SEA LEVEL RISE IMPLICATIONS AND ADAPTATION FOR SOUTH ARM SECONDARY ROAD, HOBART

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Abstract

This paper details the methods and results of an investigation into the impacts associated with inundation and sea level rise on a low-lying stretch of road, fronting Ralphs Bay, south-east of Hobart. The South Arm Secondary Road extends from Rokeby to Opossum Bay, and provides the only road access to settlements on the South Arm peninsula with a population of approximately 1000. Coastal inundation of a section of the road at a location known as “The Neck” (a narrow isthmus), has occurred several times recently during unusual events, prompting community concerns for future impacts on road integrity, access, and local fauna, as sea level rise continues to take effect. The Department of Infrastructure, Energy, and Resources commissioned Pitt&Sherry to undertake a concept development investigation for the road, with the Water Research Laboratory and Northbarker Ecosystems Services working as sub-consultants on the investigation.

Specifically, this paper outlines

- Inundation and wave runup/overtopping assessment methods and results;
- The level of inundation protection provided by the current road, including the probability and extent of inundation of the road under present conditions;
- The effects of inundation on local fauna;
- The resulting effects of sea level rise on inundation levels;
- The risk of a breach in the isthmus from the ocean side;
- The level of asset damage that may result from road inundation and wave attack;
- Costed options for improving flood protection of the road.

Key Words: Inundation, Coastal Processes, Adaptation Strategies, Road

Introduction

This paper details the methods and results of an investigation into the impacts associated with inundation and sea level rise on a low-lying stretch of road, fronting Ralphs Bay, east of Hobart. South Arm Secondary Road stretches from Rokeby to Opossum Bay, and provides the only road access to the townships on the South Arm Peninsula which have a population of approximately 1000 people. Figure 1 shows the regional location for this investigation. The 3.5 km section of the South Arm Secondary Road considered in this investigation stretches from near Goats Bluff (east of the neck) where the road emerges alongside Ralphs Bay, west to where the road again diverges from the Ralphs Bay shoreline, near the start of the township of South Arm (see Figure 2). Generally, the road is set back from the edge of Ralphs Bay by 10 – 20 m, and is at an elevation of typically 1.5 m AHD.

On a number of occasions in recent times (at least in August 2007 and March 2008) the “Neck” section of road has been inundated when low pressure weather patterns coincided with high tides. In December 2007 the South Arm Peninsula Residents Association (SAPRA) made a presentation to the Minister for Infrastructure outlining their concerns regarding:

- The current and potential future problems associated with rising sea levels, inundation and unfettered wave action on the road;
- The destruction of the population of Pied Oystercatchers that currently roosts on the shores of Ralphs Bay, adjacent to the existing roadway.

Subsequently the Department of Infrastructure, Energy, and Resources (DIER), commissioned Pitt & Sherry to undertake a concept development investigation for the site, who sub-commissioned the Water Research Laboratory (WRL) to undertake an inundation investigation.

While this investigation was undertaken for a site specific location, the inundation problems encountered at this location are expected to become common place for other locations as vulnerability of coastal assets increases due to rising sea levels. The methodology applied in this investigation provides a good template for assessing sea level rise impacts and effectiveness of adaptation strategies.

Summary of Coastal Processes

In undertaking this inundation investigation, a range of coastal processes required consideration when assessing the extent and recurrence of inundation, these being:

- Astronomical tide fluctuations;
- Tidal anomalies due to barometric pressure fluctuations;
- Water level surge due to wind setup;
- Wind generated waves;
- Water level surge due to wave setup;
- Wave run-up;
- Sea level rise.

Sea Level Rise

Sea Level Rise (SLR) values were adopted that considered a range of predicted values including those from the Intergovernmental Panel on Climate Change Summary Report (IPCC, 2007). Only SLR values for 2100 were available in the Summary Report, and not for 2050. Similar scenarios were developed in NCCOE (2004) based on the IPCC (2001) scenarios and are almost identical when ice melt is included, and as such, the NCCOE (2004) values for 2050 were used. Simplified “mid” and “high” range scenarios developed by WRL for engineering application are shown in Table 1. The 2100 “mid” scenario was estimated by averaging the central values for the six IPCC (2007) emission scenarios (0.39 m) and adding a central value (0.15 m) for ice melt. The “high” range scenario shown was estimated from the A1FI emission scenario (0.59 m) taken to 2090, adding for ice melt (0.2 m), and extending from 2090 to 2100.

Table 1 Simplified Engineering Estimates of Global Sea Level Rise (by WRL)

Scenario	**Year**	
	2050	**2100**
Adopted “Mid” range	0.2 m	0.5 m
Adopted “High” range	0.4 m	0.9 m

Tides and Tidal Anomalies

The Australian National Tide Table values for Hobart are reproduced in Table 2. Chart datum, which is used in bathymetric charts and tidal predictions was changed for Hobart on 1 January 2006.

An extensive analysis of the Hobart tide gauge data was undertaken by Hunter (2007). Hunter’s analysis found that while the gauge spanned 43 years of data, only 31.8 years of data were useable. The analysis covered measured water levels (astronomical tide plus tidal anomaly), with the extreme water level data shown in Table 3.

A plot of extreme water levels for Hobart using the results of Hunter (2007, Table 3) and extrapolated in accordance with Pugh

(1987) is shown in Figure 3. Also shown are published levels for Sydney and Fremantle (Haradasa et al, 1991; Lord and Kulmar, 2000; Fremantle in DPI, 2004). It is acknowledged that Sydney and Fremantle have different tides and storm surges to Hobart, but they have long records (of the order of 100 years) and approximately bound the shorter Hobart data.

Table 2 Published Tidal Planes for Hobart and Indicative Future Levels

	Astronomical Tidal Planes						
Datum	HAT	MHWS	MHWN	MSL	MLWN	MLWS	LAT
Old Chart datum	2.1	1.9	1.4	1.3	1.1	0.6	0.4
New Chart Datum 1/1/06	1.7	1.5	1.0	0.9	0.8	0.3	0.0
AHD	0.8	0.6	0.1	0.0	-0.1	-0.6	-0.9
2050 Mid scenario AHD	1.0	0.8	0.3	0.2	0.1	-0.4	-0.7
2050 High scenario AHD	1.1	1.0	0.5	0.3	0.2	-0.3	-0.6
2100 Mid scenario AHD	1.3	1.1	0.6	0.5	0.4	-0.1	-0.4
2100 High scenario AHD	1.7	1.5	1.0	0.9	0.8	0.3	0.0

AHD:	Australian Height Datum
HAT:	Highest Astronomical Tide
MHWS:	Mean High Water Springs
MHWN:	Mean High Water Neaps
MSL:	Mean Sea Level
MLWN:	Mean Low Water Neaps
MLWS:	Mean Low Water Springs
LAT:	Lowest Astronomical Tide
Source:	RAN Hydrographic Service (1999, 2006)

Table 3 Extreme Water Levels

	Water Level (m AHD)				
ARI (years)		**Mid range SLR**		**High range SLR**	
	2000	**2050**	**2100**	**2050**	**2100**
Sea Level Rise	0.0	0.2	0.5	0.4	0.9
1	0.97	1.17	1.47	1.37	1.87
2	1.05	1.25	1.55	1.45	1.95
5	1.13	1.33	1.63	1.53	2.03
10	1.19	1.39	1.69	1.59	2.09
20	1.26	1.46	1.76	1.66	2.16
50	1.37	1.57	1.87	1.77	2.27
100	1.44	1.64	1.94	1.84	2.34

The data from Figure 3 and Table 3 shows that a present day 100 year ARI water level would occur approximately every 3 days in 2100 with a 0.9 m rise in sea level.

Wind Setup

During times of high wind, surface water is transported downwind through surface drag. In an enclosed bay such as the southern half of Ralphs Bay, this water may “pile up” at the downwind end of the bay. Some of this piled up water may return as bed flow, however, as the bay is shallow, the shear between the bed return flow and the surface water may restrict return flow, resulting in noticeable super-elevation of the water surface known as wind setup. Regional scale wind setup (expected to be minimal) is included in measurements on the Hobart tide gauge. Local wind setup in excess of the regional scale process has been shown to be significant over the southern half of Ralphs Bay, due to the long distances of relatively shallow water depths.

The software package CRESS was used to model wind setup in this investigation. To assess the effects of different fetch for different locations around the southern Ralphs Bay foreshore, adjacent to the South Arm Secondary Road, the wind and wave analysis was undertaken at three study locations around the foreshore. The wind speeds selected for analysing extreme wind setup, were based on the 3 second wind gust speeds from AS/NZS 1170.2:2002 Structural Design Actions Part 2: Wind Actions, as shown in Table 4. The wind actions standard also contains directional multipliers for wind speed for Hobart, which vary from 0.80 for four directions from north-east to south, to 1.0 for the north-west octant. The 3 second gust wind data was reduced according to SPM (1984, Figure 3-13) for longer durations, with the wind setup predictions for present day extreme water levels summarised in Table 4.

Wind Waves

Wind wave heights were estimated using the principles of SPM (1984), the US Army Coastal Engineering Manual (EM 1110-2-1100, 2002) and the software ACES (version 4.0.3.1). Due to the convoluted shape of Ralphs Bay, the available fetch in all directions (discretised into 5º directional increments) was determined for each of the three study sites, and used in the Restricted Fetch technique of wave analysis.

The equivalent average wind speeds for other durations (which ranged from 10 to 110 minutes for fetch limited conditions to occur) were calculated as per SPM (1984) Figure 3-13.

The design wave data determined in the analysis is shown in Table 4. H_s is the significant wave height, which is defined as the average of the one-third highest. T_p is the spectral peak wave period. It should be noted that these wave heights will be subject to dissipation and depth limited breaking before reaching the foreshore of Ralphs Bay, which is expected to significantly reduce the wave height. The resulting waves impacting the shoreline were further analysed in wave setup and runup calculations using the surf-zone model by Dally, Dean and Dalrymple (1984) within the numerical model of SBEACH.

Table 4 Design Wind Speed, Wind Setup, Wave Height, Wave Period, Wave Setup

ARI (years)	**Design 3 Sec Gust Wind Velocity**		**Gauge Water Level**	**Wind Setup**	**Significant Wave Height, Hs**	**Spectral Peak Wave Period, Tp**	**Wave Setup**
	(m/s)	**(knots)**	**(m AHD)**	**(m)**	**(m)**	**(s)**	**(m)**
1	26.0	50.5	0.97	0.24	0.9	3.6	0.21
2	28.8	56.0	1.05	0.28	1.1	3.8	0.25
5	32.1	63.4	1.13	0.35	1.2	4.0	0.25
10	34.4	66.9	1.19	0.39	1.4	4.2	0.34
20	36.6	71.1	1.26	0.44	1.5	4.4	0.36
50	39.3	76.4	1.37	0.49	1.6	4.5	0.37
100	41.1	79.9	1.44	0.53	1.8	4.7	0.36

Wave Setup

Wave setup is defined as the quasi-steady increase in water level inside a surf zone due to the conversion of part of the waves' kinetic energy into potential energy. The surf zone model by Dally, Dean and Dalrymple (1984) within the numerical model of SBEACH was used in this analysis to calculate wave setup. Predictions of wave setup are shown in Table 4, based on present day extreme gauge water levels and wind setup values.

Wave Runup

Due to the close proximity of the South Arm Secondary Road to the foreshore of Ralphs Bay, and the relatively low elevation of the road, it is expected that breaking waves will runup to and exceed the elevation of the road surface during extreme events. Prediction of wave runup is best undertaken with a physical model, but this was beyond the scope of this study.

Present day water levels including the localised effects of tide, pressure, wind, and wave setup are shown in Table 5, together with the maximum predicted wave runup levels calculated using the methods of Ahrens and Titus (1985) in the ACES software package. In applying the technique of Ahrens and Titus, the "structure slope" for which the runup equation was applied was determined by the two-dimensional bathymetric/topographic profile at each of the three investigation locations considered.

Values in Table 5 show that typical present day inundation water levels (including the effects of tide, barometric, wind, and wave setup) vary from approximately 1.4 m AHD in a 1 year ARI event, up to 2.3 m AHD in a 100 year ARI event (for the existing site conditions). For design purposes, predictions of simplified inundation water levels for present day, 2050, and 2100 scenarios using the mid and high range sea level rise predictions are also shown in Table 5.

Table 5 Present Day, 2050, and 2100 Design Inundation Levels

ARI	**Present Day**				**Design Inundation Water Levels (m AHD)1**			
	Gauge Water Level	**Maximum Prediction Along Foreshore**						
		Local wind setup	**Still Water Level (incl Wave and Wind setup)**	**Maximum Wave Runup**	**Mid Range SLR**		**High Range SLR**	
(Yrs)	**(m AHD)**	**(m)**	**(m, AHD)**	**(m, AHD)**	**2050**	**2100**	**2050**	**2100**
1	0.97	0.24	1.42	1.59	1.62	1.92	1.82	2.32
2	1.05	0.28	1.57	1.77	1.78	2.08	1.98	2.48
5	1.13	0.35	1.73	1.98	1.92	2.22	2.12	2.62
10	1.19	0.39	1.85	2.13	2.12	2.42	2.32	2.82
20	1.26	0.44	1.99	2.29	2.26	2.56	2.46	2.96
50	1.37	0.49	2.16	2.51	2.43	2.73	2.63	3.13
100	1.44	0.53	2.30	2.66	2.53	2.83	2.73	3.23

The data shown in Table 5 shows that waves can be expected to runup and overtop the existing roadway on average at least once per year, and that the roadway can be expected to be inundated in a 2 year ARI storm event, with present day sea levels. When mid range sea level rise predictions are taken into consideration, it can be seen that the road will be inundated to a depth in excess of 100 mm on a sub-annual basis by year 2050.

Adaptation Strategy 1: Advisory Measures

Under present conditions the frequency of inundation of the roadway will typically be every 1 to 2 years, with the road not safely navigable for several hours during a 5 year ARI event. The simplest adaptation strategies are management measures such as suitable safety precautions and advisory strategies.

Advisory measures should include permanent signage warning road users of the hazard associated with inundation. During periods of inundation, consideration should be given to the use of flashing lights or similar to ensure all road users are aware of the hazard. This can be achieved via the use of a water sensitive switch or similar – this system could be set up to include two depth sensors, one for low level inundation (50 mm) providing a warning system and a second at a height of 300 mm to inform road users that the road is no longer navigable.

The management of the impacts by signage and advisory measures will only provide an immediate, short term solution to the inundation issues, as the frequency and severity of the events is predicted to increase over the coming years. The cost of such an option is likely to be in the order of $30,000.

The level of asset damage associated with implementing advisory measures only, without any modifications to the roadway, is difficult to quantify. However, it is expected that the combined impact of sea level rise and increased wave action will denude the existing seaward road batters of vegetation that currently contains the sand providing the base for the road pavement. Ultimately this will accelerate damage to the road pavement.

Adaptation Strategy 2: Minor Works

The road is currently at an elevation of approximately 1.5 m AHD, although it does drop to below 1.5 m AHD in one location.

To achieve any measurable reduction in the frequency of inundation (to a 5 year ARI say) the level of the road needs to be raised to in excess of 1.7 m AHD under current conditions, without considering any sea level rise. To minimise road maintenance costs in the short and medium terms, there also needs to be protection of the seaward road batters from sea level rise and wave action.

Within the minor works option three possible alternatives were considered:

a. Batter Protection Only

To protect the seaward road batters from erosion due to sea level rise and wave action, measures such as placing a layer of geofabric over the batters and armouring with appropriately sized rocks are required. This action will not reduce the frequency of inundation of the road and would in the very least also require the use of advisory measures.

b. Raising the Road above 1.7 m AHD

Raising the road by 300 mm will prevent inundation of the road for a 5 year ARI event under current conditions, but only offers limited protection under mid range sea level rise (2050), does not take into account the effects of wave runup and does not prevent the road asset damage associated with wave action. The benefit of this alternative if applied on its own is questionable given the on-going road maintenance costs that would be required.

c. Batter Protection and Raising the Road

This will achieve a measurable, albeit short term, reduction in the frequency of inundation, while also preventing road asset damage. However, the cost benefit of this alternative is also questionable given the limited level of protection it will provide under future sea level rise scenarios.

Suitable safety precautions and advisory strategies would still be required to be implemented to ensure road users are aware of the risks which will occur for this section of highway, even after a strategy is implemented to reduce the frequency of inundation of the road.

The costs of each minor works alternative are of the order of:

a. Batter protection only – $1.5M

b. Raising the road – $2.7M

c. Batter protection and raising the road – $4.2M

Adaptation Strategy 3: Major Works

It has been normal engineering practice in Australia to use the 100 year ARI event for design of “permanent” coastal structures. The 100 year ARI event is the generally accepted balance between risk and initial capital cost. However, specific projects need to be assessed individually, and it is generally considered acceptable that loss of use of roadways due to flooding can occur in more frequent events than the 100 year ARI event, so long as the integrity of the road is maintained and the road is again useable soon after the event. This is expected to be the case for the South Arm Secondary Road at the Neck, due to the relatively small population for which the road services.

The major works concept design aims to provide safe driving conditions during a 20 year ARI storm event, with 2050 mid range sea level rise predictions taken into consideration. This concept design will immediately reduce the frequency of inundation of the roadway from occurring typically every 1 to 2 years, to occurring less frequently than every 20 years (on average). The expected design life of the roadway pavement would be of the order of 20 years, and as such the roadway surface will require replacement by approximately 2028. At this time the elevation of the roadway surface can be revised in light of a better understanding of sea level rise and other climate change related processes, and the roadway surface lifted further by steepening the northern 1V:5H batter slope, if required. This adaptive style concept design provides an immediate solution to the inundation problem, as well as giving suitable consideration to a sea level rise adaptation strategy.

The major works concept design is shown on the drawings in Figure 4. The concept design proposes to raise the roadway pavement to a level of 2.6 m AHD, with a 1V:5H batter slope starting at the northern edge of the existing roadway and moving the alignment of the roadway slightly away from the Ralphs Bay foreshore. In addition to these design features suitable safety precautions and advisory strategies should be implemented to ensure road users are aware of the risks which will occur during extreme events for this section of highway, even after a strategy is implemented to reduce the frequency of inundation of the road.

A simple assessment of wave run-up and overtopping of the concept design raised roadway was undertaken, predicting wave generated overtopping rates for a range of roadway pavement levels. This analysis considered both a smooth compacted earth embankment slope and a rough rock armoured slope for the 1V:5H batter slope on the northern side of the road. Predictions indicated that a road pavement level of 2.6 m AHD, as proposed in the concept design, would provide adequate driving conditions (at restricted speeds) during a 20 year ARI storm, with consideration of mid range sea level rise to year 2050.

To highlight the effectiveness of a raised roadway pavement level of 2.6 m AHD on immediately reducing the inundation and overtopping risk, an analysis was also undertaken for present day extreme water levels. For present day extreme water levels, overtopping of the roadway would only occur in events with an ARI of 50 years and greater, and the roadway would still be considered safe for slow moving vehicles, even in a 100 year ARI event.

Predicted water levels show that for the concept design, the 1V:5H batter slope on the northern side of the roadway would be exposed to wave run-up at least several times per year and possibly several times per month by year 2100. During extreme high water level events where waves do impact the roadway embankment slope, it is likely that the embankment would suffer erosion and damage if it is not properly armoured. A basic analysis was undertaken to determine suitable armour rock size for this slope, with the results indicating that 250 mm to 300 mm rock would be required.

The cost to implement the major works concept is estimated to be $9.2M.

Conclusion

This paper details the inundation investigation undertaken by WRL and the adaptation strategy concept design undertaken by P&S, for a stretch of the South Arm Secondary Road near South Arm, Hobart, Tasmania. The townships isolated by inundation of the road have a population of approximately 1000 people. While the data presented is specific to this location, the methodology applied in the investigation is applicable for assessing sea level rise impacts on coastal assets in other locations, and possible adaptation options.

A summary of design inundation water levels for present day, 2050, and 2100 including the effects of both mid range and high range sea level rise were presented in Table 5. These predictions show that for present day sea levels, with the existing road and topographic conditions at the site, the road will be inundated every 1 to 2 years on average.

Three options have been considered for mitigating the impacts associated with inundation and sea level rise:

1. Advisory measures

Safety precautions and advisory strategies, cost $30,000

2. Minor Works

- Batter protection only – $1.5M.
- Raising the road – $2.7M
- Batter protection and raising the road – $4.2M

3. Major Works

Raise the roadway pavement to a level of 2.6 m AHD, with a 1:5 batter slope starting at the northern edge of the existing roadway and moving the alignment of the roadway slightly away from the Ralphs Bay foreshore, cost $9.2M.

A simple assessment of wave runup and overtopping of the major works concept design was undertaken, predicting wave generated overtopping rates for a range of roadway pavement levels. The analysis showed that this concept design would immediately reduce the frequency of inundation of the roadway from occurring typically every 1 – 2 years, to occurring less frequently than every 100 years (on average). Predictions indicated that a road pavement level of 2.6 m AHD would provide adequate driving conditions (at restricted speeds) during a 20 year ARI storm, with mid range sea level rise to year 2050 considered.

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Figure 1 Location Map

Figure 2: Study Area

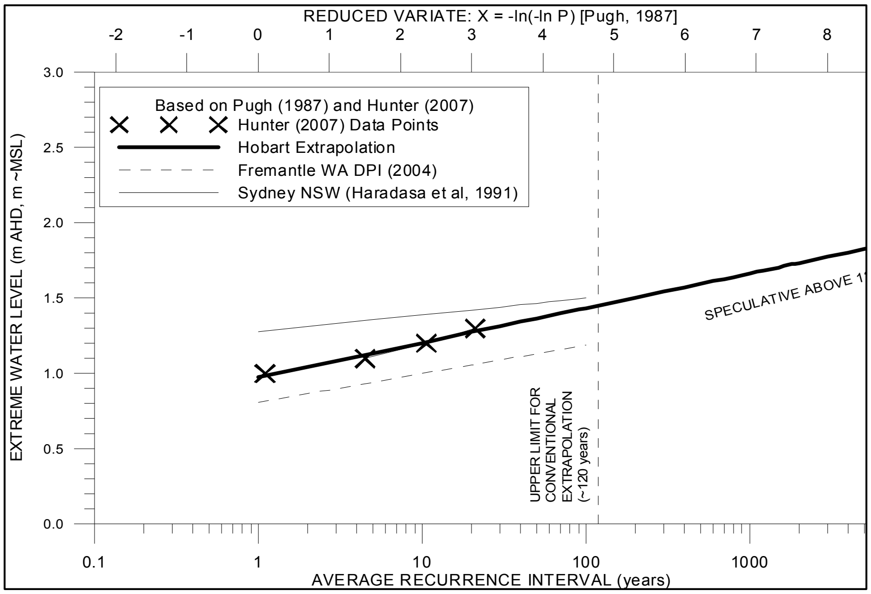

Figure 3 Extreme Water Levels for Hobart

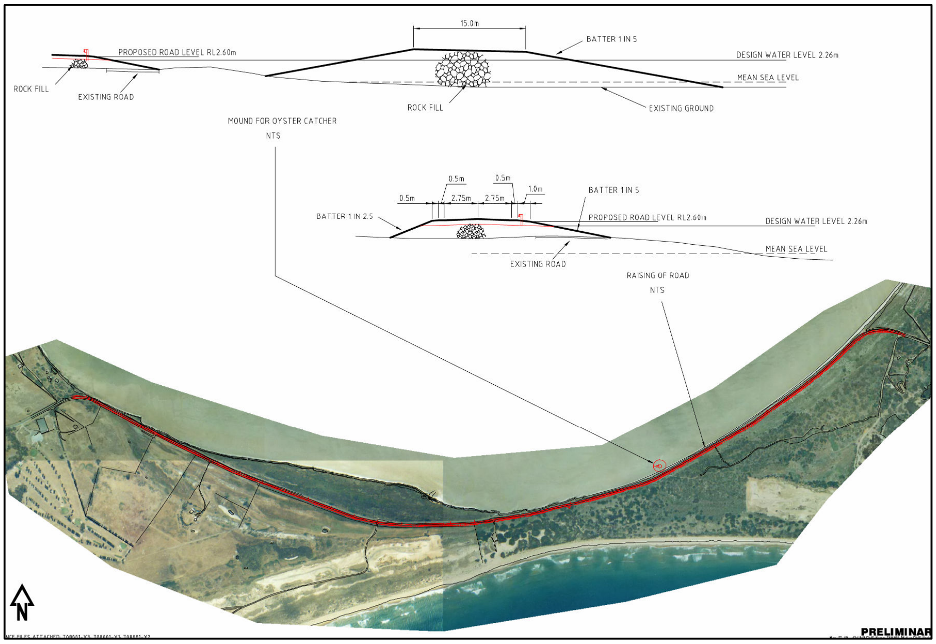

Figure 4 Major Works Concept Design