Browns Waterhole Track Feasibility Study

Ku-ring-gai Council

Options Assessment Report

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Contents

Important note about this report

The sole purpose of this report and the associated services performed by Jacobs is to undertake a feasibility study for potential track crossing upgrade options for the Browns Waterhole Track in accordance with the scope of services set out in the contract between Jacobs and Ku-ring-gai Council (the Client). That scope of services, as described in this report, was developed with the Client.

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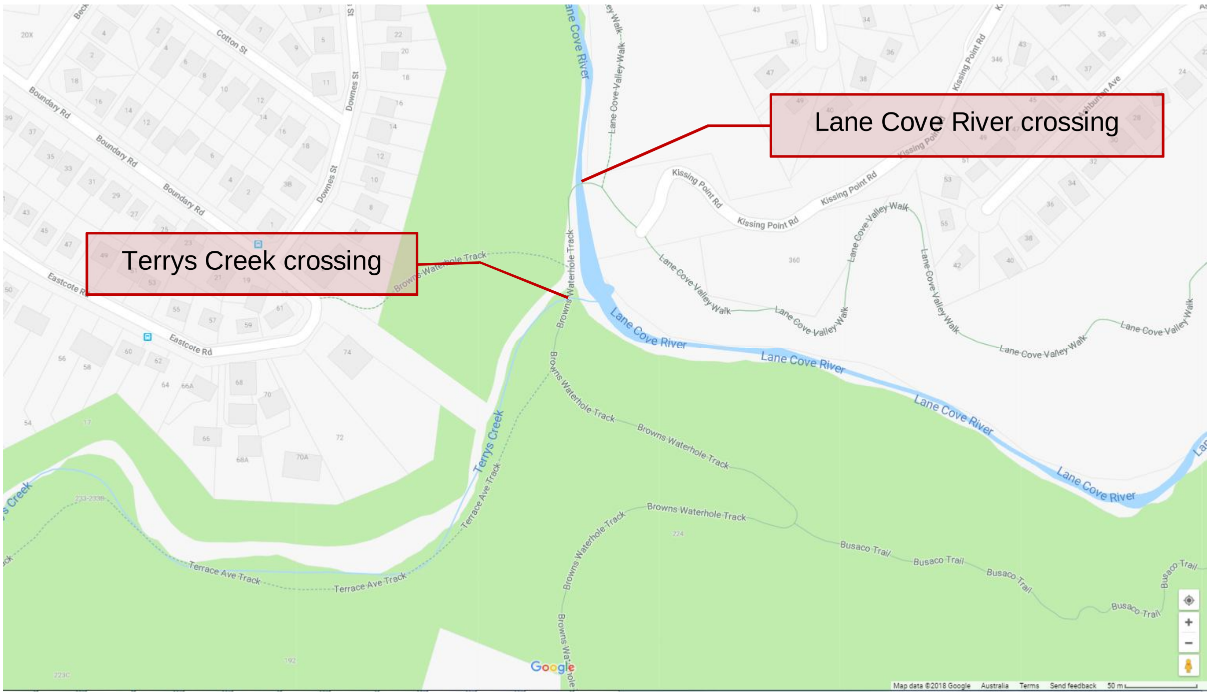
1. Introduction

1.1 General

The Browns Waterhole Track is a pedestrian and cycleway located in the Lane Cove National Park. It connects Kissing Point Road in Turramurra to Vimiera Road in Marsfield. It crosses Lane Cove River and Terrys Creek which is a tributary of Lane Cove River. Both crossings are located approximately 80m apart, as shown in Figure 1-1.

Lane Cove River has a catchment area 2,375ha at the track and Terrys Creek has a catchment area of 1000ha at the track. The track crosses Lane Cove River with 2 x 450mm diameter Reinforced Concrete Pipe (RCP) under a weir structure and the track crosses Terrys Creek with a 2 x 2400mm (W) x 1200mm (H) Reinforced Concrete Box Culvert (RCBC) with 2624mm (W) x 1400mm (H) link slab. At Lane Cove River, the track runs over a weir, which is more frequently flooded in minor storm events than the Terrys Creek crossing. The track is an important connection for both pedestrians and cyclists and flooding can render the track unusable for long periods of time and is a risk to public safety.

Figure 1-1 Location of Browns Waterhole Track. *Source: Google Maps*



1.2 Purpose of this Report

The purpose of this study is to undertake a high-level feasibility assessment of potential options for improving the flood immunity of the Browns Waterhole Track, with the assessment comprising of the following aspects:

- A flooding assessment to determine the existing flooding conditions and flooding constraints on potential options.
- Consultation with Council to select a short-list of options for further investigation.
- An investigation to assess site geotechnical conditions and identify geotechnical constraints, informing the development of the upgrade option concepts.
- Environmental assessment to identify potential impacts to terrestrial and aquatic ecological habitats.
- Development of upgrade option concepts including preliminary design and costing of selected options.

The findings of this study are to inform Council of the feasibility of the shortlisted options and to provide information suitable for consultation with the community and stakeholders to select a preferred option.

1.3 Exclusions from this Assessment

The scope for this study was limited to investigation of crossing upgrade options of the Lane Cove River at Browns Waterhole. The investigation of upgrade options for Terrys Creek is excluded, as this site is located within Ryde Local Government Area and not Ku-ring-gai.

1.4 Site Inspection

Site inspection was initially undertaken by two engineers from Jacobs with Council staff at the project inception on 23 January 2018, which informed the flooding assessment.

Technical specialists undertook inspection on 3 May 2018 of the Browns Waterhole Track including both Lane Cove River and Terrys Creek crossings and potential locations for bridge approach/tie in points for Option 2, and for possible site construction compound at the head of the track at the Kissing Point Road end. Aspects of the site inspection included general site setting, geotechnical conditions, potential engineering and construction constraints and assessment of existing terrestrial and aquatic ecology and habitats.

2. Flooding Assessment

A flooding assessment has been completed and is documented in a memo to Ku-ring-gai Council dated 29 March 2018, refer to Appendix A. Flood levels and depths over the Lane Cove River and Terrys Creek crossings are estimated for a range of design flood events from the 1 year ARI to 100 year ARI. Existing flood immunity for both crossings is significantly less than the 1 year ARI event, with depths of flow of 3.5m and 4m over the Lane Cove River and Terrys Creek crossings in the 1 year ARI event, respectively. Terrys Creek crossing is the constraint on the track as it has a lower flood immunity and is affected largely by Lane Cove River backwater flooding, meaning that increasing the culvert flow capacity at this crossing will not improve flood immunity. Further, modifications to this crossing are outside the scope of this project.

A number of potential options were identified and assessed, including:

- Option 1: Additional culverts at the Lane Cove River crossing, with the following variations considered:
  - Option 1a: Additional culverts retaining the existing weir and raising track level
  - Option 1b: Additional culverts with removal of the existing weir and maintaining existing track level
  - Option 1c: Additional culverts with removal of the existing weir and raising track level.
- Option 2: Construction of a new bridge (approximately 120m length) spanning both Terrys Creek and Lane Cove River. Retain existing crossings for NPWS maintenance vehicle access.
- Option 3: Retrofitting the existing Sydney Water Pipeline with a walkway (approximately 56m long).

Council has been consulted on these options and selected Option 1b and Option 2 for further feasibility assessment. Options 1a and 1c are not considered further as raising the track level at Lane Cove River crossing requires significantly more work than Option 1b, but does not improve the overall track immunity due to the unchanged low flood immunity at Terrys Creek crossing. Option 3 is not considered feasible due to difficulties with providing a new path to connect the bridge with the existing track through the existing bushland (much of the area is set aside for bio-banking, and the existing track is overgrown and with unsuitable steep sections) and a significant amount of consultation with Sydney Water would be required with no guarantee of approvals.

Option 1b allows maximum improvement of flood immunity at the project site (Lane Cove River crossing) while Option 2 provides opportunity for a high flood immunity access way up to or near a 100 year ARI immunity level.

The feasibility of Options 1b and 2 consider the conceptual design of the options, high level assessment of geotechnical engineering constraints on the designs, preliminary costings and environmental impacts assessment of each option. These aspects are discussed below.

3. Options Assessment

3.1 Introduction

This section of the report provides a feasibility assessment of a number of different options to upgrade the Browns Waterhole Track. The key considerations that influence the proposed options include the following;

- Provide a safe walking track with improved flood immunity;
- Provide a feasible solution that can be constructed at the site considering the difficult access; and
- Minimise the environmental impact within Lane Cove National Park and Ku-ring-gai Council Biobank land.

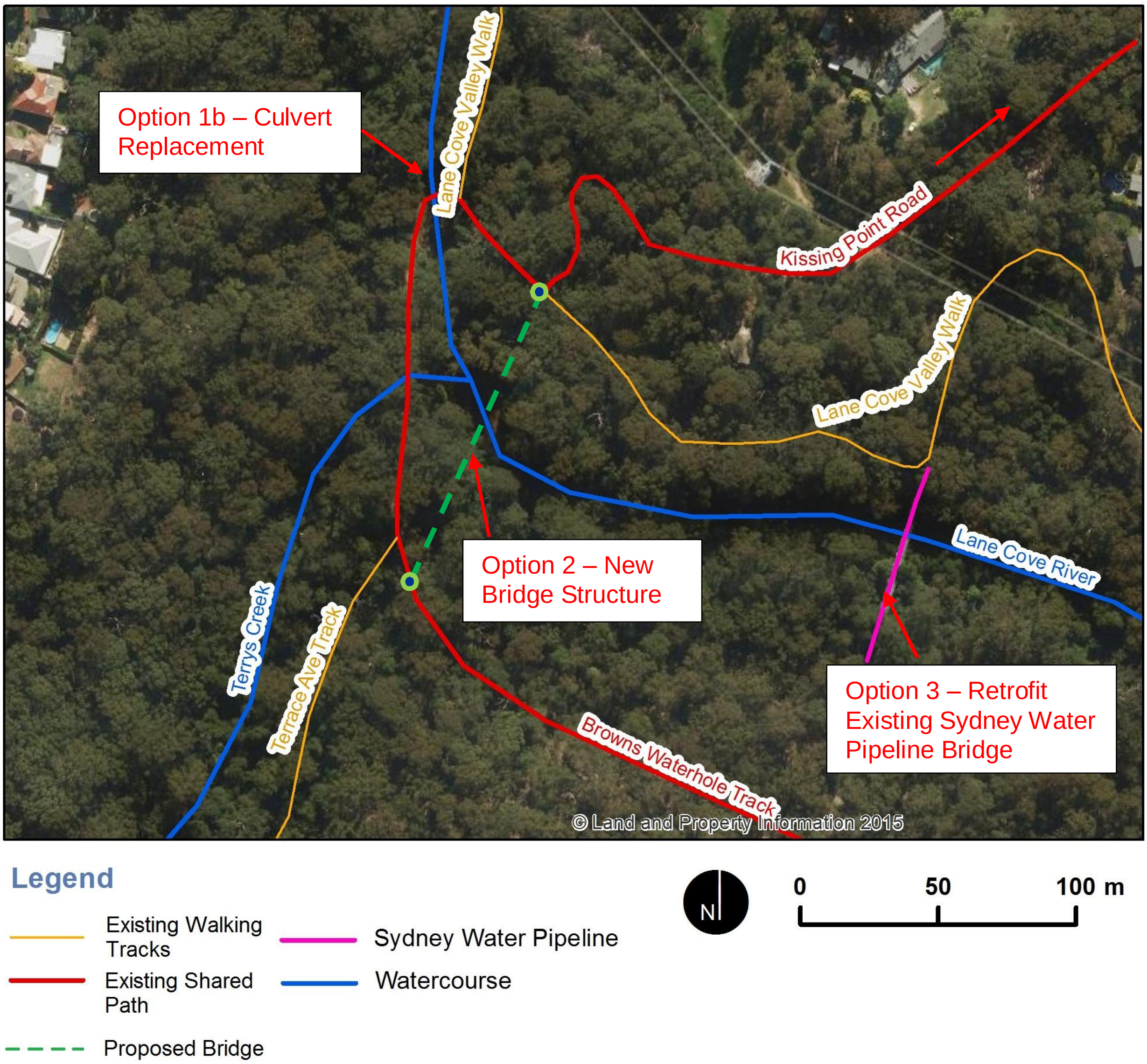
The key assumptions that surround the proposed options are as listed below;

- A flood immunity of 100 year ARI has been adopted as the baseline for Option 2 (new bridge);
- Existing ground levels used in the assessment are based on LiDAR;
- Geotechnical conditions are assumed as Colluvial soils underlain with Residual soils and Hawkesbury Sandstone;
- Aesthetic criteria have not been specified as a project requirement;
- A 3m width has been assumed on the bridge to cater for pedestrians and cyclists, matching the existing track;
- Assumed that temporary construction access (other than the existing track) is permissible within the National Park; and
- Proposed bridge in Option 2 is for pedestrians and cyclists only. Any vehicular access is to be via the existing track and culverts.

Discussion with regards to these considerations and assumptions is provided for each option in the sections below.

Refer to Figure 3-1 below for a plan illustration of proposed upgrade option locations.

Figure 3-1: Brown's Waterhole Track upgrade options



3.2 Option 1b – Culvert Replacement

Option 1b involves the replacement of the current pipe culvert at the Lane Cove River with a new Reinforced Concrete Box Culvert (RCBC). The current arrangement consists of twin 450mm diameter RCP's with associated earthworks/ground treatment and concrete path to form the track above. The new culvert consists of a 2-cell box culvert with crown unit dimensions of 3600mm x 1200mm along the same alignment of the existing culvert. Replacement or modification of the existing Terry's Creek culvert is excluded from the scope of this option. The precast culvert units are likely to be installed onto a cast-in-place base slab but the option for precast base slab units is also available. The current level of the track is to be maintained at 25.52m AHD and hence this option, whilst improves the flow performance locally at the culvert site does not provide any additional flood immunity.

The culvert replacement option is expected to stay mostly within the footprint of the existing culvert resulting in minimal additional environmental impacts for the final as constructed solution.

3.2.1 Constructability Considerations

The culvert replacement presents a number of constructability challenges. The major challenge surrounds the installation of culvert crown units. A Franna crane or small mobile crane will be needed to lift the crown units into place. The approaches on either side of the current culvert are significantly steep especially on the northern side at Kissing Point Rd with grades of up to 20%. The feasibility of allowing access for cranes and trucks is questionable along this portion of the track. Access to the construction zone will likely need to be from the southern side where shallower grades are experienced along the track but the turning paths on small radii bends will need to be investigated further to determine the maximum sized crane or truck that can access the track.

To allow for the construction of the culvert, it is expected that a small amount of clearing may be required on the approaches to the culvert. Additionally, there is a potential for environmental impacts due to runoff of sediment and construction materials into the river during the demolition of the existing culverts. This will need to be managed using sediment traps and appropriate containment within the construction zone.

During construction, the low flow conditions of the river will need to be managed with a temporary diversion to allow the construction of the base slab and associated foundation works.

3.3 Option 2 – New Bridge Structure

Option 2 involves the construction of a new bridge structure which will span both the Terrys Creek and Lane Cove River crossings. This option will provide the best flood immunity for the track and the crossing level can be adjusted to meet the nominated flood immunity level.

The alignment of the bridge follows a straight line between the Browns Waterhole Track at the intersection with the Terrace Avenue Track on the southern side and Kissing Point Road at the intersection of the Browns Waterhole Track and Lane Cove Valley Walk track on the northern side, as shown in Figure 3-1. This alignment has been chosen as the most suitable at this stage as it provides good connectivity to the existing tracks and achieves abutments levels with a 100 year ARI flood immunity as discussed below.

The bridge levels are indicatively set at 32.2m AHD and 33.5m AHD at the Northern and Southern abutments respectively based on LiDAR survey information. Indicative coordinates for the abutment locations are provided in Table 3-1. This provides a flood immunity of up to 100 years given the 100 year ARI flood level of 32.0m. With more detailed survey information, the levels and span arrangements for each of the options can be investigated further.

Table 3-1 Indicative coordinates for bridge option abutments

Location	Easting* (m)	Northing* (m)	Elevation (m AHD)
Northern abutment	324,577	6,262,737	32.2
Southern abutment	324,530	6,262,618	33.5

* Coordinate system GDA 1994 MGA Zone 56

The proposed cross-section of the bridge consists of a minimum 3m wide shared path between hand railings which matches the current width of the track on both approaches. This is within the desired range set by the Austroads Guide to Road Design Part 6A for shared paths. The grades on the bridge and approaches are proposed to be lower or within the suggested maximum range of 3 to 5%. Further investigation is required to confirm the functional requirements of the bridge in the next stage.

Given the proposed alignment, without significant approach works including raising the level of the whole track, any proposed bridge option is expected to be partially or fully submerged in an extreme flood event (e.g. 2,000 year ARI flood event, which is a typical design flood event for ultimate limit state in design of main road bridges by NSW Roads and Maritime Services).

The existing track elevation at the proposed bridge abutment locations is at or above the 100 year ARI flood level, and rises with distance away from the bridge as the track ascends the valley sides. If the bridge is to be designed with a greater flood immunity level, it is likely that the bridge abutment locations would be shifted accordingly to higher positions along the track rather than the track and approaches raised. This would require a greater bridge length which has cost implications.

The extreme event flood levels will need to be determined in the next stage to allow the bridge to be designed for the appropriate resistance against flood loading. It should be noted that particular bridge forms such as pre-cast concrete could be designed to be submerged whereas other bridge forms such as suspension or stressed ribbon may pose challenges with respect to flood design.

A number of different bridge form options are feasible for the proposed bridge span and environment. The options considered for this feasibility assessment include a:

- Multi-span Pre-cast Concrete Plank and Composite deck;
- Suspension; and
- Stressed Ribbon bridge forms.

General descriptions and constructability considerations are discussed for each option in the sections below. Indicative sketches are provided in Appendix B.

3.3.1 Option 2a – Multi-span Pre-cast Concrete Plank and Composite Deck bridge

Sub-option 2a consists of a multi-span pre-cast concrete plank and composite deck bridge structure. This type of bridge form is considered appropriate due to the economical nature of pre-cast concrete elements and the general simplicity of constructability that these elements provide. A plank bridge structure is preferred over longer spanning girder systems such Super T girders, which are heavier and entail larger cranage and handling requirements. In addition, a plank bridge structure is in the order of 30% cheaper to construct than a Super-T girder bridge.

The bridge is proposed to have seven-spans with six intermediate piers between abutments. The abutments will likely be spill-through type with in-situ headstock on piles. The superstructure is likely to consist of five no. 18m main spans and two smaller approach spans up to 12m. Preliminary structural analysis suggests that each span is likely to consist of five no. 535mm deep PSC Planks with a nominal concrete deck thickness of 200mm. Intermediate supports are likely to consist of concrete piers on piled footings.

It is expected that this option will have a large footprint in the final as-constructed state due to the multiple intermediate piers required close to the river. A significant amount of clearing and earthworks within the National Park will be required to allow for construction access as well as for footprint of the permanent structure, resulting in moderate environmental impacts.

For this option, ongoing inspection and maintenance of bearings will be required at the multiple intermediate piers. This could require the use of scaffolding set up around piers, working over water and working at heights.

The aesthetics of a plank bridge will generally be low profile for the deck structure but the frequency of the piers with relatively stocky elements may be considered visually undesirable. Further assessment will be required in the next stage.

Figure 3-2 shows an example of a PSC Plank bridge, used at a number of Sydney train stations. An indicative PSC Plank bridge cross-section is shown in Figure 3-3 below.

Figure 3-2 Example PSC Plank Footbridge – Berowra Station

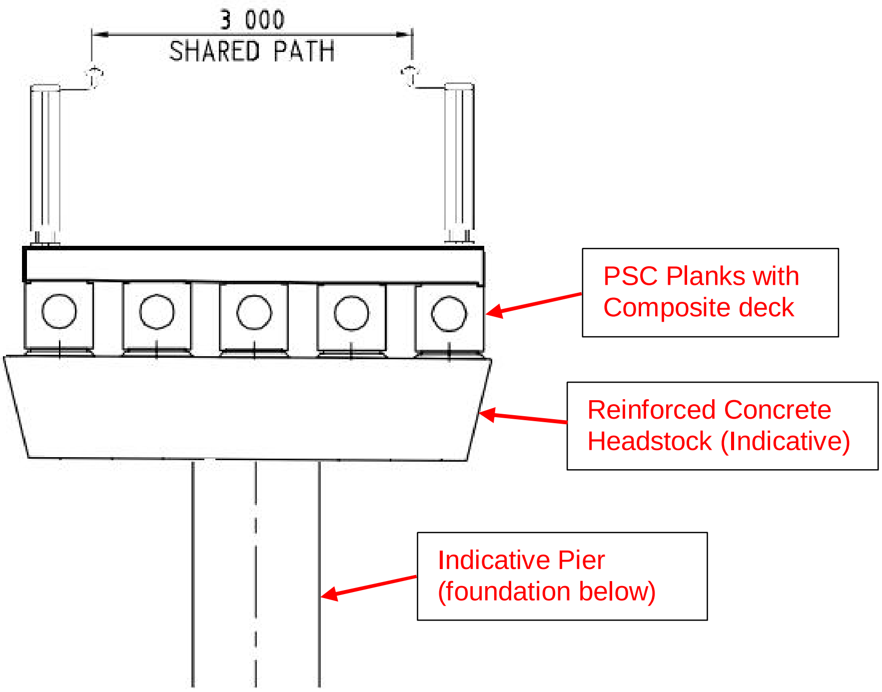


Figure 3-3: Indicative PSC Plank Bridge cross-section

3.3.1.1 Constructability Considerations

Given the multi-span concrete girder structure, the major constructability challenge is around the installation of pre-cast elements. Using a 535mm deep PSC plank and an 18m span as the basis, the weight of each girder will be approximately 12 tonnes. Preliminary assessment for the critical span that crosses the river has suggested that a minimum a 100t crane would be required to lift the girders into place. This is based on the assumption that a crane pad could be constructed adjacent to the river and a larger crane would be required if the crane is needed to be offset further back from the river banks, this would involve major clearing along the bridge.

The suitability of the existing track to accommodate a 100t crane is the biggest unknown at this stage. The construction of the existing track is 150mm thick mesh reinforced concrete slab on a select fill base course. The geometry of the track includes many turns with small radii, the minimum of which is 8m situated within the southern portion of the track. The feasibility of a 100t crane or trucks to transport precast elements using this track to access the bridge site is unlikely and would require further investigation to confirm structural capacity of the path and that the turning paths on curve radii are suitable. A new access path for construction plant is likely to be required to enable bridge construction.

Another key constructability challenge is access within the proposed bridge site corridor. The topography of the existing ground is reasonably steep especially closer to the river with maximum grades of approximately 15-20% and 20-30% on the southern and northern sides respectively. To enable access of a 100t crane or piling rigs down to the area adjacent to the river, significant earthworks and clearing would be required to construct an access track with suitable grades. This would further increase the footprint of the construction zone for this bridge option.

3.3.2 Option 2b – Suspension bridge

Sub-option 2b is a suspension bridge. The typical details of this type of bridge includes suspension cables tensioned between two towers with the deck structure suspended from the cables with hangers. This type of bridge form is considered to be appropriate for the bridge location due to the ability to span long distances without the need for intermediate supports. This results in less construction works required close to the river and within the National Park bush land.

The bridge is proposed to be three-span with two intermediate piers between abutments. The main span is expected to be approximately 60m with approach spans of approximately 30m each. The abutments are likely to consist of a reinforced concrete anchor block system which allows the suspension cables to be anchored into bedrock. The footprint of the anchorage system will depend on the quality of the rock and proximity to the surface. The towers at the intermediate piers are expected to be between 8 and 10m tall above the deck level and are likely to be manufactured from steel hollow sections on piled foundations. The deck could consist of precast concrete segments or prefabricated steel sections.

The nature of a suspension type bridge is that the structure is vibration sensitive. The resulting functionality impact in terms of rideability for cyclists will need to be investigated further in the next stage with an assessment made based on expected frequency and numbers of cyclists using the bridge. Nevertheless, it is noted that the suspension bridge example on the Thredbo Valley Trail (shown in Figure 3-4) caters for cyclists. The length of this bridge is 42m.

For this option, ongoing inspection and maintenance of the suspended cables and steel elements will be required. This is likely to involve working at heights with workers attached the tower cables using appropriate rigging systems.

The aesthetics of a suspension bridge is usually governed by the towers which may be considered visually obtrusive, especially if the towers extend above the tree line. With less intermediate supports required in comparison to a plank bridge, the impact on aesthetics within the natural environment closer to the river can be limited.

Figure 3-4: Thredbo Valley Trail Suspension Bridge (Source: https://www.thredbo.com.au/thredbo-valley-trail/)

3.3.2.1 Constructability Considerations

The most critical constructability challenge for Option 2b is the erection of the bridge towers. The towers would be approximately 10m-12m tall above the foundation and could weigh in excess of 10 tonnes each when constructed as a single piece. This would require a large sized crane to install the towers onto their foundations. As discussed in Option 2a above, the suitability of the existing track to accommodate the access of a large crane is yet to be determined but this could be the limiting factor in determining the maximum possible allowable crane size. A significant amount of earthworks would be required to construct the crane access track and crane pad. To avoid the use of a large crane, there could be an opportunity to construct the towers in sections and erect on site.

Another key constructability challenge is the construction of piled foundations for the towers. For this option the towers would be located approximately 30m from each of the abutments. Due to the long main span of this bridge form, the intermediate piers will require reasonably large footings. The feasibility of a large piling rig gaining access within the bridge construction corridor is questionable given the current grade of the banks leading down to the river. A large amount of preparatory earthworks to construct piling pads will be required. There could be an opportunity to use pad footings instead of piled footings given the presence of rock close to the surface, but this will require a significant amount of in-situ concrete work resulting in a larger footprint.

Further to construction of the towers, the anchoring of the suspension cables at the abutments may present some constructability challenges. Large tensile forces are induced in the suspension cables and this requires the cables to be anchored into suitable bedrock or with large concrete anchor blocks. The process will require the use of specialist contractors and may limit the pool of available contractors.

3.3.3 Option 2c – Stressed Ribbon bridge

Sub-option 2c is a Stressed Ribbon bridge. This type of bridge is the modern analogy of a traditional rope bridge and can be formed of high tension cables embedded within precast concrete deck segments. Due to the nature of the bridge form, the bridge deck follows a lightly draped shape which is formed by a catenary curve. The magnitude of the sag at the centre of the bridge is dependent on the span of the bridge as well as the slope of the bridge at the start of each span.

The bridge is proposed to be three-span with two intermediate piers between abutments. This span arrangement is chosen to limit the sag in the main span. The main span is expected to be approximately 60m with approach spans of approximately 30m. A single span option may be feasible depending on more detailed survey of the approach grades down to the Lane Cove River and the flood immunity required. The proposed structural forms of both Options 2c and 2b require a straight alignment across the bridge.

The abutments are likely to consist of a reinforced concrete anchor block system, providing termination for the stressed bridge cables that need to be anchored into the ground. The anchored cables need to resist the large horizontal forces induced in the bridge, requiring adequate geotechnical conditions, preferably bedrock. Intermediate piers are likely to consist of concrete piers on piled foundations, similar in principle to Option 2a. The main deck units could be precast segments which are embedded with the tension cables that form the main structure of the bridge.

With the central span of 60m, preliminary calculations result in a central sag of approximately 1m. To achieve a flood immunity of 100 years, the bridge abutments would need to be set slightly higher than the existing ground levels to take into account the central sag. Additional earthworks and regrading of Browns Waterhole Track would be required at the approaches.

It should be noted that it is believed that a stressed ribbon bridge has never been constructed in Australia. The bridge construction will require the use of specialist contactors for the stressing and anchoring of cables but this is quite similar in principle to the construction of a suspension bridge which has been constructed in Australia numerous times.

It is a vibration-sensitive structure similar to Option 2b, and the same considerations apply with respect to shared path functionality and user experience.

For this option, inspection and maintenance requirements are limited to deck elements and anchoring points. As the stressing cables are contained within the deck, their maintenance require will be limited.

The aesthetics of a stressed ribbon is generally considered to be non-obtrusive due the stressing cables being contained within the low profile deck. Similar to Option 2b, with less intermediate supports required in comparison to a plank bridge, the impact on aesthetics within the natural environment closer to the river can be limited.

An example stressed ribbon bridge from the Sacramento River Trail in Redding, California, USA is shown in below. This bridge has a span of approximately 130m.

Figure 3-5: Sacramento River Trail Pedestrian Bridge (Source: https://structurae.ne/)

3.3.3.1 Constructability Considerations

The construction of a Stressed Ribbon bridge is relatively simple as the cables are tensioned or stretched between the supports and then precast concrete deck segments are slid over the cables to the desired position. The segments are then joined by cast-in-situ deck pours. This method of construction avoids the need for falsework.

The key constructability challenge for this type of bridge is the anchoring of the cables at the abutments. Large horizontal forces are induced in the stressed cables and this requires the cables to be anchored into suitable bedrock. The process requires the use of specialist contractors and may limit the pool of available contractors.

To install the precast concrete deck segments it is envisaged that a small mobile crane or Franna crane could be used. The segments could be lifted at one end of each span and slid across the cables using an appropriate rigging system. The use of smaller cranes would reduce the amount of preparatory earthworks required to set up crane pads or access paths, reducing the construction footprint for this option.

Similar to Option 2b, another key constructability challenge is the construction of the intermediate piers. For this option two intermediate piers would be required at approximately 30m from each of the abutments. The likely construction would include concrete piers on bored pile foundations. The feasibility of a large piling rig gaining access within the bridge construction corridor would need to be assessed further and the size of the rig able to be used could be limited.

3.3.4 Bridge Option Comparison

A summary of advantages and disadvantages for each bridge form in the proposed location is presented in Table 3-2 below.

Table 3-2: Bridge Option Comparison

Option	Bridge Form	Advantages	Disadvantages
2a	Multi-span Pre-Cast Concrete Plank and Composite Deck bridge	· Standard precast elements are readily available in NSW and are cost efficient	· Limited span length · 6 intermediate piers required. Large construction and permanent footprint and impact on Lane Cove River and adjacent banks · Large crane required for plank installation and large piling rig for intermediate piers. Challenging access requirements given existing track limitations. · Inspection and maintenance access to all bearings will be challenging.
2b	Suspension bridge	· Long span length, requiring only 2 intermediate supports (cable towers), less permanent impact to Lane Cove River and banks · Deck can be constructed with limited impact to Lane Cove River · Deck elements can be concrete to minimise maintenance.	· Requires tall towers to support the suspension cables · Tall towers could be visually obtrusive in the national park · Requires large crane for tower installation if constructed as a single piece · Sensitive to vibration, further considerations required for cyclists · Needs suitable ground conditions at abutments to anchor the large forces from the cables · Inspection and maintenance access to suspended cables and steel elements relatively more complex than Option 2c.
2c	Stressed Ribbon bridge	· Long span length, requiring only 2 intermediate piers, less permanent impact to Lane Cove River and banks · Low profile deck and cable structure in comparison to a Suspension bridge · Deck can be constructed with limited impact to Lane Cove River · Smaller construction plants required in comparison to options 2a and 2b. · Relatively straightforward maintenance access to bearings. Deck elements can be concrete to minimise maintenance.	· Needs suitable ground conditions at abutments to anchor the large forces from the cables · Sensitive to vibration, further considerations required for cyclists

3.4 Option 3 – Modification of existing Sydney Water Pipeline Bridge

Option 3 involves retrofitting an existing Sydney Water pipeline crossing with a walkway. The existing bridge is located approximately 250m downstream of the existing weir and consists of five spans ranging from 8m to 13.7m. The bridge form consists of a steel girder superstructure on concrete substructure. The main girders are 500UB with back-to-back PFC sections for cross-girders. The current maintenance walkway on either side of the pipeline is a weld-lock steel grating deck. It is used for maintenance access only and a locked gate restricts public access on both sides of the bridge. The exact levels of the bridge approaches are unknown but is estimated as 30m AHD. Retrofitting a walkway to this bridge could bridge provide a flood immunity of close to a 50 year ARI given a flood level of 30.3m AHD at this location on the river. below shows the current arrangement of the existing bridge.

Figure 3-6: Existing Sydney Water Pipeline Bridge

At the current stage of this project, the existing pipeline bridge has not been structurally assessed for the additional pedestrian and cyclist loading. Given the design of the existing bridge it seems unfeasible that the existing bridge could accommodate the additional loading although the final arrangement of the retrofitted walkway is subject to detailed structural assessment.

Consultation with Sydney Water will be required to determine if their asset can be used as a public crossing of the river.

3.4.1 Constructability Considerations

Option 3 poses significant constructability challenges including the construction of a compliant track to the bridge approach and the installation of new walkway components. Although it is unclear at this stage whether a Building Code of Australia/Disability Discrimination Act (BCA/DDA) compliant track is required, a significant amount of earthworks will still be required to construct a track to the bridge approach which has grades within the recommended grades for cyclists, particularly on the southern side. The current track splits off from the concreted Browns Waterhole Track. It is currently a bush track and is not well maintained and is overgrown with vegetation. The grades leading down to the southern abutment are up to a maximum of approximately 15 to 20% which would make any construction works in this zone difficult. The need for compliant track grades would result in a track that winds its way down to the abutment, increasing the construction footprint for this option.

Another key constructability constraint is the need for a crane to lift in the new walkway components. Similar to Option 2a, components will need to be installed on the span crossing the river using a crane set up adjacent to the river bank. This will require significant earthworks to construct a suitable access track and crane pad.

3.5 Geotechnical

A desktop geotechnical assessment has been undertaken with respect to the nominated options. The results of the assessment are provided in Appendix C with a summary provided below. The expected geotechnical conditions across the site include Colluvial soils underlain with Hawkesbury Sandstone and Residuals Soils.

For Option 1b the expected ground conditions are saturated Colluvial soils over shallow sandstone. The foundation will need to be stripped to the top of the bedrock to form a good base for the new culverts Groundwater seepage and river flows are expected.

For Option 2a pile foundations for abutments are expected to be founded in a shallow layer of residual soils over sandstone bedrock. Intermediate pier foundations are expected to be founded on the Colluvial layer with residual and sandstone bedrock at a larger depth below the surface. Piers which are closest to the Lane Cover River could encounter saturated soils.

For Options 2b and 2c abutment foundations are expected to be founded in residual soil over sandstone bedrock. With the current arrangement of two intermediate piers at 30m from the abutment, the pile foundations of these piers are expected to be founded on the Colluvial layer with residual and sandstone bedrock at a larger depth below the surface. Tensioned cables at the abutments are expected to be anchored in sandstone bedrock which will likely be found under a shallow layer of residual soils.

3.6 Environmental Assessment

3.6.1 Environmental Impacts – Options

A site inspection was undertaken on 3 May 2018 to identify potential flora and fauna constraints associated with each option. Consideration was given to the likelihood of impacts to threatened flora and fauna species listed under the *Fisheries Management Act 1994,* the *Biodiversity Conservation Act* 2016, and the *Environment Protection and Biodiversity Conservation Act.*

All three options would require some extent of native vegetation clearing for the option footprint and for site access during construction. Options 2 and 3 would impact on Lane Cove National Park, requiring approval from the Office of Environment and Heritage, as well as the biobanking areas of Ku-ring-gai Council, potentially requiring changes to the biobank site management.

Option 1 would require clearing of some vegetation, mostly *Coastal Flats Tall Moist Forest* (PCT 1915) at the edges of the pathway, however overall, the option has a low impact on native vegetation and threatened species which may occur in the study area. There would be some localised impacts to the aquatic ecosystem and water quality due to disturbance associated with the culvert replacement however provided the culvert is designed in accordance with best practice fish friendly water crossings (ref: Fairfull & Witheridge, 2003. *Why do fish need to cross the road? Fish passage requirements for waterway crossings.* NSW Fisheries) it is likely to have an overall low aquatic impact.

Option 2 would require clearing of some native vegetation for the bridge deck and pylons, mostly *Coastal Flats Tall Moist Forest* (PCT 1915) and could impact the adjacent large trees through damage to their root systems. Option 2 would require the removal of some large mature *Eucalyptus pilularis* and/or *E. saligna* species which are likely to be of value to threatened birds, hollow-roosting microbats and the Grey Headed Flying Fox, presenting a moderate potential environmental impact. The multiple pylons for Option 2a would have a greater impact on vegetation and the riverbank than Options 2b and 2c. However, Option 2a may have more design flexibility with regard to possible avoidance of mature trees. Earth works associated with construction and pylon placement may have a moderate impact on water quality and the aquatic habitat. Overall however, Option 2 has a low to moderate potential to impact on native vegetation and threatened species.

Option 3 would require clearing of some native vegetation, mostly *Coastal Sandstone Gully Forest* (PCT 1250), to upgrade the currently narrow, steep and rocky access paths. Option 2 will also require the removal of sandstone vegetation on the gully slopes which may provide habitat for threatened plants. Overall however, Option 3 has a low to moderate potential to impact on native vegetation and threatened species. As there are no works within the stream channel, potential impacts to water quality and the aquatic habitat are low.

3.6.2 Environmental Impacts – Potential Site Compound

A potential site compound location is identified at the head of the Browns Waterhole Track at the end of Kissing Point Road, Turramurra. There is an existing small clearing which could be expanded for the site compound. The vegetation of the proposed compound site is dominated by exotic species and contains minimal native vegetation. The use of the compound site would have minimal impact on biodiversity.

3.7 Indicative Costing

Indicative order of magnitude costing for each option is presented in Table 3-3 below. It should be noted that given the current stage of this project the provided rates are only high-level and need to be reassessed when the site conditions, design and associated challenges are better understood. Costing for Option 3 has not been provided at this stage as the design would constitute a custom retrofit design, the cost of which cannot be easily estimated without determining further details of the structural arrangement.

Table 3-3: Indicative Options Costing

Option	Approx. Deck Area (m^2)	Indicative square metre costing	Indicative total cost ($)
Option 1b*	40	$3,000/$m^2$	$120,000
Option 2a	450	$3,000/$m^2$	~$1,500,000
Option 2b	450	$7,000/$m^2$	~$3,500,000
Option 2c	450	$7,000/$m^2$	~$3,500,000
Option 3	-	-	-

*includes demolition of existing pipe culverts

Given the preliminary nature of the design, cost estimates do not account for the following:

- Contingencies;
- Construction staging;
- Traffic management;
- Utility adjustments;
- Removal & replacement of unsuitable material;
- Client costs;
- Soft soil/ground treatments;
- Clearing and grubbing; and
- Miscellaneous earthworks including construction access and realignment of existing tracks

It should be noted that some of the items currently excluded from the estimates above may represent a significant proportion of the overall cost and could misrepresent the outcomes of the comparison.

3.8 Comparison of Options

Table 3-4: Track Upgrade Options Comparison

Option	Length *(m)*	No. of Spans	Longest Span *(m)*	Cost	Flood Immunity	Environmental	Constructability	Maintenance	Other
Option 1b: *Culvert Replacement*	8	2	4	Low	None. Slight improvement of local flow performance.	Low, low impact on native vegetation, threatened species, however some potential to impact on water quality aquatic habitat during construction.	Existing track could be restrictive for large trucks to gain access to the site.		
Option 2a: *Multi-span Pre-cast Concrete*	120	7	18	Moderate	Up to ~100 year ARI with current levels.	Low to Moderate, requires removal large trees that provide good potential habitat to threatened fauna. Greater impact on native vegetation than Options 2b & 2C. Some potential to impact water quality through earth works in channel.	Significant plants and cranage to lift in precast planks. Involves significant in-situ work along the river banks.	Inspection and maintenance access to all pier bearings will be relatively more challenging	
Option 2b: *Suspension*	120	3	60	High	Up to ~100 year ARI with current levels.	Low to Moderate - requires removal large trees that provide good potential habitat to threatened fauna. Some potential to impact water quality through earth works in channel.	Significant plants cranage to lift in cable towers. Requires specialist contractor for ground anchoring works.	Inspection and maintenance access to suspended cables and elevated tower elements may be more complex than 2c.	Requires good quality rock at the approaches for cable anchorage. Alignment needs to be straight for structural reasons Considerations on vibration sensitivity for shared path users
Option 2c: *Stressed Ribbon*	120	3	60	High	Up to ~100 year ARI with current levels.	Low to Moderate - requires removal large trees that provide good potential habitat to threatened fauna	Minor to moderate construction plants. Requires specialist contractor for ground anchoring works.	Relatively easier inspection and maintenance access to bearings and anchorages.	Requires good quality rock at the approaches for cable anchorage. Alignment needs to be straight for structural reasons Considerations on vibration sensitivity for shared path users
Option 3: *Modification of existing Sydney Water Pipeline*	56	5	14	N/A. Expected to be Low/Moderate	50 year ARI. To be confirmed with detailed survey.	Low to moderate – low impact on native vegetation, but may require removal of some marginal habitat for threatened species.	Crane to lift in prefabricated elements. Requires work adjacent to the river.		Need Sydney Water approval to use their structure. Condition and structural capacity of the existing structure, particularly of buried elements, is unknown.

4. Safety in Design

As part of the development of the design, an initial Safety in Design (SiD) review has been carried out in order to identify and document significant risks that will encountered in the construction, operation and maintenance of the structural asset.

By identifying significant risks at a very early stage in the design, it has been possible in some circumstances to design out or mitigate some of the identified risks to an acceptable level. Where this is not possible, these risks will be transferred to the construction contractor.

A Safety in Design Register is provided in Appendix D, outlining the key risks and mitigation strategies for this current phase of the project. The headline risk scenarios are summarised in Table 4-1 below.

Table 4-1: Safety in Design during construction

Project Stage	Headline Risk Scenario
Construction	· Excavations · Accessing the site · Use of heavy plant · Working near to water · Demolition of existing culvert · Working with high tensile stressing cables
In Use	· Pedestrians on walkways · Vehicles trying to drive across the bridge · Flooding
Maintenance	· General maintenance
Demolition	· Bridge demolition at end of the design life

5. Conclusions and Recommendations

5.1 Conclusions

A feasibility assessment has been undertaken of a number of options to modify the existing Browns Waterhole Track in order to provide improved flood immunity and better access for the public. However, it is recognised that it is a highly environmentally sensitive site and the proposed options pose moderate to significant challenges and impacts depending on the target level of flood immunity to be attained. In summary, of the potential upgrade options assessed:

- Culvert upgrade Option 1b provides a low cost option (~$120K) with low environmental impact, but flood immunity is only improved slightly from the existing low immunity and access would continue to be cut in frequent flow events. Relatively low demolition/construction access and maintenance requirements.
- Bridge upgrade Option 2a provides a moderate cost option (~$1.5M) with moderate environmental impacts, though higher than other options including alternative bridge options due to increased number of piers and higher requirements for large tree removal.
- Bridge upgrade Options 2b and 2c provide a high cost option (~$3.5M) with moderate environmental impacts, with Option 2b posing a relatively higher potential for aquatic ecology impacts. Both these options need good quality rock for cable anchorages and alignment needs to be straight.
- All bridge options pose potentially challenging or complex maintenance issues, although Option 2c has relatively less complex inspection and maintenance issues. All bridges offer a ~100 year ARI level of flood immunity.
- Option 3 (modification of existing pipe crossing) is expected to have low to medium cost with low environmental impact but may require removal of some marginal habitat for threatened species. Constraints include unknown condition and structural capacity of the existing structure, particularly of buried elements, and requirement for Sydney Water consent, which is expected to not be readily granted. A ~50 year ARI level of flood immunity is expected.

Refer to further details in Section 3.8. Note that the preliminary costs involve a number of exclusions, and these may represent a significant proportion of the overall cost and could affect the outcomes of the comparison.

5.2 Recommendations

The recommendation for the next steps is for:

1) Confirmation of design criteria including;
   a) Required flood immunity and ultimate design flood recurrence interval and levels;
   b) Functional requirements of the bridge including widths and grades required;
   c) Horizontal alignment and position of the bridge;
   d) Environmental constraints; and
   e) Aesthetic requirements.
2) Further stakeholder engagement, including with the NSW National Parks and Wildlife Service (NPWS) and the Ku-ring-gai Council to better understand the priorities of the competing objectives; and
3) Further site and desktop investigations to better understand the constraints and construction methodology to confirm feasibility of access and to develop a more accurate cost estimate. This includes requirements for additional earthworks and vegetation clearing for construction plant access.

A multi-criteria assessment involving all parties may also be considered to arrive at a preferred solution or an aligned strategy between the stakeholders.

Appendix A. Flooding Assessment Memo

JACOBS Memorandum

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Subject	**Preliminary Flood Assessment**	**Project Name**	Browns Waterhole Track Feasibility Study
Attention	Guy Thomas	**Project No.**	IA174600
From	Michael Reeves, Lih Chong		
Date	29 March 2018		
Copies to			

1. Introduction

The Browns Waterhole Tack is a pedestrian and cycleway located in the Lane Cove National Park. It connects Kissing Point Road in Turramurra to Vimiera Road in Marsfield. It crosses Terrys Creek (catchment area 1000ha) with a 2 x 2400mm (W) x 1200mm (H) RCBC with 2624mm (W) x 1400mm (H) link slab, and Lane Cove River (catchment area 2,375ha) with 2 x 450mm diameter RCP under a weir structure. Both crossings are within a short distance of approximately 80m, as shown in Figure 1-1.

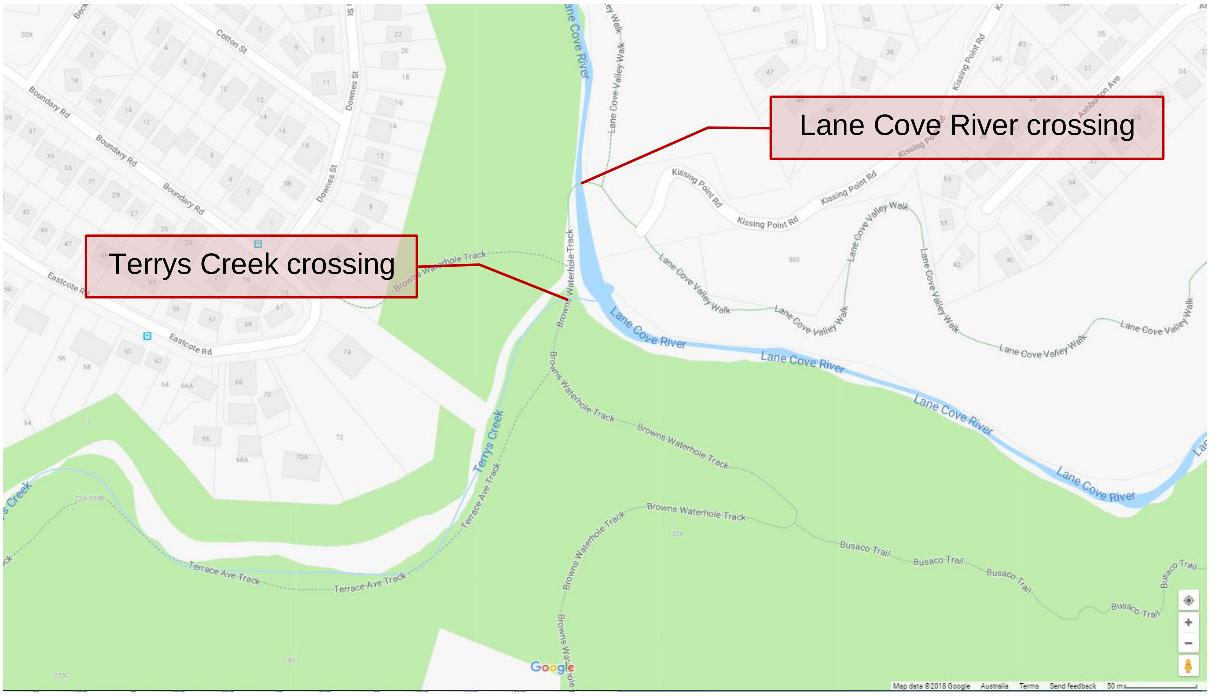


Figure 1-1 Location of Browns Waterhole Track. ***Source: Google Maps***

At Lane Cove River, the track runs over the weir structure located on the river, which is frequently flooded in minor storm events. The track is an important connection for both pedestrians and cyclists and flooding can render the track unusable for long periods of time and is a risk to public safety.

Ku-ring-gai Council (Council) has engaged Jacobs to undertake a feasibility study of upgrading the Browns Waterhole Track to improve its flood immunity.

The aim of this feasibility study is to provide preliminary options, costs and potential impacts to improve the flood immunity of the Browns Waterhole Track. This memo provides the results of a preliminary flood assessment of the track and potential upgrade options for discussion with Council to target the options to assess in detail.

2. Flood Modelling

2.1 Hydrologic Modelling

The catchment draining to the confluence of Terrys Creek and Lane Cove River was delineated using LiDAR survey data held in house by Jacobs. This included data from the 'Sydney North' dataset, obtained in 2013 and 'Hawkesbury South' dataset captured in 2011. The 1m digital elevation model (DEM) was used to delineate the catchments and subdivide them into subcatchment areas. In total 21 subcatchments were delineated for the entire catchment area of Terrys Creek, ranging in size from 18ha to 115ha covering the 1,000ha catchment. Also 21 subcatchments were delineated for the 2,735ha Lane Cove River catchment just upstream of its junction with Terrys Creek, with areas ranging from 42ha to 223ha. Impervious fractions were assigned to each subcatchment by defining three land use types, as outlined in Table 2-1.

Table 2-1 Land use types

Land use	Impervious Fraction (%)
Urban / Residential	50
Industrial	90
Bushland	5
Open grassed areas	0

This information was used to develop an XP-RAFTS model, using the 'split catchment' function for the pervious and impervious fractions of each subcatchment. A Manning's 'n' value and rainfall losses were applied to each subcatchment type, as shown in Table 2-2.

Table 2-2 Parameters used for each subcatchment type

Land Type	Manning's 'n'	Initial loss (mm)	Continuing loss (mm/hr)
Pervious	0.04	15	2.5
Impervious	0.015	1	0

Subcatchment slopes were obtained from the DEM. Flow from each subcatchment is routed through channels with representative cross sections selected from the DEM. Australian Rainfall and Runoff (ARR) 1987 was used to obtain the intensity-frequency-duration relationships for the combined Terrys Creek and Lane Cove River catchment. No areal reduction factors were applied and each storm event was considered to occur concurrently in each catchment. There are no gauges in either catchment to calibrate the hydrology model to, however, the *Eastwood and Terrys Creek Floodplain Risk Management Study & Plan* (Bewsher Consulting, 2008) has modelled flows reported at Forrester Park on Terry's Creek (this represents the most downstream location where flows are reported, with a catchment area of approximately 535ha). The verification of flows at this location is presented in Table 2-3. The flows simulated by the XP-RAFTS model are lower than those presented in the *Eastwood and Terrys Creek Floodplain Risk Management Study & Plan* (Bewsher Consulting, 2008), however, are considered reasonable given the different hydrology models employed by each study.

Table 2-3 Flow verification at Forrester Park

Flood Event	Terrys Creek Floodplain Risk Management Study & Plan[1] (m^3/s)	XP-RAFTS[2] (m^3/s)	Difference (m^3/s)
5 year ARI	64.5	53.4	-11.1
10 year ARI	75.4	62.3	-13.1
20 year ARI	89.1	74.4	-14.7
50 year ARI	98.5	85.9	-12.6
100 year ARI	106.5	97.4	-9.1

1 As reported in Bewsher Consulting, 2008 in Table 6 at Forrester_Pk Total for unblocked culvert conditions

2 Peak flows for the critical duration storm as simulated by the XP-RAFTS model developed by Jacobs

The XP-RAFTS model was run for the 1, 2, 5, 10, 20, 50 and 100 year average recurrence interval (ARI) events for a range of storm durations to obtain the peak flows for each catchment as well as the combined catchment for the critical durations.

2.2 Hydraulic Modelling

A one-dimensional (1D) HEC-RAS hydraulic model was developed to simulate flood behaviour at the Browns Waterhole Track crossings of the Lane Cove River and Terrys Creek. Two separate river reaches were defined for Lane Cove River and Terrys Creek. The 1m LiDAR DEM was used to define cross sections for approximately 800m upstream and downstream of the crossings. A junction was defined downstream of both crossings at the confluence of the two reaches. A Manning's 'n' of 0.08 was applied to the channel and overbank areas. The two crossings were also defined in the model, based upon issued for construction drawings obtained from City of Ryde Council. Pertinent structure details are presented in Table 2-4.

Table 2-4 Summary of structure details on the Browns Waterhole Track

Crossing	Culvert size and type	Culvert upstream invert level (m AHD)	Overtopping (track) level (m AHD)
Lane Cove River	2 x 450mm diameter RCP	23.95	25.52
Terrys Creek	2 x 2400mm (W) x 1200mm (H) RCBC with 2624mm (W) x 1400mm (H) link slab[1]	23.19	25.01

1 Modelled as 3 x 2620mm (W) x 1200mm (H) culvert structure

The structures were assumed to be clear, however, during a site visit it was seen that there was a reasonable blockage of the Terrys Creek culvert due to debris, as shown in Figure 2-1. There is a high potential for blockage of both of these culverts.

Figure 2-1 Blockage of the Terrys Creek culvert

Upstream and downstream boundary conditions were applied based on a normal depth criteria using the slope of the streambed. Flow rates were obtained from the XP-RAFTS model for the total Lane Cove River and Terrys Creek catchments and these were applied at the upstream end of each respective reach. The simulated combined flow of the two catchments in the XP-RAFTS model was used at the confluence of the two reaches. The HEC-RAS model was run in steady state.

3. Existing Flood Behaviour

The existing flooding conditions for the range of events simulated are presented in Table 3-1 below.

Table 3-1 Summary of the existing flooding conditions at the Browns Waterhole Track crossings of the Lane Cove River and Terrys Creek

Flood event	Percentage of total flow in culvert (%)	Upstream flood level (m AHD)	Depth over the track (m)
Lane Cove River crossing			
1 year ARI	0.2	28.99	3.5
2 year ARI	0.1	29.53	4.0
5 year ARI	0.1	30.17	4.7
10 year ARI	0.1	30.54	5.0
20 year ARI	0.1	30.96	5.4
50 year ARI	0.1	31.42	5.9
100 year ARI	0.1	31.84	6.3
Terrys Creek crossing			
1 year ARI	8	29.03	4.0
2 year ARI	7	29.59	4.6
5 year ARI	4	30.25	5.2
10 year ARI	4	30.62	5.6
20 year ARI	4	31.06	6.1
50 year ARI	3	31.53	6.5
100 year ARI	2	31.96	7.0

The results indicate that both crossings have a flood immunity of less than the 1 year ARI event, with water overtopping the track level by over 3m at both crossings. The Lane Cove River culvert carries a negligible percentage of the flow, and the Terrys Creek culvert can carry between 2 and 8% of the flow across the range of events simulated.

4. Preliminary Options Assessment

The scope of this assessment is to look at options to look at options for upgrading the Lane Cove River crossing. The following options have been assessed using the HEC-RAS model to provide an indication of the improvement in flood immunity:

- Option 1: Additional culverts at the Lane Cove River crossing
- Option 2: Construction of a new bridge spanning both Terrys Creek and Lane Cove River
- Option 3: Retrofitting the existing Sydney Water Pipeline with a walkway

Each of these options has been assessed with the removal of the existing weir and retaining the existing weir structure. The results of each of these assessments is provided in the following sections.

4.1 Option 1: Additional culverts at the Lane Cove River crossing

Option 1 involves the construction of additional culverts at the Lane Cove River crossing. Three different options have been assessed, depending on whether the existing weir is removed or maintained, and whether the track level is raised or not. For each of these options, the flood immunity of the Terrys Creek crossing remains the same. Both crossings currently have a flood immunity less than the 1 year ARI event, so improvement in the Lane Cove River crossing would not improve the flood immunity of the entire track if the Terrys Creek crossing is flooded.

4.1.1 Option 1a: Additional culverts retaining the existing weir and raising track level

Option 1a includes a bank of 5 x 3600mm (W) x 1200mm (H) box culverts sitting on top of the existing weir, as demonstrated in Figure 4-1. All culverts were set with an invert level of 25.66m AHD, although in reality these invert levels may vary along the length of the weir. The culverts were also assumed to be aligned parallel to the flow of the river. The weir is curved and placement of culverts on top of this curve may result in the skewed waterway area of some culverts being reduced. This was the estimated number of culverts that could fit along the length of the weir as observed on site. A culvert height of 1.2m was selected as a higher culvert may require a railing or barrier along the footpath that would be on top of it. This is also consistent with the Terrys Creek culvert. The new track level was set at 27.27m AHD This culvert configuration was run in the HEC-RAS model and the results are presented in Table 4-1, relative to the existing conditions run.

Figure 4-1 Indicative schematic of Option 1a with additional culverts to be placed on top of the existing weir. Note: not to scale

Table 4-1 Summary of the change in flood level and flows at the Lane Cove River crossing with Option 1a

Flood event	Percentage of total flow in culvert (%)	Change in upstream flood level (m)	Flood depth over the track (m)	Change in flood depth over the track (m)
1 year ARI	23	+0.01	1.7	-1.7
2 year ARI	19	+0.02	2.3	-1.7
5 year ARI	15	+0.02	2.9	-1.7
10 year ARI	13	+0.02	3.3	-1.7
20 year ARI	11	+0.01	3.7	-1.7
50 year ARI	10	+0.01	4.2	-1.7
100 year ARI	9	+0.01	4.6	-1.7

The flood level upstream increases slightly (up to 0.02m), however, however, with the track raised, the flooding over the track is reduced by approximately 1.7m across the range of events. The track, however, is still flooded by approximately 1.7m in the 1 year ARI event.

4.1.2 Option 1b: Additional culverts with removal of the existing weir and maintaining existing track level

Option 1b involves removal of the existing weir (estimated based on the design drawings and field measurements) and installation of twin box culverts, as shown in Figure 4-2. In order to maintain a similar track level, a culvert height of 1200mm was selected, being consistent with the Terrys Creek crossing and the other culvert options. A width of 3600mm was selected as the two culverts were estimated to fit across the existing channel. This culvert configuration was run in the HEC-RAS model and the results are presented in Table 4-2, relative to the existing conditions run.

Figure 4-2 Indicative schematic of Option 1b with removal of the weir and culverts to be installed with the track at the existing level. Note: not to scale

Table 4-2 Summary of the change in flood level and flows at the Lane Cove River crossing with Option 1b

Flood event	Percentage of total flow in culvert (%)	Change in upstream flood level (m)	Flood depth over the track (m)	Change in flood depth over the track (m)
1 year ARI	7	0.00	3.5	0.0
2 year ARI	6	+0.01	4.0	0.0
5 year ARI	5	+0.02	4.7	0.0
10 year ARI	5	+0.01	5.0	0.0
20 year ARI	4	+0.01	5.5	0.0

Flood event	Percentage of total flow in culvert (%)	Change in upstream flood level (m)	Flood depth over the track (m)	Change in flood depth over the track (m)
50 year ARI	4	+0.01	5.9	0.0
100 year ARI	3	+0.01	6.3	0.0

While the new culverts reduce the flow overtopping the track by increasing the percentage of flow in the culvert, the depth of flooding over the track does not change and hence the flood immunity of the track, for the events assessed, does not change.

4.1.3 Option 1c: Additional culverts with removal of the existing weir and raising track level

Option 1c is a combination of Option 1a and 1b. It consists of the removal of the weir and installation of the culverts for the channel as in Option 1b, with the additional culverts identified in Option 1a. The result is 3 x 3600mm (W) x 1200mm (H) box culverts at an invert level of 25.66 mAHD for high flows, and 2 x 3600mm (W) x 3000mm (H) box culverts for the channel flow. The culvert configuration can be seen in Figure 4-3. The results of this configuration remain very similar to Option 1a and are presented in .

Table 4-3 Summary of the change in flood level and flows at the Lane Cove River crossing with Option 1c

Flood event	Percentage of total flow in culvert (%)	Change in upstream flood level (m)	Flood depth over the track (m)	Change in flood depth over the track (m)
1 year ARI	33	+0.01	1.7	-1.7
2 year ARI	28	+0.02	2.3	-1.7
5 year ARI	23	+0.02	2.9	-1.7
10 year ARI	19	+0.02	3.3	-1.7
20 year ARI	18	+0.01	3.7	-1.7
50 year ARI	15	+0.01	4.2	-1.7
100 year ARI	13	+0.01	4.6	-1.7

Figure 4-3 Indicative schematic of Option 1c with removal of the existing weir, installation of culverts and raising the track level. Note: not to scale

4.2 Option 2: Construction of a new bridge structure

Option 2 involves the construction of a new bridge structure which will span both the Terrys Creek and Lane Cove River crossings. This will provide the best flood immunity for the track. The option for a bridge structure is yet to be investigated in detail, however, an indicative alignment of the bridge is provided in Figure 4-4. The bridge will tie in at the northern end with the Kissing Point Road track at its intersection with the Browns Waterhole Track and Lane Cove Valley Walk. At the southern end, the track will tie in with Browns Waterhole Track near its intersection with the Terrace Ave Track.

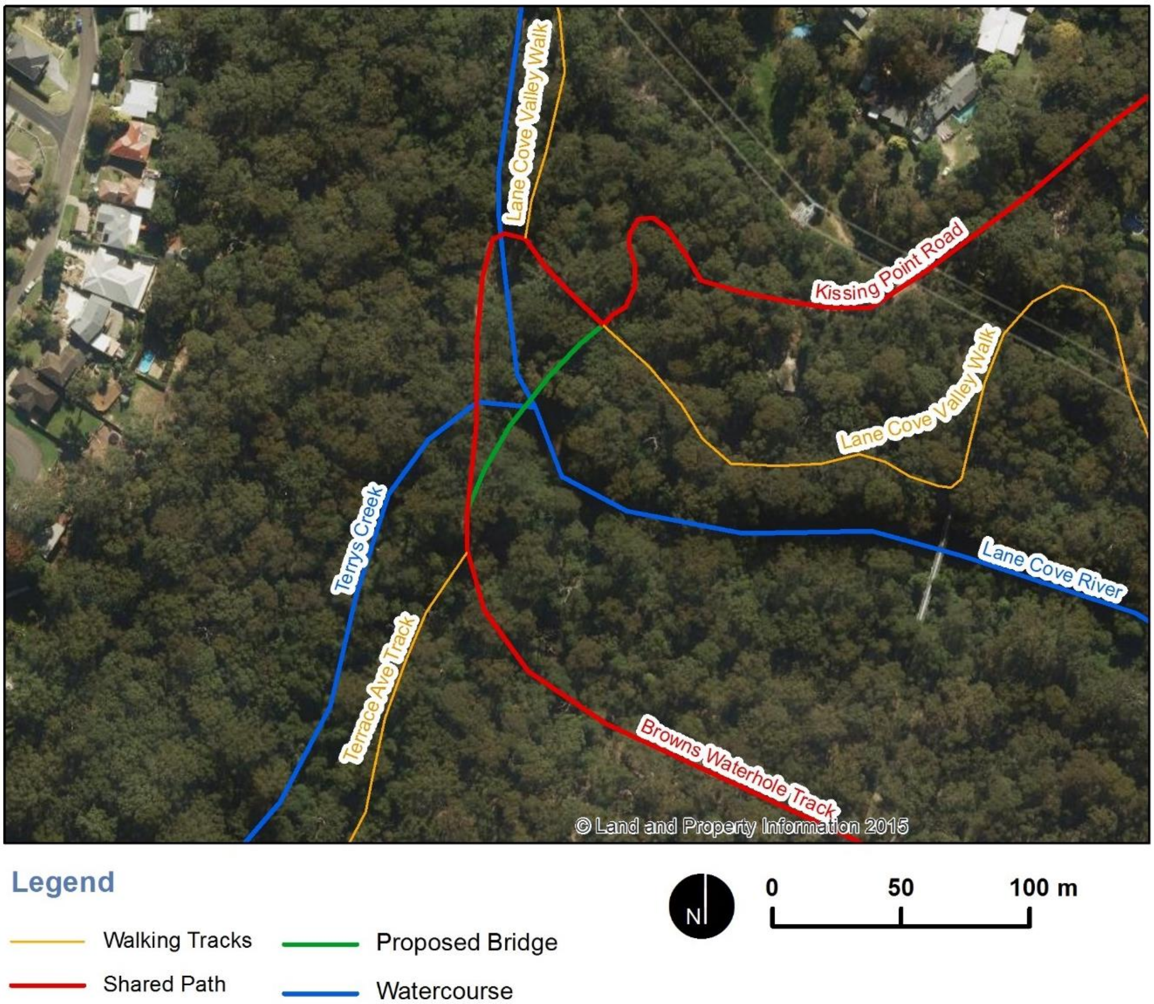


Figure 4-4 Indicative alignment of the proposed bridge

The bridge, spanning approximately 90m would require the construction of piers and would be within the Lane Cove National Park. Consultation with National Parks and Wildlife Services would be required if this option is to be investigated.

This option could be constructed either with or without the removal of the existing weir. A run was completed with the removal of the weir in the HEC-RAS model to see how much the flood level decreases. A decrease in flood level may lead to a lower and shorter bridge being required. The results indicate that the removal of the weir results in a negligible change in flood level, hence it is recommended to keep the existing weir structure in place. This will also serve as an alternate route to the bridge and maintain access for vehicles as well.

The flood levels around the location of the proposed bridge can be seen in Table 4-4. These are based on the existing flood conditions, provided that the waterway obstruction caused by the piers of the bridge is minimal and flood levels remain similar. The ground elevation at the indicative tie in locations is approximately RL 31.5m at the northern end and RL 29.5m at the southern end. The bridge could be designed for a certain level of flood immunity, which would influence the length and height of the required bridge.

Table 4-4 Approximate flood levels at the proposed bridge location

Flood event	Flood level at the proposed bridge location (m AHD)
1 year ARI	29.0
2 year ARI	29.6
5 year ARI	30.3
10 year ARI	30.6
20 year ARI	31.1
50 year ARI	31.5
100 year ARI	32.0

4.3 Option 3: Retrofitting the existing Sydney Water Pipeline with a walkway

Option 3 involves retrofitting an existing Sydney Water pipeline crossing with a walkway. The pipeline is approximately 180m downstream of the confluence of the Lane Cove River and Terrys Creek, as shown in Figure 4-5.

Figure 4-5 Location of the existing Sydney Water pipeline crossing

A photograph of the pipeline is shown in Figure 4-6.

Figure 4-6 Existing Sydney Water Pipeline

A shared path would need to be constructed either above the existing pipeline or next to the existing pipeline structure. The elevation of the pipeline is unknown, as RL's are not provided on the 'as constructed' drawings, but it is estimated to be at approximately RL 30m. The flood levels in the vicinity of the pipeline are shown in Table 4-5.

Table 4-5 Approximate flood levels at the existing Sydney Water pipeline

Flood event	Flood level at the proposed bridge location (m AHD)
1 year ARI	27.9
2 year ARI	28.4
5 year ARI	29.1
10 year ARI	29.4
20 year ARI	29.9
50 year ARI	30.3

Flood event	Flood level at the proposed bridge location (m AHD)
100 year ARI	30.8

If this option is to be considered, consultation with Sydney Water is required as they own the asset. Initial consultation suggests that Sydney Water would be open to the prospect of this structure being retrofitted with a public walkway. Further details regarding Sydney Water's requirements about access for inspection and maintenance of the pipeline will need to be sought. In addition, construction of a path will need to be considered to connect the bridge to the existing shared path. This may prove difficult since much of the bushland area is set aside for bio-banking. The pipeline easement is separate to this protected area and may provide a corridor to construct the access track, however, Sydney Water will need to be consulted further on the possibility of this option.

5. Conclusions

An XP-RAFTS hydrologic model and HEC-RAS hydraulic model have been developed to assess the potential upgrade options to improve flood immunity of Browns Waterhole Track, which crosses both Terrys Creek and the Lane Cove River . The existing flood conditions at the crossings indicate that the track has less than 1 year ARI flood immunity, with the track being inundated by over 3m at both crossings in the 1 year ARI event. Three options have been assessed at this preliminary stage to improve the flood immunity and a summary of the results is as follows:

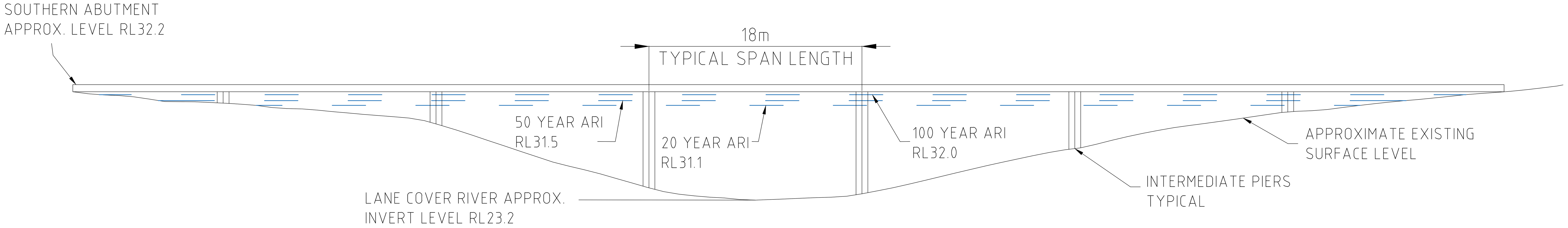
- Option 1: Additional culverts at the Lane Cove River crossing. Three different configurations were tested, including both removing and retaining the existing weir structure. The flood immunity did not improve if the existing track level was maintained. The flood immunity was increased if the track was raised and culverts were provided underneath, however it still remains flooded in the 1 year ARI event and the flooding at the Terrys Creek crossing is not improved.

- Option 2: Construction of a new bridge spanning both Terrys Creek and Lane Cove River. This requires a 90m bridge to be constructed. An indicative bridge location has been provided and flood levels for this location based on existing conditions. The location of the bridge allows it to tie in with existing high ground, although providing greater flood immunity will require a longer spanning bridge. The removal of the weir does not reduce flood levels greatly, and hence the existing weir and track should be retained. This option also improves flood immunity for both crossings.

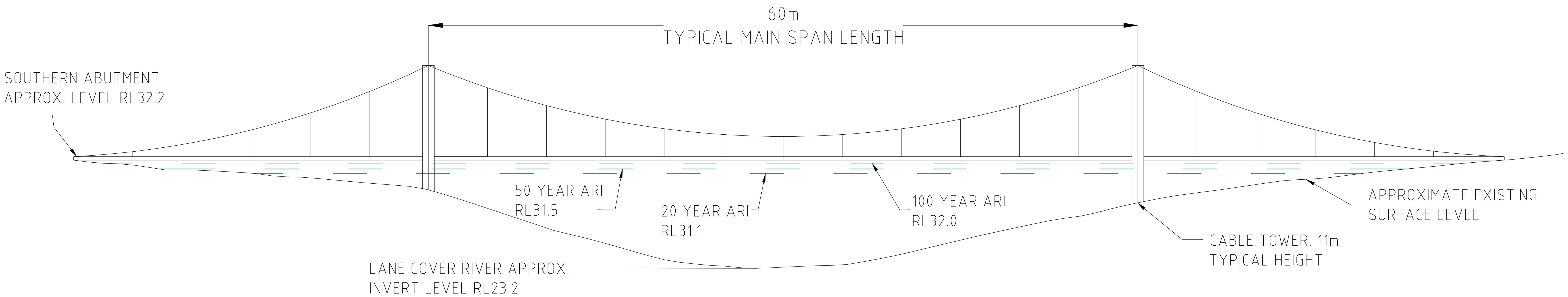
- Option 3: Retrofitting the existing Sydney Water pipeline with a walkway. The Sydney Water pipeline, located approximately 180m downstream of the confluence of the Lane Cove River and Terrys Creek could be retrofitted with a walkway to provide increased flood immunity. For both crossings. Consultation with Sydney Water would be required, as the asset owners and constructing access tracks to either end of the bridge may be difficult and requires consultation with National Parks and Wildlife Services.

To progress with the study, these results will be discussed with Council and three options will be shortlisted to be investigated in the feasibility study, which will incorporate a geotechnical, environmental and structural investigations.

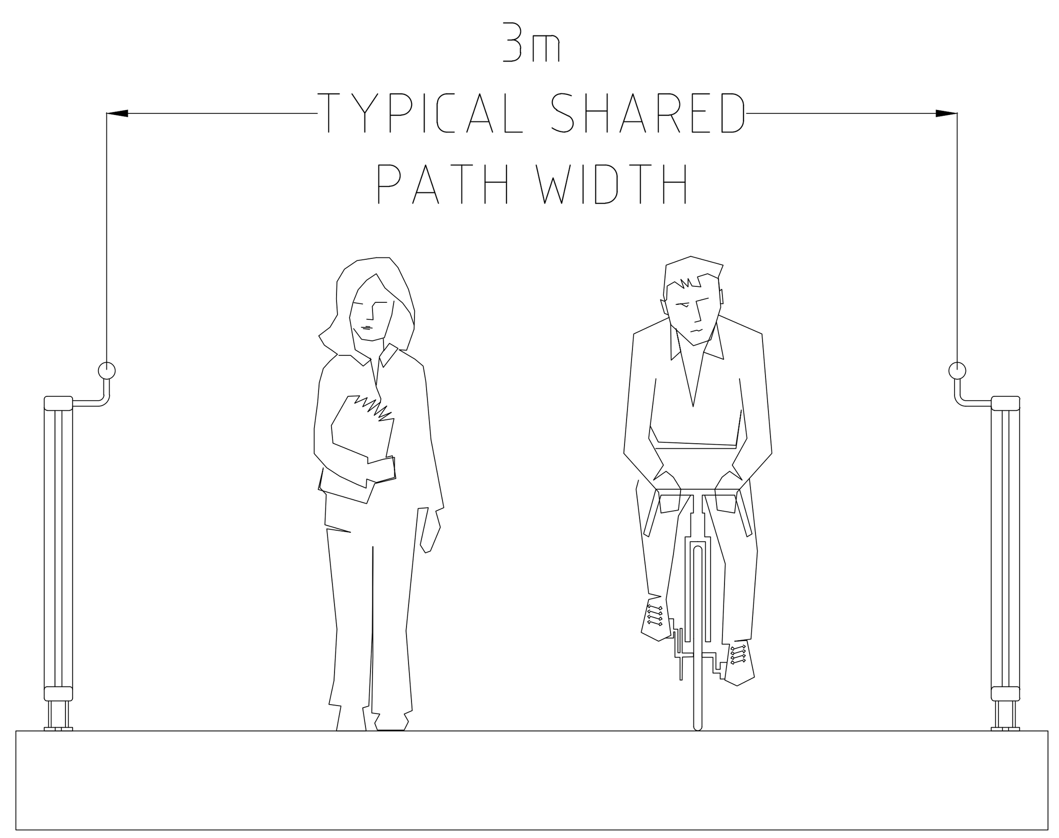
Appendix B. Bridge Option Sketches

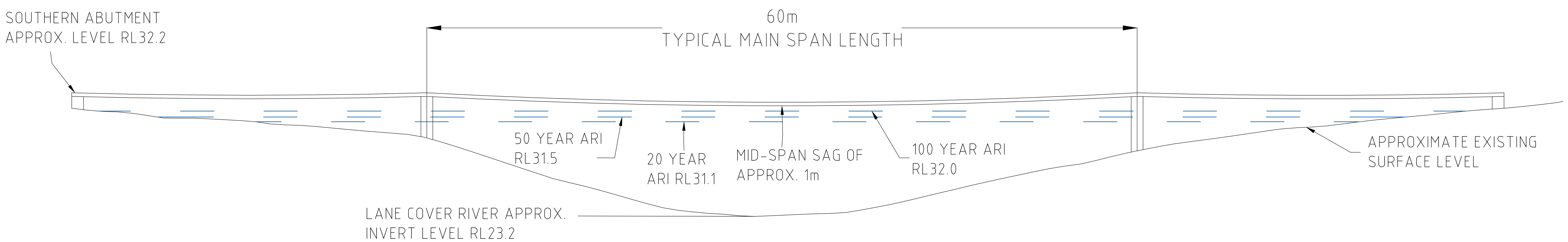


OPTION 2A - MULTI SPAN CONCRETE BRIDGE



OPTION 2B - SUSPENSION BRIDGE





OPTION 2C - STRESSED RIBBON BRIDGE

PRELIMINARY

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BROWNS WATERHOLE TRACK UPGRADE
STRUCTURAL FEASIBILITY OPTIONS

Appendix C. Geotechnical Investigation Memo

Memorandum

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Subject	**Geotechnical Assessment of Options**	**Project Name**	Browns Waterhole Track Feasibility Study
Attention	Lih Chong (Jacobs)	**Project No.**	IA162800
From	Scott Raynsford (Jacobs)		
Date	18 May 2018		
Copies to	Hayden Ibanez (Jacobs)		

Lih,

Find attached geotechnical assessment of the ground conditions and general issues and constraints that may impact on the options being considered for the Browns Water Hole Track to improve flood immunity, based on current viable options presented.

1. Introduction

The Browns Waterhole Track is a pedestrian and cycleway located in the Lane Cove National Park. It connects Kissing Point Road in Turramurra to Vimiera Road in Marsfield, where it crosses Terry's Creek and the Lane Cove River. At the Lane Cove River crossing, the track runs over a constructed weir, which frequently floods during minor storm events. The track is an important connection for both pedestrians and cyclists and flooding can render the track unusable for long periods of time and is considered a risk to public safety. The aim of the overall study is to provide preliminary options to improve the flood immunity of the Browns Waterhole Track, with this geotechnical desktop study/assessment prepared to develop and understanding of the geotechnical conditions and how they may impact on the feasibility and constructability of the concepts being considered.

This report provides the findings of the geotechnical inspection and desk study, outlining geotechnical issues, constraints and opportunities to assist in the development and evaluation of options.

2. Available documents

The following information was available at time of undertaking this assessment:

- Geology Map, 1:100 000 prepared for Sydney, by the Geological Survey of NSW (Sheet 9130, edition 1).
- Soil Map, 1:100 000 prepared for Sydney, by the Department of Environment, climate change and water Survey of NSW (Sheet 9130, edition 4).
- Design Drawings, Proposed Bikeway, Vimiera Road Macquarie Park to Kissing Point Road South Turramurra (Sheets 1, 2, 13 and 16).

Relevant information from these references is discussed in following sections and used in Figures prepared in **Attachment 1**.

3. Site Inspection

A site inspection was undertaken on the 3 May 2018 by a Jacobs Geotechnical Engineer, consisting of a site walkover, visual inspection, and photographic survey. The purpose of the site walkover was to develop an understanding of the subsurface conditions across the area to identify key geotechnical constraints that may impact on proposed options. Details and notes from the site mapping are discussed below and provided on Figures 1 to 3 in **Attachment 1.**

The site is divided into four main areas (as shown on Figure 1 in **Attachment 1**), with a description of site and specific observations summarised below:

- **Exiting Weir:** At the track crossing over the Lane Cover River, a weir has been constructed by placing fill across the waterway with 1(V):3(H) side slopes. A concrete seepage cut-off is shown on the drawings through the fill, with a reinforced concrete facing slab and embedded/mortared scour rock to prevent scour during overtopping. A concrete path has been constructed across the weir with twin 450 mm diameter pipes shown, fir the river low flow condition (invert approximately RL23.9m AHD). The top of the weir is estimated at approximate RL24.6 m AHD. Sediment/sand build up is noted on the banks on the upstream side of the weir with exposed soils within bank profile. Rock outcropping is noted on the downstream bank (northern side). It is not shown on the drawings, but inferred that the existing weir foundation may have been built up over a previous structure, with cut-off taken down to top of rock. Inferred ground conditions are included on Figure 2 in **Attachment 1**, with site photographs of the weir provided on Plates 2.1 and 2.2 below.

Plate 2.1: Down steam view of the weir

Plate 2.2: Concrete path and view of weir

- **Terry’s Creek Culvert:** The culvert at this location is not part of the scope but was inspected as part of the site walkover in case other options may be considered involving this structure. From available drawings it is understood to comprise three a cell box culvert constructed from twin 2400mm by 1200 mm precast concrete units with central concrete link slab, forming a central 2.6 m wide opening. The invert of the culverts is shown as RL23.2m AHD, with approximate track height of RL24.6m AHD. Significant debris and build up is noted on the upstream side impacting the flow from Terry’s Creek. Steep soil batters/slopes and extensive vegetation are noted on the inlet side. Downstream, the flow area widens, with rock outcropping on the outside bend in the river with the connection/merging with the upper reaches of the Lane Cover River. Sediment/sand build up is noted on the banks, with the southern bank area likely comprising deeper colluvial soils. Site photographs of the culvert are provided on Plates 2.3 and 2.4 below.

Plate 2.3: View culvert structure

Plate 2.4: view downstream, near planned bridge crossing option

- **Proposed Bridge Alignment:** It is understood that consideration is being given to installation of an elevated walkway/bridge to provide flood immunity for certain events, with track levels increased to around RL31 to 32 m AHD (1 in 20 year to 1 in 100 ARI). It is understood that the southern abutment area (Plate 2.5), will be near or close to the connection with the walking tracks near the picnic area. This area is generally flat and with slopes dipping downwards towards the river (approximate grade of 15 to 20%). The northern side (Plate 2.6), is on a steeper area of the path connecting to Kissing Point Road with ground levels dipping more sharply towards the river in this section (20 to 30%) and steeper near the river bank. A view of the area between the abutments is provided on Plate 2.7, with the area heavily vegetated and overgrown preventing any observations of the river banks. It is expected that the southern approach to the river is on more gently dipping ground, comprising alluvial/colluvial soils and slope wash, with the northern approach likely shallow residual soils and sandstone outcropping and ledges on the immediate northern bank.

Plate 2.5: Proposed new bridge location (Southern side) – view north

Plate 2.6: Proposed new bridge location, (Northern Side) – view south

Plate 2.7: Proposed new bridge location (across Lane Cove River)

- **Sydney Water Pipe Bridge/Aqueduct:** The existing bridge is located approximately 250m downstream of the existing weir across the Lane Cover River (approximate total span of 56 m). The bridge consists of five spans ranging from 8 to 13.7m, supported on concrete abutments and piers. The deck is steel girder supporting the pipe, with weld-lock walkway and handrail on either side. Currently pedestrian access is restricted with a locked gate. The bridge is accessed from the south via a walking track off the main concreted bikeway. The track has not been well maintained and is overgrown. The track is also relatively steep (15 to 20%) on uneven ground, and is not considered suitable for use as formalised pathway for the public without alignment modifications and grade improvements. Access to the northern side of the bridge is off the main concreted bikeway (Kissing Point Road side) and is of moderate grade (approx. 5 to 10%) on a better defined unsealed pathway, although the path would still need to be improved for public access. Select photographs are provided on plates 2.8 and 2.9 below.

Plate 2.8: Southern side existing Sydney water pipeline across the Lane Cover River

Plate 2.9: View northern side existing Sydney Water pipeline across the Lane Cover River

4. Geology and Soils

An understanding of the soils and geology has been based on the 1:100 000 soil and geology maps for Sydney, supplemented by site mapping as no geotechnical information was available at the time of this review. The mapping indicates that the area is primarily underlain by the following units (refer Figure 3.1 and 3.2).

- Soils **(ha)**: The site is mapped within the Hawkesbury Colluvial landscapes (ha). This area comprises rugged, rolling to very steep hills on Hawkesbury Sandstone, including narrow crests and ridges, incised valleys (associated with minor creeks and water courses), steep side slopes with rock benches, and broken scarps and boulders. Soils are typically shallow (0.5 to 1 m) comprising siliceous sands and sandy clays with rock outcrop. Limitations include soil erosion and rock fall hazard.
- Geology **(Rh)**: The site is mapped as being underlain by the Hawkesbury Sandstone Unit (Rh). The Hawkesbury sandstone unit in this area comprises medium to coarse grained quartz sandstone, with minor shale and laminate lenses. This rock unit is typically overlain by a shallow depth of residual and colluvuial soils (less than s metre thick), including sandy clay/clayey sands. On the steeper slopes, soil thicknesses are expected to be less than 500 mm with outcropping.

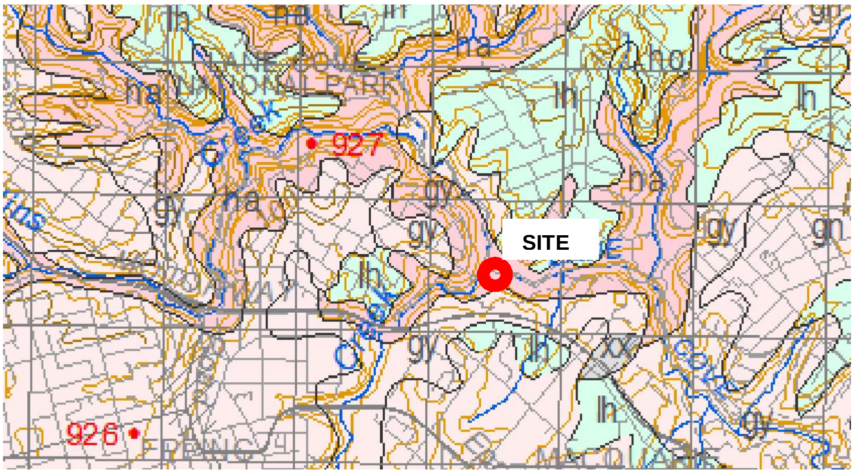

Plate 3.1: Soil Map Extract

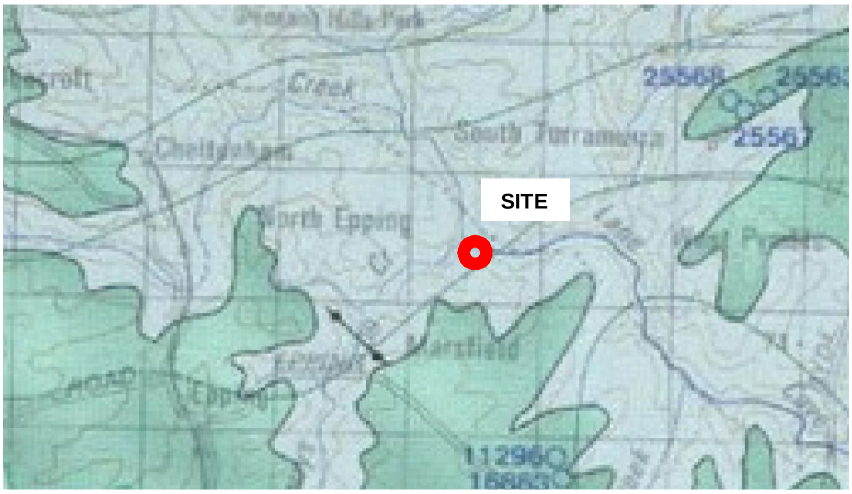

Plate 3.2: Geology Map Extract

5. Geotechnical Assessment

Based on the desktop study and site walkover, the site has been divided into three broad geotechnical zones as indicatively shown on Figures 1 to 3 in **Attachment 1**. The following summarises the expected ground conditions in each zone, to assist in the understanding of the geotechnical conditions and risks/opportunities and how they may need to be considered in the options development:

- **(Zone A) Minor fill zones:** These areas are expected to comprise local filling as part of establishing grades for local paths. Shallow fills are expected along the existing and constructed cycleway (<1 m) with 1 to 1.5 m of engineered fill understood to have been placed to form the weir structure.
- **(Zone B) Colluvial and terraced rock areas**. These areas are heavily vegetated and overgrown located on rugged, steep to very steep side slopes. Site levels are expected to be locally steep and variable, with shallow colluvial soils expected with sandstone cobbles and boulders in a sandy soil matrix. There is the potential for some land instability in the steeper areas and gully features associated with Terry's creek and the upper reaches of the Lane Cover River.
- **(Zone C) Hawkesbury Sandstone and Residual Soils.** Underlying the above colluvial soil units, Hawkesbury Sandstone Unit is mapped with shallow residual soils overlying medium grained, medium to high strength sandstone and minor shales. Common sandstone outcropping and boulders expected in steeper areas. Residual soils depth could vary, but in steeper area, soils depths expected at around 500mm.

The implications of the above geotechnical units on the options is discussed below.

6. Geotechnical Issues, Risk and Opportunities

A brief description of the options being considered is listed below to assist in the geotechnical assessment of options:

- **Option 1:** This option comprises the replacement of the low flow piped culverts with twin 3600 mm wide by 1200 mm high reinforced concrete box culverts. The level of the track is to be maintained at 245.6m AHD. Works would require saw cutting of the existing concrete lined bund and laying back the excavation to enable construction, with temporary diversion of river flows.
- **Option 2:** This option includes the construction of a bridge across the Lane Cover River, approximately 105 m span (as indicatively shown on Figure 1 in **Attachment 1**) to provide flood immunity. Design deck height will vary depending on level of flood immunity required, but estimated to range between RL31 to 32 m AHD for the 1 in 20 to the 1 in 100 ARI. Options for the bridge will be depended on access/load requirements (i.e. vehicle access or pedestrian/cyclists only), with initial options including multi span precast concrete bridge, steel suspension bridge or stressed ribbon type bridge. All options will require intermediate piers to reduce the total spans.
- **Option 3:** This option includes the upgrade of the existing Sydney Water pipe bridge/aqueduct to permit pedestrian access. The works would require establishing a suitable compliant walkway/path to the bridge (north and south) and modification of the existing inspection access for pedestrian and/or cyclist access.

Table 6.1 provides a list of some broad geotechnical issues, risks and opportunities that have been identified for each of the options described above.

Table 6.1: geotechnical options assessment

Option	Ground Conditions	Issues, Risks and Opportunities
Option 1: Upgrade Weir *Install twin 3600 mm wide box culverts*	Ground conditions are expected to comprise saturated/colluvial soils over shallow sandstone. Groundwater seepage and river flows are expected.	- Construction will need to manage the low flow with a temporary diversion to enable culvert base slab construction. - Foundation will need to be striped to top of rock to form a good base/subgrade for new culverts and to prevent seepage underneath the structure. - The existing weir's concrete cut-off wall will be an obstruction that will need to be carefully treated during placement of the new culverts. - The existing concrete facing slab and revetment will need to be cut and reinstated on completion with tie in to the new structure, as the structure will still operate as a weir during high flow over topping events. Internal scour and erosion a risk if weir batters not appropriately reinstated and treated.
Option 2: New bridge	***(Refer Figure 3 in Attachment 1)***	
2a) Multi-span Precast Units *18 m mid spans* *5 to 6 span bridge*	Northern and southern abutments expected to comprise shallow residual soils over sandstone bedrock. Groundwater not expected. The mid spans for this bridge option would be located within colluvial side slopes/flanks of the Lane Cover River. Possible saturated soils closer to the river and bolder obstructions for intermediate pier construction.	- Requires additional spans and piers across the river section, with difficult access (steep ground) where crane lifts will be required. - Potential for saturated ground around central piers near river. Will require casing and or use of rock platforms for equipment. - Will require cane pads and access for lifting in precast units. Due to terrain and ground conditions, will require crane access paths to be established and working platforms for equipment to ensure stability during lifts. - Existing tracks and paths may not have sufficient subgrade strength for this equipment and turning circle and geometry for large cranes may be problematic for access.

Option	Ground Conditions	Issues, Risks and Opportunities
2b and c) Suspension or stressed ribbon bridge. *60 m central span* *3 span bridge*	Northern and southern abutments expected to comprise shallow residual soils over sandstone bedrock. Groundwater not expected. The mid spans for this bridge option would be located within colluvial side slopes/flanks of the Lane Cover River. Possible saturated soils closer to the river and bolder obstructions for intermediate pier construction.	n These options have flexibility in the position on central piers (and reduced number). Generally favourable ground conditions for the abutment (footings and anchors) with shallow rock expected. n Suitable intermediate pier positions can be selected to minimise any works near or directly in the waterway areas. Will require construction tracks to access these areas over moderately steep ground. n Review of equipment requirements will be necessary to assess whether existing tracks and paths have sufficient subgrade strength for equipment requirements. Turning circle and geometry for larger vehicles may be problematic for access.
Option 3: Retro-fitting the existing Sydney Water Pipeline Bridge	Northern and southern abutments and central piers expected to be founded on good quality sandstone, however current information/drawings do not confirm as built information on the footings (and or size/founding levels). The southern approach/path is located on steep ground with potential land instability.	n Steep ground conditions on the southern approach requiring modification to the existing track alignment to establish a suitable grade for public access. n Further information required to assess the current foundation capacity and if any strengthening required to modify the existing structure for use as designated walkway and access.

7. Recommendations

The above assessment has been made in relation to the geotechnical risks and opportunities based on limited geotechnical information. On development and refinement of the preferred option, further geotechnical input and targeted site investigations are considered important to address the issues and risks raised above. Additional tasks to further evaluate the options could include:

- **Option 1: Upgrade Weir.** Obtain further information and details on the existing weir construction to assess foundation conditions and backfilling and construction quality. May also require geotechnical borehole investigation to assess the fill and foundation levels for new culverts base slabs.
- **Option 2a to 2c: New bridge.** Boreholes will be required (if this option progresses to concept) to confirm founding levels for bridge abutments/piers and anchor design for all options. Investigation into equipment requirements (crane sizes, trucks etc) to assess whether the existing concrete cycleway has sufficient structural capacity to support the vehicle loads will be necessary. Vehicle turning envelopes will need to be assessed for required equipment given restricted geometry of the existing cycle way track.

- **Option 3: Retro-fitting the existing Sydney Water Pipeline Bridge.** Obtain as built foundation records for the Sydney Water pipe bridge/aqueduct and undertake foundation assessment based on proposed load changes from any planned modifications to the existing structure.

If you have any questions or require any further input, please contact the undersigned.

Regards,

Scott Raynsford
Senior Geotechnical Engineer
Phone: 02 9032 1435
E-mail: scott.raynsford@jacobs.com

Attachments:
Attachment 1: Site Plan and Mapping

Limitations

Jacobs has prepared this report for the use of the client in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. If ground conditions vary from those outlined above, then further geotechnical advice or investigations should be sought.

The purpose of the assessment documented in this short report was to provide high level constraints mapping to assist with development of options only. No validation or site specific geotechnical information was available at the time of this review. This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. Jacobs has made no independent verification of this information beyond the agreed scope of works and Jacobs assumes no responsibility for any inaccuracies or omissions or for any changes that may have occurred since preparing this report

Attachment 1: Site Plan and mapping

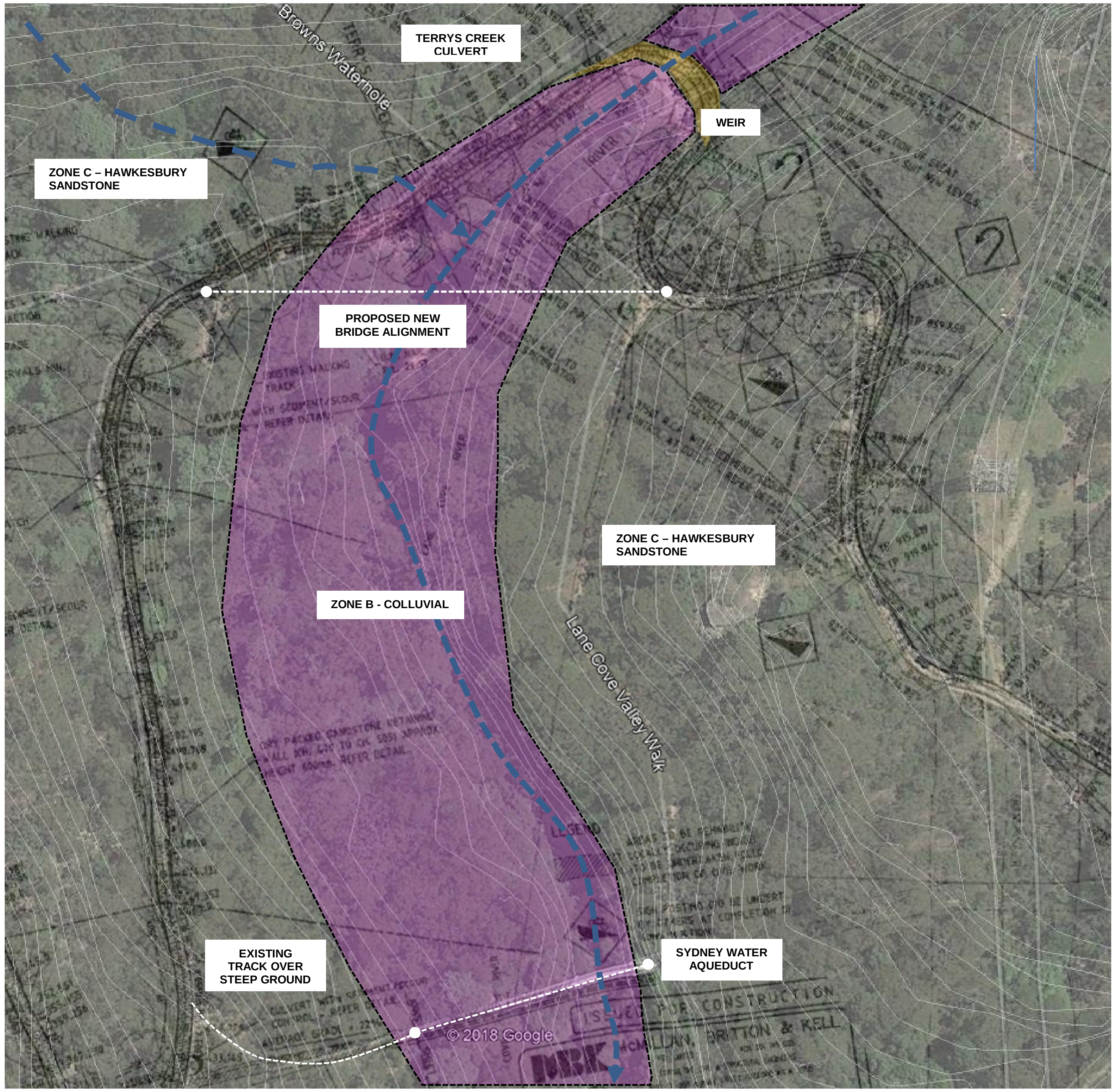

Figure 1 – Site Plan

Scale 1:1000 (Approximate@A3)

Note: 1 m contours from Lidar. Slopes are inspected as steeper on northern approach than currently shown

JACOBS

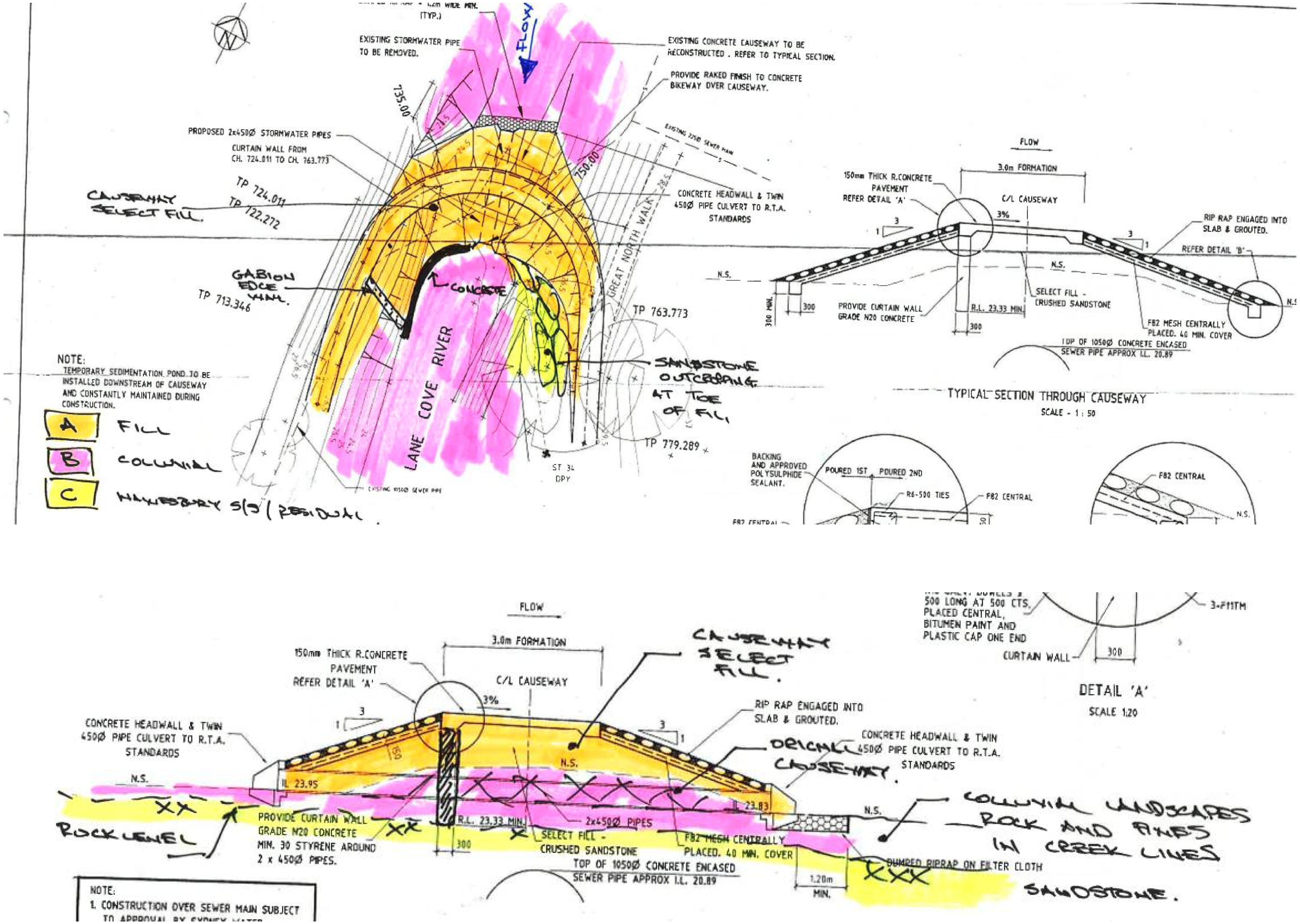

Figure 2 –Weir (NTS)

PLAN

Scale1:500 (approx. @A3)

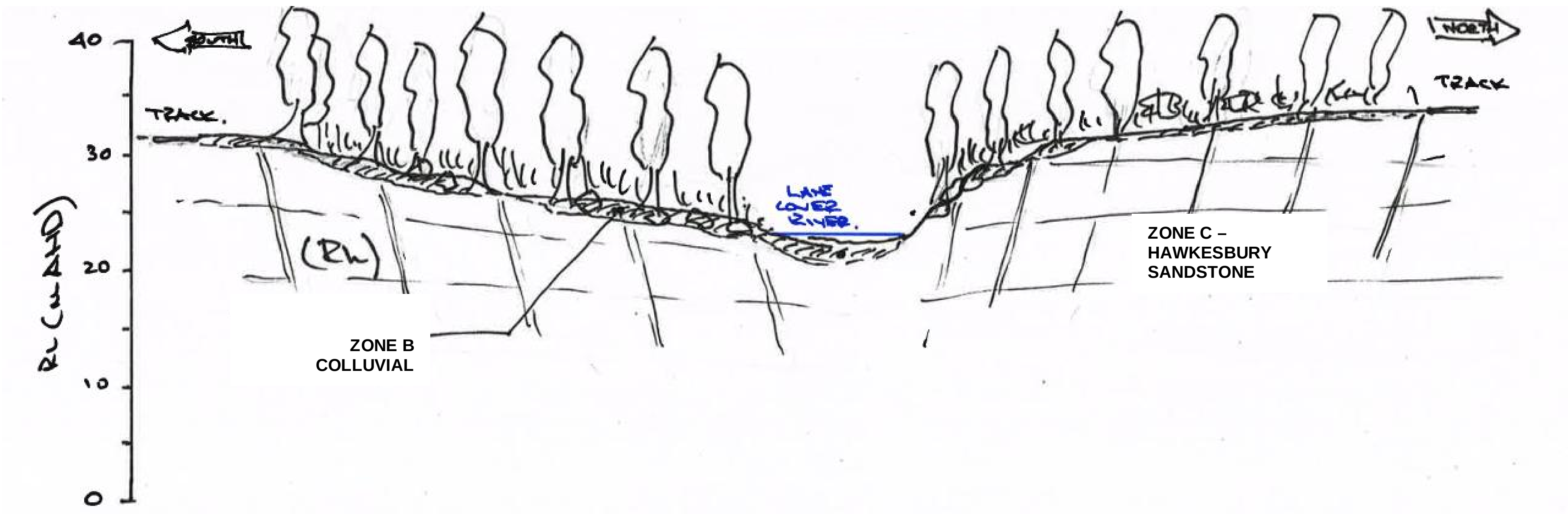

Figure 3 –Bridge Long Section

(1:500 – Approximate @A3)

Note: 1 m contours from Lidar. Slopes are inspected as steeper on northern approach than currently shown

Appendix D. Safety in Design Register

SAFETY IN DESIGN REGISTER

Stage	Scenario	Hazard	Initial Risk: Consequence	Initial Risk: Likelihood	Initial Risk: Risk Rating	Improvement Action	Residual Risk: Consequence	Residual Risk: Likelihood	Residual Risk: Risk Rating	Responsibility for Managing Residual Risk
Construction	Excavations	Damage to / contact with existing utilities	4	3	High	A services search should be undertaken as the design progresses.	4	3	High	Designer
Construction	Accessing the site	Instability of vehicles due to steep, narrow and winding access paths	4	4	Very High	Minimise the size of consruction elements to allow the use of smaller plant. New haul routes may be required.	4	4	Very High	Designer
Construction	Accessing the site	Clash between costruction activities and members of the public	4	4	Very High	Unavoidable risk. Constructor to prepare and implement a site specific safe work method statement. Client to consider closing sections of the park to the public during specific construction activities	4	4	Very High	Client / Contractor
Construction	Use of heavy plant	Instability during lifting	4	4	Very High	Minimise the size of construction elements.	4	4	Very High	Designer
Construction	Working near to water	Drowning	4	3	High	Unavoidable risk. Constructor to prepare and implement a site specific safe work method statement. Consider use of cofferdams or channel flow diversions if possible to minimise/eliminate working over waterway for the culvert replacement option. Develop flood evacuation protocols.	4	3	High	Contractor
Construction	Demolition of existing culvert	Uncontrolled collapse or flying debris	4	2	High	Client to ensure the chosen Contractor is competent for demolition work. Unavoidable risk. Constructor to prepare and implement a site specific safe work method statement.	4	2	High	Client / Contractor
Construction	Working with high tensile stressing cables	Explosive release of tension in cables	4	2	High	Client to ensure the chosen Contractor is competent in specialist cable stressing techniques if a suspension bridge or stressed ribbon bridge is selected. Unavoidable risk. Constructor to prepare and implement a site specific safe work method statement.	4	2	High	Client / Contractor
In Use	Pedestrians on walkways	Falls off structure	4	3	High	Pedestrian barrier provided along full length of structures. Height suitable for both pedestrians and cyclists.	4	3	High	Designer
In Use	Pedestrians on walkways	Slipping	2	3	Medium	Provide an appropriate slip resistant surface.	2	3	Medium	Designer
In use	Vehicles try to drive across bridge	Bridge not designed to accommodate vehicles	5	2	Very High	Provide obstruction to prevent unauthorised access across the bridge i.e. bollards.	5	2	Very High	Designer
In use	Pedestrians on walkways	Objects falling off walkway into watercourse	1	4	High	Provide a kicker plate along the edge of the bridge.	1	4	High	Designer
In use	Flooding	Bridge collapse or people swept off bridge in a flood event	5	3	Very High	Bridge to be positioned above flood levels or appropriately designed for flood loads.	5	3	Very High	Client / Designer
Maintenance	General Maintenance	Falling from height and over water	4	3	High	Bridge elements to be durable and specified to minimise maintenance. -Specify concrete in lieu of steel where possible -Design cable protection systems to minimise maintenance -Special detailing or provisions to allow maintenance access where feasible Unavoidable risk. Maintainer to prepare and implement a site specific safe work method statement.	4	3	High	Designer / Maintainer
Demolition	Bridge demolition at end of design life.	Uncontrolled collapse, flying debris or explosive release of energy from stressed cables / strands.	4	2	High	Client to ensure the chosen Contractor is competent for demolition work. Unavoidable risk. Constructor to prepare and implement a site specific safe work method statement.	4	2	High	Client / Contractor

Residual Risk Level & Management Action Required

Very High/High	
Medium/Low	

Consequences		*Likelihood*	
1	*Insignificant*	*1*	*Rare*
2	*Minor*	*2*	*Unlikely*
3	*Moderate*	*3*	*Possible*
4	*Major*	*4*	*Likely*
5	*Catastrophic*	*5*	*Almost Certain*