Best Management Practices for Foreshore Stabilisation

BRUSHWALL

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For Department of Biodiversity Conservation and Attractions

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Cover Page: Brushwall at Centenary Avenue, Canning River foreshore three years after installation (Syrinx, 2019)

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1.0 DESCRIPTION

Brushwalls are vertical structures constructed from brush logs placed horizontally on top of each other over a shallow trench and secured by wire onto timber retaining vertical piles or stakes (Figure 1). Brush logs are bundles of woody stems or branches made from *Melaleuca* or *Kunzea* shrub species tied with wire. In the international literature brush logs are also referred to as brushwood fascines, and the brushwalls as brush fences.

Figure 1 Example of brushwall (main photo) and a brush fabrication (insert) (Source: Syrinx)

The use of brush logs (or fascines) for slope stabilisation and riverbank protection is well recorded for many parts of Europe, Asia and United States where they have been used for centuries, alongside other bioengineering methods. The earliest uses of brush bundles to control water erosion date back to 28BC in China (Lewis, 2000, Evette et al., 2009). While the use of live (*Salix* spp .or willow) brush logs or fascines for river bank stabilisation is well described (Schiechtl & Stern, 1997; Grey & Sotir, 1996; Stoir & Fischenich, 2001; Gerstgraser, 1998), the use of inert brush is rarely referenced in the literature and is generally confined to construction of brush mattress structures and stabilisation of dryland slopes (Lewis, 2000; Sotir & Fischenich, 2001) rather than river bank protection. As such no specific data on the performance of inert brushwall structures is available. This chapter aims to present the design criteria and outline construction of the brushwalls using case studies from the Swan-Canning foreshore restoration projects.

The first recorded use of brushwall technique for river foreshore stabilisation in its current form was at Ashfield Parade in the Town of Bassendean and a little later at Point Resolution in Nedlands in mid 2000s. However, the use of a similar technique called 'wattling' was recorded for construction of 'Convict Fence' which helped retain silt and mud excavated to dredge a deeper channel to facilitate timber transport (Hutchinson and Davidson, 1979). While detailed construction of the 'fence' is not available, records show that it was made from Jarrah piles behind which logs and branches of locally harvested Casuarina trees and local shrubs (likely *Kunzea glabrescens* and *Melaleuca viminea* as they were prevalent in the area) (Hutchinson and Davidson, 1979). These structures are still performing their intended purpose in small sections of the Canning River such as Shelley section near Centenary Avenue indicating that use of natural materials is a viable method of stabilising sediments.

Given the relative success of the brushwall technique at trial sites in slowing erosion and promoting revegetation, the technique has become more popular in recent years particularly in low wave energy / low impact environments. Currently, brushwall techniques are used by several local governments to supress erosion of the river foreshore and optimise vegetation establishment, although with varying levels of success mainly due to poor placement/site selection or poor maintenance.

Unlike hard engineering structures, brushwalling is intended to be a temporary structure that prevents or reduces scour at the toe of the bank and, subsequently, protects newly planted vegetation behind the brushwall until it has established enough to replace the function of the brushwall. As such, brushwalls are generally installed in areas that are not impacted by severe waves or currents and where installation of hard structures would have a negative impact up or downstream of the structure due to flanking. At highly eroded sites, brushwalls can still provide flexible bank protection, and possibly trap excessive sediments, however, the material has to be replenished regularly and the brushwall maintained more frequently than would be generally required of rock revetment structures.

The advantages of brushwalls are the relative low cost of construction, small footprint of the vertical structure, provision of habitat for fauna and a more natural appearance of the foreshore. The porous structure of brushwalling helps to dissipate wave energy, providing less wave reflection than vertical walling, which reduces scour (lowering of bed elevation) in front of the structure and consequently decreases flanking erosion, updrift and downdrift. In addition, the brushwall allows for free groundwater movement towards the river while capturing sediment behind the brushwall. Due to small size and weight of the logs and relative ease of fabrication, the entire brushwall can be constructed in the field efficiently and installed in areas that are difficult to access with construction plant.

The disadvantages of brushwalls are a short structural life span, their limitation for use in areas with low to medium wave and flow impacts and the requirements for ongoing maintenance (especially if designed and implemented poorly). Brush material is not an ‘off the shelf’ product and requires 4 – 6 weeks to source from a registered grower limiting possibilities of urgent repairs.

1.1 CASE STUDIES AND EXAMPLES

Case Study 1: Point Resolution Foreshore

Site characteristics

Point Resolution is characterised by steep slopes, limestone cliffs and long beaches. The southern beaches have a rock cobble surface, rather than sand, which is dominant on the north/west beach.

The site is predominantly exposed to waves generated by strong south westerly winds, and frequent wake from boats and watercraft. The low topography of the beaches makes them subject to inundation during high tide and particularly during storm events. Consequently, southern beaches required use of limestone rock toe at the base of the brushwall whereas northern / western beach did not.

The objective of the project was to implement bioengineering and revegetation techniques to slow erosion, by reducing undercutting of the bank and the loss of sand/sediment.

What was done

Brushwalls were installed at the bottom of the steep southern and south eastern slopes in 2011 and the slopes behind brushwalls were matted and densely revegetated (Figure 2 and Figure 3).

Figure 2 Brushwall use at Point Resolution: (a) against steep slope, (b) the same steep slope 8 years later, (c) double brushwalling for steep banks with high wind wave impact and (d) brushwall without rock rip rap in low impact area 5 years after installation (Source: Syrinx)

The height of the brushwall corresponded to high water levels recorded during storm surges as marked by top of the eroded bank face. Limestone rock rip rap was used at the toe of the brushwall in the southern area to reduce scour as much as possible. Rock toe was not used in front of the western beach brushwall constructed in 2015, as the scour in the area is low (Figure 2).

The brushwalls were regularly maintained since installation, and additional brush logs were placed every 3 – 5 years, dependant on the location/erosion impacts, to sustain brushwall height and function.

Figure 3 Extent of brushwalling at Point Resolution (north west beach): (a) in early 2015 and (b) in 2020 showing sedge and rush establishment (Source: Nearmap, 2020).

The result and lessons learnt

- Rock rip rap is essential in dissipating wave energy in areas frequently impacted by wind waves and boat wash.
- Where scour impact is low, brushwall can be embedded into the sediment and it will continue to function as intended (i.e. reduce erosion during high flows).
- Regular maintenance is essential for the success of the technique. At this site, where high wave energy and erosion rates reduce the lifespan of brushwalls, brush refill is required every 3 – 5 years, or until surrounding vegetation has matured enough to mitigate erosion without brushwalls.
- When adding further brush logs to maintain brushwall height, additional stakes were installed next to existing stakes as this was the most time efficient way of reinstating brushwall height. However, a stake remover should be used to remove stakes that no longer provide anchoring function.

Case Study 2: Success Hill Reserve

Site characteristics:

Success Hill Reserve site incorporates precipitous slopes and cliffs with several springs and groundwater seeps. The erosion impacts generally stem from boat wake, winter high river flows and drying climate which causes soils in cliff areas to become less cohesive. Recreational and fishing activities have caused several undercut areas to collapse and create scalloped banks in the lower bank elevations 300 – 700 mm high.

What was done

Due to high sensitivity of the site (the area is a registered Aboriginal site of high significance), as well as difficulties with site access, the brushwall technique was chosen to reduce the impact on the riverbed and provide opportunities for vegetation establishment. Brushwalls with limestone rock toe and woody debris, and brushwalls alone, were used to control erosion (Figure 4 a-f).

Double brushwalling was used in areas where cliff or precipitous slope was actively eroding, to capture soils and prevent the planted areas from being buried.

The site banks that were lower in height and showed scalloping and undercutting were protected by brushwalls only. The bottom of the brushwall is almost always submerged and given it is protected at each end of the wall, no rock rip rap was installed in front of the brushwall.

Lessons learnt

- Undercutting in the scalloped areas with brushwalls continued despite successful growth of vegetation, however, this has occurred at a much lower rate, with no bank collapses recorded in 4 years.
- Double brushwalling is useful to capture upper bank sediments that erode due to drying or surface water runoff (Figure 4b).

Figure 4 Use of Brushwall to treat erosion at Success Hill Reserve – steep cliffs (a - d) and low elevation scalloped shoreline (e and f) (Source: Syrinx)

Case Study 3: Clontarf Foreshore

Site characteristics

Clontarf foreshore was subject to infill of various rubble and sand, leading to a landscape and soil profile that is vastly different from the original profile. Following removal of asbestos and placement of clean fill, a bioengineering technique was required to help mitigate erosion. The boat traffic in the area is low and most erosion is caused by wind waves, influenced by the opposite riverbank (Wadjup Point), which results in a natural indentation / curvature of the foreshore in this area.

What was done

Brushwalls were installed between the high and low water mark, in line with the existing sedges and at an angle that is almost perpendicular to river flows (Figure 5a-f).

Figure 5 Brushwall at Clontarf Foreshore showing the site (a) before works in 2016 and (b - f) after works in 2019 (Source: Syrinx and Nearmap)

Lessons learnt

- Analysis of the surrounding environment in altered landscapes is crucial in determining future erosion patterns and the best placement of erosion control structures.
- Embedment of 0.2 m was sufficient to allow brushwalls to function as intended.
- Alignment of the brushwall at an angle that reduces scour and enhances deposition of sediment by river flows is promoted (Figure 5e and 5f).
- A 24-month maintenance period was required to ensure that the vegetation planted behind the brushwall is well established and that the brush wall was performing as intended under different water conditions.

Examples of unsuccessful use of Brushwalls

The failure of brushwalls to perform is generally due to incorrect positioning (e.g. wall height is too low or too high) or poor materials and construction. Some of the most common examples showing issues with brushwall placement are outlined in the figures below.

Figure 6 shows an example of a brushwall height that was too low (yellow arrow) causing erosion of the bank behind the wall (currently a coir log is installed in this area to help capture sediment during high water levels). Brush wall height was subsequently raised as well.

Figure 6. Example of a low height brushwall causing overtopping and bank erosion (Source: Syrinx)

Incorrect positioning of the brushwall with respect to bank tie in is shown in (Figure 7). The gap between the bank and the brushwall was caused by high velocity flows created behind the brush wall at the time of river flooding. In this case the brushwall position is too far from the bank. A greater success would have been achieved if the brushwall was tied back into the bank few metres back from the original position in line with the upstream section of the brushwall.

Figure 7 Incorrect tie in with the bank (Source: Syrinx)

Using brush logs with blunt end prevents intertwining of brush material within the brushwall and can subsequently cause weak points along the brushwall particularly if the overlaps are small or misaligned (Figure 8). Same figure shows a good overlap to the bottom left.

Figure 8 Use of blunt end brush logs with small overlap causing weak points in the brushwall (Source: Syrinx)

Installing brushwalls in high erosion environments without toe protection is also a common error. In the example shown in Figure 9, lack of toe protection has caused undercutting and accelerated erosion underneath the brush wall. In addition to this the brushwall was installed at a steeper angle to river flows than recommended (i.e. >30°) and the position of the wall was extended too far into the river channel. While this was done with the aim of deflecting flows from the downstream section of the foreshore the flow velocities are far too great for the brushwall in its standard configuration. the force exerted onto the wall can destabilise stakes that are not embedded deep enough to avoid movement due to sand liquefaction during flooding.

Undercutting like this was also observed in areas where tree roots might be present close to soil surface thus preventing appropriate embedment of the brush. Therefore, it is always important to check and trench brush logs to prevent brushwall undermining by waves and currents.

Figure 9 Use of brushwall without toe protection causing undercutting and erosion (Source: Syrinx)

2.0 PURPOSE AND APPLICATION

The main purpose of brushwalling is to provide a temporary and biodegradable structure that prevents bank toe scour and supports replanting of riparian vegetation. This provides time for plants to establish, until they are able to withstand erosive forces without the protective brushwall. Where banks are subject to overland flow (overbank scour), brushwalls may also capture sediment behind the brushwall.

The brushwall technique is applicable to banks with small to moderate undercutting that are susceptible to low to medium flow velocities and short period wave heights of low amplitude (i.e. wind-waves or small-craft wakes). The technique is also useful in areas where access to machinery is not possible and where bank width is too small to construct other means of protection such as rock revetment. The applicability of brushwalls for controlling different types of erosion are provided in Table 1.

Table 1 Brushwalling applicability

USEFUL FOR EROSION PROCESSES		**PROFILE SPATIAL APPLICATION**	
Description	**Feasibility**	**Description**	**Feasibility**
Toe erosion with upper bank failure	■	Toe	▒
Scour of middle and upper banks by currents	□	Midbank	□
Local scour	□	Top of bank	■
Erosion of local lenses/layers of non-cohesive sediment	▒	**HYDROLOGICAL GEOMORPHIC SETTING**	
Erosion by overland flow/overbank runoff	▒	**Description**	**Feasibility**
General bed degradation	▒	Resistive	▒
Head cutting	▒	Redirective	▒
Piping	▒	Continuous	□
Erosion by navigation waves	□	Discontinuous	▒
Erosion by wind waves	□	Outer bends	▒
Erosion by debris gouging	□	Inner bends	□
Bank instability/susceptibility to mass slope failure	■	Incision	▒
Erosion due to uncontrolled access (either boat launching, human or animal trampling)	□	Lateral migration	■
Erosion due to inappropriate focusing of drainage	▒	Aggradation	▒
Enhance erosion due to sedimentation of the channel	▒	**Feasibility method** 'White' = feasible 'Grey' = possibly feasible 'Black' = not feasible	
Erosion due to interruption of sediment transport	▒		

2.1 CONDITIONS WHERE PRACTICE APPLIES

Brushwalls are applicable in areas which require mitigation from toe erosion or undercutting in low to medium wave and flow impact areas, that are not adjacent to high value economic assets (e.g. road or other essential infrastructure).

The vertical nature of the structure allows for its use in the foreshore areas where space is limited and where other foreshore treatments may not be possible for this reason (e.g. rock revetment). Brushwalls should be used in areas where high water levels or stormwater levels are less than 0.8m above the existing bed level and peak annual significant wave height < 0.3 m. The technique should be used in areas where riverine habitat must be vegetated, and overall natural aesthetic of the foreshore restored/maintained.

Brushwalling is not suitable if the riverbed shows large fluctuations in bed elevation or where the river bed is hard or highly compacted. This technique should also be avoided when there are adjacent high-value assets or where commitment to maintenance is uncertain.

2.2 COMPLEXITY AND SENSITIVITIES

The complexity in designing brushwalling is relatively low. However, there are several sensitivities that should be considered when designing or planning to use this technique:

- **Maintenance** — maintenance funding is required to maintain and extend the functional life of the brushwall structure. If undercutting of the brushwall or gaps form between the logs (e.g. at overlaps), the likelihood of damage to revegetation and any other implemented foreshore protection measures, such as erosion fabrics, increases. Sand / sediment loss can intensify in areas damaged by wave action and any other small breaches. When constructing the wall, always set aside several brush logs that can be used for urgent repairs as brush material is often not readily available.

- **Site access** — While the brushwalling can be installed on sites with difficult access, installation should only occur if personnel can reach those areas safely. This is important for maintenance of the structure as well.

- **Design specifications** — the design should consider the appropriate location of the brushwall on the bank profile, crest elevation, length of the structure, selection of brushwall toe protection (e.g. rock rip rap, embedded brush material extending perpendicular to the brushwall) and embedment.

- **Adjacent foreshore** — any vertical structure, including porous surfaces such as a brushwall placed on an eroding bank, will result in exacerbated erosion of the adjacent foreshores. This is due to a combination of factors, including reduced sediment supply for the downdrift foreshore due to stabilisation of the bank. A design for brushwalling should incorporate plans to manage and mitigate erosion of adjacent banks.

- **Buoyancy** — buoyancy effects must be considered in the design to minimise uplift of the stakes holding brush logs within the ‘wall’ configuration (e.g. if the brushwall is positioned in an area where significant undercutting occurs, brush logs may move up and down within the brushwall alignment acting as a pump eroding sands under and behind the brushwall at a faster rate).

- **Public use of the area** – If the brushwall is installed in an area frequented by fisherman and public it is likely that the brushwall could be used for seating or access during high tides. This can result in the faster deterioration of the brushwall. In such circumstances, public exclusion via fencing should be considered. Revegetation the area immediately behind the brushwall with large plants can assist with faster plant establishment and lower chances of accessing and damaging the brushwall.

- **Boating and debris —** debris (flotsam) containing large items like logs can damage the brushwalling. Frequent waves caused by boating activities can also deteriorate brushwalls faster and cause undercutting. Careful positioning of the wall, as well as the strategic placement of rock rip rap, can assist in maintaining functionality of the brushwall.

3.0 DESIGN GUIDELINES

Key steps in producing the brushwall design are defining the area that can be protected using this technique and developing the layout (i.e. position and height of the wall) both of which are determined by site conditions, erosion dynamics and the overall project objectives.

Identification of erosion

Applications of brushwalling can be notionally distinguished between wave and current dominated erosion cases (Figure 10). Wave dominated conditions occur more commonly in the lower estuary, as larger wind waves can be generated across Melville, Perth or Canning Waters and the boat traffic is common and frequent. Current dominated conditions commonly occur in the mid to upper channel sections. While wind waves may not be strong in these sections as they are in the estuary, boat wakes can cause severe disturbance particularly where boat traffic is frequent.

Initial evaluation of the viability of using brushwalling should determine the nature of the erosion issue being addressed and ensure that it can ultimately be addressed through revegetation (see Chapter 2). Erosion must be on the upper bank (i.e. above mean water level), with low to moderate wave and current conditions. For bank grades flatter than 1V:3H, typical riparian vegetation can withstand wind waves with significant height of Hs<0.3 m and typical currents U<0.5 m/s without experiencing disturbance and approximately double these criteria causing vegetation stripping (Shafer et al. 2003). For steeper grades or more energetic conditions, riparian vegetation requires structural reinforcement, such as erosion control matting (see Chapter 1), geocell or terracing.

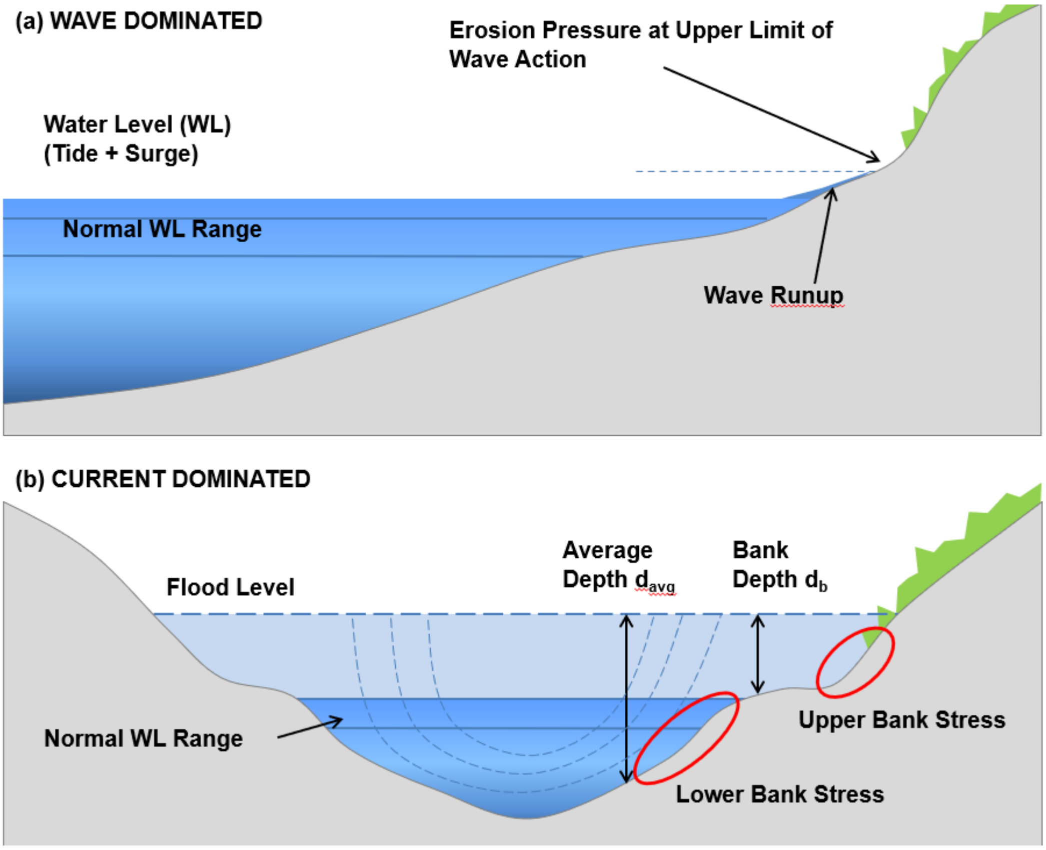


Figure 10 Wave and current dominated modes of erosion (Source: Seashore Engineering)

Optimal application of brushwall for foreshore protection

The application of the brushwall technique to reduce river bank erosion can be executed as: a wave baffle (e.g. case studies at Point Resolution and Clontarf), a flow retarder (Case study: Success Hill) or a flow deflector (see brushwall in Figure 9). A graphical representation of these modes of protection is shown in Figure 11 below.

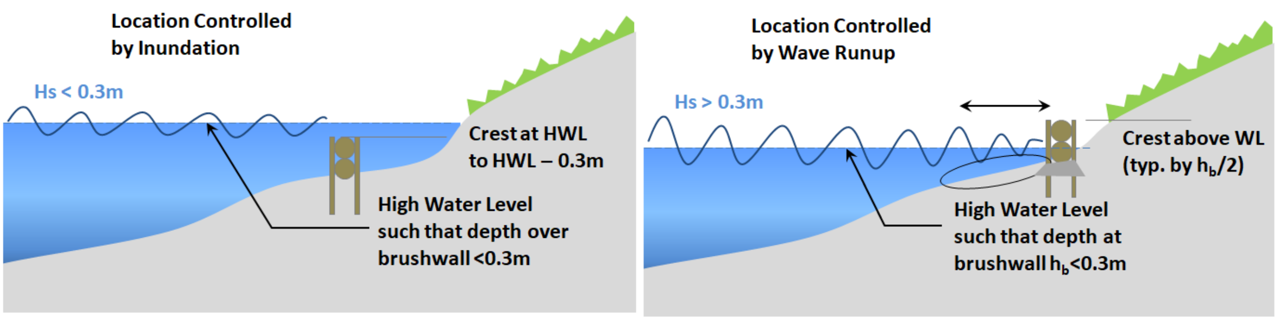
Wave baffle - In the lower estuary of the Swan and Canning Rivers, erosion of the 'upper bank' occurs mainly through wave action. As such in most cases brushwalling serves as a wave baffle, reducing wave energy behind the brushwalling. A distinction can be made between the low wave energy case where the brushwalling is installed at approximately mean water level (Figure 11a); and the higher wave energy conditions where the brushwalling is positioned higher up the slope to reduce exposure to wave action (Figure 11b).

Flow retarder – Brushwall can be sued as a flow retarder in the narrower river channel, where erosion of the upper banks occurs mainly during high water level and flow conditions. Here brushwalling reduces currents behind the brushwalling, but otherwise does not alter flows (Figure 11c).

Flow deflector - The attempt to place brushwalling at an angle to the shore represents application as a *flow deflector*, which aims to move flows away from the whole bank (Figure 11d).

For all applications, there are direct equivalents constructed from timber (Biedenharn et al., 1997), with brushwalling units effectively acting as lightweight, highly permeable panels.

(a) MID-LEVEL WAVE BAFFLE **(b) HIGH-LEVEL WAVE BAFFLE**



(c) FLOW RETARDER **(d) FLOW DEFLECTOR**

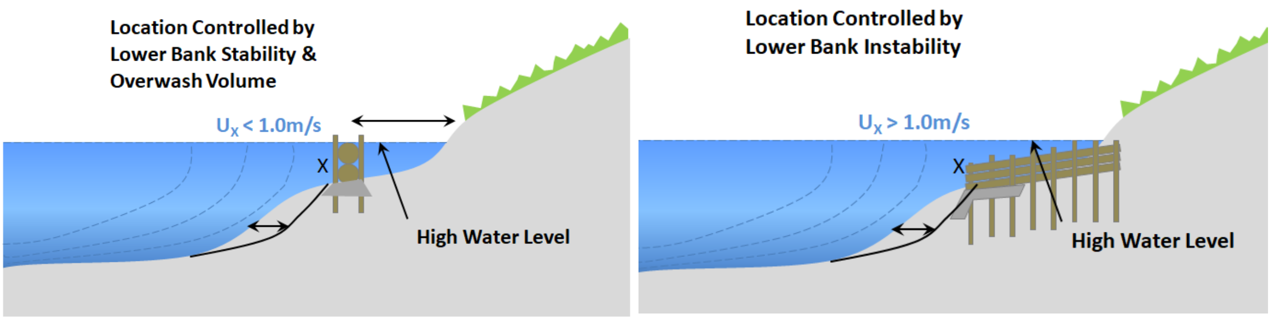


Figure 11 Modes of application for brushwalling (Source: Seashore Engineering)

(Notes: **HWL** = High Water Level, **h_b**= bank height, **Ux** = water/shear velocity)

Toe Protection

Where small bed movement is identified, or in cases where the brush log walling has been elevated to reduce active wave heights (Figure 11b), then a rock toe may be used to reduce potential for undermining. Embedment of the toe should be at least 50% of the average annual maximum significant wave height (i.e. the 1-year average recurrence interval or ARI). Under typical estuary conditions, this requires an embedment depth of approximately 0.2 - 0.3 m.

Brushwall placement with respect to undercutting

The appropriate position for a brushwall on the riverbank is influenced by the nature of bed/bank movements, the size of the active hydraulic zone (combined wave and water level variation), and the hydraulic transfer of water through the brushwalling.

Brushwalling is highly sensitive to undercutting, with focused flow occurring if a breach occurs underneath the brushwalling. This is amplified by the width between the brushwall and eroded bank and with increased spacing between breaches (Figure 12). Consequently, it is crucial to locate the brushwall at a position on the profile where it is less likely to experience bed or bank movements. This typically involves placement of the brushwall on a nearly flat section of profile, preferably landward. If repeated profile surveys are available, the brushwalling should be located near the point of least vertical change over time above mean water level, dependent upon the degree of wave shelter.

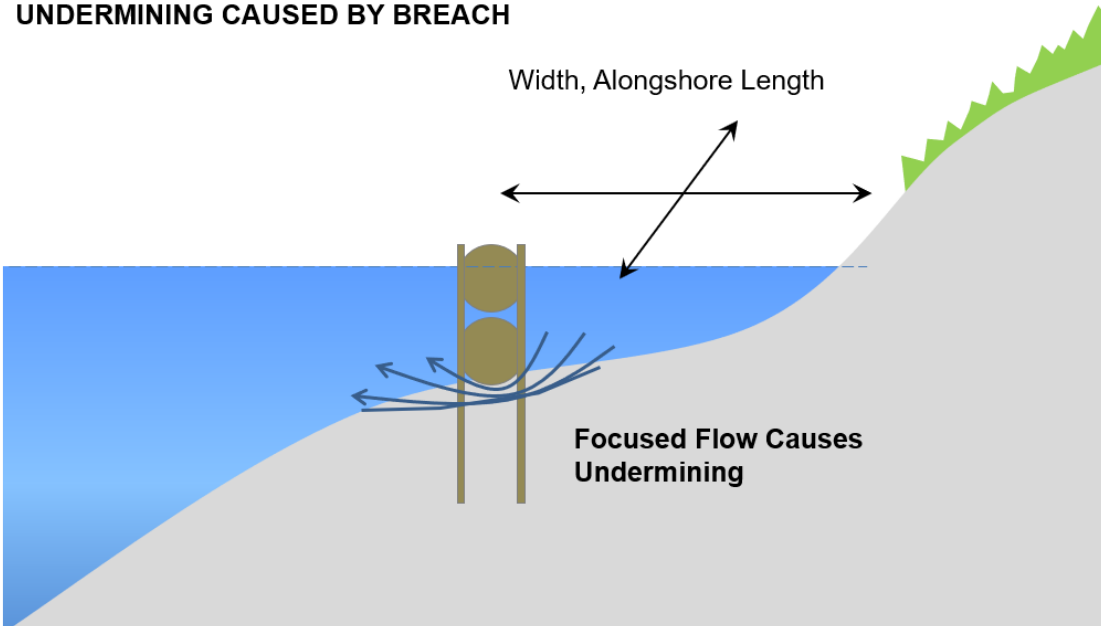


Figure 12 Flow focusing through breach point as a result of tidal fluctuations and poor embedment (Source: Seashore Engineering)

Other implications resulting from movement of the bank or bed include:

- If erosion is identified to be occurring from the lower bank (i.e. below mean water level), then brushwalling will be susceptible to catastrophic failure and should not be used;

- For locations subject to erosion-recovery cycles, placement of the brushwalling may restrict landward sediment transfer during the recovery phase. In these situations, the brushwalling should preferably be placed landward, close to the eroded bank.

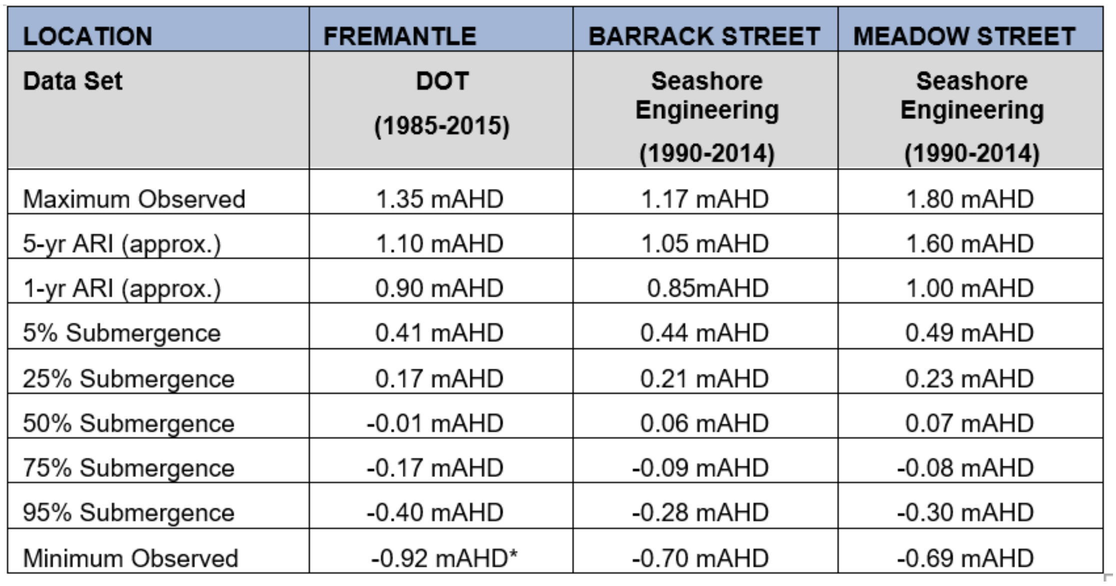
Determining brushwall position with respect to inundation and wave height

The hydraulically active zone is determined by combinations of tide, storm surge, runoff flooding, wind waves and boat wakes (Figure 10). For common applications of brushwalling, occasional overtopping is acceptable, and therefore target conditions typically vary in the range of 5% submergence to around 1 year ARI. Based on tide gauge data from sites in the Swan River (Eliot 2018), this gives a water level of WL = 0.4 to 0.9 m AHD (Table 2), to which a wave allowance should be added. An approximate top level (UL) for the brush log walling is therefore:

$$UL = WL + Hs/2$$

The 0.5m range of ‘design water level’ represents a significant variation in the consequent occurrence of overtopping, and it is generally preferable to have a higher crest level. However, due to limitations when using stakes brushwall height must typically be less than 0.8 m in height. Consequently, there is a need to locate brush log walling on the least active part of the profile or above excessive wave action, it may not always be practical to build to a higher level.

Table 2 Comparison of submergence statistics (Source: Seashore Engineering)



LOCATION	FREMANTLE	BARRACK STREET	MEADOW STREET
Data Set	**DOT** **(1985-2015)**	**Seashore Engineering** **(1990-2014)**	**Seashore Engineering** **(1990-2014)**
Maximum Observed	1.35 mAHD	1.17 mAHD	1.80 mAHD
5-yr ARI (approx.)	1.10 mAHD	1.05 mAHD	1.60 mAHD
1-yr ARI (approx.)	0.90 mAHD	0.85mAHD	1.00 mAHD
5% Submergence	0.41 mAHD	0.44 mAHD	0.49 mAHD
25% Submergence	0.17 mAHD	0.21 mAHD	0.23 mAHD
50% Submergence	-0.01 mAHD	0.06 mAHD	0.07 mAHD
75% Submergence	-0.17 mAHD	-0.09 mAHD	-0.08 mAHD
95% Submergence	-0.40 mAHD	-0.28 mAHD	-0.30 mAHD
Minimum Observed	-0.92 mAHD*	-0.70 mAHD	-0.69 mAHD

* This is a historic lowest record on Fremantle submergence curve, from 13 January 1886

The top level of continuous brushwalling should be maintained, or varied gradually, to avoid focused flow if inundation occurs. If using the same number of brush layers for continuous brushwalling, this determines that installation of the brushwalling should approximately occur along a fixed elevation contour.

In situations where wave conditions exceed an average annual maximum significant height Hs>0.3 m, the brushwall may need to be located higher on the shoreline profile, to ensure it is not damaged by wave action (Figure 13). When placed in this manner, a brushwall should always be installed with a rock toe.

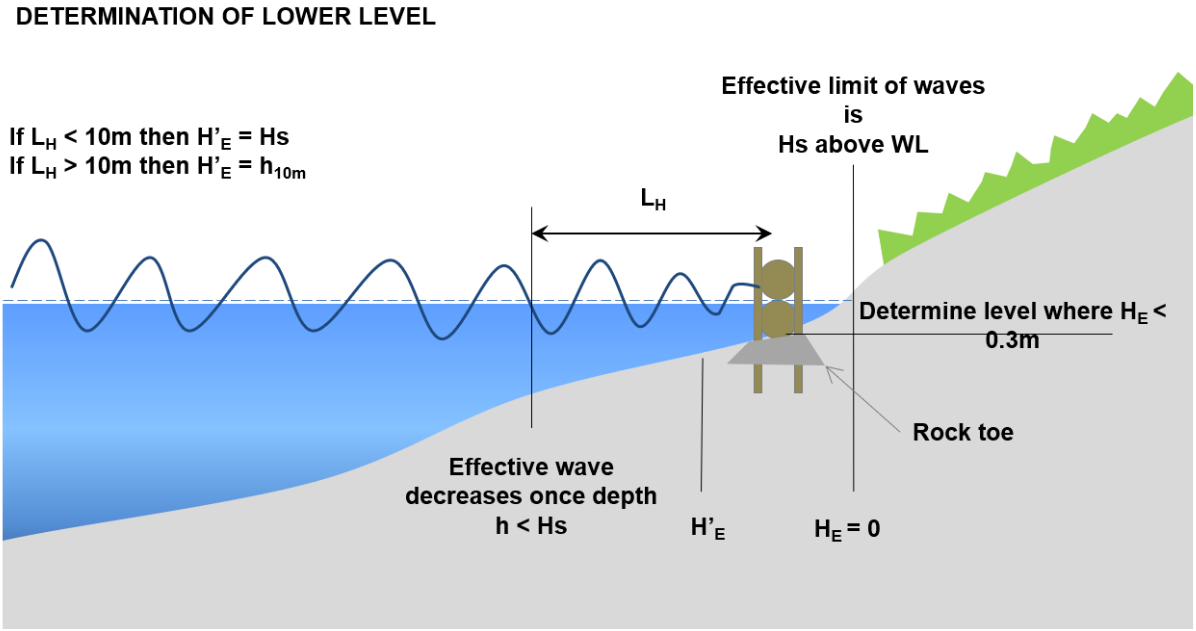


Figure 13 Brushwalling location due to (a) Inundation or (b) wave loading (Source: Seashore Engineering)

The method illustrated by Figure 14 to determine the lower level of the brushwalling is a highly simplified version of nearshore wave energy loss and wave runup processes, determined for a short wave period of 2 - 3 seconds (USACE 2003). The effective wave height at the shoreline H'_E is estimated as the minimum of the significant wave height Hs and the depth 10m from shore, h_{10m}. The required lower level is then based on interpolation between the shoreline and the limit of wave runup, estimated to reach a height of Hs above the water level.

Positioning of brush walling is consequently a function of the wave climate and the profile shape:

- For an incident wave height Hs < 0.3 m, the lower level of the brushwall should be located on a near horizontal level, no more than 0.8 m below the upper level (Figure 14a). This is the optimal situation for use of brushwalling. If the lower bank is steeper than 1V:6H, then the brushwalling should be positioned at the base of the erosion, with a rock toe installed to reduce potential for undercutting (Figure 14b). This is not a preferred situation for installation, and if erosion is experienced more than 0.8 m below the upper level, brushwalling will likely experience failure through undercutting;

- For an incident wave height above 0.3 m, the lower level of the brushwall should be moved up the profile so that it experiences lower wave conditions. Where there is a shallow approach to the shore (Figure 14c), brushwalling may be viable, although it will typically require a higher level of maintenance than for a lower wave conditions. It is not recommended to install brushwalling on a high wave energy foreshore that has a deep approach (Figure 14d).

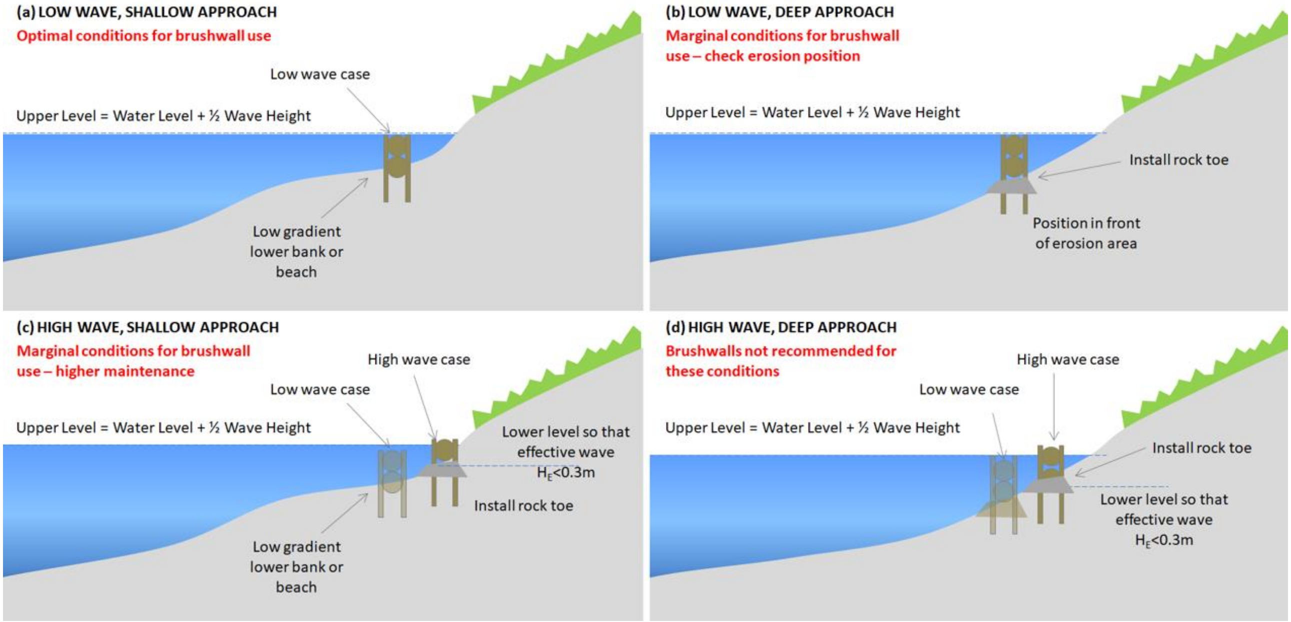


Figure 14 Determination of brushwall position on the profile (Source: Seashore Engineering)

Determining brushwall position with respect to currents

Use of brushwalls in strong currents is constrained by their permeability. Although a ‘typical’ brushwall is structurally capable of withstanding 1.2-1.5 m/s flows, interactions between the brushwall and underlying bed are likely to occur at lower flows. Flow passing through the brush matrix is accelerated and jets out through small gaps, potentially with sufficient speed to cause scour, undermining the brushwall. This can be partly managed using a rock toe.

It is noted that under strong flow conditions, the bed and riparian vegetation will become unstable for flows typically in the range of 0.5-1.0 m/s. Consequently, for existing bank flows above this, it is not possible to transition from brushwalling to a vegetated upper bank without installation of additional reinforcement or sheltering.

Characterisation of river flows is typically available as a discharge velocity U_D which is the average flow across the entire channel cross-section (Figure 15).

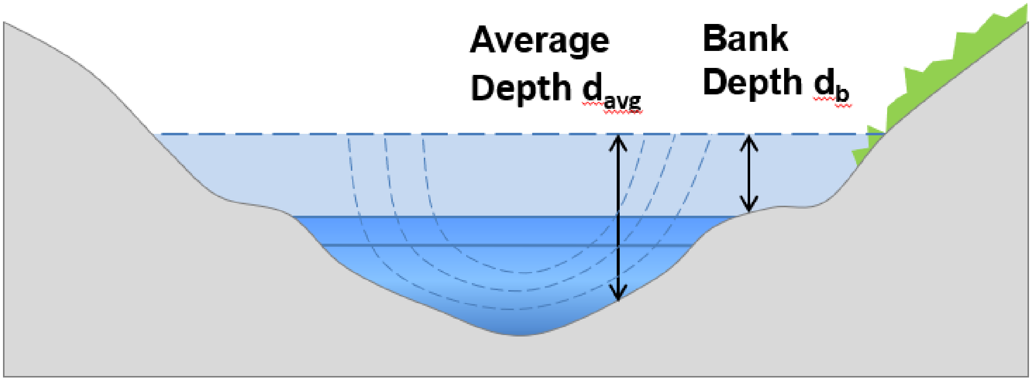


Figure 15 Definition of relative depths (Source: Seashore Engineering)

Flow at the shallow margins is slower than this average, and therefore it is appropriate to determine the bank flow when designing the brushwalling. For detailed design, bank flow should be estimated using numerical modelling, preferably supported by in-stream measurements. For preliminary design, an estimate of bank flow speed is:

$$U_{bank} = (d_b / d_{avg})^2 \times U_D$$

Once an estimate of the bank current is available, the pressure developed by the flow on the brushwall can be estimated. This is a function of the brushwall angle relative to the stream-flow (Figure 16)

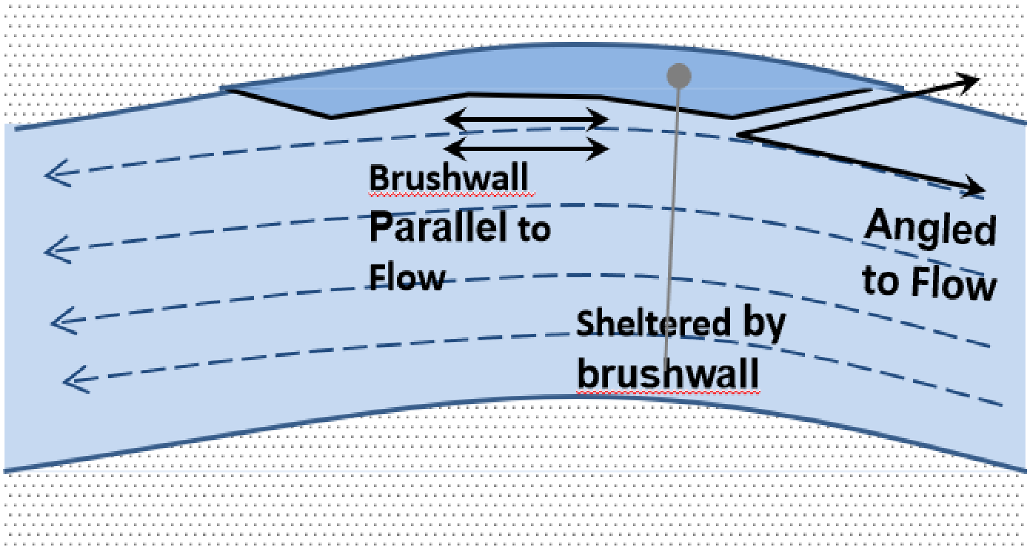


Figure 16 Definition of angle to flow

$$P_U = (0.2 + 0.6 \tan\theta)\, U_b^2 \qquad \text{(in kPa)}$$

Where the maximum pressure due to current (Pu) for ‘typical’ brushwalling is approximately 2 kPa.

Because of the significance of brushwalling angle relative to the flow, it is generally preferable to have brushwalls mainly parallel to the flow. Transitions at the ends should typically be locked in to existing hard points, or otherwise sloped at less than 30° to flow, to limit flow acceleration at the corner of the brushwall.

Current-driven pressure generates flow through the brush logs, which may be capable of mobilising sediment and causing scour. In the absence of test cases or measurements, it is recommended to always incorporate a rock toe when the brushwalling is being used as a flow retarder.

The cross-shore position of the brushwalling is also influenced by the volume of water able to be trapped landward of the brushwalling and the speed of its release when there is a difference in water level on either side of the brushwall. The difference in level drives flow, which is accelerated as it passes through narrow gaps, whether breaches (Figure 12) or the gaps through the brush logs, potentially creating scour. It is therefore preferable to locate the brushwalling to landward, close to the eroded bank as this reduces the flow rates caused by subtidal water level fluctuations, or effects of retained water. Less differential in water level occurs if there is more rapid exchange water exchange to either side of the wall, which may require deliberately constructed breaks in the structure.

Anchoring Systems

The brushwalls have limited embedment and therefore rely upon stakes to provide an effective anchoring system. Structural requirements for stakes vary significantly depending on the ground conditions:

- In sandy soils, which are predominant in the lower estuary, resistance to movement is provided by soil friction which is determined by soil pressure. Anchoring capacity is therefore a function of soil density, compaction and the depth of the stake (more so than width);
- For clay soils, which mainly occur in the riverine sections of the Swan-Canning, resistance to movement is determined by the cohesive strength of the soil. Anchoring capacity is therefore affected by ground disturbance, including changes to moisture content, and the surface area of the stake. For this reason, it is possible to use shorter, wider stakes for installation in clay, compared with sandy soils.

Modifications to Common Practice

Typical brushwalling dimensions, as outlined in Figure 18, provide brushwalling that is approximately tolerant of a significant wave height of Hs=0.3m (i.e. maximum wave of Hmax~0.55 m), or (separately) can withstand a 0.5 m difference of water level from one side of the brushwall to another.

Failure through currents is not generally caused by structural stress, but by erosion of the bed/bank outside the brushwalling, which is highly likely once flow U>1.0 m/s. These conditions are also not conducive for the role of brushwalling as a transition to vegetation, because riparian vegetation is typically damaged by U>0.5 m/s.

Strengthening of the brushwalling can be provided through:

- Increasing the depth and/or dimensions of the vertical stakes used to anchor the brushwalling;
- Reducing the spacing between stakes;
- Increasing the width of brushwalls;
- Increasing the effective timber density of the brush logs which may involve using larger diameter branches, denser packing or harder wood. It is noted that higher packing density will reduce permeability and increase hydrostatic loading.

Placement of the brushwalling can be undertaken to modify the way in which the brushwalling interacts with waves and flows, including changing the alignment of different sections (e.g. zig-zag or *en echelon* placement), or using overlapping rather than a continuous line, to facilitate shoreward sediment movement.

Typical drawings of brushwalling are illustrated in Figure 17 and Figure 18, comprising a cross section and a typical brushwall detail. Please note that the details of the brushwall will be different depending on site conditions – hence embedment of stakes and the brush wall height will vary in the drawings.

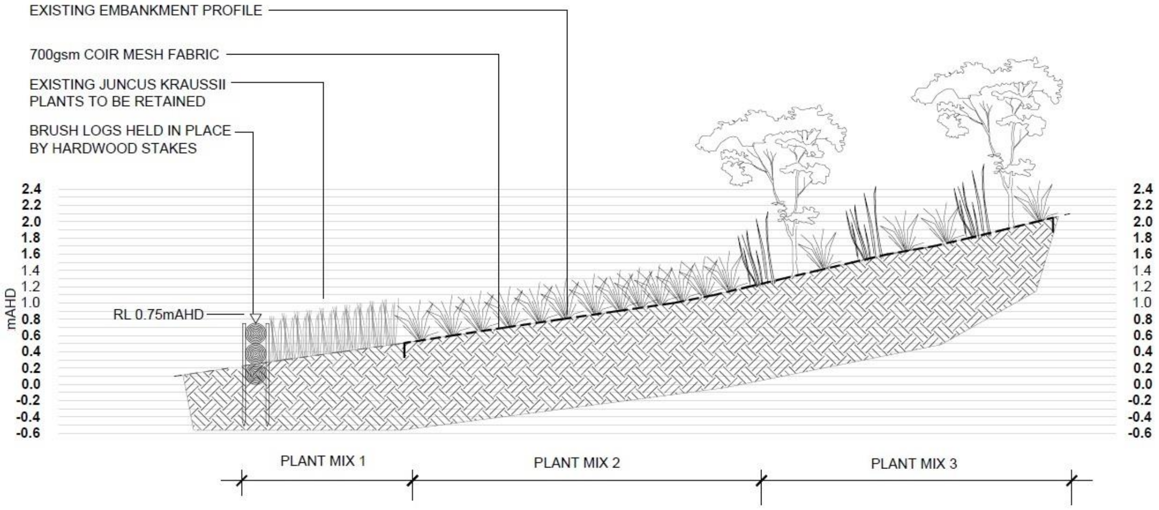


Figure 17 Example of a typical section showing brushwall on foreshore profile (Source: Syrinx)

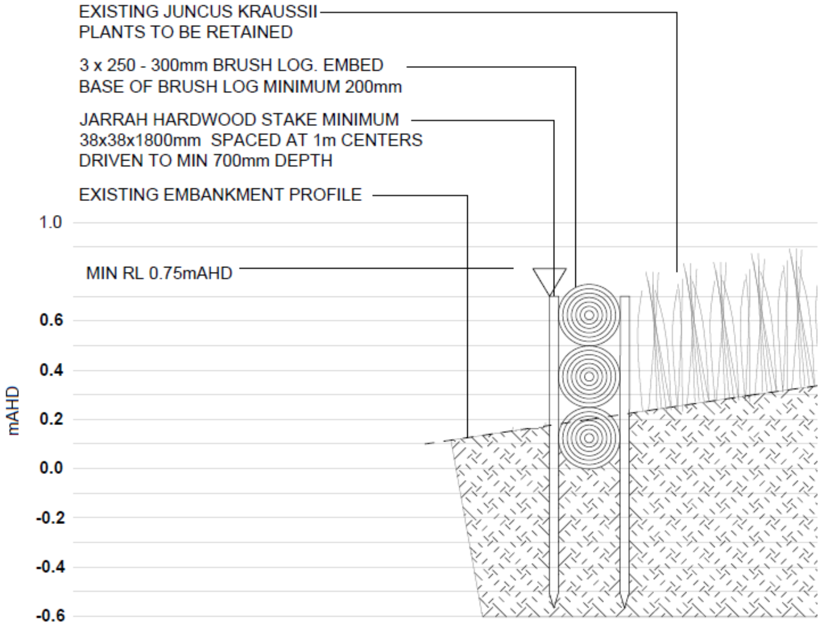


Figure 18 Typical brushwall detail (Source: Syrinx)

3.1 LOADING

The permeable nature of the brushwall substantially reduces hydrostatic load, associated with differences in water level to either side of the brushwall. However, the brushwall acts as a barrier to hydrodynamic motions, including waves and currents, which therefore, provide destabilising pressures.

Hydraulic stresses from wave-induced pressure and shear from currents generally act to push the brushwall horizontally. These loads are resisted by the stakes and transferred through to the ground in which they are embedded. The horizontal resistance of hand-driven stakes provides a key limitation for brushwall structural capacity and a practical limit to brushwall height of 0.5 - 0.8m.

An approach suitable only for preliminary design, follows:

1. Estimate required brushwall loading based on wave loading and current (Figure 19). Note that loading under currents must be multipled by U^2 (U=stream velocity).

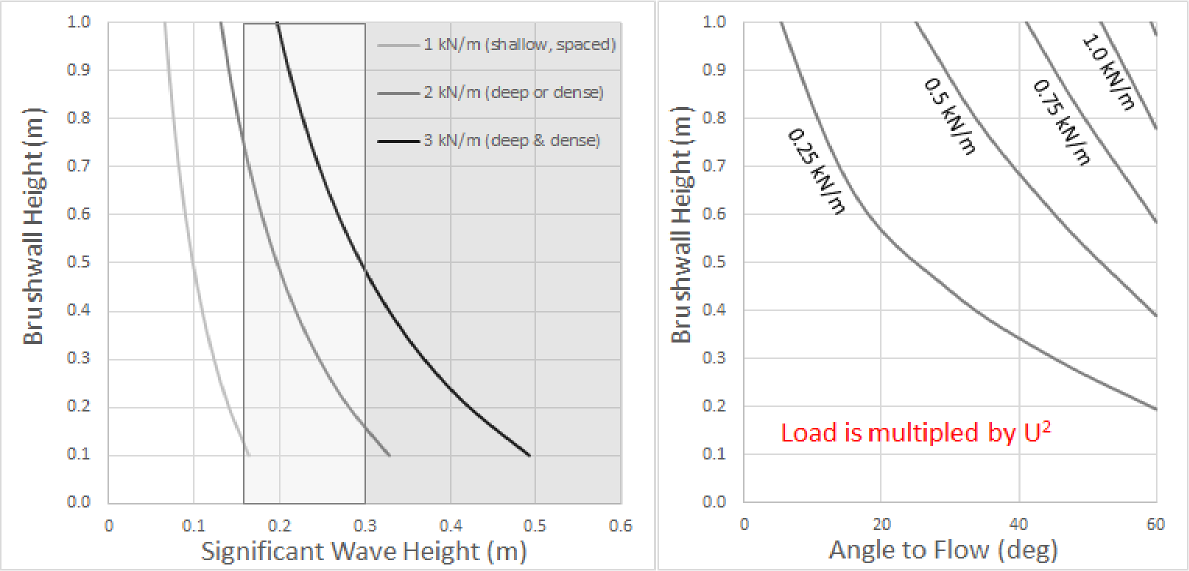


Figure 19 Brushwall loading curves

2. Determine the minimum span between brushwall stakes (Figure 20). Note, that no less than three pairs of stakes should be placed per brushwall section, which typically provides appropriate spacing;

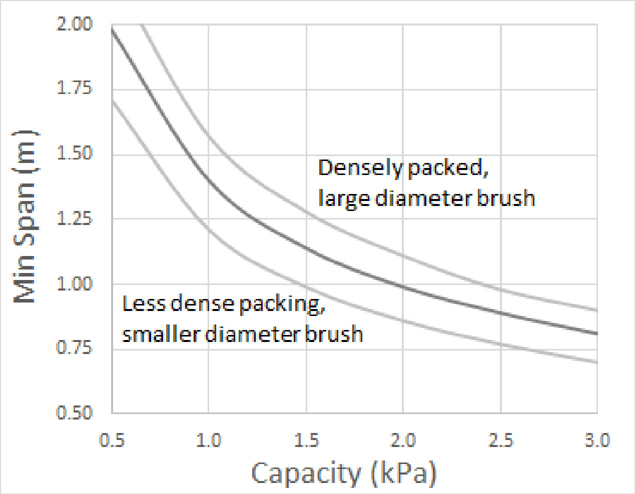


Figure 20 Minimum span length

3. Determine required embedment of stakes (Figure 21), to achieve the appropriate resistance, for different soil types. It is noted that any slackness in the wire or brushwall may result in one stake taking a greater load. Note that the load is in kN/m, and individual stakes are in kN, therefore the spacing between stakes is also a factor.

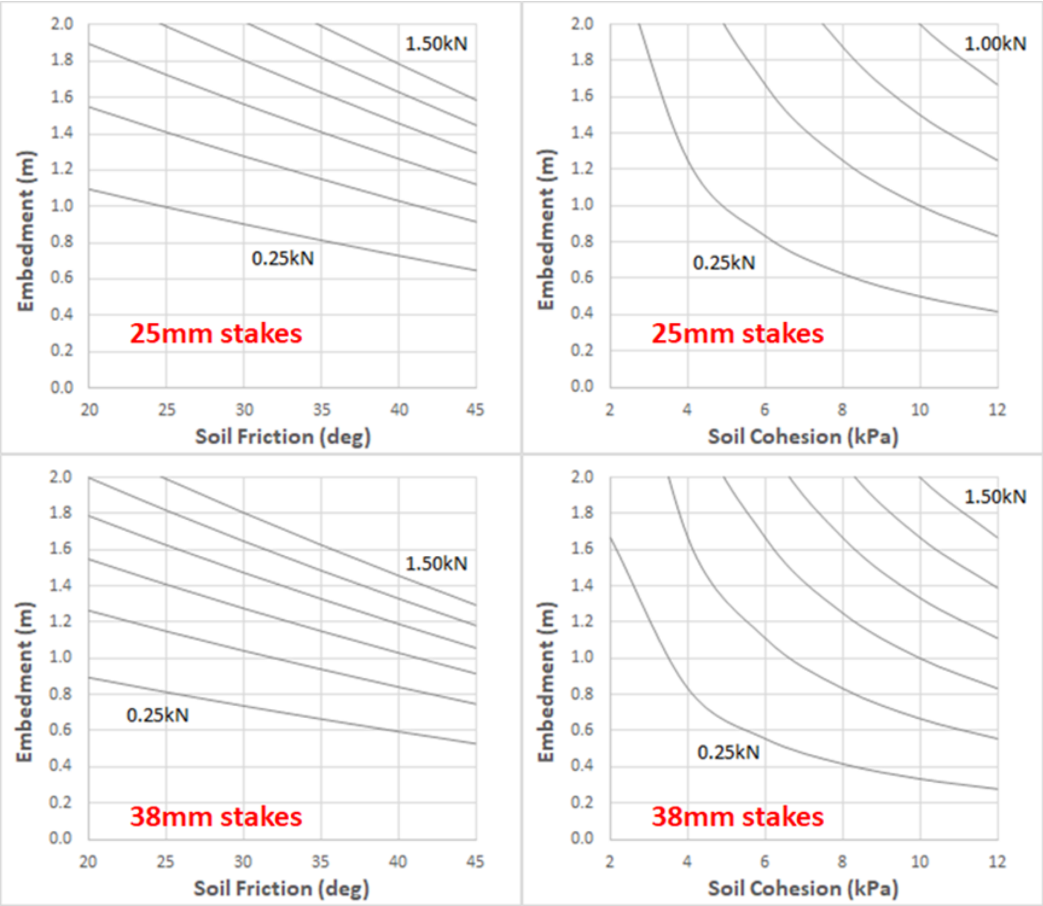


Figure 21 Embedment requirements

4. Determine if a rock toe is required, Hudson’s equation should be used for wave dominated conditions. For construction on a slope (steeper than 1V:6H) the rock toe should be on both sides of the brushwall. Otherwise it may be placed in front of the brushwall only.

To illustrate loading guidelines presented above, two worked examples are provided below for sandy and cohesive soils situations (generally estuary and upper river channel).

Wave Loading in Sandy Soil:

For a proposed 0.5m high brushwall,in wave height of 0.2 m, the design load is 2 kN/m. This requires a minimum span of 1.0m between stakes for brush logs that are 0.25 m diameter. Consequently, each pair of stakes would require capacity of 1.5 kN (2 kN/m x 0.75 m spacing), giving a 0.75 kN requirement per stake. This would require 1.6 m embedment with 25 mm stakes in typical Perth sand (ϕ= 30°), and would require 1.3 m embedment with 38mm stakes.

Current Loading in Cohesive Soil:

For a proposed 0.5m high brushwall, in a current of 1.2 m/s at 20° to the brushwall, the design load is 0.79 kN/m (0.55 kN/m x 1.44). This requires a minimum span of 1.5 m between stakes for for brush logs that are 0.25 m diameter. Consequently, each pair of stakes would require capacity of 1.2 kN (0.79 kN/m x 1.5 m spacing), giving a 0.6 kN requirement per stake. This could not be practically achieved using 25 mm stakes in silty-clay soil (c=6 kPa), but 1.3 m embedment with 38 mm stakes would be sufficient.

3.2 ADDITIONAL CONSIDERATIONS FOR DETAILED DESIGN

With every set of design drawings, a detailed technical specification document needs to be produced, which outlines the specifics of brushwall construction (including positioning and height of the wall) and future maintenance requirements and schedules. Other considerations should include likely changes in the water levels due to climate change including mean sea level rise and increased frequency of storm surges and flood events. This should be done using most recent guidelines and climate change projections by the Intergovernmental Panel on Climate Change (IPCC), Department of Planning, Lands and Heritage (DPLH), Department of Water and Environmental Regulation (DWER) and Department of Biodiversity Conservation and Attractions (DBCA).

3.3 DESIGN LIFE/EXPECTED TIMEFRAME

Brushwalling has a design life of 5 – 12 years with an average life span of seven years. The longevity is highly variable and is dependant on the site conditions, thickness of the wall, type of brush material used, the maintenance effort undertaken after construction and the frequency of adverse events such as storm surges. Deterioration of the brush, particularly the fine material, is generally caused by mechanical degradation via wave or flow impact, human use (e.g.: frequent use for seating or trampling), or by wood rot.

Installation of toe protection (e.g.: rock rip rap) in medium to high wave impact areas extends the brushwall life by reducing wave energy and toe scour. Dependant on site conditions, the life span of the brushwall can be increased by topping up of brush material and reinstatement of stakes generally every three to five years. Stakes can be recycled by using a stake lifter (

Figure 22 a-c) and then undamaged stakes can be reinstalled in the new position. Removal of stakes and remaining brush material (if required) is relatively straightforward, however it is labour intensive.

Figure 22 Use of stake puller to remove stakes embedded in sand – stake puller tool (a), and stake puller in use (shovel used to assist initial grip on the stake) (b) (Source: Syrinx, 2016)

3.4 MATERIALS AND EQUIPMENT

The following materials and equipment are recommended for installation of brushwalls along foreshores. These are provided as a guide and alternative materials and equipment can be considered, depending on the site conditions, costs and availability of resources.

Materials (Brushwall structure)

Brush material: Branches of WA native vegetation (non-suckering and with minimal seed) are typically sourced from brushwood plantations and commonly include species from the *Melaleuca* or *Kunzea* genera. The material is ideally cut-to-order and installed soon after harvest to ensure logs are flexible, which assists with installation. Older material may still be suitable, although it can be more difficult to install. Following are some basic specifications for the branches:

- 1.5 m to 3 m lengths;
- <30 mm base diameter – a range of sizes is preferred, although ~15 mm typically provides a combination of workability and durability;
- Good mixture of woody material and smaller branchlets with leaves;
- No root wads or other larger material.

Stakes: Plain, hardwood stakes (Jarrah or similar) that are pointed. Stakes should be a minimum of 38 mm in diameter. The maximum width should not exceed 50mmx50mm as such stakes are difficult to install and remove and are also more expensive with only marginally better support to 38mm stakes. Length should be determined using guidelines under loading (Section 3.1) based on soil conditions (i.e.; sandy soils = longer stakes, harder soils (clays/loams) = shorter, thicker stakes typically between 1200 – 2100 mm long). These lengths provide the structural integrity of the brushwall and ensure rigidity.

Wire: Galvanised steel wire (2.5 – 3 mm) is preferred for its durability and lifespan.

Equipment:

- Straps or ropes for fabricating brush logs.
- Saws (chainsaw or hand saws) / loppers for trimming/separating brush and/or stakes.
- Electric drill for drilling holes in the stakes to allow for wire to be secured.
- Pliers for installing and securing wire.
- Hammers / stake-driver for installing stakes.
- Shovels for trenching-in brushwalls.
- Stake lifter / remover (for removing old stakes (if present) or removing stakes that are broken / erroneously installed.
- Suitable personal protective equipment (e.g. gloves, earmuffs, etc.)

NOTE: Equipment listed above would be utilised for typical projects undertaken on the Swan/Canning River. Larger-scale projects can utilise mechanical equipment and machinery if access is not limited or is more cost-effective. However, using machinery in sensitive river environments can create additional risks and this must be considered prior to mobilising machinery.

3.5 CONSTRUCTION / INSTALLATION

The brushwall is generally installed as the last structure prior to revegetation of the slope behind the brushwall. In some instances where erosion fabric is used behind the wall, the erosion fabric (e.g.: coir mesh) is trenched in and the brush logs laid on top. There are several steps in brushwall installation. These generally comprise fabrication of brush logs, site preparation and the subsequent installation.

Brushwall Fabrication

While brush logs can be bought on the market pre-fabricated, they usually come as pieces that require construction. The construction of separate brush bundle units (brush logs) is the most efficient and effective means for constructing brushwalls. These units assist with quantifying the amount of material required, facilitate transportation and installation and improve structural integrity/rigidity of the structure.

Each brush log is fabricated by laying out bundles of branches, with an even distribution of branch sizes and orientation so that the thickness and density of the brush is consistent through the entire length of the brush log. Logs are typically 2.5 to 3.5 metres in length and with a diameter of approx. 300 mm. The bundles need to be made as tightened/compressed as much as possible by using ropes or straps to tighten the bundle, before using loops of wire around the brush log to secure/hold shape. A loop of wire should be added to at least every metre of brush log with a minimum of three wire loops per brush log. Brush ends should be left uneven and somewhat thinner than the middle of the log, to assist with interlocking of logs and producing a more even height of the structure. Once complete, logs can be transported to site, or stored until required. It is important to ensure that the brush logs are not too long or heavy so that they can be manually transported and easily manoeuvred, particularly if site access is difficult. Logs made from fresh material are easier to work with as they are more pliable and should be used in preference to dry logs where brush walls need to conform to bank curvature.

Site preparation

The key components of site preparation relevant to brushwall installation are:

1. Ensure the tidal and stream flow conditions are favourable for brushwall construction (i.e. tides are low and water is calm as this reduces siltation of the water and allows for easier/more efficient construction). Generally late spring to mid-summer is the best time for construction, dependant on weather conditions – check weather and tidal forecasts regularly.

2. Install silt curtains or silt fences prior to any works to protect the river from influx of sediment that may result due to construction works (generally associated with reshaping of banks, foot traffic etc.).

3. Make certain the site is appropriately marked – use a surveyor to mark out planned brushwall position and height. Check if the conditions have changed since the design stage and make adjustments in consultation with DBCA and a coastal engineer to achieve the best result.

4. Clear the area in which the brushwall is to be installed. This can include removal of rocks, logs, overhanging branches or other obstructions that may limit access or the ability to install the brushwall.

5. Check ground and sub-surface conditions by driving in test stakes along brushwall alignment.

6. Unless the shoreline is muddy and the bottom brush sinks into the mud with slight pressure (e.g. by stepping onto the log), a trench should be dug along the brushwall alignment to assist with embedment of the structure and reduce scour. All excavated material should be placed landward of the brushwall alignment where possible.

Placement and securing of brush logs

The correct alignment of the brushwall is critical for the structure to function as intended. This should be a key design consideration and included in any plans / specifications prepared prior to commencing installation. The key parameters are outlined in previous sections; however, during installation, it is important that the finished alignment and height is as close to the design as possible.

1. Bottom brush logs should be laid into the pre-dug trench with all brush log ends overlapping each other by a minimum of 300 -500 mm to minimise weak points in the structure. The first layer will guide the location of the overall brushwall, with subsequent layers overlaid on the previous layer once stakes have been installed. It is important to ensure that the joins of one layer do not directly line-up with other layers, as this will create weak points in the structure. It is also important that the terminal ends of the brushwall are tied-in with the end of the site, as this is often a vulnerable point in the structure and can have long-term negative effects if left open or loose. The tie in can be achieved through installing the brushwall behind existing features such as trees or rocks, or gently curving the brushwall landward and progressively reducing the brushwall height.

2. Following placement of the first layer of brush logs along the brushwall alignment, stakes are to be placed in pairs (one on each side) at a minimum of one metre intervals and hammered into the ground by approx. 300 mm along the full length of the brushwall. Additional brush logs can be slotted in between the stakes, to maintain the brushwall height when required.

3. Once the location and height of the brushwall is satisfactory, the stakes can be hammered down close to their planned finish height. Holes should be drilled near the top of each stake (approx. 200 - 300 mm from the top of the stake) and wire attached between each pair of stakes and over the top of the brush logs. Following the completion of wiring, stakes can be further driven down progressively across the structure until the wires are taught and the brush logs are compressed and rigid. The top of all stakes should remain higher than the top of the brush to allow for easier maintenance (i.e. driving stakes further into the ground once brush fines are lost).

   It is important to note that uncompressed brush logs will reduce in height (by approx. one third under correct tension), so it is critical that this be accounted for when adding brush layers so as to achieve the final design height.

4. Ensure the brushwall is rigid and secure along the entire length and ensure that any loose wires are tightened, protruding branches / wires are trimmed and any stakes that are excessively long are also trimmed.

5. It is advisable to leave tops of stakes high until the green leaf matter from the brush is lost – generally 6 - 10 weeks or preferably longer (i.e.; until winter storms have passed), at which time stakes are driven into the ground further to re-tighten the brushwall. After this time stakes can be left as they are or, if amenity is a concern, stakes can be cut to be just above the brushwall height to ensure a more even finish.

   NOTE: In many instances brushwalls will be placed in areas that are frequented by public and, as with any other structure, all efforts should be made to reduce the possibility of injury from protruding wires or tripping hazards. For the brushwall this means that all wire ties and ends should face downwards so that no injury could occur by sitting on the brushwall or walking alongside it. Likewise, all stakes should have a neat finish on the top (no splintered or broken wood).

3.6 FAILURE MECHANISMS

The main failure mechanisms for brushwalls are:

- **Inadequate tie-ins:** The brushwall structure and the general site itself requires protection from flanking erosion and must be adequately secured to the adjacent shoreline to reduce loss of sediment. Loose terminal ends of the brushwall will rapidly deteriorate if not secured correctly and the overall integrity of the structure can be compromised should this not be adequately addressed.

- **Overtopping:** This can occur if the brushwall is not placed on the correct alignment, is not constructed high enough, or during extreme storm events where water flows over the structure. Overtopping can result in significant erosion behind the brushwall and possible additional flanking. Some irregular minor overtopping will not create too many issues, but significant or frequent overtopping can result in severe erosion of the site being protected.

- **Undercutting / scour**: this can occur at the base of the brushwall if not embedded into the soil and/or there is a lack of frontal scour protection. This can destabilise the structure and lead to erosion of the protected zone. Ensuring a detailed specification is prepared and the brushwall is installed as per the specification is important to reduce the likelihood of scour or undercutting.

- **Loss of structural rigidity:** The brushwall must always remain rigid through sufficient tightening when installing and maintaining brushwalls. The integrity of the structure relies on this rigidity and any looseness will result in significantly reduced lifespan and function of brushwalls.

- **Structural weak points:** These can occur where insufficient overlap of brush logs occur during construction or where too many joins are created in the same area of the brushwall. This can greatly reduce the lifespan of the structure.

- **Short / broken stakes:** Stakes that are not sufficiently driven into the ground can easily be dislodged and result in significant loss of structural integrity. Soil type and porosity should be considered when determining stake depths.

- **Broken wires:** The wires holding the brush logs in place may break prematurely as they are under tension. It is expected to occur infrequently and broken wires should be replaced as soon as possible.

- **Failed revegetation:** may occur with no subsequent replanting and where vegetation fails to establish before the brushwall deteriorates.

4.0 MONITORING AND MAINTENANCE

Monitoring and maintenance of the brushwall should be undertaken to retain the integrity of the structure and ensure the expected design life is met or exceeded. Maintenance should be conducted regularly after installation, with frequency of maintenance occurring at less regular intervals as the vegetation behind the brushwall becomes established and can function as an erosion protection barrier. Additional inspections and maintenance should be conducted following significant storm events as required.

The following outlines the key inspection / maintenance items specific to brushwalling:

- Inspect the brushwall for any damage and repair damage immediately. This may include brush replacement, re-tightening of loose wires by driving stakes further into the ground or replacing rusted or damaged wires, etc.

- Implement a monthly monitoring and maintenance regime for newly constructed brushwalls for the first two years as this timeframe provides the best outcome for vegetation establishment. If the brushwall is performing well, the frequency of monitoring and maintenance can be moved to a bi-monthly or quarterly basis. The brushwall must be inspected and repaired immediately after any major storm events.

- Maintenance should be performed by personnel trained and experienced in brushwall installation and maintenance and with sufficient materials available to complete repairs (e.g. brush material, wires and stakes can be stored at the depot).

- Maintain structural rigidity of the brushwall by securing wires that hold brush logs in place. The wire becomes loose as the fine material (i.e. leaves and fine branchlets) are lost through wave action. Loose wires can be tightened by progressively driving the stakes further into the ground to tighten the wires. Broken wires should be replaced and re-tightened as soon as possible after they are discovered.

- Replace or top up damaged or old/degraded sections of the brushwall. Additional brush logs can be laid over the top of the existing brushwall and secured with new stakes and wire, which are then tightened.

- A new brushwall can be added behind the existing brushwall further up the bank profile where space allows to improve the overall protective function of the brushwall.

Maintenance of the brushwall should continue for at least three years after installation and additional inspections and maintenance should be undertaken following significant storm events. All other maintenance tasks related to best-practice foreshore revegetation should be undertaken as required and in conjunction with brushwall maintenance (including, but not limited to, weed control, rubbish/detritus removal, infill planting and watering).

5.0 COST

Cost estimates are based on 2019 prices from various Western Australian suppliers. These figures are estimates only and significant variations in market rates, discounts and availability, are likely.

Economies of scale is an important factor when examining pricing for these types of works (i.e. typically the larger the scale of the project, the lower the unit rate will be for any given material or product).

Proponents should obtain direct quotes from suppliers for budgeting purposes.

Table 3 outlines the costs specifically related to brushwalls. Additional ancillary foreshore works are included in the other relevant chapters.

Table 3 Average costs for brushwall construction

ITEM	APPROXIMATE COST (EX GST)
Brushwood material	\$1,400 - \$2,000 per tonne (Significant variation exists with this product due to infrequent supply – can be salvaged from vegetation clearing areas)
Hardwood stakes (38x38x1500mm)	\$5 - \$7 each
Wire (2.5mm galvanised fencing)	\$40 - \$50 per 100 linear metre
Labour: Supervisor	\$100 - \$120 per hour
Labour: field technician	\$60 - \$85 per hour

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