INVESTIGATING STRATEGIES TO REPAIR HISTORIC TIDE WALLS ON THE CLARENCE RIVER AND ADJACENT BEACH AND RIVER BANK PROTECTION

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Abstract

Over the last ten years, large flooding events in the Clarence River have resulted in separation of the Collis Wall from Goodwood Island. A series of storms over 2009–2013 has been assessed to have driven the main changes, including the development of a channel between the Collis Wall and Goodwood Island, and deep scour along the wall. This has initiated damage to the wall as the destabilised wall collapses into the scour hole. This damage is progressing as the scour hole moves to the lee of each new head of the collapsing wall. Currently, 120 m of the head has been damaged, with crest levels well below the constructed level of 0–0.2 m AHD.

The well-accepted numerical model MIKE 21 WS was used to obtain an understanding of wave penetration during recorded extreme events, and to assess wave and current interactions during tidal cycles into the study area. In consultation with DPI – Lands, MHL also modelled the influence of 100 m and 220 m tee groynes at the base of the Clarence south entrance training wall to investigate the influence of this on the wave height at the middle wall and subsequently at Whiting Beach.

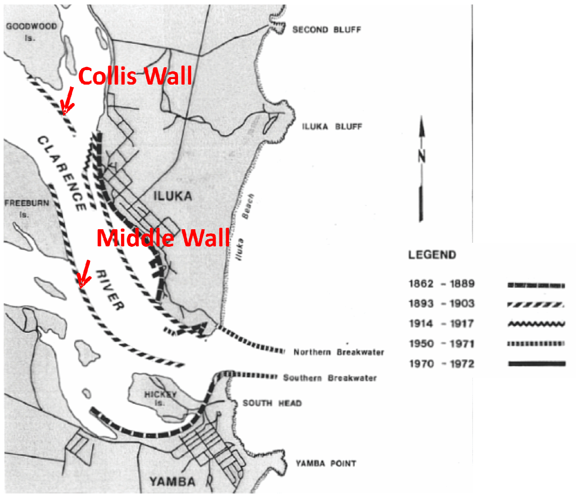
This paper draws on the extensive combined experience of DPI – Lands and MHL to trace the history of the Clarence tide walls and provides sustainable repair strategies to the Collis Wall, Middle Wall and the adjacent river banks at Goodwood Island and Whiting Beach cognisant of the dominant physical processes operating based on historic tide data, flood data, aerial photographs and numerical modelling.

The primary focus of this investigation was to assess the function of the Collis Wall and provide repair strategies if deemed necessary for improved shoreline and navigation channel stability. Given the concurrent and integrated coastal/estuarine processes operating, MHL also took the opportunity to investigate design options to repair the Middle Wall and to reduce erosion at Whiting Beach to maximise the value and benefits from the study.

Historic Context

A brief history of the construction of the training wall is provided in Coltheart (1997). **Figure 1** indicates the three training walls that had been completed by 1903. No details are available of the design specifications for these walls similar to those available for Moriartys Wall, hence, any repairs will be based on assessment of the armour of the existing wall and the design values obtained from numerical modelling.

The history of the wall indicates that the wall was built to reduce the meander of the river and provide a stable channel for shipping in 1903. In more recent times the dredge spoils have been disposed offshore other than the landward side of the wall due to probable awareness of environmental concerns. The loss of injected 'sink material' may also have contributed to the initial separation of Collis Wall and Goodwood Island (**Figure 2**). There is no documented evidence of previous repair of both the Collis Wall and the middle wall.



Source: *Yamba Waters - A Summary of the Yamba Waters Coastal Engineering Study*, PWD 1984

Figure 1: Construction history of training walls on the Clarence River, NSW

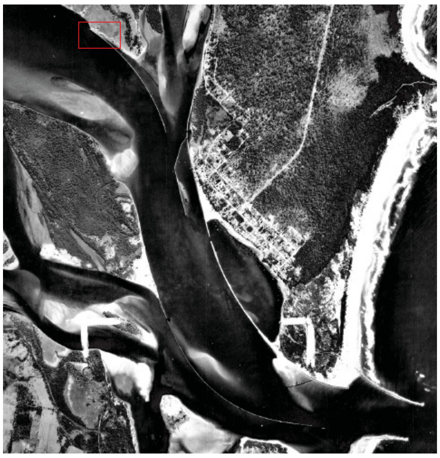


Figure 2: 1966 aerial photo indicating Collis Wall connected to Goodwood Island

At Risk Infrastructure

Several key components of infrastructure are at risk around the Collis Wall–Goodwood Island area. This includes the wall, the island and navigation aids that are founded on the wall, island or riverbed (**Figure 3**).

The responsible party for each of the components includes:

- Crown Lands – DPI for Collis Wall
- Port Authority of NSW for the navigation aids
- Land owners for Goodwood Island.

Collis Half-Tide Wall

Collis Wall is a half-tide training wall that guides the river in a near-perfect semi-circle (radius 1825 m) towards the entrance to the south (**Figure 3**). As constructed crest length was approximately 1300 m, but is now somewhat shorter due to damage to the wall. The crest level is at 0.0–0.2 m AHD throughout.

Collis Wall is experiencing ongoing damage to both the western and southern ends of the wall. This is progressive damage that has been shortening the wall at each end over approximately the last five to ten years as evidenced by recent aerial photos and bathymetry and profile measurements (**Figure 3**–**Figure 5**).

The mechanisms for damage at each end are different, but both may be due to loss of armour material into deep scour holes caused by flood events. A cluster of floods between 2009 and 2013 probably has caused scouring both where flood flow first encounters the head of the wall, and where the curve of the wall induces increased hydraulic forces and hazards, including increased bottom scour against the wall near the southern end.

It can be reasonably expected that further damage will occur to the wall in the presence of large floods in the Clarence River if a ‘do nothing’ strategy is established.

Goodwood Island

Goodwood Island is experiencing a rapid rate of bank erosion, as evidenced by the steep scarp and loss of vegetation into the river (**Figure 4a**). Discussions with local residents and the harbour master provide further anecdotal evidence that the island is receding. Aerial photos establish that the island was connected to the wall in 1966 (**Figure 2**).The drivers of this recession include tidal and catchment runoff in the river, wind waves generated by strong south to south-easterly winds, and boat wakes.

Navigation Aids

Navigation aids located on Collis Wall and Goodwood Island are at risk due to failure of the wall and significant erosion of the island (**Figure 4a**).

Middle Wall and Whiting Beach

Recent investigations (RHDHV 2014) indicate that Whiting Beach has been undergoing severe erosion. The following preliminary modelling strategies were used to investigate the influence of tee walls built from the shoreline into the river to investigate possible reduction in wave height at Whiting Beach and at the middle wall which has been subject to gradual damage and disrepair:

- 100 m of tee wall at the base of the southern Clarence breakwater (**Figure 6a**)
- 220 m of tee wall at the original location of the tee wall (**Figure 6b**).

Figure 4a: Erosion at Goodwood Island

Figure 4b: Imminent danger to navigation aids on Goodwood Island

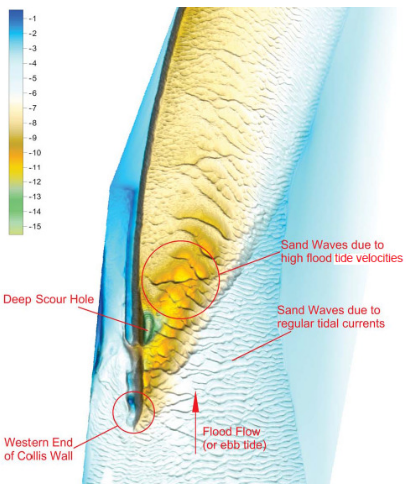


Figure 5: Scour processes indicated by bathymetry measurements in 2015

Summary of Relevant Coastal Processes and Concept Designs Modelled Using MIKE 21 SW

Waves

Obstructions such as Moriartys Wall and the river bend restrict the propagation of waves further upstream to Collis Wall. MIKE 21 SW modelling software was used to model wave heights within the river along the middle and Collis tidal walls (**Figures 6a, b and c**). The modelling indicated that the maximum wave heights from the ocean reaching the wall were less than 10 cm.

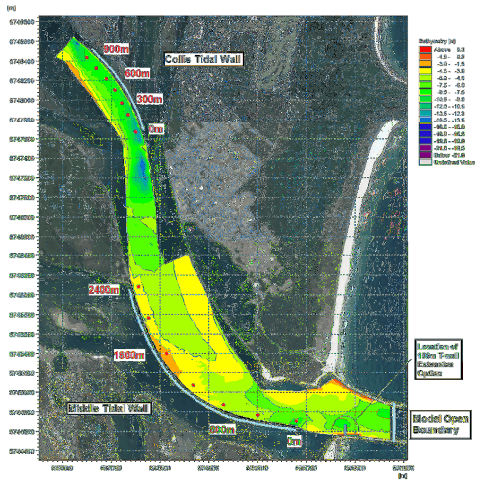


Figure 6a: Model boundary conditions for estimating wave heights at Collis Wall and middle wall with 100m groyne on Yamba training wall base

MIKE 21 SW (spectral wave) modelling software was used for this investigation. The model uses a fully spectral formulation based on the wave action conservation equations to calculate wave propagation across a bathymetry given certain environmental and calculation parameters and user determined input boundary conditions.

The model was constructed to extend from inside the breakwater entrance to upstream of the Collis Wall (**Figure 6a**). The open boundary with independent wave conditions was chosen to be approximately 300 m within the Clarence River breakwater entrance to reduce wave breaking within the model calculations. The model extent and bathymetry are shown in **Figure 6a, 6b** and **6c**.

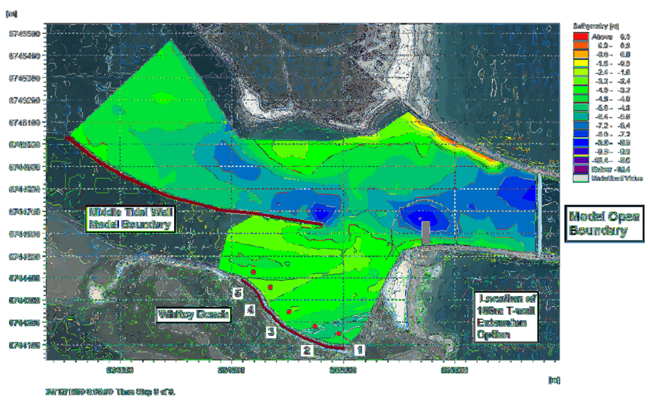


Figure 6b: Wave heights at Whiting Beach with 100 m groyne

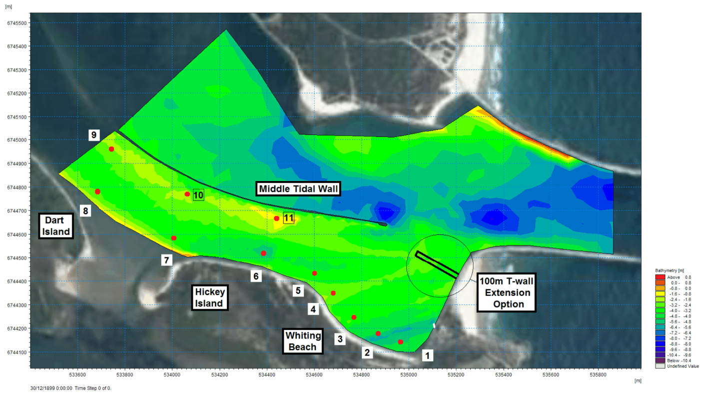


Figure 6c: Wave at Whiting Beach and surrounds with 220 m groyne

Wave conditions at the open boundary were extracted from previous modelling undertaken using both spectral and Boussinesq wave models (MHL2553) which forecast entrance wave heights for extreme offshore wave conditions (Hs of 6 m, 7 m and 9.5 m for 12 and 15 second wave periods). The largest wave heights produced by the offshore forcing conditions of period 12 and 15 seconds were selected for boundary conditions in two model scenarios. These conditions selected from previous modelling are presented in **Table 1**.

Table 1: Selected model boundary conditions

	H_s	T_p
Boundary conditions 1	3.5 m	12 s
Boundary conditions 2	3 m	15 s

The wave conditions at the walls for each boundary condition are given in **Table 2** and **Table 3**. Chainage for each structure and the beach start at the easternmost end of the walls and the beach (**Figures 6b** and **6c**). **Table 2** indicates that during an extreme wave event wave penetration to the Collis Wall is insignificant. The table also indicates that Hs is approximately 1.0 m at the western end of the middle wall during an extreme event.

Wave conditions were extracted 25 m out from points spaced along the length of each wall. The locations of the model output points are shown in **Figures 6b** and **6c**.

Table 2: Model results with boundary condition 1
H_s = 3.5 m, T_p = 12 s

Chainage from upstream head of wall (m)	H_S (mm)	T_p (s)	Mean Direction (°)
Collis Wall[1]			
0 (Head) to 900	<10	-	-
Middle Wall			
0 (Head)	0.95	11.8	75
800	0.65	11.8	92
1600	0.27	11.9	103
2400	0.12	10.6	121

[1] Incident waves modelled at Collis Wall were too small for period or direction measurements

Table 3: Model results with boundary condition 2
H_s = 3 m, T_p = 15 s

Chainage from upstream head of wall (m)	Hs (mm)	T_p (s)	Mean Direction (°)
	Collis Wall[1]		
0 (Head) to 900	<10 mm	-	-
	Middle Wall		
0 (Head)	0.81	14.9	75
800	0.56	14.9	92
1600	0.23	14.9	103
2400	0.11	14.9	121

[1] Incident waves modelled at Collis Wall were too small for period or direction measurements

Severe wave conditions produced a maximum incident wave height of 0.95 m at the eastern tip of the wall, besides a small increase in wave height at 800 m from its tip, incident wave height drops along its length.

The model confirms the expected result that ocean waves would not reach as far upstream as Collis Wall, with negligibly small wave heights (<5 cm) recorded in both models.

Influence of 100 m of Tee Wall at the Base of the Clarence South Breakwater

Table 4 indicates results when a 100 m tee wall is constructed at the base of the southern breakwater. The results indicate that when a tee groyne is constructed at the base of the southern Clarence breakwater a maximum 8.5% difference lowering of significant wave height at the middle wall eastern end is observed. The maximum wave height is very similarly influenced. The directionality of the wave reaching the Collis Wall and the middle wall remain almost unchanged by the tee section construction.

Table 4(a): Model results with boundary conditions 2 (Figure 6b)
H_s = 3 m, T_p = 15 s

Chainage from upstream head of wall (m)	Hs (mm)	T_p (s)	Hs (mm) with 100 m tee wall	T_p (s) with 100 m tee wall
		Collis Wall[1]		
0 (Head) to 900	<10	-	<10	-
		Middle Wall		
0 (Head)	0.81	14.9	**0.74 (>8.5%)**	**14.9**
800	0.56	14.9	**0.53**	**14.9**
1600	0.23	14.9	**0.23**	**14.9**
2400	0.11	14.9	**0.11**	**14.9**

Table 4(b): Model Results with Boundary Conditions 2 (Figure 6b)
H_s = 3 m, T_p = 15 s

	Whiting Beach				
Points on Figure 5.2	**Hs (m)**	**T_p (s)**	**Hs (m) with tee wall (% difference)**	**Wave Direction Before and (After) Construction (angle)**	**T_p (s) with tee wall (% difference)**
1	0.27	15.0	**0.12 (>50%)**	**35 (28)**	**15.0**
2	0.35	15.0	**0.22 (>35%)**	**54 (42)**	**15.0**
3	0.66	15.0	**0.46 (>30%)**	**54 (47)**	**15.0**

4	1.0	15.0	**0.66 (>30%)**	**63 (56)**	**15.0**
5	0.61	14.9	**0.48 (>29%)**	**68 (66)**	**14.9**

Influence of 220 m of tee wall at the original position of a tee wall at the base of the Clarence South Breakwater

Table 5 indicates results when a 220 m tee wall is constructed at the base of the southern breakwater at its originally constructed position. The results indicate that when a tee groyne is constructed at the base of the southern Clarence breakwater (Figure 6c) a lowering of significant wave height at Whiting Beach of 85% to 14% is realised. This is significantly greater than the 100 m tee groyne located at the previous location. Also for locations 1 to 5 on Whiting Beach the wave direction is far more perpendicular to the beach (**Table 5**) resulting in smaller alongshore currents and hence less westward longshore sediment transport. The maximum wave height, too, is very similarly influenced. The directionality of the wave reaching the Collis Wall and the middle wall remain almost unchanged by the tee section construction.

Table 5: Model results at Whiting Beach with boundary conditions 3 (Figure 6c) H_s = 3 m, T_p = 15 s

	Whiting Beach				
Points on Figure 5.2	**H_S (m)**	**T_p (s)**	**H_S (m) with tee wall**	**Direction before and (after) construction**	**T_p (s) with tee wall (% difference)**
1	0.28	15.0	**0.04 (>86%)**	**35 (4)**	**15.0**
2	0.40	15.0	**0.12 (>69%)**	**54 (23)**	**15.0**
3	0.65	15.0	**0.32 (>51%)**	**54 (35)**	**15.0**
4	0.90	15.0	**0.56 (>38%)**	**63 (48)**	**15.0**
5	0.57	14.9	**0.49 (>14%)**	**68 (65)**	**14.9**

Wind waves

Wind waves generated by strong south to south-easterly winds have the potential to erode the Goodwood Island banks. This direction has a relatively long fetch of 3–4 km and waves may grow to damaging heights. Indicative 100-year ARI significant wave heights for the 3.4 km fetch are 0.25–0.30 m, and wave periods are 1.5–2.0 s. Clearly this is most damaging on high tide levels, as Collis Wall protects Goodwood Island from the longest fetch.

Wave and current interaction

The design processes involved for rock armour would have to factor in current and wave interactions. Hales and Herbich (1972) indicate that the maximum increase in wave height for a 1.0 m/s to 1.5 m/s ebb current is approximately 15%. This was taken into consideration when designing armour size for Collis Wall and the middle wall in particular. **Table 5.6a** indicates the variation in wave height in close proximity to Whiting Beach when 0.7 m/s flood and ebb velocity interacts with the simulated 3.5 m, 12 s wave height boundary condition. The wave heights and current interaction was simulated with no structures in order to obtain an appreciation of the influence of current on wave heights in close proximity to the beach. Due to limitations in the scope of the study the 0.7 m/s current was applied to the entire domain. It is observed that although the current does not have significant influence on the wave direction, it does have influence on the wave heights in close proximity to the model boundary. This aspect of current/wave interaction may be more applicable to MIKE 21 BW modelling rather than the SW modelling that was utilised.

Table 6: Influence of ebb and flood current on wave height at Whiting Beach (with no lee wall)

	No Tide		Flood Tide		Ebb Tide	
Points on Figure 5.2	H_S (m)	Direction (angle)	H_S (m)	Direction (angle)	H_S (m)	Direction (angle)
1	0.33	31	**0.36**	**31**	**0.31**	**31**
3	0.74	52	**0.72**	**50**	**0.76**	**55**
5	0.66	69	**0.57**	**67**	**0.75**	**73**

The 'no tide' results in **Table 6** indicate a reasonable and accurate validation for the flood and ebb tide results.

Table 7: Influence of ebb and flood current on wave height at Whiting Beach (with 220 m tee wall)

	Flood Tide		Ebb Tide	
Points on Figure 5.3	H_S (m)	Direction (angle)	H_S (m)	Direction (angle)
1	**0.09**	**11**	**0.03**	**1**
4	**0.62**	**47**	**0.68**	**50**
7	**0.16**	**74**	**0.23**	**98**
10	**0.20**	**92**	**0.28**	**116**
11	**0.14**	**115**	**0.22**	**141**

It is evident that the flood tide with the tee wall causes the least amount of longshore current sediment transport due to the lowered wave height and the reduced obliquity of the wave directions.

Bank Erosion on Goodwood Island

The field visit indicated that there is active bank erosion on the southern side of Goodwood Island (**Figures 4a** to **4c**). It is also apparent from the 1949 chart that the line of the bank was much closer to the line of Collis Wall. A review of the available charts and aerial photos from 1949 onwards indicates that there is steady erosion of Goodwood Island, rather than a dramatic erosion starting at a particular time. Further, it can be seen the original location of the Collis channel leads are different from the current location, with the forward lead actually located at the head of Collis Wall. The Goodwood Island reach front lead has also been moved from the crest of Collis Wall to the edge of Goodwood Island between 2009 and 2014, though this lead at the crest of Collis Wall could not be found during the site inspection.

Table 8: Historical evidence for the attachment/detachment of the Collis Wall with Goodwood Island

Year	Condition	Source
1932	Attached	Chart
1949	Attached	Chart
1963	Attached	Chart
1966	Attached	Aerial Photo (Figure2)
1999	Attached	Chart
2005	**Detached**	Aerial Photo
2006 and 7	**Detached**	Chart
2009	**Unclear**	Chart
2014	**Detached**	Chart

The following observations were made from the aerial photos and charts and site visit:

- The aerial photos and charts (**Table 8**) indicate that Collis Wall detached from Goodwood Island during 1999 and 2005. Observations indicate that strong south to south-easterly winds generate wind waves that cause dramatic erosion.
- The rate of erosion observed during the site visit is at odds with the relatively slow rate of erosion identifiable in the charts and aerial photos. This would indicate that the current rate of erosion is much greater than that which has occurred over a long period. A factor in this is the channel that has formed between the wall and the bank. Tidal and catchment runoff through this channel, as well boat wake, have dramatically increased the rate of erosion of the bank.
- Boat wake is a contributing factor to river bank erosion. The channel between Collis Wall and Goodwood Island allows passage to small vessels.
- Ongoing erosion to Goodwood Island is a risk to Collis Wall, as a significant deepening of the channel will undermine the wall. It is assumed that the wall was built as a single-sided revetment type structure, so erosion on the landward side will cause the structure to fail at relatively shallow depths. Ongoing erosion on the river side of the wall will exacerbate damage to the structure, most likely continuing the degradation of the head at each end.
- Sediments in the channel transition from marine sands to mixed fluvial sands, with marine sands extending as far as the north-western tip of Palmers Island (MHL1309).

Dredging and other anthropogenic factors

Dredging is conducted in the Clarence River in several locations, but for this study the main dredge area to impact Collis Wall is immediately west of the wall. Dredging is done to maintain a channel depth greater than –4.5 m Iluka Port Datum (0.895 m below AHD). Since the scour in the wake zone of Collis Wall keeps the bed level far lower than this depth, all dredging is done upstream of the wake zone.

Dredging in close proximity to the wall may have influenced the sediment available for recovery of the bed between flood events. Future strategies to reduce erosion of the Goodwood Island river bank in close proximity to the wall could be centred around dredge spoil being disposed on the river bank and enclosed by a repaired wall (**Figure 7**).

According to RHDHV (2014), 30,000 m^3 was extracted from this area. Sediment in this area is essential for accretionary processes on the Goodwood Island bank and for infilling of the Collis Wall scour holes. There is no indication from the 2014 survey that significant accretion has occurred in the dredge area since 2009.

Physical processes influencing wall stability

Tidal currents and flooding

The Clarence River is subject to regular flooding as indicated by tide gauge records from Goodwood Island and from the Maclean gauge further upstream. Foregoing a detailed statistical analysis, it can be seen that major floods occur approximately every five years. It can also be seen that the period 2009 to 2013 was uncharacteristic, with five major floods occurring within four years.

There is limited information available on flow velocities at or near Collis Wall. Tidal gaugings have been performed at the entrance and other locations in the river which provide some data on tidal currents.

The Whiting Beach Erosion Process Study (RHDHV 2014) reported the following unreferenced tidal current results:

- A survey in 1964 found peak speeds of around 1 m/s in the channels on either side of the middle training wall and in the main channel at Palmers Island. Surface currents of up to 1.3 `m/s were recorded near the sea entrance on the flood tide, while elsewhere within the entrance channels surface currents were typically 0.5–1.0 m/s.
- Measurements in 1971 found peak ebb velocities of up to 2.7 m/s and peak flood velocities of 1.3 m/s at the reef located inside the entrance of the Clarence River (MHL662).
- In 1977 tidal current measurements found peak velocities of approximately 1 m/s between the entrance training walls and between 0.5 m/s and 0.75 m/s in other channels.
- The most complete measurement campaign was undertaken in 1996, when the maximum current velocities were recorded in the entrance, approximately 700 m from the ocean, with a peak ebb speed of 1.51 m/s and a peak flood speed of 1.46 m/s. As part of the campaign, tidal current, water level and water quality measurements were made at a total of 39 sites from offshore of the entrance to inland of Grafton (MHL798).

It should be noted that these velocities are recorded at the entrance and average channel velocities near Collis Wall will be significantly lower.

The Whiting Beach Erosion Process Study (RHDHV 2014) estimated that during floods, current velocities in the Clarence River can exceed 6 m/s, though there is no justification for this value.

Physical processes resulting in damage to wall

River currents

The impact of catchment runoff is clearly evident in recent high resolution bathymetric scans of the river bed (see **Figure 5**). The scour pattern shows deep and long sand waves, indicating either very fast or turbulent flows in this region. The bathymetry and levels indicated the following:

- The large scour hole present immediately adjacent to the half-tide peak of the wall is very deep, approximately –15 m AHD. This is much lower (by 3–4 m) than any recorded depth in the earlier surveys. The April 2007 survey did record a depth of 12.4 m in a similar area.
- The scour hole appears to be moving with collapsed head. The western 120 m of Collis Wall has been damaged in this way.
- A long section of wall (150 m) is then subject to scour depths of around –14 m AHD. This has caused a destabilisation of the rock wall, with the southern end of the wall collapsing into the scour hole. Approximately 60 m of crest length (**Figure 5**) has been lost in this way.

Floating debris

A secondary mechanism for damage to the walls, island and navigation markers most probably is the impact of debris being washed downstream during floods. This may act in conjunction with toe scour to provide the final impact that damages a destabilised structure, or may be damaging in itself.

Waves

It is unlikely that ocean waves propagate as far upstream as Collis Wall. Other obstructions such as Moriartys Wall and the river bend will further restrict the propagation of waves into the river. This understanding was further supported by detailed wave transformation modelling undertaken and reported above as part of this study.

Key outcomes – repair options and strategies

Do nothing

Through a passage of over 100 years since the construction of the Collis Wall, accelerated degradation has most probably taken place since the separation of the wall from Goodwood Island establishing an alternative tidal flow path. Without further action it can be expected that Collis Wall will continue to be damaged at each end during large flood events. Erosion to the banks of Goodwood Island will continue at a rapid rate, both during floods and under regular stresses of wind waves, boat wakes and tidal currents.

Associated with the ongoing damage to the wall and island, navigational aids will continue to be damaged through undermining of their foundations.

Concept design 1 – piled support for navigation markers

A relatively simple solution for the support of the navigation aids without extensive repairs to Collis Wall is to drive deep piles for each of the aids. The piles would need to be sufficiently deep to allow future erosion, so a design will need to estimate the maximum rate of erosion.

The use of piles may be much cheaper than rock rubble solutions for protection of the navigation markers, though mobilisation may be expensive. Piles may have to be moved if the channel migrates over time, particularly if the effectiveness of the Collis Wall diminishes over time if not repaired.

Concept design 2 – scour blanket

A well designed scour blanket is an effective tool in mitigating scour that may undermine a structure. Without scour protection of some form it is highly likely that Collis Wall will be further damaged by future flood events. This is recommended regardless of any of the other repair options selected, and can be implemented in conjunction with any of the other recommendations.

The actual toe depth of the original structure is not known. This information would be useful in determining the extent of scour blanket required, however, it can reasonably be assumed that the majority of the length of the wall is at risk. So it is recommended scour protection be added to the full length of the river side (south-western side) of the wall.

A preliminary estimate of the scour blanket material quantity is based on the parameters in **Table 9**.

Figure 7: Extension of wall to protect erosion at Goodwood Island

Table 9: Estimate of quantities for scour blanket solution

Design Details	Quantities
Armour density	2600 kg/m^3
Porosity of armour layer	70%
Depth of armour	0.5 m
Width of armour	3 m
Wall length	1300 m
Volume	1950 m^3
Mass	3550 t

It is expected that a rock grading similar to that used in in the construction of the rock wall be used, with rock mass in the order of 10–50 kg (CERC 2006). This is working on the premise that the wall stood firm through 100 years of exposure – the root cause of the current damage is through toe scour rather than undersized armour.

This repair option is highly recommended. It ensures that no further damage is done to the existing structure or to other repairs performed on the structure.

Concept design 3 – repair western and southern end of Collis Wall

The primary advantage of repairing the western end is to re-establish a footing for the channel marker that originally marked the end of the training wall. However, there is no other clear incentive for rebuilding this part of the wall.

It is estimated from the 2014 survey and existing structure slopes that 5540 m^3 of rock material would be required to re-establish the western head of Collis Wall.

Concept design 4 – repair southern end of Collis Wall

It is expected that a rock grading similar to that used in in the construction of the rock wall be used, with rock mass in the order of 10–50 kg. This is working on the premise that the wall stood firm through 100 years of exposure – the root cause of the current damage is through toe scour rather than undersized armour.

Concept design 5 – filling in the channel

A simple strategy is to armour the banks of Goodwood Island, noting, however, that the property is somewhat diminished in size.

This option is likely to be relatively cheap, as it can be constructed largely from land, by use of backtipping or excavator.

Concept design 6 – repair and connect Collis Wall to Goodwood Island

Figure 9 indicates two repair strategies for the western end of the Collis Wall. Option A would be approximately 200 m long and require 6800 m^3 of rock. Option B would be 100 m long and require 3300 m^3 of rock material. The rock mass will be in the order of 10–50 kg as specified for the optional designs 3 and 4 (**Table 9**). The longer option (200 m) wall repair would provide a greater length of protection for the Goodwood Island shoreline and provide increased protection from flanking effects of erosion due to wind waves.

Protection to middle wall

The conceptual design and modelling of a 100 m tee wall with crest at 0.5 m AHD at the base of the Clarence south breakwater indicated a 15% decrease to wave heights at the middle wall. Detailed modelling of further protective structures may provide guidance to reduce waves reaching the wall during extreme events and causing further damage.

Protection to Whiting Beach

The 100 m tee wall and the 220 m tee wall reduced wave heights at Whiting Beach by 30% to 50% and 15% to 85% respectively. The 220 m wall also results in increased obliquity of the waves to Whiting Beach which in turn would considerably reduce longshore currents due to wave action and therefore reduce erosion.Around 20,000m3 of clean marine sand (dredged from the navigation channel at the western end of Dart Island) was pumped onto the beach in 2016. The sand has withstood several ECL events in that time (including one during construction).
Whiting beach holds significance to the community for recreation and is currently retreating rapidly. The recently placed sand protects substantial infrastructure (car parks, public toilets, boat ramps, roads, several buildings, moorings) but more importantly a break through to Yamba Bay would be catastrophic to the system and has the potential to effect the tidal prism. Historically the original river channel actually went through Yamba bay.

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