Building a Bridge with a House Slab

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ABSTRACT

This paper describes the investigation and assessment process involved in developing an innovative technique for upgrading a small causeway in rural NSW. The final result has improved the level of service of the roadway, maintained the existing creek habitat, improved fish passage through the structure and installed a fit-for-purpose low maintenance structure that will service the community for years to come. The engineering design, which is considered a first, utilises residential house (waffle pod) slab construction methods to install a low-cost, in-situ concrete culvert with a minimum of road closure time and disruption to the watercourse. In order to avoid a long detour, Council along with the construction contractor facilitated access for the local residents at all times. The methodologies described in this paper may provide a blueprint for Local Governments faced with similar causeway upgrade requirements into the future.

KEYWORDS: *Causeway repair, waffle pod slabs, rural road culverts*.

1 INTRODUCTION

This paper outlines the journey of the Greater Taree City Council design team in dealing with a small concrete causeway on Belbora Creek Road, in rural NSW. The solution involved residential house slab technology (waffle pods), and we believe this was the first time this system has ever been used to create an in-situ concrete box culvert (Figure 1).

Figure 1: Looking upstream over the new Belbora Creek Road causeway during a freshet.

While the end result appears deceptively simple, it meets many of the requirements we deal with every day. It fulfilled the requirements of those little catch phrases that abound in

Council offices. It was ‘cost effective’, ‘fit for purpose’, ‘environmentally friendly’ and ‘provides an improved level of service’ to those residents who use the road.

2 LOCATION, DEFINITIONS AND BACKGROUND

Belbora Creek Road runs north off The Bucketts Way between Taree and Gloucester. It services the areas between Belbora and Bundook. This road predominately services rural properties ranging from 40 to 200 ha, primarily grazing beef cattle. Belbora Creek Road is about 23 km east of Gloucester, heading north off the Bucketts Way towards Bundook. Causeway #1 is, as the name suggests, the first causeway on the road and is located 5 km north of The Bucketts Way (Figure 2).

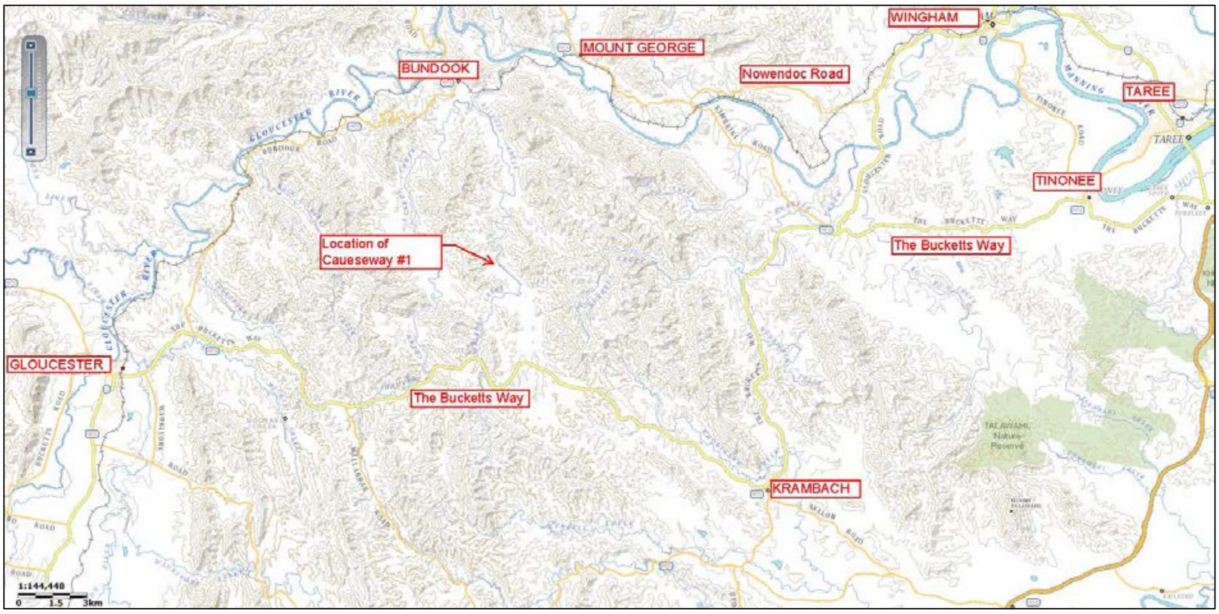

Figure 2: Locality map.

According to the English Oxford dictionary, a causeway is “a raised road or track across low or wet ground” (Oxford University Press, 2017). In this instance, the causeway acts as a road crossing Belbora Creek. As shown in Figure 3, Causeway #1 was a concrete slab near the level of the creek. A small Ø375 mm pipe is installed adjacent to the southern shore.

Older generations of the causeway can be seen off to the left of the current roadway. For many years and a number of generations of slabs, these low level causeways were considered ‘fit for purpose’ and provided the appropriate ‘level of service’ for this road. In this context, the level of service can be defined as “a qualitative measure representative of the operation of a road for a given traffic flow that takes into account a group of factors (speed, manoeuvre, safety, comfort and cost) that take place on it.”

Belbora Creek Road meanders from side to side across Belbora Creek, crossing the creek 10 times between The Bucketts Way and the rural area of Bundook. The road also wanders across the Local Government Area boundary passing between the former Greater Taree City Council and neighbouring former Gloucester Shire Council. However, Gloucester Shire Council had a higher priority on causeway upgrades in the early 1990s and upgraded all its causeways further along Belbora Creek Road, installing low-level bridges across the creek

(Figure 4). A bridge can be defined as "a structure that is built over a river, road or railway to allow people to cross from one side to the other" (Oxford University Press, 2017).

Figure 3: The original Causeway #1, looking north.

Figure 4: One of Gloucester Shire Council's upgraded causeway bridges (downstream side showing girders and mass concrete abutment).

These low-level bridges allow residents to cross the creek with a medium level of flow. Unfortunately, Greater Taree Council had different priorities and had not upgraded the very first causeway on the road. Residents from north of the causeway might negotiate the Gloucester Shire Council bridges all the way to #1 but were unable to negotiate the flooded causeway just short of The Bucketts Way, the main road to the rest of the district. Backtracking to exit the road via Bundook was a 30 km detour to get around the flooded causeway.

After Gloucester Shire Council completed its causeway upgrades, Causeway #1 ceased being a 'fit for purpose' rural creek crossing, providing a suitable 'level of service'. Despite absolutely no physical change to Causeway #1, users of this rural road reported that it had become a 'dangerous' and 'sub-standard' piece of infrastructure. The letters and complaints came in from the neighbouring Council's residents about this dramatic change in circumstances. The number of complaints waxed and waned with the weather as the level of inconvenience shifted. Particularly wet years in 2008 and 2009 brought the causeway upgrade to the Councils' Capital Works Programme in around 2010, marked by the Investigation & Design Project No 10/06.

3 BELBORA CREEK ROAD CAUSEWAY #1

3.1 General Information

Belbora Creek Road Causeway #1 was a concrete causeway on a rural road. Generally, these old causeways are made up of kerb or side log placed on either side of the roadway across the stream. A concrete slab, often un-reinforced, poured between these logs acts as the causeway deck. A small pipe may be fitted to the structure to take the low base flow that occurs between rainfall events. In the instance of Causeway #1, our investigations revealed that the causeway had three or four different generations of concrete poured at different levels making up the current structure and that the adjoining farmer would block the low flow pipe (with a sheet of ply or large rocks placed in the inlet) in order to maintain a higher level of water upstream of the causeway for irrigation purposes.

The Investigation & Design team was tasked with upgrading this causeway. However, flood disasters significant enough to attract disaster relief funding in 2011, 2012 and two in 2013 dropped the priority of the upgrade of this minor causeway. It is significant to note this creek crossing suffered very little damage in these major flood events. The design that had initially been started in 2010 did not really get underway until 2014.

The standard upgrade of a causeway is to rip it out, remove the existing causeway, install concrete box culverts and reinstate the causeway slab over the top of these box culverts. This was the initial design thinking and plans for a 5 x 2.4 m wide x 0.9 m high concrete box culvert had been prepared. The 45° skew of the road in relation to the creek made this a relatively expensive construction. In addition, Council construction crews were extremely wary of this as a methodology, having lost all their groundworks to rainfall events on several other comparable projects during the recent wet years.

The catchment of the causeway comprises approximately 4,453 ha of grazing country. The run-off was calculated using storage routing model (RAFTS) available in the DRAINS software and the flood modelling along the creek simulated using HEC-RAS. The depth of flow above the creek bed (and causeway) was assessed. The results of that assessment of the existing conditions at the crossing are shown in Table 1 for storms of various frequencies (Average Recurrence Interval – ARI).

Table 1: Assessment of the existing water flow conditions at the old Causeway #1.

ARI Storm Event	1- year	2-year	5-year	10-year	20-year	50-year	100-year
Depth of flow above creek bed (m)	2.05	2.56	3.10	3.38	3.66	4.00	4.30
Max. velocity of flow (m/s)	3.35	3.87	4.46	4.79	5.14	5.38	5.58

Clearly, significant flows occur at this location. The potential for Council to construct a bridge that remained flood-free at the ARI 100-year or 1% Annual Exceedance Probability (AEP) level was quickly discounted. A number of possible permutations and configurations of box culverts were assessed.

3.2 The Neighbour's Blueprint: Elegant Simplicity

Our investigation team went beyond the causeway and looked at how our neighbouring Council had addressed the identical problem just downstream of this site. Gloucester Shire

Council's Manager Technical Services, Gill Gendron, had designed and overseen the upgrade of the downstream causeways as low concrete bridges. These bridges, supported on girder logs, were considered, by the local residents, to be 'fit for purpose'. They provided conveyance over the creek during dry times and up to a low level of flow in the creek. These bridges were by no means flood-free and were cut off in larger flows once or twice each year, but this was only considered an inconvenience by the residents and an adequate 'level of service' was being provided. In comparison, Causeway #1 was cut off with minimal rainfall.

The design of these Gloucester Shire Council bridges was simple in structure, very cost effective at the time, required no specialised skills of the workforce and could easily be done using the machinery available at Gloucester Shire Council's disposal. As evident in Figure 5, the structure is made up of a series of bridge girder logs, of about 450 mm diameter, laid across the existing concrete causeway parallel with the flow of the stream. The logs are spaced at 1.5 m centres. This spacing enables a standard sheet of 19 mm form ply to be fixed between the logs and a 250 mm concrete slab to be poured over the logs. The form ply was simply left to rot and be washed away. The girders extend upstream and are fixed to a small series of piers installed in the stream bed. This tie-down on the upstream side of the structure prevents overturning of the entire structure in times of flood.

Figure 5: One of Gloucester Shire Council's upgraded causeways (upstream side showing extension of girders bolted to piers to prevent overturning).

The load of the structure and traffic is spread across a significant area under the girder logs, so the structural integrity of the original concrete causeways was not compromised. Clearly, these structures do not cater for runoff from any significant rainfall events in this catchment. They do, however, provide the locals with a 'level of service' that they are satisfied with. The structure does catch some debris as it floats downstream. However, apart from some rot or damage to the timber kerbs, these structures have stood the test of time to the satisfaction of the nearby residents and road users.

3.3 Design Challenge

The simplicity, low cost and ease of construction led our design team to reconsider its previous plans. Why not just copy the design of the neighbouring Councils' efforts?

- This design simply left the causeway in place. Even though this maintains the upstream habitat, these causeways are not considered fish friendly. Any modern construction would need approval of Fisheries NSW and fish passage would need to be part of the design.

- For longevity, the logs appear to have been treated. The green tinge is most likely Copper Chrome Arsenate (CCA). Leaving logs treated with these chemicals in a waterway would currently not be considered environmentally friendly.
- Girder logs have significantly increased in price. Logs that used to cost $500 would now cost in the range of $5,000 each, and a number of these would be required for a similar construction.
- Steel girders are currently relatively cheap! Could we simply replace the girder logs with steel beams?

A local consultant, Matrix Thornton Consulting Engineers (MTCE), was contracted to develop potential solutions, generally based on the Gloucester Shire Council example, and provide a suite of possible alternatives. Matrix Thornton evaluated 20 different options starting with girder logs, precast concrete beams, steel girders, box culverts, plastic arches (as used in sewer trenches) Bondek slab over concrete piers and waffle pod construction. The evaluation looked at construction costs of the various elements, the pros and cons for each and provided a method diagram for each of the options.

Being engineers who had designed many house slabs using the waffle pod technology, MTCE was comfortable with this method of construction and advocated for it, noting the potential negatives of some of the other alternatives and the specific advantages of the waffle pod product. MTCE noted particularly the speed of construction, the ability to leave the existing causeway in place, and minimal disturbance to the bed of creek. This gave Council officers the confidence to go on with the design process using the waffle pod system.

One significant challenge was the requirement for fish passage and requisite approvals of Fisheries NSW. Council could see that there was limited fish passage available on the other nine crossings on Belbora Creek Road and that all these crossings were between this causeway and the main river. Despite Fisheries NSW acknowledging this was the case, they explained that as each crossing was upgraded the ability for fish to access this upstream site would improve and this site would be ready when it finally happened (Figure 6).

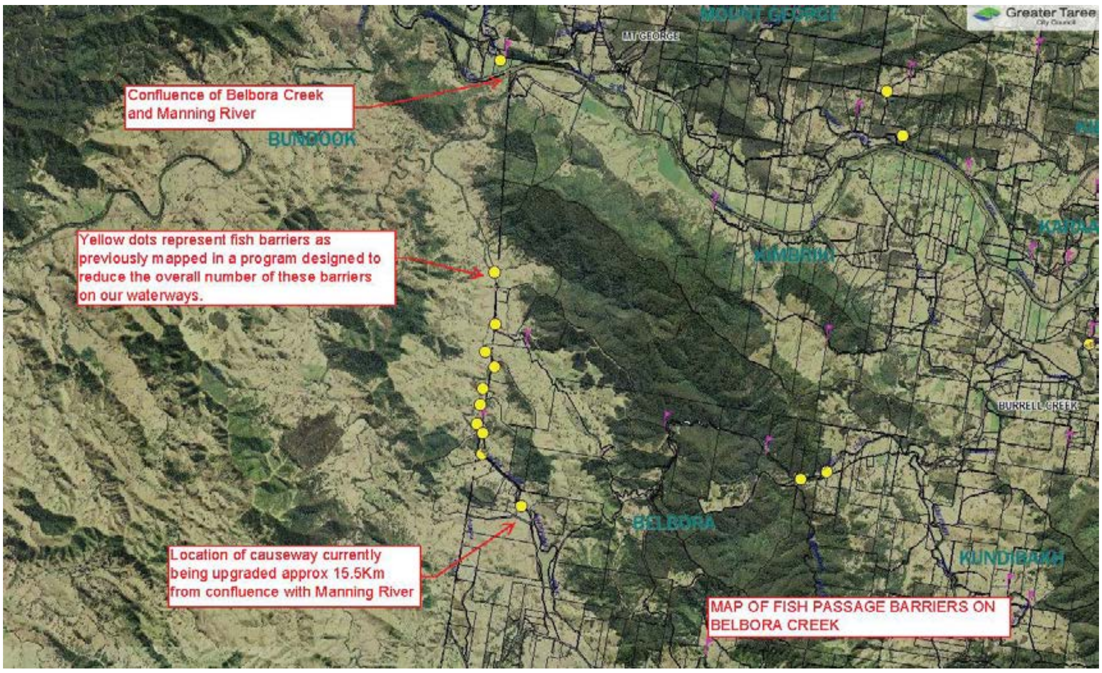

Figure 6: Fish barriers on Belbora Creek.

3.3.1 Waffle Pod Design

Waffle pods have been used in house construction for many years. First developed in South Australia to cater for the highly reactive clays of Adelaide, they have become widely used across Australia. The pods are boxes, 1.09 m square and varying in height. Depths of 175, 225, 300 and 375 mm are available to suit different ground conditions. They are made of light Styrofoam much like an old coolite surfboard. These boxes are basically void formers that suspend a concrete slab over the boxes between concrete beams that are formed between the pods. For houses this creates a stiff slab that is very strong.

For the waterway area of this project the pods were used as formwork that sat on the causeway and subsequently removed to create a skewed in-situ box culvert resting on the old causeway. The pods, stacked 2 high and 2 wide, created openings 2.18 m wide x 0.60 m high in the box culvert sections. Beyond the waterway, the pods were placed on the road and remain in place. The size of the pods was reduced as the road rose out of the causeway until it basically joined back to the level of the top of the new causeway. These approach pods significantly reduced the amount of concrete that was used in the abutments.

Removal of the pods from the causeway was considered a challenge. The pods were wrapped in plastic to prevent adherence of the concrete. MTCE engineers tested the varying amounts of solvent required to cause the pods to collapse primarily to prevent any excess solvent leaching into the river. Ultimately this solvent process proofed too slow for the contractors who found that mechanically breaking up the pods with a crow bar and shovel, and removing the material by hand, was the quickest and best method. The Styrofoam of these pods held together well, so there was very little breakout and the pieces were easily removed, collected and stored.

When these pods were first introduced into NSW, legislators foresaw a problem with the left-over sections of pods being a litter problem and determined a requirement whereby the manufacturer or supplier must collect all unused portions of the Styrofoam and remove it from site for re-use in the manufacturing process. On this project, all left-over foam was packaged into large bags and the supplier picked it up and returned it to the manufacturer for recycling.

3.3.2 Working with the Old Causeway

The design was by no means straight forward. The initial plan sets contained only three pages. The final plan set that went to tender was 20 pages long, containing numerous cross sections detailing the various stages of construction as foreseen when working with the existing structure (Figure 7).

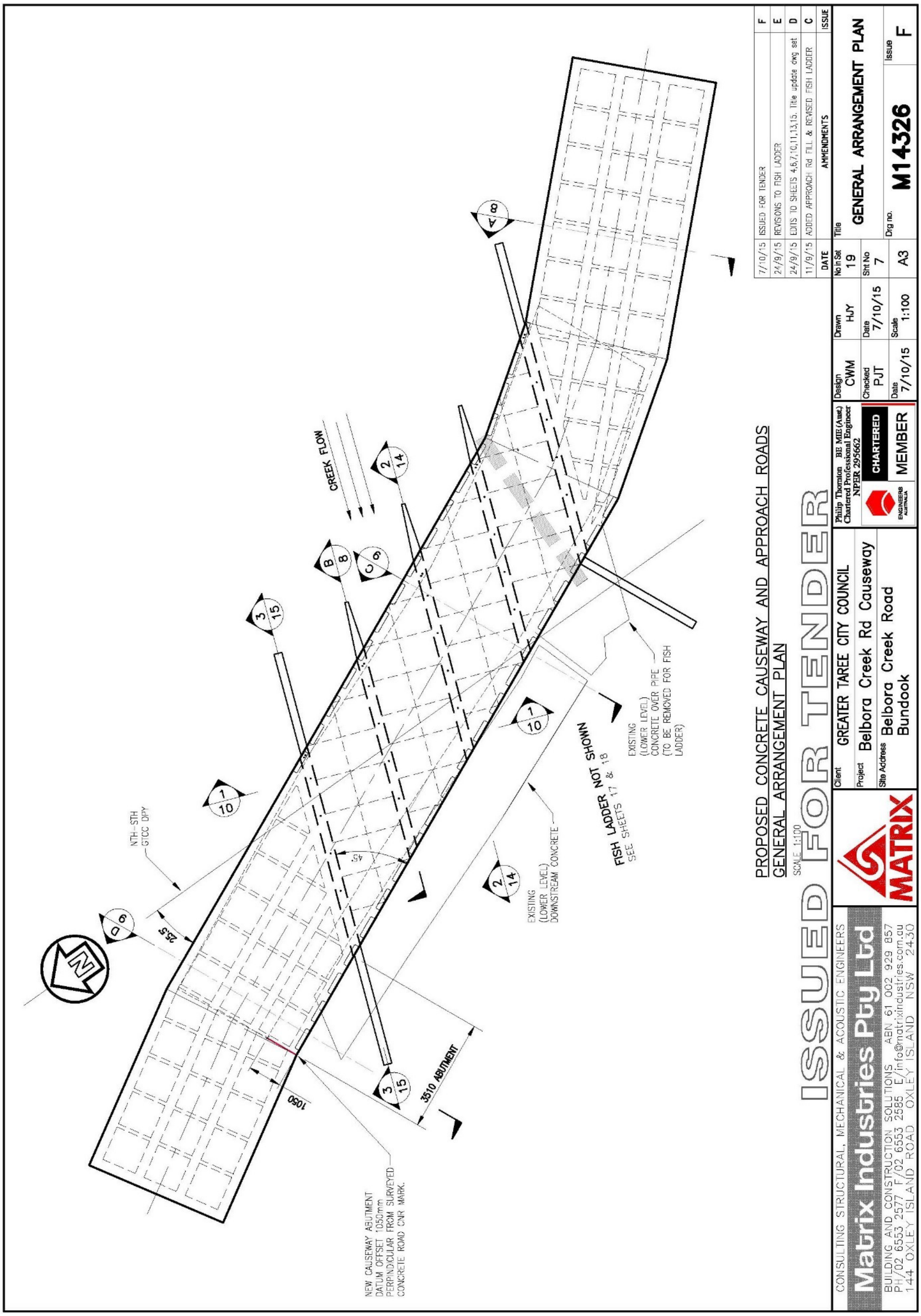

Figure 7: General arrangement of Waffle pods and concrete beams on the causeway and approach road slabs.

The old causeway was found to consist of a number of concrete slabs separated by gravel cobbles with the edges held in place by old timber (Figure 8).

Figure 8: Original causeway and edge timbers.

The design called for the removal of these old timbers. The voids left were replaced with concrete beams. These edge beams also gave the opportunity to widen the causeway so it would no longer be limited to the current width of causeway. The legs of the skew culvert rested on the old causeway. At these points, holes were drilled through the various slabs, shear connectors installed and grouted into the cobbles below.

The potential for overturning of this structure was similar to the Gloucester Shire Council causeway bridges. This was overcome by extending the legs of the culvert upstream and fixing them to the bedrock below. In order to ameliorate the debris problem noted previously on the downstream structures, these extensions were designed with a sloping face to act as deflectors channelling debris through or over the boxes (Figure 9). The debris is indicative of a flood that over-topped the causeway.

Figure 9: Upstream debris deflectors and northern approach slab.

Figure 10 illustrates the stages of construction for the new Causeway #1 structure.

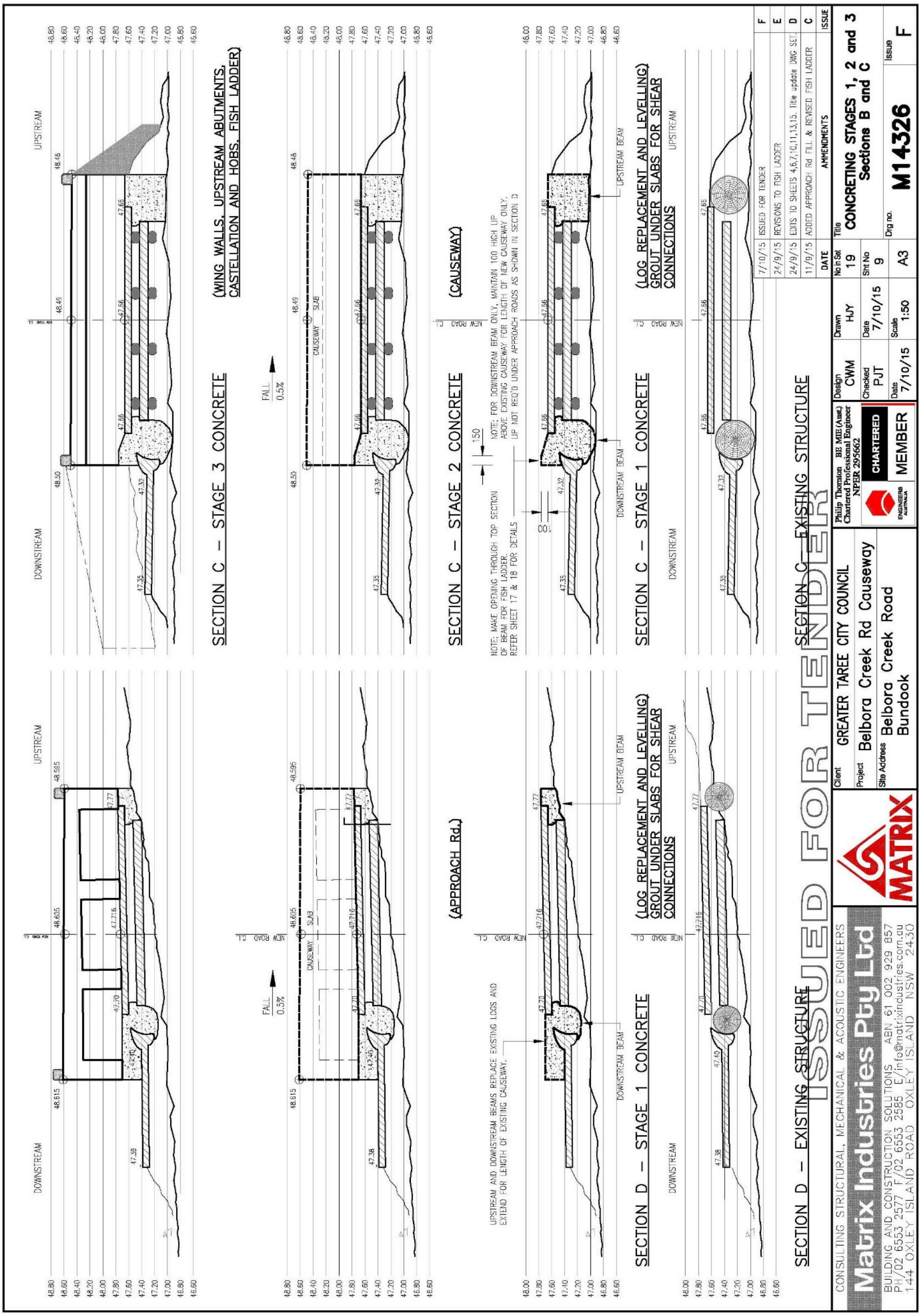

Figure 10: Stages of construction on existing causeway structure.

3.3.3 Fish Passage

One aspect of the design was to attain the approval of Fisheries NSW. Fish passage in engineering terms is a bit of an anathema because good hydraulics seldom equates to the provision of good fish passage. However, with some consideration and clever design it was achieved relatively simply.

In Hydraulics 101, basically there are two types of flow: subcritical flow and supercritical flow. In these terms, good fish passage requires maximum subcritical flow and minimum lengths and drops of supercritical flow.

Consider a causeway that has a cross fall with the flow, i.e. the high side on the upstream edge. To most people this is the most logical layout, however, water passes over the width of this kind of structure as a thin laminar sheet of supercritical flow. A fish, to swim upstream, must swim like mad through a thin film of water for the entire width of the causeway.

When the cross fall is against the flow, i.e. the high point is on the downstream side, the flow across the structure is generally deeper subcritical flow with only a short section of supercritical flow at the highest point. In this scenario, a fish can negotiate the same structure with a short burst of speed through the critical section and be in deeper, slow-flowing water just over the lip. For this project, the downstream beam was raised 100 mm over the top of the old causeway slab (see Plan 2, Stage 1 in Figure 10). The beam created subcritical flow over the entire deck of old concrete causeway.

Similarly, pipes are not generally considered good fish passage. Flow in a standard pipe configuration is all supercritical where a head of water is placed over the inlet and the downstream is flowing freely. In this project, this was overcome by incorporating the existing pipe into the fish ladder. The downstream outlet was bounded by the wall of the first step in the fish ladder to the level of the beam. This meant that all flow within the existing pipe remained subcritical. The short length of the pipe meant there was light, so it could easily be negotiated by fish making their way in either direction. Two separate sources have already reported seeing small fish and an eel negotiating the fish ladder.

Taking a fish ladder from concept to design and then to construction can be quite difficult. The concepts include sculpting the bases of the ponds for self-cleansing, minimising hydraulic jumps between the ponds (60 mm) and creating sections of laminar flow between the rocks at these jumps. For something that is really free-form concrete sculpting, it is a very difficult design to conceptualise and draw. Fortunately, Carey Molloy from MTCE went above and beyond to make his design a success, attending the site, adjusting to the site conditions and assisting with the actual construction, monitoring flow after the construction and even going back to adjust the structure once flow had settled through the structure.

Though there were some initial reservations about the design, Fisheries NSW recognised the preservation of the upstream habitat, design principles of the fish ladder and provided a permit for construction of the structure (Figure 11).

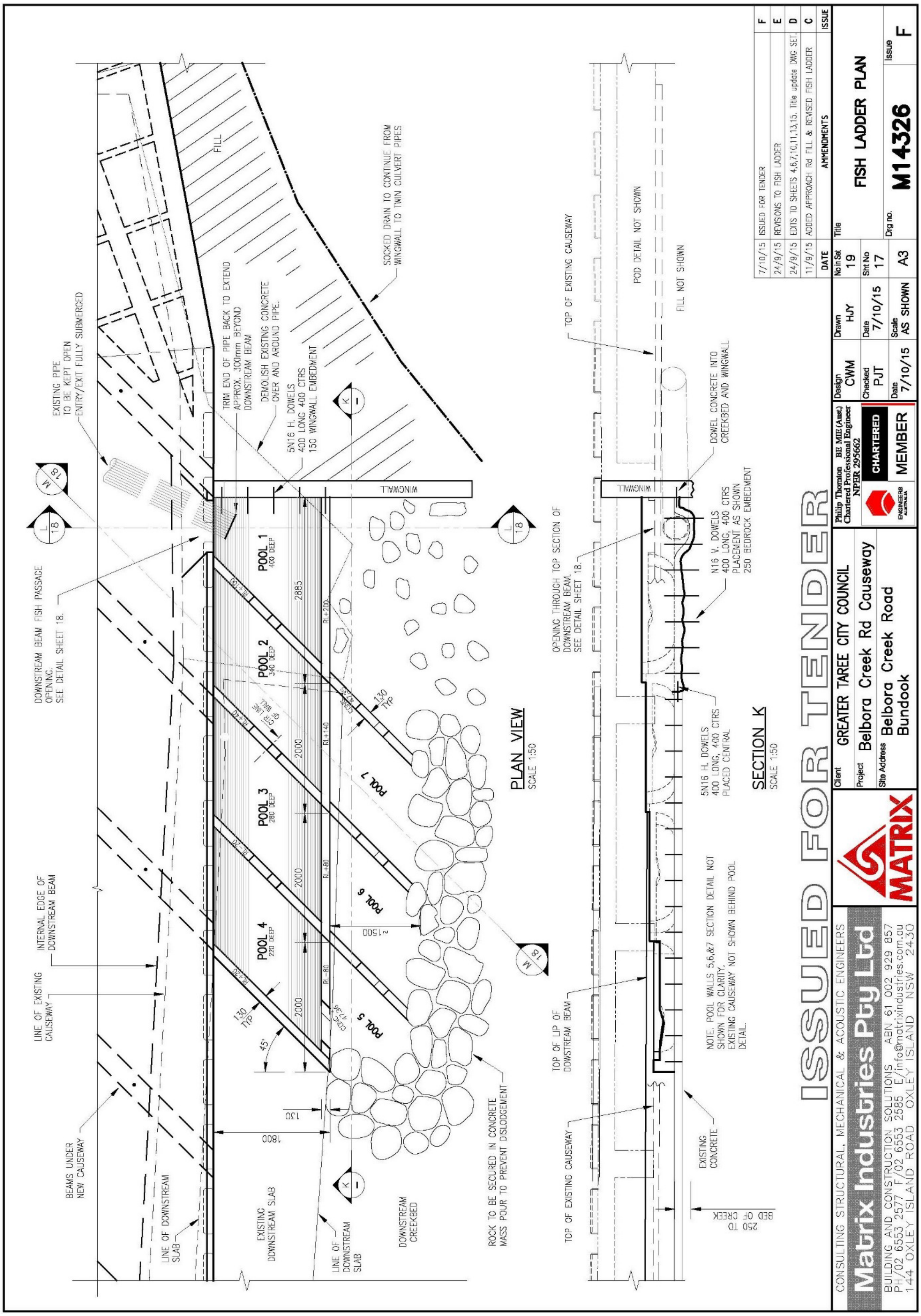

Figure 11: Plan of fish ladder and sections through upper level pools 1 to 4.

The site conditions, once the downstream headwall was removed, led to an on-site design change of the fish ladder. As can be seen in Figures 12 & 13, Pool 1 on the right back drops into Pool 2 right foreground and Pool 3 in the middle foreground before flowing back toward the causeway into Pools 4, 5 and 6 to the back left of the photographs and eventually flowing into the downstream environs in the lower left of the photographs.

Figure 12: Fish ladder in high-flow scenario.

Figure 13: Fish ladder in low-flow scenario.

3.4 The Contract

An open tender went out and some selected local concreters were alerted to the tendering process. As may be expected of a new-design construction system, the tendered prices varied wildly reflecting the unknown nature of working in a waterway on an old existing structure using an untried construction system. Local building firm Reece Construction won the tender and carried out the work in a professional manner. The project was completed successfully and without mishap in 8 weeks with a road closure period of only 3 weeks.

Continuity of access was raised as a concern to residents of the road. Council arranged with the adjoining land owner to provide local residents with secure (camera monitored) parking on the southern (Bucketts Way) side of the causeway. The contractors maintained pedestrian access across the work site at all times. This enabled the residents to park vehicles on either side of the causeway during construction and avoid the long detour around the site.

4 CONCLUDING REMARKS

The waffle pod system outlined in this paper provided a quick, cost-effective method to install a low-level bridge or culvert over the existing concrete causeway. This method maintained and built upon the existing infrastructure, provided a higher level of service to the road and in this instance preserved significant aquatic habitat and irrigation access upstream of the structure. Local tradesmen were comfortable with the construction method which did not require specialist or large lifting equipment. Thoughtful and clever design in consultation with Council officers, MTCE engineers and Fisheries NSW overcame and fulfilled the fish passage requirements of the structure. The design and construction methodology may be a useful tool for other Councils dealing with similar rural causeways in the future and looking for a cost effective solution.

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REFERENCES

Oxford University Press (2017) English Oxford Living Dictionaries, https://en.oxforddictionaries.com/ (accessed Feb 2017).