Stream design principles

May 2018

River Lake Ltd

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NZ TRANSPORT AGENCY WAKA KOTAHI

Mt Messenger Bypass

New Zealand Government

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1 Introduction

These Stream Design Principles will guide for the creation and restoration of streams that are being diverted as part of the Mt Messenger Project. The overall aim is to recreate stream sections that have the same or better hydraulic and ecological functions as sections being lost. In general, the profile of new stream sections will be constructed to replicate adjacent channels or will be improved to reflect more natural conditions by use of riparian planting and adding habitat complexity.

The general design principles for stream diversions are provided in section 2 with specific design considerations for each diversion discussed in section 3.

2 General design principles

2.1 Structure and morphology

- Maintain existing or restore towards a more natural stream structure.
- Where practicable, create at least the same length of stream as what is lost. Where this is not practicable, the reduction in stream habitat has been accounted for in the offset calculations for the Mt Messenger Project (see Freshwater Ecology Technical Report (December 2017) and Supplementary Report (February 2018).
- Create a stream profile which provides a base flow channel, bank-full channel and a flood plain. This will help ensure appropriate water depth, flood conveyance and connection with a flood plain. This may not be practicable in steep, incised gullies. In these situations, the focus should be on ensuring pool habitat below cascades or drops.
- Ensure the stream profile is consistent with the hydrological regime. As a rule-of-thumb use:
    - The bank-fill width should be sufficient to convey up to a 1 year return period flood. This sizing helps maintain stream habitat features and avoid excessive erosion and or sediment deposition.
    - In low gradient streams the baseflow channel should be provided. It is better to undersize the baseflow channel and manage flood flows by increasing the width and/or lowering the height of the stream's immediate flood plain. This helps ensure the stream channel maintains sufficient water depth and energy for the stream to evolve to a more reference state condition over time. The stream and flood plain profile should be shaped like a 'key hole' or stepped and allow riparian vegetation to extend close to the water.
    - The width of the stream-belt (i.e. flood plan) should be at least 4 times the bank-fill width to allow the stream to meander. If constraints mean that the belt is less than 3.5 times than the stream may need to reflect a step-pool morphology. Wider meanders are preferable if topography allows.
- Incorporate meanders in situations where the stream would naturally meander. This helps to increase complexity of the instream habitat and hydraulic regimes and improve

hydraulic functions. A natural meander wavelength is typically about 7-14 times the bank-fill width, but is often less (Madsen 1995, Harman and Starr 2011).

- Steeper channel sides allow for vegetation to provide cover for fish through over-hang foliage and roots. Batters on the outside bend should be steeper than on the inside bend (Figure 2.1).
- The created channel should provide a range of meso-habitat types, e.g. riffles, rapids, runs, pools, backwaters. A primary driver of meso-habitat is channel slope, flow variability, geology and sediment supply. This creates habitat and improves ecological functions.
- The design should include a vertical wave within the base flow channel that interacts with meanders, e.g. pools on the outside of bends and plunge pools below cascades (see generic design Figures 2.1 to 2.3). It is often the pools that provide habitat and refuge for fish.
- Use similar substrate to the existing stream and of a size consistent with natural sources (e.g. gravel, cobble, boulders etc.). Placement of boulders or logs should be used to reinforce stream morphology rather than counter-act it – e.g. as part of v-vanes or j-hooks on the outside, downstream part of meanders, or as part of constructed riffles.
- Incorporate plenty of woody debris within the stream channel. The wood used should be large (stems >150mm) and complex (i.e. a range of sizes). It can be clustered together in high energy streams. Wood increases the retention of leaves and provides habitat for fish. Large logs can be used to enhance morphology, e.g. log weirs or cover logs in association with pools (Figure 2.5). Woody debris is particularly important as a stable substrate and habitat in the soft sediment streams near Mt Messenger.
- Instream structures can be used to plant vegetation closer to the stream and provide immediate bank edge habitat.
- Allow the stream room to move over time. Where there are practical constraints on allowing a stream to move it is still often possible to allow movement in the base flow channel by appropriate sizing the channel width and substrate material.

2.2 Substrate on stream bed and banks

- Substrate should be similar to that naturally occurring in similar types of streams in the area.
- Take care not to over-size the substrate, e.g. lining of a small stream with 250 mm riprap. If the substrate is too large to be moved by floods it is likely to result in excessive periphyton growth and can result in small streams flowing under the rock instead of over it. Smaller substrate size can be used in conjunction with large rock if needed.
- In some sections it may be appropriate to add additional gravels to create riffle habitat mid-way between bends. The gravel section should be about three to four meters in length, extend across the width of the channel and be about 200 mm in depth. The natural gravel material around Mt Messenger is papa mudstone but this may not be practical to use because it is very soft. An alternative material would be acceptable so

long as it is appropriately sized. Alluvial gravels should be used in preference to angular quarried rock.

- If the stream bed needs to be armoured, then care is need to ensure that the water will continue to flow over the streambed rather than disappear into the rock layer. One approach is to establish any short sections of rock protection below the level of the natural streambed; this allows the steam bed to act as a crest and water will continue to flow over the top of the armoured later. Another approach is to layer smaller gravels to fill voids between layers of large rock; for example, place a layer of gravel (< 20 mm), then a layer of rock protection (300 mm), then a layer of gravel (<20 mm), then a layer of rock protection, then a final layer of gravel (<40 mm). The top most layer should match natural stream bed material. Using a component of all-pass grade (e.g. gap 20 mm) can be effective for the layers to ensure some fines and reduce permeability through the stream bed armour.
- Pools are important habitat for fish in steep streams. Any bed armouring should be placed in a way so as to still allow pools to develop in the stream. This may require constructing depressions along the channel prior to placing the rock armour. The depth of the depressions should be at least 300 mm greater than the depth of the layer of rock armouring. These can later form plunge pool to help dissipate energy.
- Boulders and large wood can be used to provide habitat diversity or bank protection (e.g. v-vanes, J-hooks). Where clusters of boulders are used to provide habitat then allowing voids between them is beneficial.

2.3 Stream bank stabilisation

- New stream banks may need to be stabilised. Use biodegradable geotextile matting (e.g. coconut fibre matting) and hydro-seeding.
- Rock lining of stream banks should be minimised as it reduces vegetation connection with the stream bank. If possible, any bank lining should be set back from the baseflow channel. Generally, any stream bank lining should be incorporated with instream features such as j-hooks to reduce bank velocity and shear stress on the outside bend. J-hook vanes need specific design and construction in order to protect stream banks, direct flow, stay in place during floods and not be ‘out flanked’ during floods. Details designs should be made prior to construction including the grade of material. In general, they should look like the diagrams in Figure 2.4.

2.4 Riparian vegetation

- Riparian vegetation is an important part of stream ecosystems. It helps to stabilise banks, provides hanging habitat for aquatic life, shade the stream, reduce high water temperatures, provide leaf and woody debris to the stream, acts as a filter, reduce flow velocities, provide habitat for adult insects that use the stream.
- Plant riparian vegetation close to the edge of the baseflow channel to provide shade and over-hanging.
- The riparian planting should occur within the stream-belt flood plain and ideally extend about 10 m beyond the floodplain as a buffer.

- Use native species that have been eco-sourced from the district.
- Exclude stock from the planted area.
- Plant and animal pest management will be required for at least 3 years while vegetation is establishing.
- New stream banks may need to be stabilised. Use biodegradable geotextile matting (e.g. coconut fibre matting) and hydro-seeding.

2.5 Incorporating wood into the stream

Large wood is an important component of natural stream channels, providing habitat and food for insects, koura, fish and birds. It helps store sediment, retains organic matter, provides hydraulic diversity and cover for many fish (Figure 2.5). In low gradient streams with fine sediment substrate, large wood is an important stable microhabitat. Large wood is usually defined as >100 mm diameter and >1m long, however larger pieces with more complexity provide for better stability and habitat.

For the purpose of stream restoration root wads can provide excellent habitat. They can be secured by pushing the trunk into the stream bank and leaving the root wad extending into the stream channel. Branching sections are also good as they provide more habitat diversity and are easier to secure in the stream than straight logs.

There are multiple ways to secure large wood in the stream channel, including: pushing one end into the stream banks/bed, partially cover with gravels, use large boulders, anchor to the stream bed (e.g. a duck-bill anchor) secure to the stream bank, or hold in place with posts.

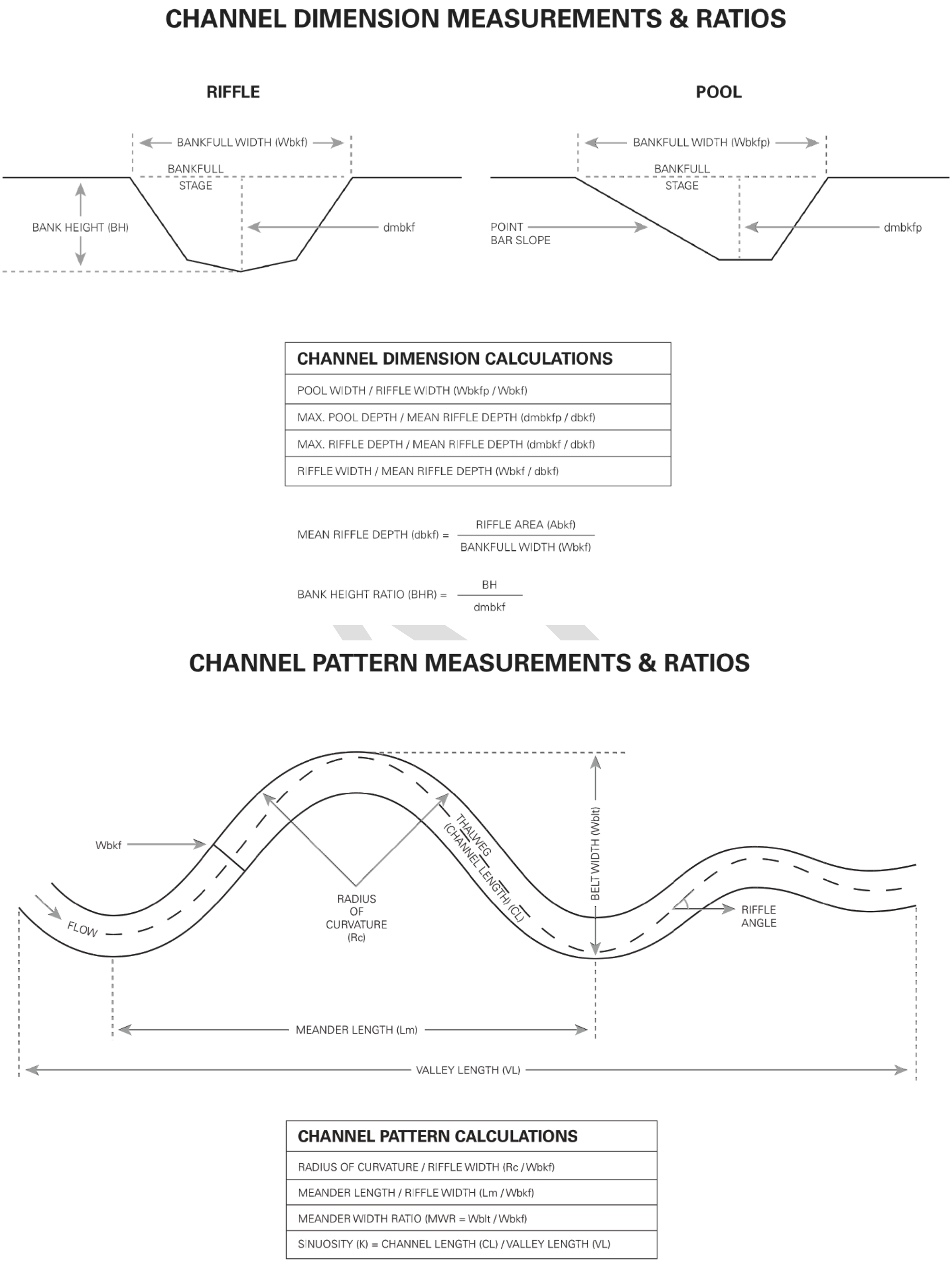
It is not necessary for the wood to be fixed in place permanently, however they should be sufficiently secure to stay within the reach while the stream channel stabilises and riparian vegetation grows. Wood naturally moves through river systems. The design of stream channels, substrate and wood features should allow the stream to adapt and reassemble itself over time.

In stream restoration sites the amount of large wood placed in the stream should be similar to what occurs in natural forested systems. This is in the range of about 1 to 5 pieces per 20m of stream length (Jenson et al. 2013).

During the process of vegetation removal some large wood should be put aside for use in stream restoration. Pieces to put aside include: root wads and hole tree tops and cover a range of sizes in diameter classes of >600 mm, 300-600 mm. Some lengths should be long, i.e. about 6 m. Pole kanuka should be set aside to be used as posts to secure wood to stream beds (sized about 100-200 mm diameter, and >1.2 m long).

2.6 Generic design drawings

Generic drawings are shown below for a meandering stream (cross section and plan view) (Figure 2.1 and Figure 2.2). Note that the centre line of the main current flow (thalweg) takes the outside of the bends. Figure 2.2 shows channel measurements and typical design for a pool–riffle sequence and step/pool sequence. Figure 2.3 illustrates the typical location of pools and riffles in a low gradient meandering stream.



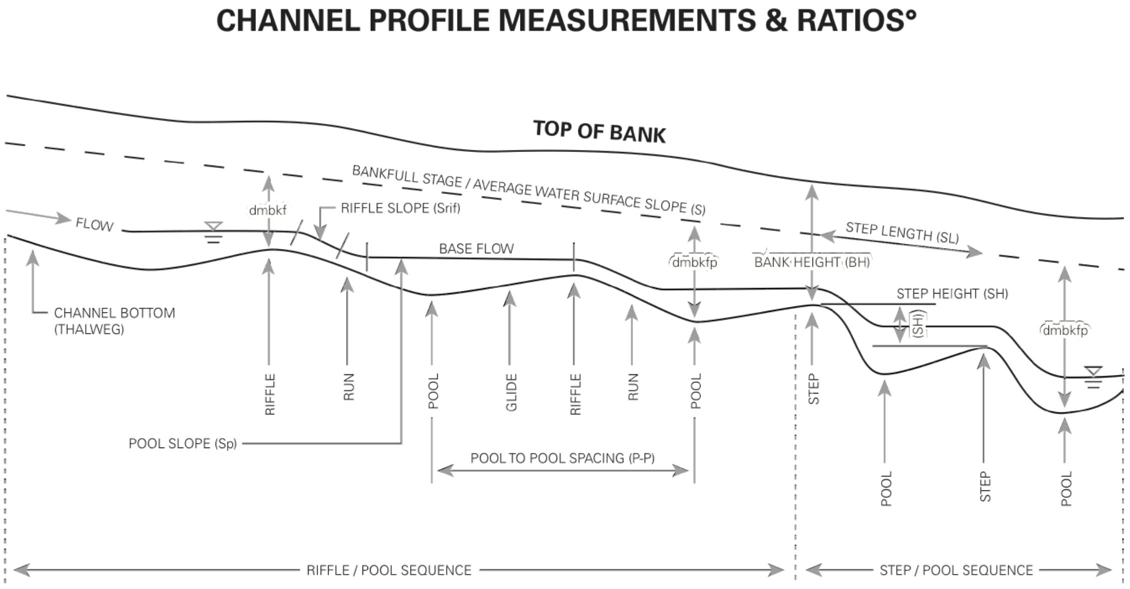
CHANNEL DIMENSION CALCULATIONS
POOL WIDTH / RIFFLE WIDTH (Wbkfp / Wbkf)
MAX. POOL DEPTH / MEAN RIFFLE DEPTH (dmbkfp / dbkf)
MAX. RIFFLE DEPTH / MEAN RIFFLE DEPTH (dmbkf / dbkf)
RIFFLE WIDTH / MEAN RIFFLE DEPTH (Wbkf / dbkf)

$$\text{MEAN RIFFLE DEPTH (dbkf)} = \frac{\text{RIFFLE AREA (Abkf)}}{\text{BANKFULL WIDTH (Wbkf)}}$$

$$\text{BANK HEIGHT RATIO (BHR)} = \frac{\text{BH}}{\text{dmbkf}}$$

CHANNEL PATTERN CALCULATIONS
RADIUS OF CURVATURE / RIFFLE WIDTH (Rc / Wbkf)
MEANDER LENGTH / RIFFLE WIDTH (Lm / Wbkf)
MEANDER WIDTH RATIO (MWR = Wblt / Wbkf)
SINUOSITY (K) = CHANNEL LENGTH (CL) / VALLEY LENGTH (VL)

Figure 2.1: Meandering channel measurements and typical design profile and plan view (from Harmen and Starr 2011).



CHANNEL PROFILE CALCULATIONS
PROFILE SLOPE / AVERAGE WATER SURFACE SLOPE (Srif / S)
POOL SLOPE / AVERAGE WATER SURFACE SLOPE (Spool / S)
POOL TO POOL SPACING / RIFFLE WIDTH (P-P / Wbkf)
BANK HEIGHT (BH) / MAX RIFFLE DEPTH (Dmbkf)

Figure 2.2: Channel measurements and typical design for a pool-riffle sequence and step/pool sequence (from Harmen and Starr 2011).

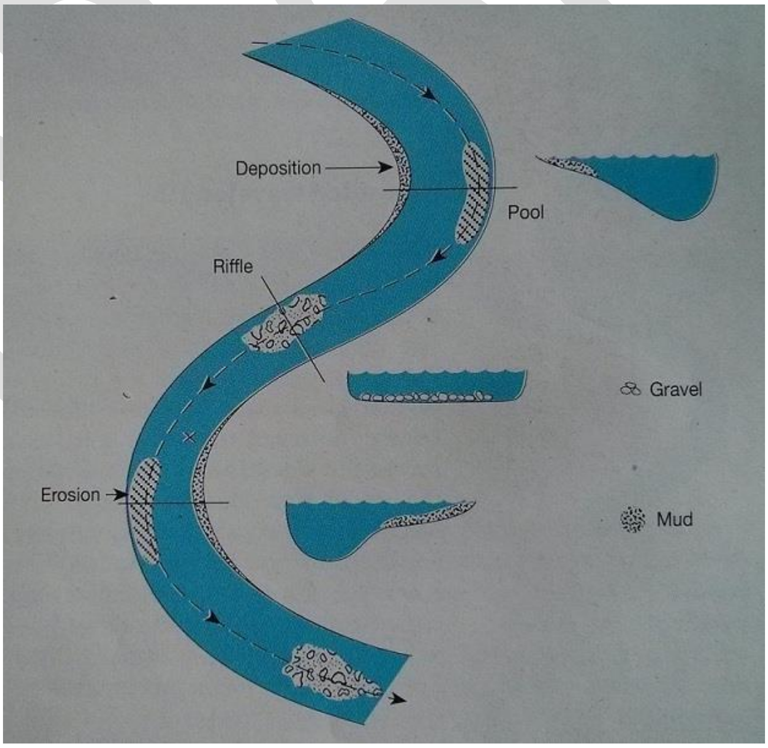


Figure 2.3: Formation of regular current, bend and depth conditions with a meander pattern (from Madsen 1995)

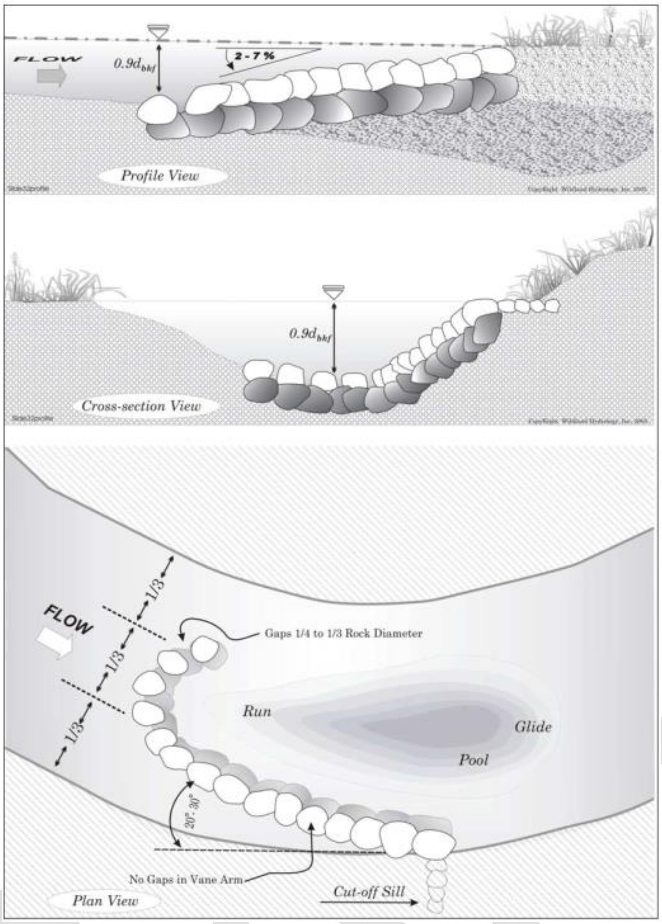


Figure 2.4: J-Hook vane in cross-section, profile and plan view (from Rosgen 2006)

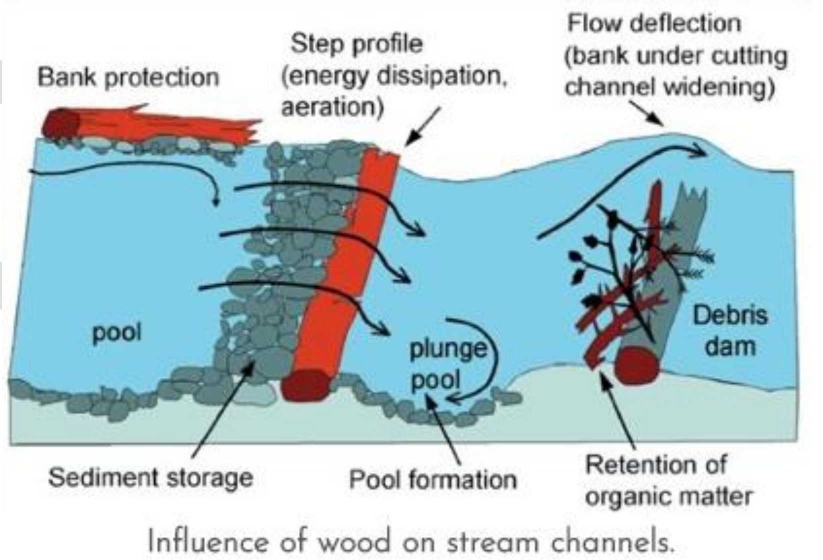


Figure 2.5: Benefits of wood in stream channels, providing habitat and food for insects, koura, fish and birds (source Brenda Baillie, Scion).

3 Site specific design considerations

There are 18 stream diversions proposed for the Mt Messenger Project including three small diversions to link culverts with the existing stream and several swales to replace (and often extend) existing cut-off drains (Figure 3.1 and Figure 3.2). The detailed design of the stream diversion is being developed, some dimensions are provided in Table 1 below.

Table 3.1: Stream diversion lengths and proposed dimensions.

Site	Chainage	catchment area (ha)	Length of diversion	Project impact	Type	Bankfill width (m)	Bottom width (m)	Channel height (m)
Ea3	570	6.3	45	Culvert 3 and d/s diversion. The consent shows this as a new stream diversion but it is the existing channel.	meander	0.9	0.5	0.4
Ea4	750	1.8	75	Shift cut-off drain upslope. Existing drain replaced by similar length of grassed swales. No waterway exists where culvert is shown.	swale	1	0.5	0.4
Ea5	870	4.2	60	Culvert 5	swale	1	0.5	0.4
Ea6	1050	4.4	90	Stream cut-off at the top of the cut and directed to stormwater. No fish passage provided unless allowed via stormwater pond. No culvert at present.	step-pool	0.8	0.5	0.5
Ea7	1300	6.8	60	Culvert 6 + stream diversion. Road drainage runs to treatment pond.	step-pool	0.8	0.5	0.5
Ea8	1500	5.8	40	Culvert 7 + stream diversion.	step-pool	0.8	0.5	0.5
Ea10b	1850-1950	149	110	total of 190m of stream lost in this area. More stream lost than culvert length because diversion is shorter.	meander	2	1.1	0.7
E3	1650-1750	133	120	Stream diversion for wetland W2 near culvert 8 (chainage 1650-1750). Design change could reduce impact length from 200m to 110m. Added 100m to account for shortened stream length	meander	2	1.1	0.7
E5	2800-2900	64	80	250m of stream lost d/s Ea16. 80m to stream diversion.	step-pool	2	1.1	0.7
Ea17	3000-3350	17	300	Clean water diversion made into stream diversion.	step-pool	1.3	1	0.6
Ea18	3650-3930	6	250	Diversion both sides of CU16.	step-pool	0.7	0.8/1.1	0.6
Ea22	4600-4700	1.5	100	Collected by grass swales to stormwater treatment pond.	swale	0.9	0.5	0.4
Ea23a	4750	25	230	Fill upstream of SH3 with diversion around the disposal site (CU19)	step-pool	1.1	0.7	0.5
Ea29	5450-5750	12	340	Replace existing culvert with Culvert 21. 340m grass swale at u/s end.	swale		0.5	0.5
Ea30	6250	2	260	Main stream avoided. Cut-off drain replaced.	swale		0.5	0.4
Ea31	5225-5300	4.1	75	Cut-off drain shifted, main tributary avoided.	meander	0.8	0.5	0.4
E TL3	1050	2.1	90	Fill - diversion section.	step-pool		0.5	0.4
E TL4	1100	6.6	200	Fill - diversion section.	step-pool	0.8	0.5	0.5

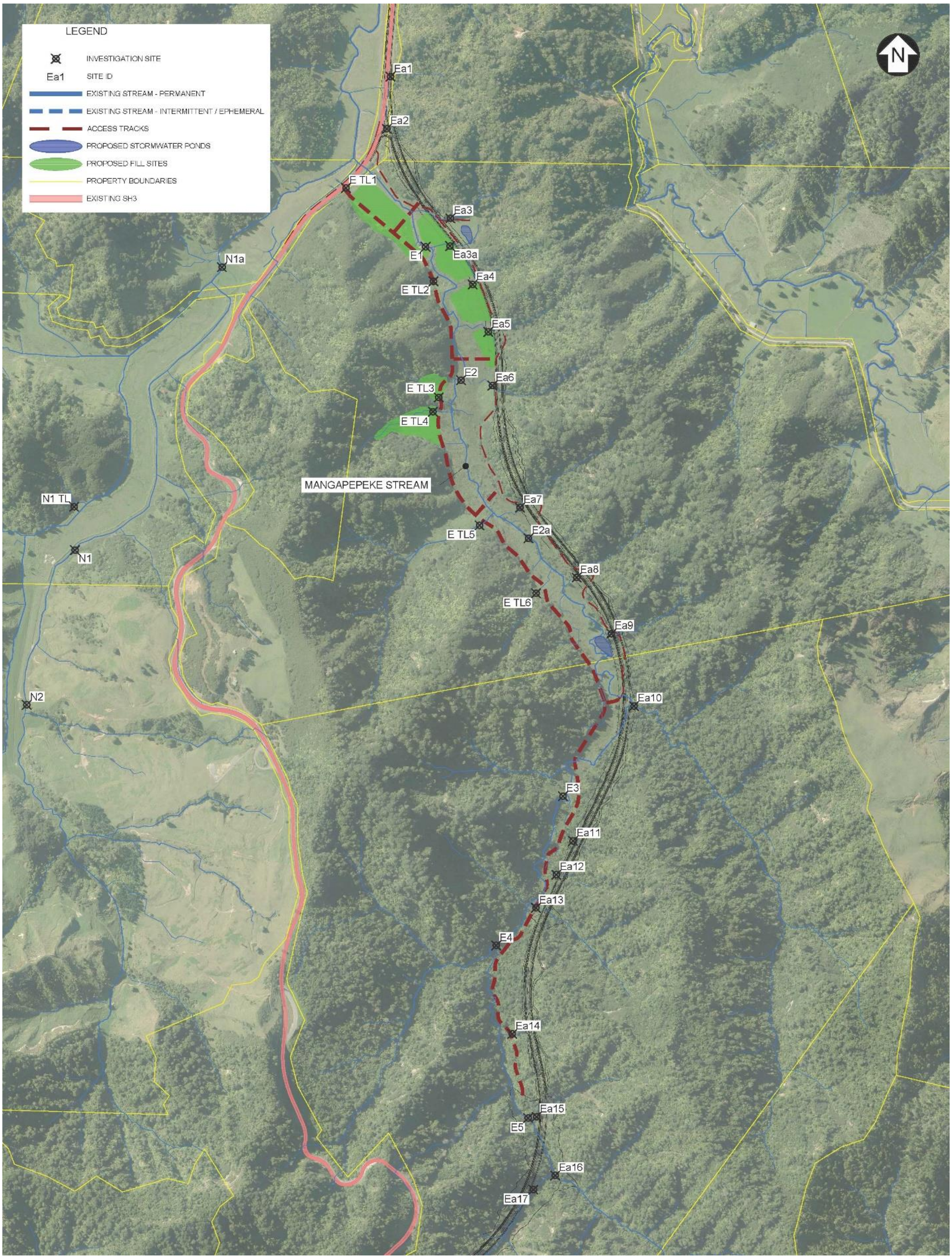


Figure 3.1: Mt Messenger stream diversion, culverts and stream numbers, Mangapepeke Stream catchment.

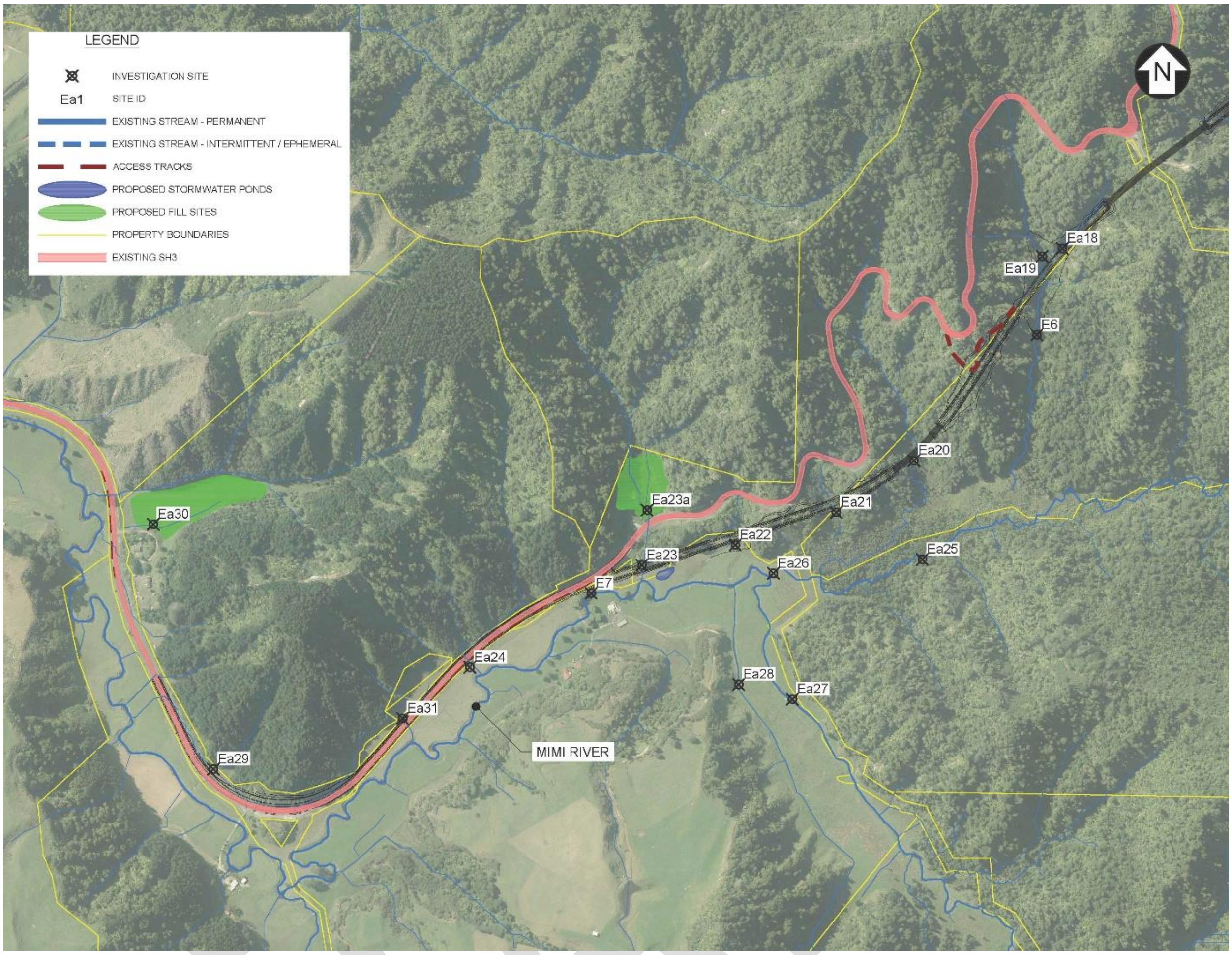


Figure 3.2: Mt Messenger stream diversion, culverts and stream numbers, Mimi River catchment.

4 References

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