li>✗ walls will reflect wave energy back into the Marine Estuary potentially causing scour/erosion of the sea bed</li> <li>✗ walls structures do not resemble the existing Causeway</li> </ul>	2	<ul style="list-style-type: none"> <li>✓ elevation of Causeway can be sufficient to prevent inundation</li> <li>✓ pavement layers are less likely to be inundated by static storm tide levels. Life span of proposed pavement increased</li> </ul>	4	<ul style="list-style-type: none"> <li>✗ induced settlement of the existing Causeway</li> <li>✗ foundation issues – the wall structures would require deep piled foundations. These would have to be very deep (uneconomical) to achieve adequate capacity</li> </ul>	1	<ul style="list-style-type: none"> <li>✗ phased construction required to allow temporary traffic management, facilitating widening and raising of the Causeway</li> <li>✗ deep soft marine mud would result in extensive and heavy engineered wall structures and foundations</li> <li>✗ cost of retaining walls expected to be high</li> </ul>	1	<ul style="list-style-type: none"> <li>✓ sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✗ maintenance of retaining walls required</li> </ul>	3	11
		<ul style="list-style-type: none"> <li>✓ narrow footprint reduces reclamation</li> <li>✓ rock armour dissipates wave energy, as opposed to reflecting wave energy back into the sea, minimising impacts to the existing hydrodynamic conditions</li> <li>✗ future traffic demands may require additional widening, resulting in further disturbance to the CMA</li> </ul>		4		<ul style="list-style-type: none"> <li>✓ resembles the existing Causeway thus unlikely to have adverse hydrodynamic effects</li> <li>✓ elevation of Causeway can be sufficient to prevent inundation</li> <li>✓ pavement layers are less likely to be inundated by static storm tide levels. Life span of proposed pavement increased</li> <li>✗ partial encroachment into three tidal channel locations within the Marine Estuary is required</li> </ul>		5		<ul style="list-style-type: none"> <li>✓ rock armour is a proven coastal protection solution that will adjust to changes like local settlements</li> <li>✗ induced settlement of the existing Causeway</li> <li>✗ design tolerance for a cartridge system is relatively stringent and finite, resulting in reduced flexibility to counteract the effects of settlement across the Causeway</li> <li>✗ high level of risk associated with a more complex and design heavy system compared to the Bio-filter option associated with a wider Causeway footprint</li> </ul>		

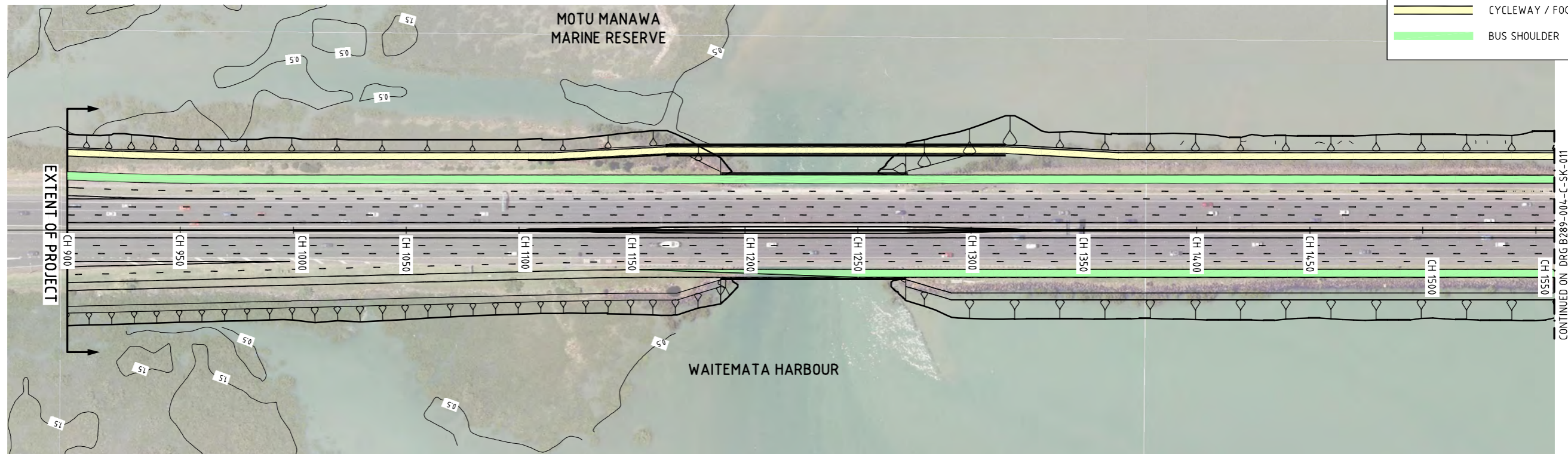


Option/Sub-option		Comments and Scores (1 = Worst, 5 = Best, ✓ = Positive Effect, ✗ = Negative Effect)								Overall Score		
		Environmental	Score	Coastal	Score	Geotechnical	Score	Constructability and Construction Cost	Score		Maintenance and Future Flexibility	Score
D(1)	Widening (asymmetrically to the North) and raising of the existing Causeway with revetments	<ul style="list-style-type: none"> <li>✓ rock armour dissipates wave energy, as opposed to reflecting wave energy back into the sea, minimising impacts to the existing hydrodynamic conditions</li> <li>✓ the intertidal bird feeding areas are marginally further away from the Causeway on the northern side</li> <li>✗ the north side has a slightly higher ecological value as there is a greater diversity of invertebrates present in the marine mud</li> <li>✗ significantly affects the Chenier shell banks</li> </ul>	2	<ul style="list-style-type: none"> <li>✓ encroachment into three tidal channel locations within the Marine Estuary is not required</li> <li>✓ resembles the existing Causeway therefore unlikely to have unknown adverse hydrodynamic effects</li> <li>✓ elevation of Causeway can be sufficient to prevent inundation</li> <li>✓ pavement layers are less likely to be inundated by static storm tide levels. Life span of proposed pavement increased</li> </ul>	5	<ul style="list-style-type: none"> <li>✓ rock armour is a proven coastal protection solution that will adjust to changes like local settlements</li> <li>✗ induced settlement of the existing Causeway</li> <li>✗ significant area of ground improvements needed</li> </ul>	3	<ul style="list-style-type: none"> <li>✓ no retaining wall structures</li> <li>✗ the existing Rosebank on-ramp viaduct structure would require demolition and re-construction at significant additional cost</li> <li>✗ phased construction required to allow temporary traffic management, facilitating widening and raising of the Causeway</li> <li>✗ requires replacement of the Causeway Bridges</li> </ul>	1	<ul style="list-style-type: none"> <li>✓ sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✓ maintenance of revetment coastal protection relatively straight forward (i.e. add more rock armour when required)</li> <li>✓ replacement of the Causeway Bridges would reduce maintenance costs</li> <li>✗ the deficient horizontal curve on the eastbound carriageway over Traherne Island would be exaggerated</li> </ul>	4	15
D(2)	Widening (asymmetrically to the South) and raising of the existing Causeway with revetments	<ul style="list-style-type: none"> <li>✓ rock armour dissipates wave energy, as opposed to reflecting wave energy back into the sea, minimising impacts to the existing hydrodynamic conditions</li> <li>✓ the south side has a slightly lower ecological value as there is a lesser diversity of invertebrates present in the marine mud</li> <li>✗ the intertidal bird feeding areas are marginally closer to the Causeway on the southern side</li> </ul>	4	<ul style="list-style-type: none"> <li>✓ resembles the existing Causeway therefore unlikely to have adverse hydrodynamic effects</li> <li>✓ elevation of Causeway can be sufficient to prevent inundation</li> <li>✓ pavement layers are less likely to be inundated by static storm tide levels. Life span of proposed pavement increased</li> <li>✗ full encroachment into three tidal channel locations within the Marine Estuary is required</li> </ul>	5	<ul style="list-style-type: none"> <li>✓ rock armour is a proven coastal protection solution that will adjust to changes like local settlements</li> <li>✗ induced settlement of the existing Causeway</li> <li>✗ significant area of ground improvements needed</li> </ul>	3	<ul style="list-style-type: none"> <li>✓ no retaining wall structures</li> <li>✗ phased construction required to allow temporary traffic management, facilitating widening and raising of the Causeway</li> <li>✗ requires replacement of the Causeway Bridges</li> </ul>	3	<ul style="list-style-type: none"> <li>✓ sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✓ maintenance of revetment coastal protection relatively straight forward (i.e. add more rock armour when required)</li> <li>✓ replacement of the Causeway Bridges would reduce maintenance costs</li> </ul>	4	19

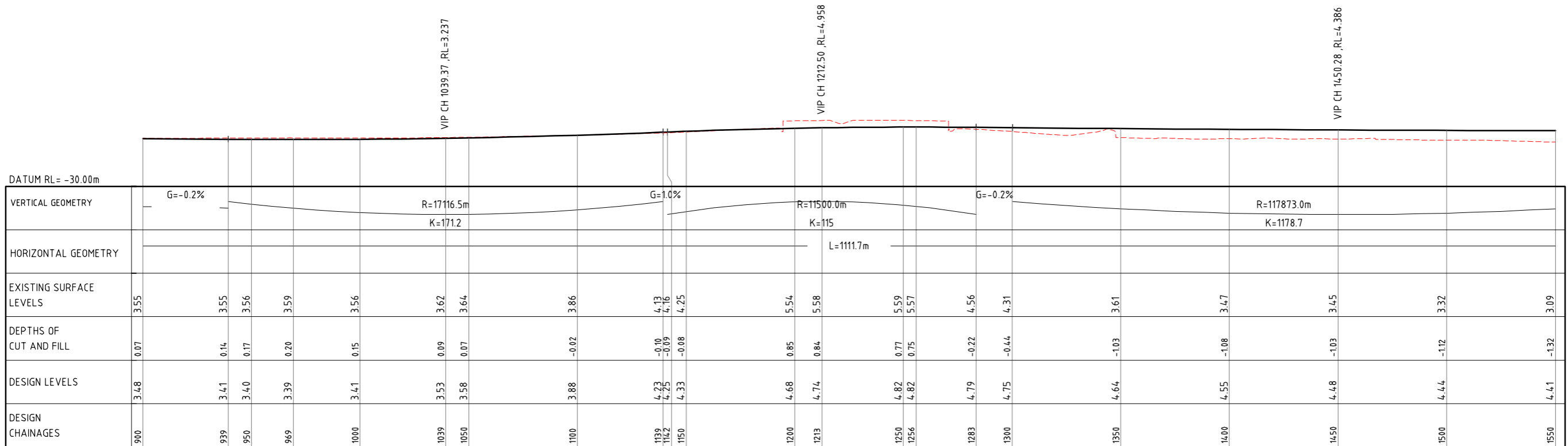
Option/Sub-option		Comments and Scores (1 = Worst, 5 = Best, ✓ = Positive Effect, ✗ = Negative Effect)									Overall Score	
		Environmental	Score	Coastal	Score	Geotechnical	Score	Constructability and Construction Cost	Score	Maintenance and Future Flexibility		Score
D(W)	Widening (symmetrically) and raising of the existing Causeway with revetments – incorporating Bio-filters resulting in a wider footprint	<ul style="list-style-type: none"> <li>✗ wide footprint increases reclamation</li> <li>✓ rock armour dissipates wave energy, as opposed to reflecting wave energy back into the sea, minimising impacts to the existing hydrodynamic conditions</li> <li>✓ Bio-filters provide excellent removal of diluted heavy metals, thereby improving water quality for organisms currently inhabiting the mudflat</li> <li>✓ Bio-filters compensate for loss of marine environment and provide a natural buffer</li> </ul>	4	<ul style="list-style-type: none"> <li>✓ resembles the existing Causeway therefore unlikely to have adverse hydrodynamic effects</li> <li>✓ elevation of Causeway can be sufficient to prevent inundation</li> <li>✓ pavement layers are less likely to be inundated by static storm tide levels. Life span of proposed pavement increased</li> <li>✗ encroachment into three tidal channel locations within the Marine Estuary is required</li> </ul>	5	<ul style="list-style-type: none"> <li>✓ design tolerances for the installation of Bio-filters provide greater flexibility in combating the effects of differential settlement across and along the Causeway</li> <li>✓ rock armour is a proven coastal protection solution that will adjust to changes like local settlements</li> <li>✗ induced settlement of the existing Causeway</li> </ul>	4	<ul style="list-style-type: none"> <li>✓ wider Causeway cross-section will allow greater width and flexibility during the construction staging process, and will allow bus shoulder operation through the majority of the construction period</li> <li>✗ wider Causeway cross-section may possibly demand a longer construction period, resulting in longer inconvenience to the travelling Public</li> <li>✗ the capital cost associated with a wider Causeway cross-section will be greater than that of a minimum Causeway section</li> </ul>	3	<ul style="list-style-type: none"> <li>✓ non-intensive maintenance required for Bio-filters</li> <li>✓ maintenance of revetment coastal protection relatively straight forward (i.e. add more rock armour when required)</li> <li>✓ sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✓ no retaining wall structures</li> </ul>	5	21
		E	Viaduct structure	<ul style="list-style-type: none"> <li>✓ very little or no reclamation required</li> <li>✗ shadow cast over the existing Causeway will result in a 'dead area' which would be difficult to convert into an amenity capable of sustaining ecological habitat</li> <li>✗ jettison, flotsam and debris will accumulate under the viaduct structure</li> <li>✗ viaduct structure will alter the appearance of the Marine Estuary</li> </ul>	4	<ul style="list-style-type: none"> <li>✓ height of bridge can be such that sea level rise is not an issue</li> <li>✓ the need or application of coastal defence mechanisms is greatly reduced</li> <li>✗ piles penetrating the Marine Estuary along either side of the Causeway, in places, may cause scour issues</li> </ul>	4	<ul style="list-style-type: none"> <li>✓ minimal settlement risk if piles are driven into bed rock or stronger alluvial layers</li> <li>✓ removes the need to accommodate settlement in the completed/operational motorway</li> <li>✗ bed rock is deep resulting in very long piles</li> <li>✗ deep marine mud will require large earthquake loading design to the viaduct structures</li> </ul>	3	<ul style="list-style-type: none"> <li>✗ phased construction required to allow temporary traffic management, facilitating construction of the viaduct above the existing Causeway</li> <li>✗ construction cost of viaduct expected to be high</li> <li>✗ deep soft marine mud would result in extensive and heavy engineered foundations</li> <li>✓ no bespoke engineering practices required, allowing bridge to be built using traditional engineering techniques</li> </ul>	2	<ul style="list-style-type: none"> <li>✓ sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment</li> <li>✓ long design life can be achieved with viaduct</li> <li>✗ maintenance costs expected to be high in saline/exposed CMA</li> <li>✗ unlike grassed Bio Filters, the cartridge system will require regular invasive cleaning and cartridge replacement</li> </ul>

Option/Sub-option		Comments and Scores (1 = Worst, 5 = Best, ✓ = Positive Effect, ✗ = Negative Effect)								Overall Score		
		Environmental	Score	Coastal	Score	Geotechnical	Score	Constructability and Construction Cost	Score		Maintenance and Future Flexibility	Score
<b>F</b>	Combined raising of the Causeway and widening with viaduct structures	<p>✓ very little or no reclamation required</p> <p>✗ jettison, flotsam and debris will accumulate under the viaduct structures</p> <p>✗ viaduct structures on either side will alter the appearance of the Marine Estuary</p>	<b>4</b>	<p>✓ height of bridge can be such that sea level rise is not an issue</p> <p>✗ piles penetrating the Marine Estuary along either side of the Causeway, in places, may cause scour issues</p>	<b>3</b>	<p>✗ longitudinal differential settlement risk between viaducts and raised Causeway section will be difficult to mitigate</p> <p>✗ induced settlement of the existing Causeway</p> <p>✗ bed rock is deep resulting in the need for long piles</p> <p>✗ deep marine mud will require large earthquake loading design to retaining walls and viaduct structures</p>	<b>1</b>	<p>✗ phased construction required to allow temporary traffic management, facilitating raising the Causeway and construction of the viaducts above the existing Causeway</p> <p>✗ deep soft marine mud would result in extensive and heavy engineered wall structures and foundations</p> <p>✗ cost of retaining walls and viaducts expected to be high</p>	<b>1</b>	<p>✓ sufficient head available between road elevation and high tide levels to provide gravity reticulated water quality treatment</p> <p>✗ maintenance costs expected to be high in saline/exposed CMA</p> <p>✗ unlike grassed Bio Filters, the cartridge system will require regular invasive cleaning and cartridge replacement</p>	<b>2</b>	<b>13</b>

APPENDIX E: Option D(W) – Cross Sections, Plans and Longsections  
(2010)

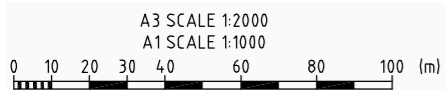


**PART PLAN**  
(CH 1000 TO CH 1462)  
1:1000 (A1)



**PART LONGSECTION - ON CONTROL LINE**

HORIZ. 1:1000 (A1)  
VERT. 1:1000 (A1)



**DRAFT FOR REVIEW**

Base Level:	MSL AUCK. VERT. DATUM 1946
Grid Reference:	Mt Eden 2000
Originator No.	
Project No.	20.111-3-D-C-109-203
Rev.	A

No.	Revision	By	Chk	Appd	Date
A	FOR REVIEW				

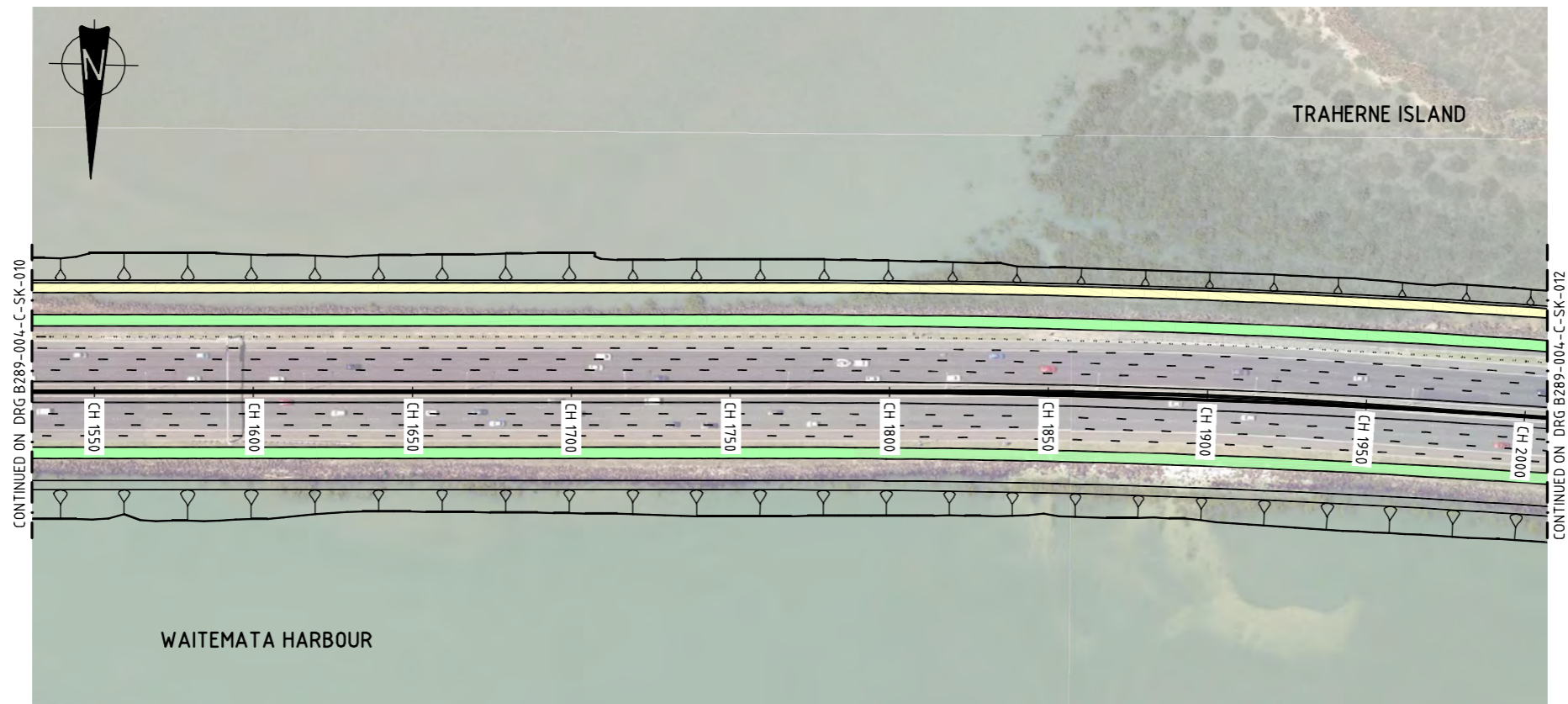
Drawing Originator:  
**aurecon**  
Aurecon New Zealand Limited  
139 Carlton Gore Road (PO Box 9762) Newmarket, Auckland, New Zealand  
Telephone: +64 9 520-8019  
Facsimile: +61 9 524-7815  
Email: auckland@aurecongroup.com

Original Scale (A1)	1:1000
Reduced Scale (A3)	1:2000
Design Engineer	
Review Engineer	
Drafting Checked	
Consultant Approval	
Reviewed by Beqa	



Project: **WATERVIEW CONNECTION PROJECT**  
SH16 / SH20

Title: **PART PLAN AND LONGSECTION CAUSEWAY OPTION D SHEET 1**



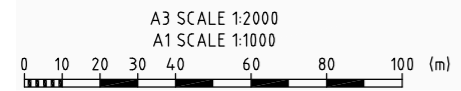
LEGEND	
	CYCLEWAY / FOOTPATH
	BUS SHOULDER

**PART PLAN**  
(CH 1462 TO CH 1957)  
1:1000 (A1)

DATUM RL = -30.00m

VERTICAL GEOMETRY	R=117873.0m K=1178.7		L=1111.7m		R=1500m L=107.5m		G=0.0%	
EXISTING SURFACE LEVELS	3.09	2.92	2.85	2.64	2.62	2.74	2.70	2.62
DEPTHS OF CUT AND FILL	-1.32	-1.48	-1.56	-1.78	-1.81	-1.69	-1.74	-1.82
DESIGN LEVELS	4.41	4.41	4.41	4.41	4.42	4.43	4.44	4.44
DESIGN CHAINAGES	1550	1584	1600	1650	1700	1750	1800	1840
								1850
								1894
								1900
								1948
								1950
								2000

**PART LONGSECTION - ON CONTROL LINE**  
HORIZ. 1:1000 (A1)  
VERT. 1:1000 (A1)



**DRAFT FOR REVIEW**

Base Level:	MSL AUCK. VERT. DATUM 1946
Grid Reference:	Mt Eden 2000
Originator No.	
Project No.	20.1.11-3-D-C-109-204
Rev.	A

No.	Revision	By	Chk	Appd	Date
A	FOR REVIEW				

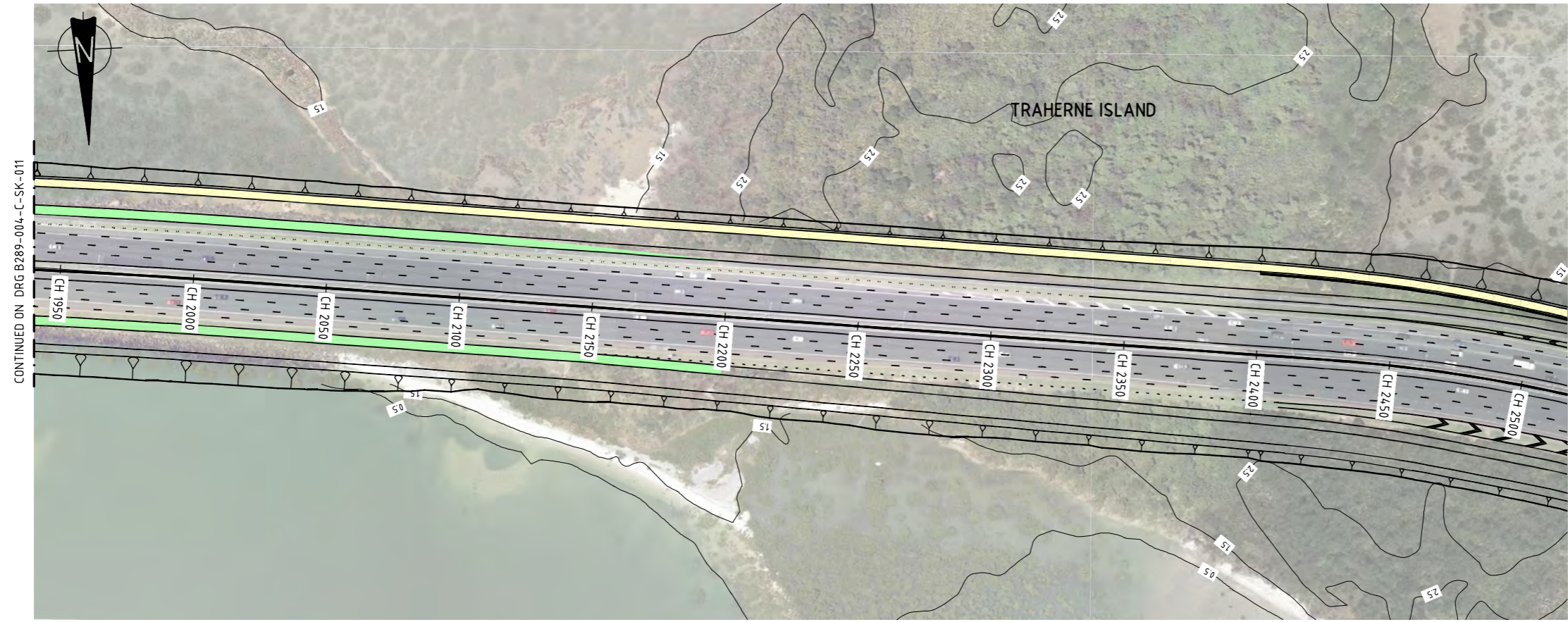
Drawing Originator:  
  
 Aurecon New Zealand Limited  
 138 Carlton Gore Road (PO Box 9762) Newmarket Auckland New Zealand  
 Telephone: +64 9 520-8019  
 Facsimile: +61 9 524-7818  
 Email: auckland@aurecongroup.com

Original Scale (A1)	1:1000	Design Engineer	
Reduced Scale (A3)	1:2000	Review Engineer	
		Drafting Checked	
		Consultant Approval	
		Received by Becca	

  
 NZ TRANSPORT AGENCY  
 WAKA KOTAHU

Project: **WATERVIEW CONNECTION PROJECT**  
SH16 / SH20

Title: **PART PLAN AND LONGSECTION CAUSEWAY OPTION D**  
SHEET 2



**LEGEND**

- CYCLEWAY / FOOTPATH
- BUS SHOULDER

**PART PLAN**  
(CH 1957 TO CH 2419)  
1:1000 (A1)

DATUM RL= -30.00m															
VERTICAL GEOMETRY															
G=0.0%															
HORIZONTAL GEOMETRY															
L=479.3m															
L=479.3m															
EXISTING SURFACE LEVELS	2.49	2.75	2.71	2.67	2.62	2.68	2.82	2.88	2.96	2.85	3.05	3.03	3.12	3.14	3.17
DEPTHS OF CUT AND FILL	-1.97	-1.71	-1.76	-1.80	-1.86	-1.81	-1.68	-1.63	-1.55	-1.67	-1.48	-1.50	-1.41	-1.39	-1.36
DESIGN LEVELS	4.46	4.46	4.47	4.48	4.48	4.49	4.50	4.51	4.51	4.52	4.52	4.53	4.53	4.53	4.53
DESIGN CHAINAGES	1950	2000	2050	2100	2150	2200	2250	2300	2350	2400	2427	2450	2465	2485	2500

**PART LONGSECTION - ON CONTROL LINE**  
HORIZ. 1:1000 (A1)  
VERT. 1:1000 (A1)



**DRAFT FOR REVIEW**

Base Level:  
**MSL AUCK. VERT. DATUM 1946**  
Grid Reference:  
**Mt Eden 2000**  
Originator No.  
Project No.  
**20.1.11-3-D-C-109-205**

No.	Revision	By	Chk	Appd	Date
A	FOR REVIEW				

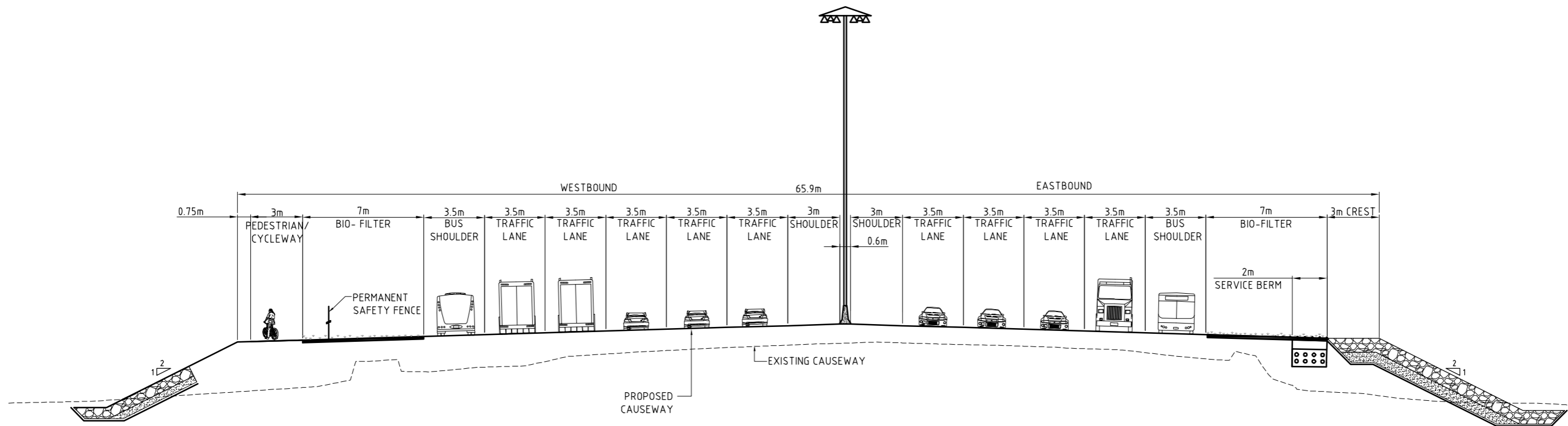
Drawing Originator:  
**aurecon**  
Aurecon New Zealand Limited  
139 Carlton Gore Road (PO Box 9762) Newmarket, Auckland, New Zealand  
Telephone: +64 9 520-8019  
Facsimile: +61 9 524-7818  
Email: auckland@aurecongroup.com

Original Scale (A1) 1:1000	Design Engineer
Reduced Scale (A3) 1:2000	Review Engineer
	Drafting Checked
	Consultant Approval
	Received by Becca

**NZ TRANSPORT AGENCY**  
WAKA KOTAHU

Project:  
**WATERVIEW CONNECTION PROJECT**  
SH16 / SH20

Title:  
**PART PLAN AND LONGSECTION**  
CAUSEWAY OPTION D  
SHEET 3



**TYPICAL CROSS SECTION OPTION D (W)**  
**WIDENING & RAISING OF THE EXISTING CAUSEWAY WITH REVETMENTS INCORPORATING BIO-FILTERS (2010)**  
 1:125 (A1)  
 1:250 (A3)



**DRAFT FOR REVIEW**

Base Level:	MSL AUCK. VERT. DATUM 1946
Grid Reference:	Mt Eden 2000
Originator No.	
Project No.	20.1.11-3-D-C-109-206
Rev.	A

No.	Revision	By	Chk	Appd	Date
A	FOR REVIEW				

Drawing Originator:  
**aurecon**  
 Aurecon New Zealand Limited  
 139 Carlton Gore Road (PO Box 9762) Newmarket, Auckland New Zealand  
 Telephone: +64 9 520-8019  
 Facsimile: +61 9 524-7816  
 Email: auckland@aurecongroup.com

Original Scale (A1)	1:125	Design Engineer	
Reduced Scale (A3)	1:250	Review Engineer	
		Drafting Checked	
		Consultant Approval	
		Received by Becca	

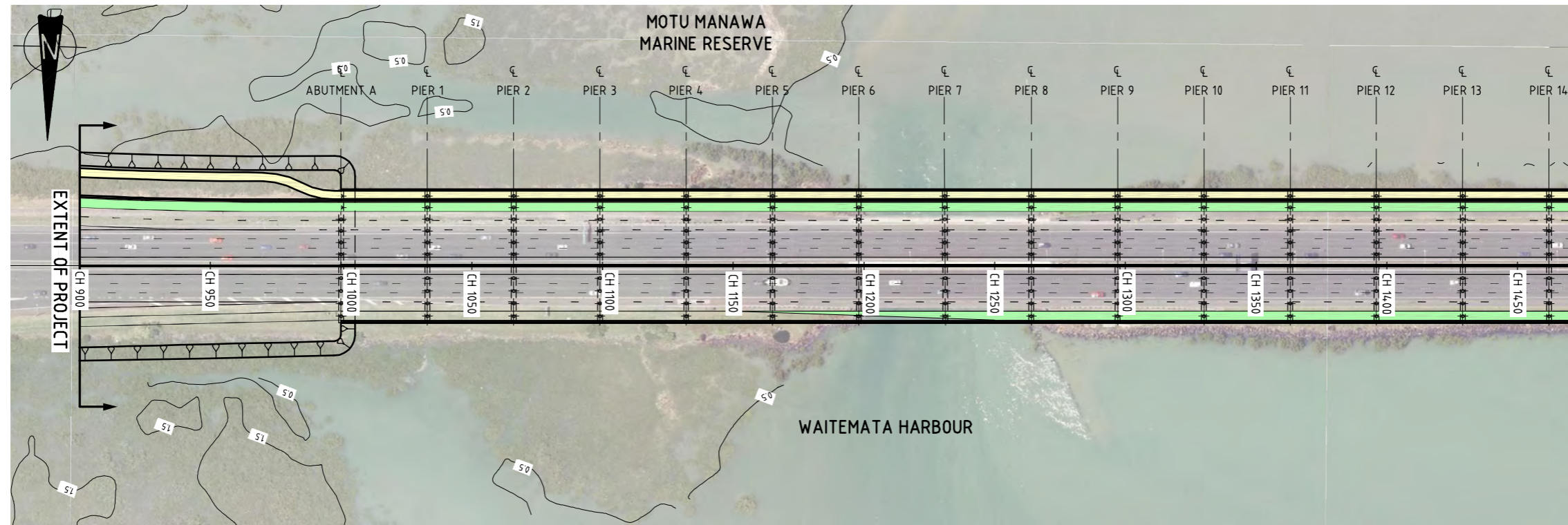


Project: **WATERVIEW CONNECTION PROJECT**  
**SH16 / SH20**

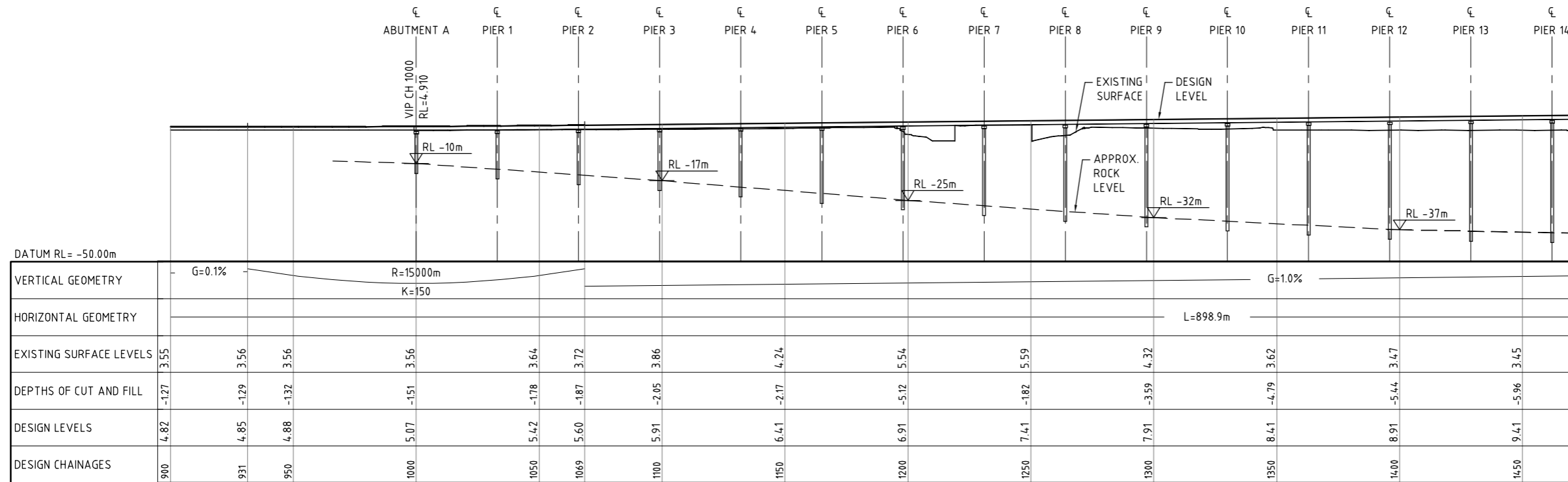
Title: **PROPOSED TYPICAL CROSS SECTION CAUSEWAY OPTION D (W)**



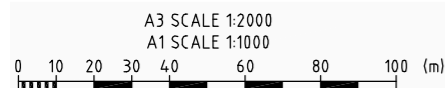
## APPENDIX F: Option E – Cross Section, Plans and Longsections (2010)



**PART PLAN**  
(CH 1000 TO CH 1462)  
1:1000 (A1)



**PART LONGSECTION - ON CONTROL LINE**  
HORIZ. 1:1000 (A1)  
VERT. 1:1000 (A1)



No.	Revision	By	Chk	Appd	Date
A	FOR REVIEW				

Drawing Originator:  
**aurecon**  
Aurecon New Zealand Limited  
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Original Scale (A1) 1:1000  
Reduced Scale (A3) 1:2000  
Design Engineer  
Review Engineer  
Drafting Checked  
Consultant Approval  
Reviewed by Becca

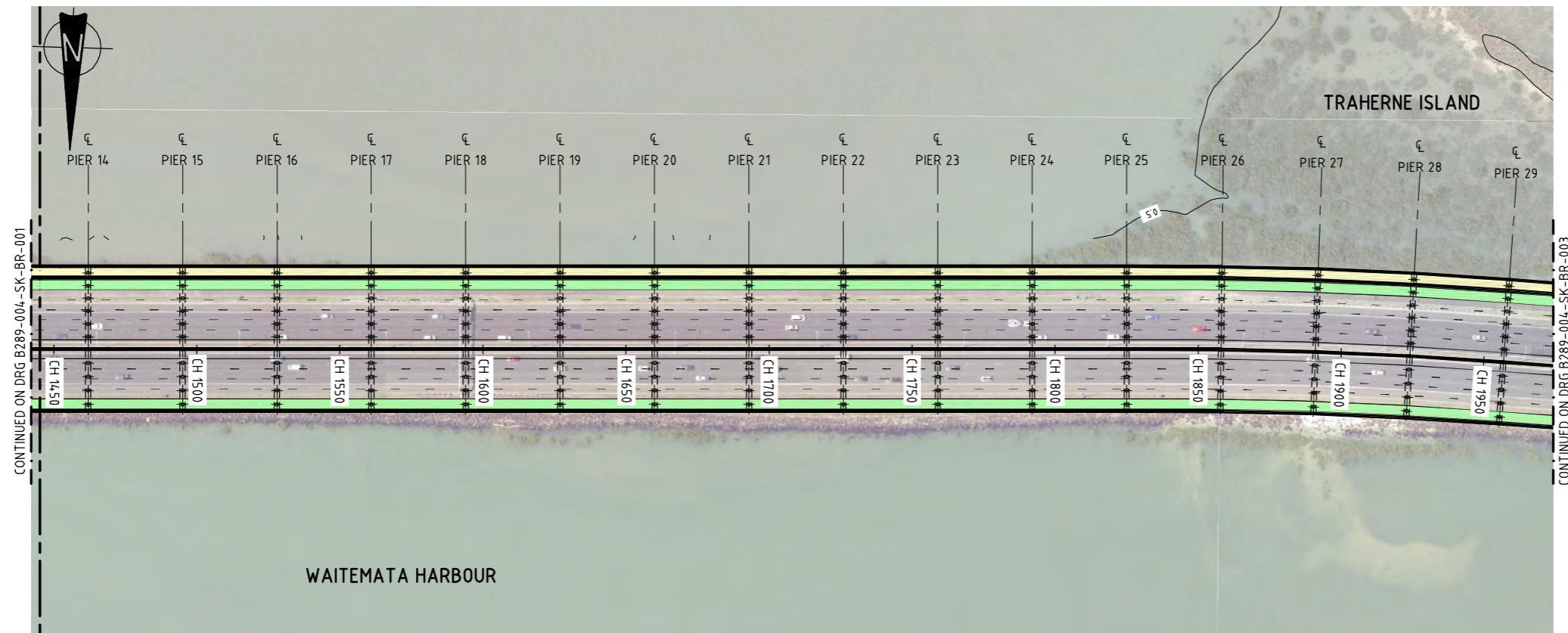


Project: **WATERVIEW CONNECTION PROJECT**  
SH16 / SH20

Title: **PART PLAN AND LONGSECTION CAUSEWAY OPTION E SHEET 1**

**DRAFT FOR REVIEW**

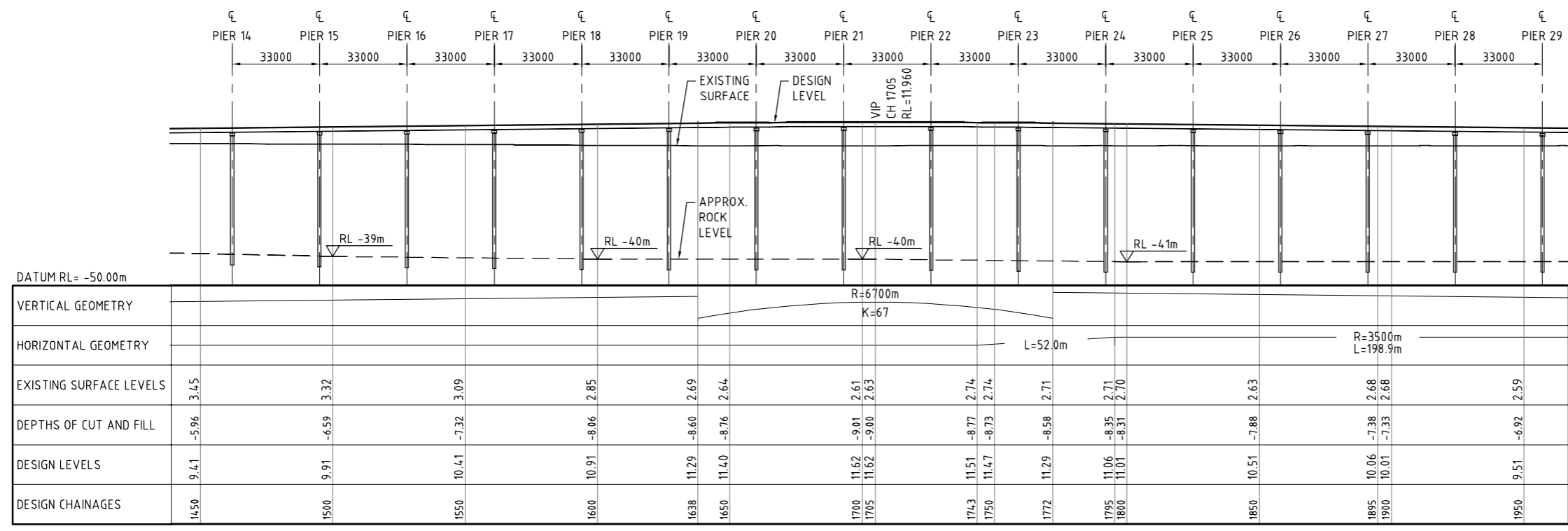
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Grid Reference: **Mt Eden 2000**  
Originator No.  
Project No. **20.1.11-3-D-C-109-207**  
Rev. **A**



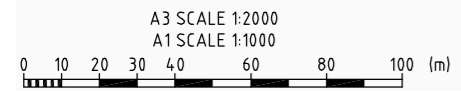
**LEGEND**

- CYCLEWAY / FOOTPATH
- BUS SHOULDER

**PART PLAN**  
(CH 1462 TO CH 1957)  
1:1000 (A1)



**PART LONGSECTION - ON CONTROL LINE**  
HORIZ. 1:1000 (A1)  
VERT. 1:1000 (A1)



No.	Revision	By	Chk	Appd	Date
A	FOR REVIEW				

Drawing Originator:  
**aurecon**  
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Original Scale (A1) 1:1000	Design Engineer
Reduced Scale (A3) 1:2000	Review Engineer
	Drafting Checked
	Consultant Approval
	Reviewed by Beca

**NZ TRANSPORT AGENCY**  
WAKA KOTAHU

Project: **WATERVIEW CONNECTION PROJECT**  
SH16 / SH20

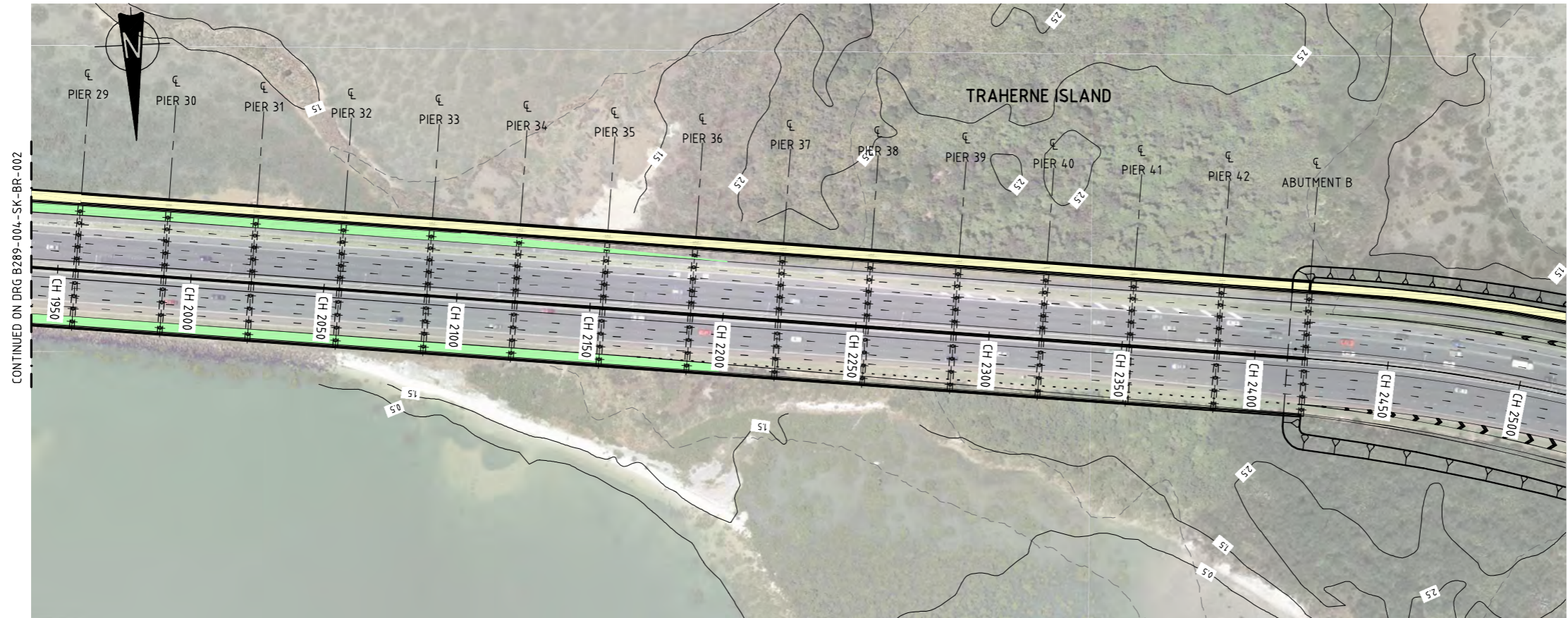
Title: **PART PLAN AND LONGSECTION CAUSEWAY OPTION E SHEET 2**

**DRAFT FOR REVIEW**

Base Level:  
**MSL AUCK. VERT. DATUM 1946**  
Grid Reference:  
**Mt Eden 2000**

Originator No.  
Project No.  
**20.1.11-3-D-C-109-208**

Rev.  
**A**

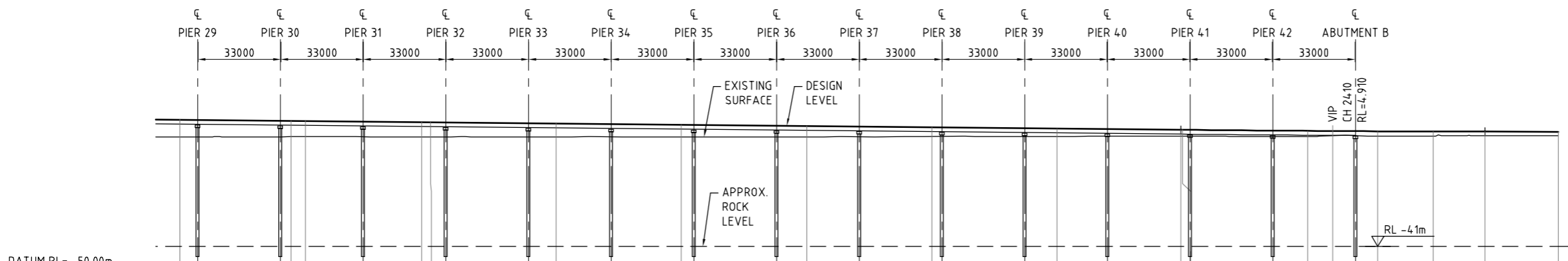


**LEGEND**

- CYCLEWAY / FOOTPATH
- BUS SHOULDER

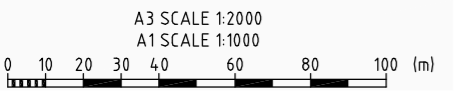
CONTINUED ON DRG B289-004-SK-BR-002

**PART PLAN**  
(CH 1957 TO CH 2419)  
1:1000 (A1)



CH	29	30	31	32	33	34	35	36	37	38	39	40	41	42	ABUTMENT B			
VERTICAL GEOMETRY	G=-1.0%														R=15000m K=150		G=-0.2%	
HORIZONTAL GEOMETRY	L=52.0m														L=381.6m		R=625m L=315.4m	
EXISTING SURFACE LEVELS	2.59	2.74	2.75	2.71	2.71	2.67	2.61	2.68	2.81	2.88	2.96	2.96	2.85	3.11	3.05	3.04	3.13	3.17
DEPTHS OF CUT AND FILL	-6.92	-6.32	-6.26	-5.83	-5.80	-5.34	-4.90	-4.33	-3.70	-3.13	-2.56	-2.55	-2.25	-1.93	-1.89	-1.81	-1.66	-1.57
DESIGN LEVELS	9.51	9.07	9.01	8.55	8.51	8.01	7.51	7.01	6.51	6.01	5.57	5.51	5.10	5.03	4.94	4.85	4.79	4.74
DESIGN CHAINAGES	1950	1994	2000	2046	2050	2100	2150	2200	2250	2300	2349	2350	2400	2410	2428	2450	2471	2500

**PART LONGSECTION - ON CONTROL LINE**  
HORIZ: 1:1000 (A1)  
VERT: 1:1000 (A1)



**DRAFT FOR REVIEW**

Base Level: **MSL AUCK. VERT. DATUM 1946**  
Grid Reference: **Mt Eden 2000**  
Originator No. \_\_\_\_\_  
Project No. **20.1.11-3-D-C-109-209** Rev. **A**

No.	Revision	By	Chk	Appd	Date
A	FOR REVIEW				

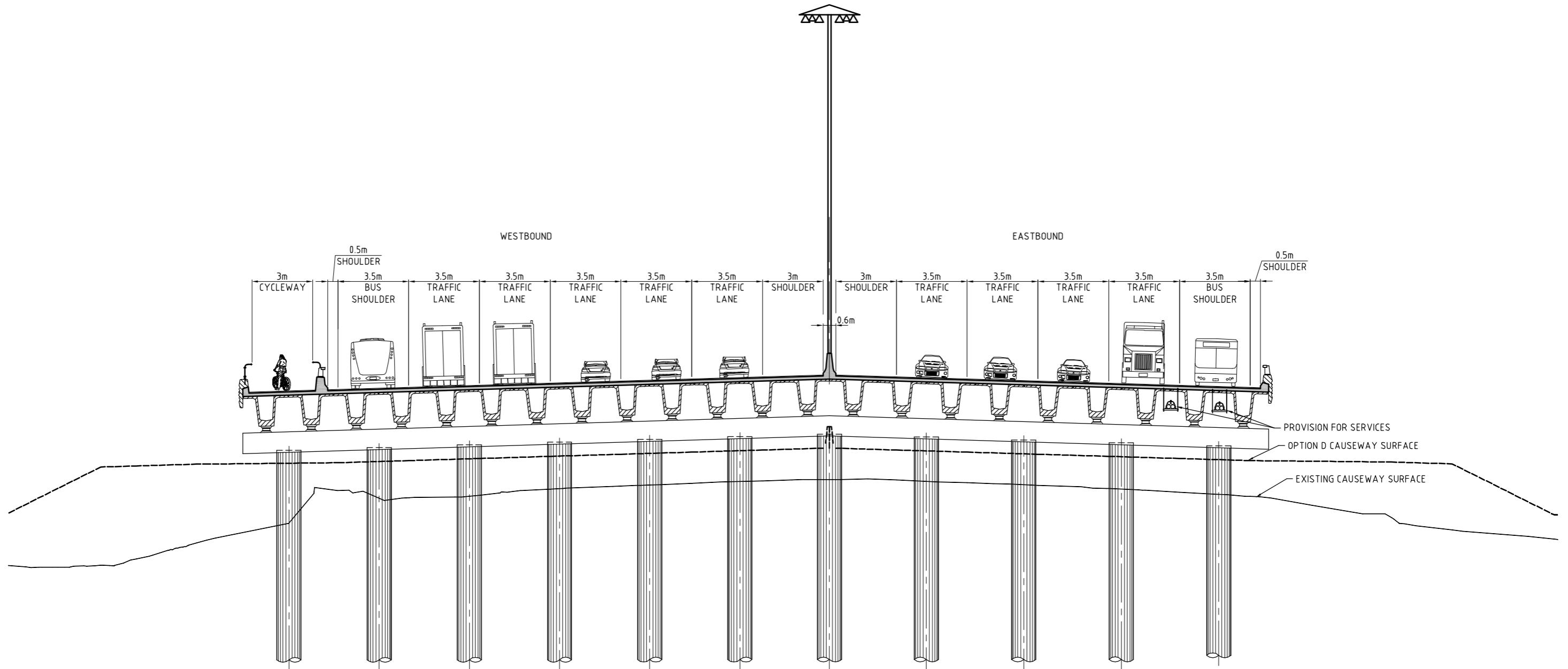
Drawing Originator:  
**aurecon**  
Aurecon New Zealand Limited  
139 Carlton Gore Road (PO Box 6762) Newmarket, Auckland New Zealand  
Telephone: +64 9 520-8019  
Facsimile: +61 9 524-7815  
Email: auckland@aurecongroup.com

Original Scale (A1) 1:1000  
Reduced Scale (A3) 1:2000  
Design Engineer: \_\_\_\_\_  
Review Engineer: \_\_\_\_\_  
Drafting Checked: \_\_\_\_\_  
Consultant Approval: \_\_\_\_\_  
Released by: **Beca**

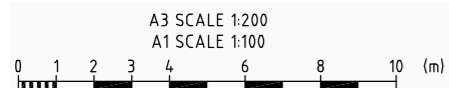
**NZ TRANSPORT AGENCY**  
WAKA KOTAHU

Project: **WATERVIEW CONNECTION PROJECT SH16 / SH20**

Title: **PART PLAN AND LONGSECTION CAUSEWAY OPTION E SHEET 3**



INDICATIVE TYPICAL CROSS SECTION  
 OPTION E - VIADUCT STRUCTURE ABOVE EXISTING CAUSEWAY  
 1:100 (A1)



**DRAFT FOR REVIEW**

Base level: <b>MSL AUCK. VERT. DATUM 1946</b>	
Grid Reference: <b>Mt Eden 2000</b>	
Originator No.	
Project No. <b>20.1.11-3-D-C-109-210</b>	Rev. <b>A</b>

No.	Revision	By	Chk	Appd	Date
A	FOR REVIEW				

Drawing Originator:  
**aurecon**  
 Aurecon New Zealand Limited  
 138 Carlton Gore Road (PO Box 9762) Newmarket  
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 Facsimile: +61 9 524-7818  
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Original Scale (A1) 1:100	Design Engineer
Reduced Scale (A3) 1:200	Review Engineer
	Drafting Checked
	Consultant Approval
	Received by Becca



Project: **WATERVIEW CONNECTION PROJECT SH16 / SH20**

Title: **TYPICAL CROSS SECTION CAUSEWAY OPTION E**