REPORT

Tonkin+Taylor

Muri Catchment Feasibility Study for Stormwater Management

Prepared for
Infrastructure Cook Islands

Prepared by
Tonkin & Taylor Ltd

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1 Introduction

Infrastructure Cook Islands (ICI) has engaged Tonkin + Taylor International (T+TI) to provide technical assistance to the International Waters Ridge to Reef Project (R2R). This report sets out the feasibility study for the part of the Ngatangiia Catchment, being Aroko to Parengaru sub-catchment (referred hereafter as 'Muri catchment'). This report has been completed under the R2R Project scope, being the demonstration activity to increase knowledge-base and capacity for effective environmental stress reduction measures and integrated catchment management. Sedimentation has been identified as a major contributor to environmental stress in the catchment, particularly in relation to Muri Lagoon.

1.1 Project objectives

The objective of this feasibility study is to assess appropriate storm water management solutions, both natural and engineered, to improve storm water quality (sediment) and quantity impacts on the receiving environment and to reduce environmental stress within the project area, the Muri catchment.

Our assessment sets out a "tool-box" approach, and identifies a range of storm water management options that could be applied within the project area and serve as a model across the Cook Islands. A focus of this study has been to identify engineering options that make use of natural features, or where possible are "masked" by natural elements (e.g. plants) in the visual landscape (i.e. "naturalised").

In assessing a range of options, we have considered the application of 'best practise storm water management' in order to achieve an integrated catchment management approach that includes:

- Reducing the potential for sediment and stormwater flow generation (source control);
- **Providing treatment pathways for stormwater flow (physical treatment)**; and
- **Providing attenuation of stormwater flow (discharge control).**

The options identified and assessed in this feasibility study will look at physical treatment and discharge control only. We understand from consultations with ICI that options for source control are to be identified as a separate study.

1.2 Report structure

We have structured the feasibility study into the following sections:

- Existing information:
  - Section 2: Data review;
- Project Context:
  - Section 3: Catchment hydrology and ecology;
  - Section 4: Human impacts;
- Options feasibility:
  - Section 5: Options identification. The "tool-box" of individual devices are set out in this section;
  - Section 6: Options assessment;
  - Section 7: Staging and cost implications; and
- Next steps:
  - Section 8: Conclusions and recommendation.

Information supporting this study are attached as **Appendix A –C**.

1.3 Acknowledgements

A number of information sources have been made available to support this feasibility assessment. In particular, we would like to acknowledge the following sources:

- Infrastructure Cook Islands staff:
  - Photographs;
  - Topographical survey and geospatial data;
  - Rainfall data;
- Ministry of Marine Resources:
  - Water quality monitoring data;
  - Muri Lagoon Ecological Assessment;
- Meteorological Cook Islands and NIWA:
  - Rainfall frequency and intensity analysis on historic data. NIWA have noted that some of the datasets used contain less than 20 years of data, and/or contain notable data gaps. The analysis should be interpreted in context to the errors reported; and
- Mei Te Vai Ki Te Vai:
  - Reporting of the environmental investigation study is currently under draft, and not available for public use. This feasibility report sets out our interpretation of relevant contextual information carried out for this Project. We have not reproduced any part of the draft environmental investigation reports.

2 Summary of data reviewed

We have reviewed and collated a large number of relevant existing studies and investigations for Ngatangiia and Rarotonga areas to form the basis of this feasibility study (refer **Figure 2.1**). We collated information from three topical areas:

- Catchment characteristics:
  - Historic land use;
  - Current topography and land use;
  - Future land use and climatic changes;
- Drainage infrastructure: Existing condition and issues; and
- Monitoring data and analysis:
  - Hydrology and hydrogeology;
  - Water quality.

Our review has also identified some information gaps. Where indicated below, we recommend further work is completed to support the detailed design of storm water management solutions.

A reference list has been included as **Section 9**.

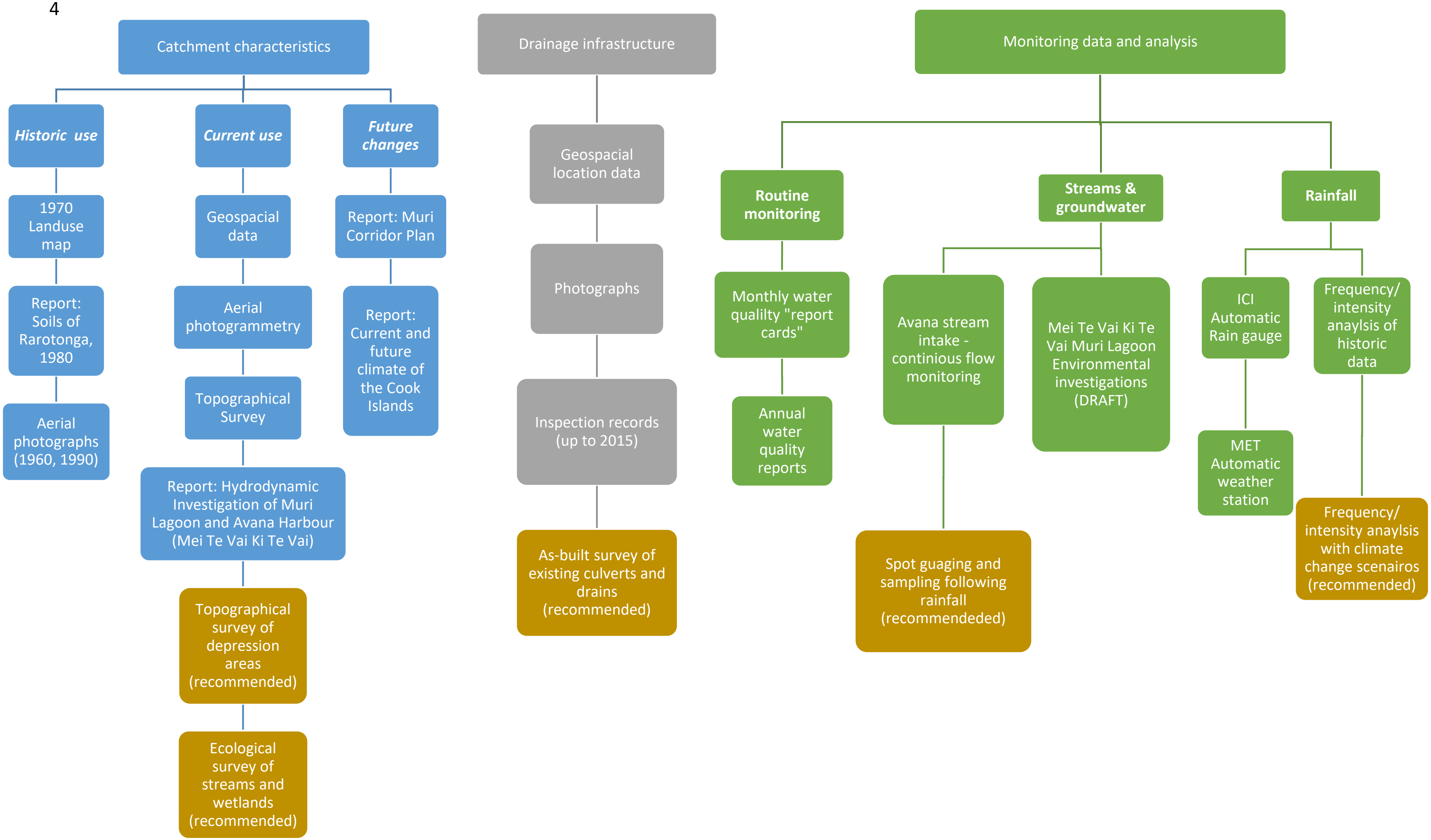


Figure 2.1: Summary of reviewed information (refer section 9 for complete report references).

3 Catchment hydrology and ecology

3.1 Catchment overview

The Muri catchment is a sub-catchment draining to Ngatangiia Lagoon, located on the southeast side of Rarotonga Island. This sub-catchment area comprises approximately **239 ha**, between Avana and Parengaru Streams where development is located. A further 70 ha on the southern side of the Avana Stream catchment with little to no development also discharges to Ngatangiia Lagoon. The Muri catchment also includes a number of intermittent streams and tributaries (refer **Figure 3.1**). Broadly speaking, land use of the Muri catchment comprises:

- About **28 ha** is flat land occupied by existing commercial and residential developments, which abuts the coastal beach ridge adjacent to Ngatangiia Lagoon. We understand backfilling of a number of pre-existing areas of swamp was carried out by private landowners to enable this development;
- About **78 ha** is moderately steep to gently sloping pasture, with agricultural and residential development. Recent years have seen an increase of residential development and reduction of agricultural land use in this part of the catchment. This change may be contributed to by an increased number of private dwellings contributing to the tourism market (e.g. AirBnB); and
- About **133 ha** is steep, densely vegetated forest which remains largely undeveloped, based on historic records dating back to 1960.

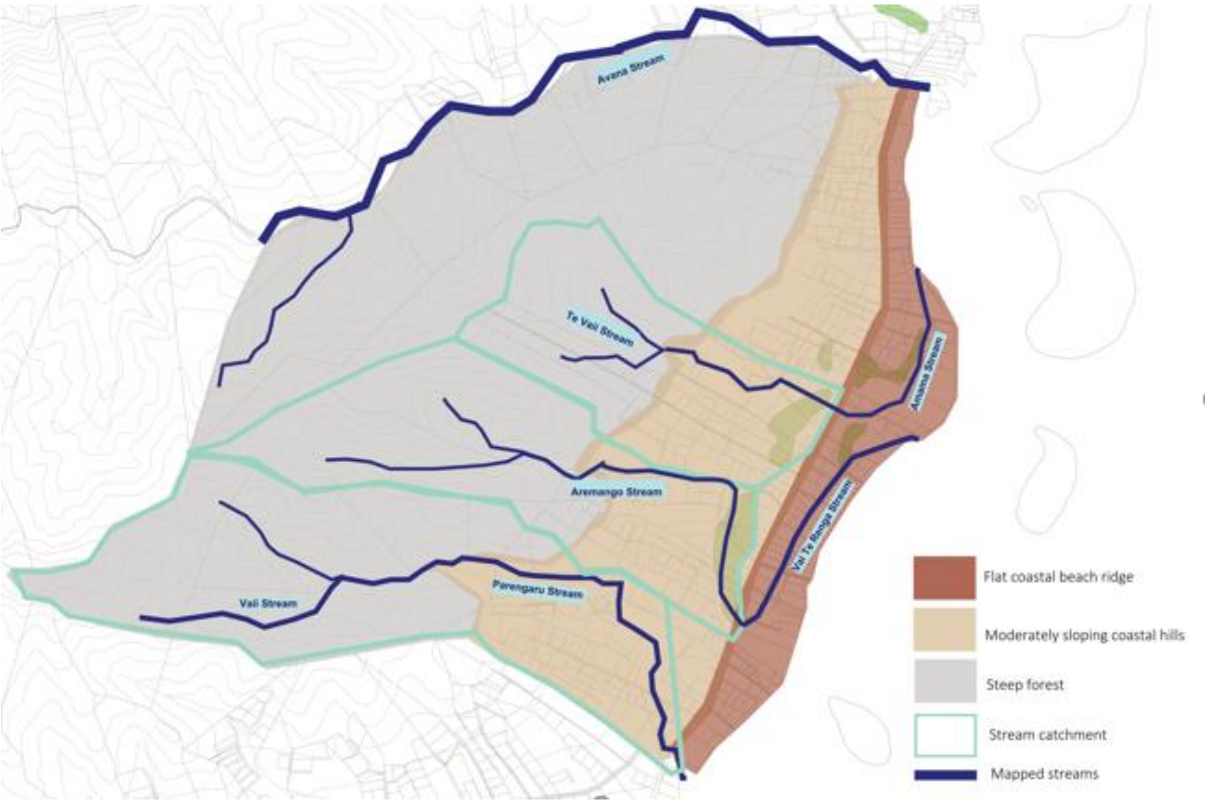


Figure 3.1: Muri Lagoon catchment.

3.2 Muri Lagoon receiving environment

Rarotonga Island is fringed by a reef system which is distinguished by a number of lagoons between the beach shore and reef crest. Muri Lagoon is one such lagoon, and is the receiving environment for storm water run-off from the Muri Catchment. Two studies focusing on the Lagoon environment have been completed for the Mei Te Vai Ki Te Vai project:

- Hydrodynamic investigations [ref 1]of Muri Lagoon noted water levels within the lagoon are very different to the surrounding ocean. The investigation results concluded that:
  - During wave conditions, the lagoon level is about 0.3 m (normal) to 0.5 m (large) above the surrounding ocean;
  - Lagoon flow is to the north towards Avana Passage. At high water levels, flow through the lagoon are at its highest. When the lagoon drains to low tide levels (around 0.05 Mean Sea Level), flow through the lagoon reduces (and almost stops when at low tide);
  - About half of the lagoon volume water is intertidal, and is exchanged by the rise and fall of tide. Depending on the conditions, the main lagoon volume is exchanged (flushed) every 8-30 hours. During very low flow this may be up to a 2 day cycle; and
  - The area with the lower rate of tidal movement is the immediately adjacent to the Muri Beach area between Pacific Resort and Taakoka. The assessment noted these areas are likely to be more sensitive to changes in lagoon contaminants;
- An ecological assessment[ref 2] focusing on algae habitat and bloom within the lagoon noted terrestrial based nutrients as a key issue for management of lagoon biodiversity. Further investigations [ref 3] completed on groundwater also noted nutrient contribution from both shallow groundwater, and the deep aquifer (refer **Section 3.3**).

3.3 Geology and hydrogeology

The soils for the Muri catchment [ref 4] have been broadly classified into three categories:

- Coastal beach ridge, where the upper soils (typically > 1.2m) comprise:
  - *Koromiri soils;* estuarine muds and sands, poor draining;
  - *Muri Soils;* sand from reef coral, free draining; or
  - *Vaikai soils;* long, flat swamp depressions, which could be remnants of a historic waterway running parallel to the coast;
- Lowland alluvium and coastal hills (up to 50 mRL); and
- Upland hilly and steep land (interior forest between 50 to 200 mRL upwards).

A map of the Muri catchment area showing these classification extents is included in **Appendix A2.**

In our evaluation of options, we have assumed that for current development conditions, the underlying soils remain largely the same as the 1980 investigations, with the exception of historic swamp depressions that have already been backfilled. This is consistent with recent geological cross sections produced from borehole investigations [ref 3] completed for the Mei Te Vai Ki Te Vai project.

A detailed hydrogeology investigation has been completed for the Mei Te Vai Ki Te Vai project [ref 3]. The results of the study show that:

- Shallow groundwater is present at the coastal beach ridge, and is subject to fluctuations from rainfall, and other surface inputs including the tide signal of Muri Lagoon;
- Shallow groundwater contributes to the recharge of the streams and wetlands. In the dry season, wetlands are predominantly recharged by groundwater and act as headwaters for the catchment streams;

- Groundwater flow, particularly upslope of the main road, is generally horizontal towards the coast. For the inland area, in particular the sub-catchments of Aremango and Areiti streams, low permeability of underlying material limits vertical infiltration;
- The deep aquifer is isolated from surface inputs by a confining layer. Groundwater levels in the deep aquifer was measured to respond to the oceanic tide signals, which is different to the tide signals of Muri lagoon; and
- Shallow groundwater quality is influenced by both wastewater and the mineralogy of the geological layer. The deep aquifer water quality is more influenced by the mineralogy and natural nutrients of the geological layer. Surface contaminants (e.g. wastewater) are considered unlikely to influence the deep aquifer quality, based on minimal vertical flow. This was confirmed by radon-222 tracer results.

3.4 Rainfall and runoff

3.4.1 Analysis of historic data

NIWA have completed Annual Recurrence Interval (ARI) analysis of the automatic rainfall data collected from 12 stations across the Cook Islands (refer **Appendix A3**). It is noted that the analysis has returned significant statistical errors, in particular for the larger events. NIWA advise this is primarily due to the small period of data available (typically less than 15 years), but also from large gaps in the data.

For the Muri catchment, the nearest data comes from the Avana gauge, which has been operational since 2008. Based on the ARI analysis for Avana, we assessed one heavy rainfall event (9 April 2018) which resulted in flooding and land damage in Muri; this corresponded to an event occurring once in 10-50 years, based on 12 hour accumulation of about 200 mm (refer **Appendix A3**). To provide a New Zealand comparison, this corresponds to an event occurring once every 250 years in Northland.

This suggests that heavy rainfall events occur more frequently in Rarotonga when compared to New Zealand, which is not unexpected given the tropical climatic setting. This context is important when considering New Zealand guidelines for storm water design.

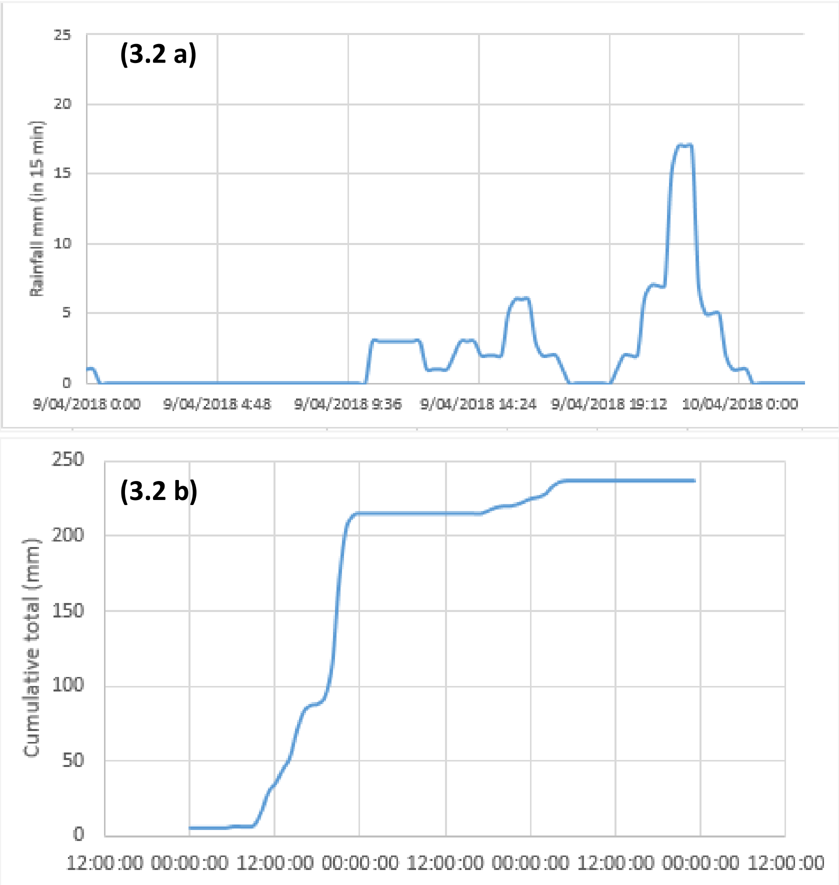


Figure 3.2: Rainfall measured at Avana rain station on 9 April 2018. 3.2a: rainfall over 15 min intervals, 3.2b: Cumulative total.

3.4.2 Sediment mobilisation

Sediment sources and pathways to surface water have been investigated for the Mei Te Vai Ki Te Vai project [ref 3]. The conclusions from those investigations show that:

- Stream water quality (turbidity and dissolved organic matter) is highly influenced by rainfall events, through mobilisation of sediment from surface runoff;
- Following rainfall, suspended sediment concentrations tend to increase for streams that travel through Muri. These sediment laden waters remain largely untreated and discharge into the Muri Lagoon;
- After sustained dry periods, concentrations increased following high intensity rainfall, which is likely due to a ‘first flush’ response, where “dust” and other sediments are quickly mobilised into surface water; and
- Suspended sediment concentrations are highest for Vai Te Renga Stream; maximum values are more than double those observed in Parengaru Stream and four times greater when compared to Te Vai Ama. This suggests that sediment management and treatment of the Vai Te Renga Stream catchment alone may have a beneficial reduction of total sediment loads to the Muri Lagoon.

3.4.3 Climate change

A climate change study has been carried out for the Cook Islands [ref 5]. In summary:

- Measured annual maximum temperatures have increased in Rarotonga since 1950, at a rate of 0.04°C per decade. These temperature increases are part of the global warming pattern (refer **Figure 3.3**);
- Satellite data indicates that the sea level has risen near the Cook Islands by about 4 mm per year since 1993;
- A series of scenarios have been developed, based on set assumptions about future population changes, economic development and technological advances. Climate projections for the Cook Islands indicate:
  - Temperatures will continue to increase, in the order of 0.5 – 1.0°C by 2030 (high emissions scenario);
  - Changing rainfall patterns and more extreme rainfall days; and
  - Sea level will continue to rise, in the order of 40-150 mm by 2030 (high emissions scenario).

We understand these climate projection scenarios can be applied to the rainfall ARI analysis algorithms, and it would be appropriate to consider these climate change scenarios in detailed design. This application would follow New Zealand based design practices.

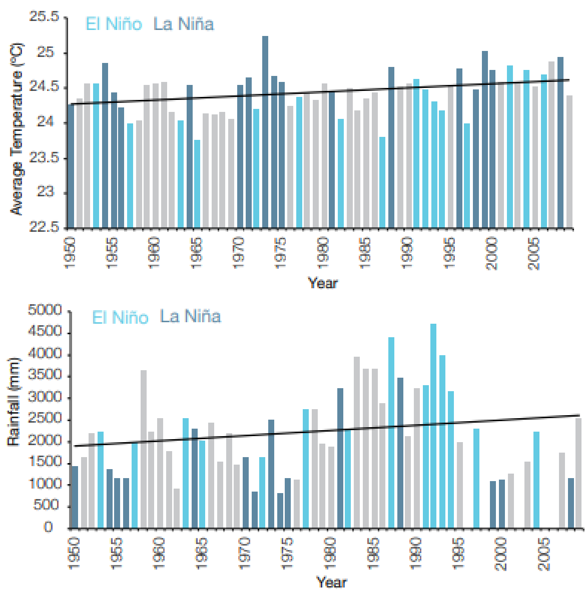


Figure 3.3: Annual average temperature and rainfall change. Light blue bars indicate El Niño years, dark blue bars indicate La Niña years and the grey bars indicate neutral years (reproduced from.Current and future climate of the Cook Islands).

3.4.4 Storm water runoff

The rational method is a simple empirical model suitable for estimating peak flow from storm water runoff (refer Eq. 1) and which is widely accepted in New Zealand applications for runoff flow estimations. For rural catchment areas typically greater than 50 ha, a modified rational method can be applied (refer Eq. 2).

Eq. 1:

$$Q = \frac{CiA}{360}$$

Where:

Q = Peak discharge (m^3/s)

C = Runoff coefficient

i = Rainfall intensity (mm/hour)

A = Area of catchment (hectares)

Eq. 2:

$$Q = \frac{CiASF}{360}$$

Where:

Q = Peak discharge

C = Runoff coefficient (dimensionless)

i = Rainfall intensity (mm/hour)

A = area of catchment (hectares)

S = Shape factor

F = Area Factor

Design storm:

The design storm can be defined to achieve a set level of protection for the storm water channels, ponds and culverts. A wide range of Pacific based guidance is available on selecting a design storm for the necessary level of protection (refer **Table 3.1**). An assessment of which guidelines is appropriate for the Cook Island rainfall context should be completed at detailed design stage.

Table 3.1: Design storm guidelines

Guidelines	Water quality treatment	Primary systems	Secondary systems
Auckland Council, NZ Guidance Document 01	90%tile of 24hr storm event (~25mm)	10 year ARI	100 year ARI
NZ Transit Authority Stormwater Treatment Standard for State Highway Infrastructure	greater of (2 yr-1hr ARI, 90% storm)	2yr & 10 yr peak discharge ~ predevelopment conditions	peak discharge ~ 80% of 100 yr predevelopment
Wellington, NZ Regional Standard for Water Services	-	10 – 20 year ARI (depending on land zone)	100 year ARI
Victoria, Australia Water Sensitive Urban Design guidelines	Mean Annual Rainfall method	-	-
Fiji Roads Authority Roadworks standards and specifications	Nominal pipe diameter less than 1200 mm is not permitted for road culverts		

4 Human impacts

4.1 Change in land use and ground cover

Historic aerial photos (1960, 1990) and the 1965 land use map (ref 6) indicates that there was little to no residential development in the coastal beach ridge area pre-1965 (refer **Appendix A2)**. We can infer this area served as the primary flood plain for the Muri catchment, and natural swamp depression areas likely provided attenuation of flood flows before discharging to Muri Lagoon. When comparing historic photos with recent aerial imagery (refer Photo 1 – 2), the coastal ridge area has experienced the greatest change, including (but not limited to):

- Backfilling of swamp depression areas and reduced attenuation;
- Increased surface runoff due to more impervious surfaces (roads, driveways, roofs);
- Constraining of waterways through residential areas with reduced flood flow capacity; and
- Loss of the flood plain.

The lowland alluvium and coastal hills area has also undergone an increase of impervious areas from a larger number of residential dwelling. The changes in land use and ground cover has resulted in reduced opportunities for infiltration and evapotranspiration, and increased storm water runoff. These changes have also resulted in an increased flood risk, both from larger floods, but also higher potential for damage to occur from a flood (by development within the flood plain).

Photo 1: North Muri area. Left to Right: 1960, 1990, 2019.

Photo 2: South Muri area. Left to Right: 1960, 1990, 2019.

4.2 Existing drainage system

With development, the natural stream paths have been modified and culverts installed to convey the streams through a number of private land boundaries, roads and access ways before discharging to Muri Lagoon. In some areas, private drains collect overland run-off and discharge to the natural stream systems. In other areas, private landowners have installed dams and other barriers within the stream channel, as it passes through private land. There is no reticulated storm water system in the catchment.

Inspections by ICI staff following rainfall events have noted the following issues:

- Undersized culverts;
- Maintenance issues highlighted by culvert blockage due to vegetation debris and sediment accumulation;
- Streams blocked by artificial barriers, resulting in water backing up and sometimes overtopping the channel; and
- Uncontrolled overflow pathway through, or flood of, private land.

Photographs and a locality plan of these observed issues are included in **Appendix B**.

ICI engineers also provided anecdotal accounts that correlate flooding incidents to king tide conditions, suggesting that tidal conditions and associated elevated groundwater add further constraints to drainage capacity and existing hydraulic gradients of the network.

5 "Tool box" identification

We have completed an assessment of options to achieve the objectives of the project brief, which are as follows:

The **treatment objective** is to reduce environmental stress from sediment carried by storm water flows when entering Muri Lagoon. In line with the Project objectives, we have assessed "naturalised" systems which provide physical settlement and filtration, rather than artificial devices (e.g. filter cartridges) or chemically assisted treatment.

The **discharge control objective** is to ensure safe conveyance of storm water runoff, and reduced flood risk to human life and property. This is typically achieved by:

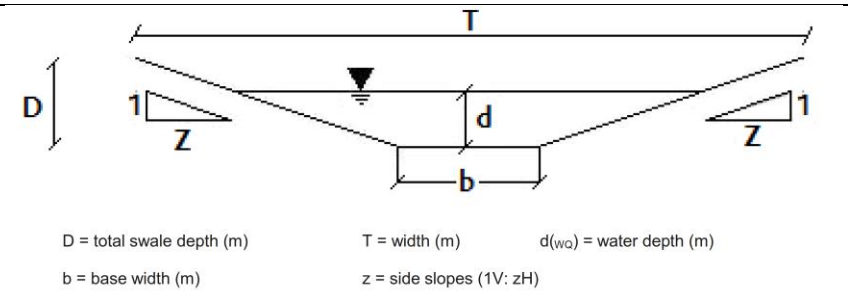
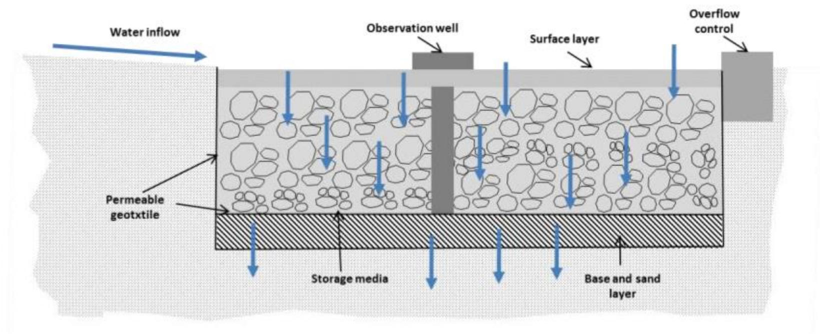
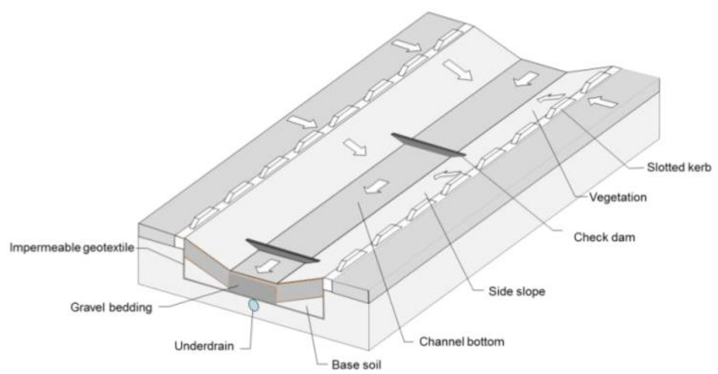
- Provision of a **primary system** of pipes, drains and treatment pathways for a determined rainfall event; and
- Provision of a **secondary system** of attenuation areas and overland flow paths, and aligns with natural flow paths and publically accessible land where possible.

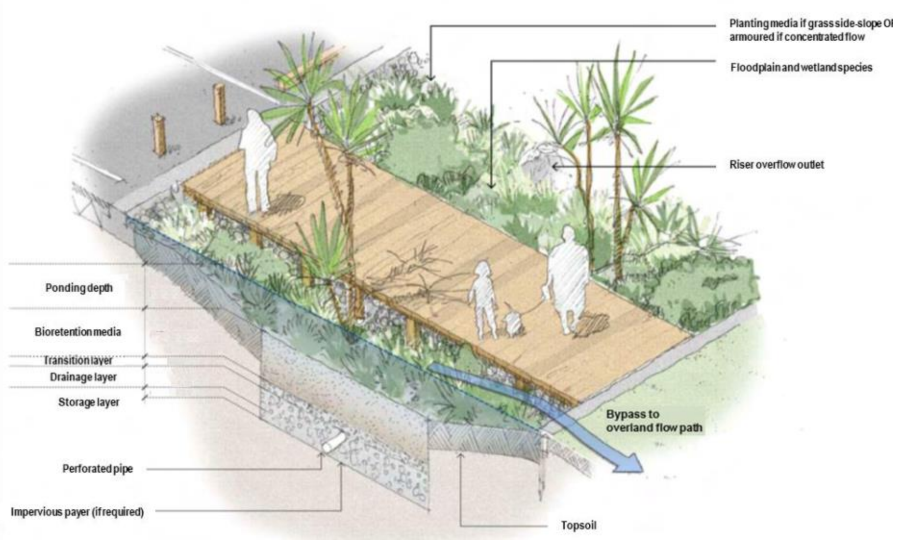
The issues ICI identified on the existing drainage systems (refer **Section 4.2**) was used as the starting point to determine the minimum “functions” the storm water management solution would need to contain. These functions are:

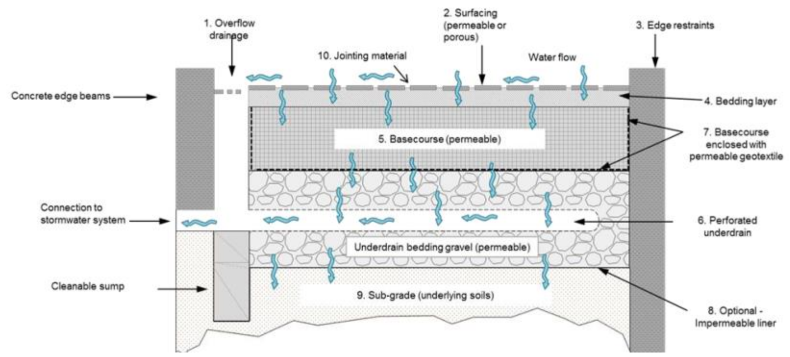
- **Conveyance:** collecting and directing storm water runoff;
- **Attenuation:** collection and slow release of storm water/flood waters;
- **Sediment treatment:** removal of sediment through physical settling; and
- **Inlet & outlet control:** hydraulic structures designed to control flow into or leaving storm water management devices.

A range of storm water management devices considered relevant to the Muri catchment and appropriate to other sites across the Cook Islands have been identified. These align with the four functions above (refer **Table 5.1** below). High level design guidance is also set out below. Where available, a typical detail has also been provided.

Table 5.1: Toolbox for storm water management

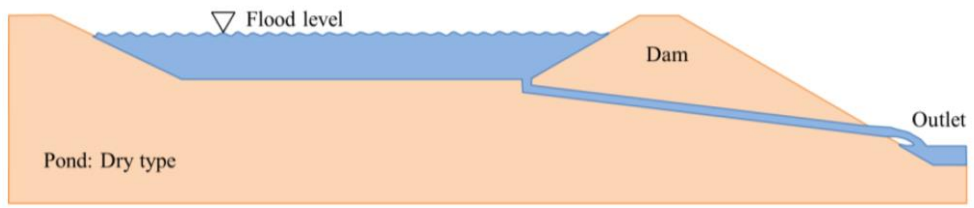
	Item	Purpose	Design guidance		
			Relevance to Muri Outcomes	***Design considerations***	***Typical detail***
Conveyance	Constructed drains	An excavated or natural open channel to collect and convey storm water runoff and/or stream flow to be collected	**Primary systems:** Constructed channels adjacent to the road corridor for road drainage **Secondary systems:** Stabilised drains with sufficient freeboard may provide an overflow path	Consider invert scour protection where flow velocities > 1 m/s Consider grade control structures (e.g. check dams) where channel grades > 10% Freeboard: Consider minimum 300 mm freeboard at all drains Underdrainage: consider for grades < 0.5%, where free draining soils are not present	 *Reference: Auckland Council GD01*
	Infiltration trenches/pits	An excavated trench or pit filled with gravel or crushed rock that allows storm water to infiltrate to groundwater	**Primary systems:** Constructed channels adjacent to the road corridor for road drainage **Treatment:** May provide water quality benefits, if surfacing is designed to enable trapping of sediment	Consider applying minimum 1m freeboard above normal groundwater levels Suitable for locations where the underlying soils are free draining Not suitable for secondary overflows, under heavy rainfall conditions, as groundwater levels are likely to rise under heavy rainfall	 *Reference: Auckland Council GD01*
	Swale	A shallow drain with gently sloping sides, designed to convey water runoff, filter pollutants, and enable increased rainwater infiltration	**Primary systems and secondary:** Constructed swales adjacent to the road corridor for road drainage **Secondary systems:** Shallow gradient grass swales with sufficient freeboard may provide an overflow path **Treatment:** Runoff from impervious surfaces, such as roads, parking lots and developed sites where space is constrained	Consider local grasses and plants resilient to inundation, and suitable for filtration and heavy metal uptake Consider minimum 300 mm freeboard at all drains Consider incorporating in-line sediment drop-out areas for ease of maintenance	 *Reference: Auckland Council GD01*

<table>
<tr><th rowspan="2"></th><th rowspan="2">Item</th><th rowspan="2">Purpose</th><th colspan="3">Design guidance</th></tr>
<tr><th>Relevance to Muri Outcomes</th><th>Design considerations</th><th>Typical detail</th></tr>
<tr><td></td><td>Shared use corridors</td><td>A stabilised pathway for emergency overflows, which acts to provide redundancy of primary conveyance systems</td><td>Secondary systems:
Overflow paths could be located within stabilised extents of shared use corridors (e.g. driveways, access ways). These shared use coridoors could provide</td><td>Consider combining the function of shared use corridors to provide both primary and secondary conveyance
Where the wetted depth encroaches on foot or vehicle traffic area, consider limiting design water depths to no more than 300 mm (health and safety consideration)
Energy dissipation to be assessed for the overflow conditions where overflow paths terminate on beach sands (or other erodible material)</td><td>

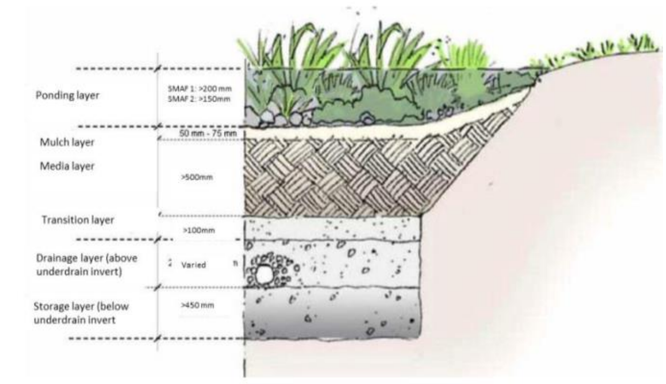
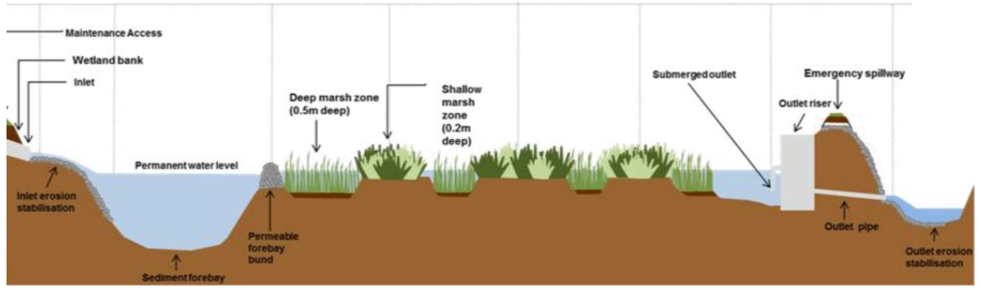
Example of shared use corridors for secondary systems (Auckland Council GD01)</td></tr>
<tr><td rowspan="3">Attenuation</td><td>Permeable surfacing</td><td>Surfacing of vehicle and pedestrian pathways that allows for rainfall to infiltrate to ground and/or groundwater</td><td>Primary systems:
Roads, paths, and parking lots that are subject to light vehicular traffic, such as cycle-paths, service or emergency access lanes, road and airport shoulders, and driveways</td><td>Suitable for areas where the underlying soils are free draining
Not suitable for secondary overflows, under heavy rainfall conditions, as groundwater levels are likely to rise under heavy rainfall</td><td>

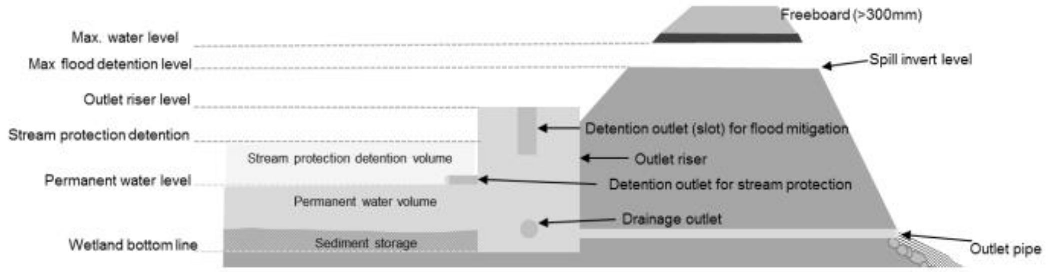
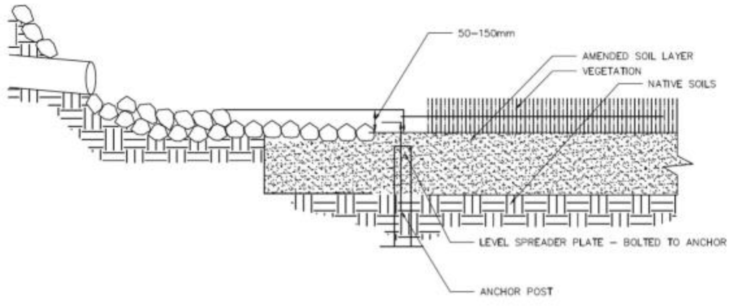
Reference: Auckland Council GD01</td></tr>
<tr><td>Detention basins</td><td>Natural/enhanced or constructed new basin or depression
Can be designed to drain completely (i.e. dry under non-flood conditions), or provide dead water storage (e.g. stays wet)</td><td>Primary and/or secondary systems: Reduces total runoff volumes by providing storage (detention). Slows down flows by storing and releasing in a controlled manner (attenuation)
Treatment:
Traps soil in the basin</td><td>Geotechnical stability of side walls/bunds must be considered
Detention basins can be considered for:
Stream protection; and/or
Flood management.

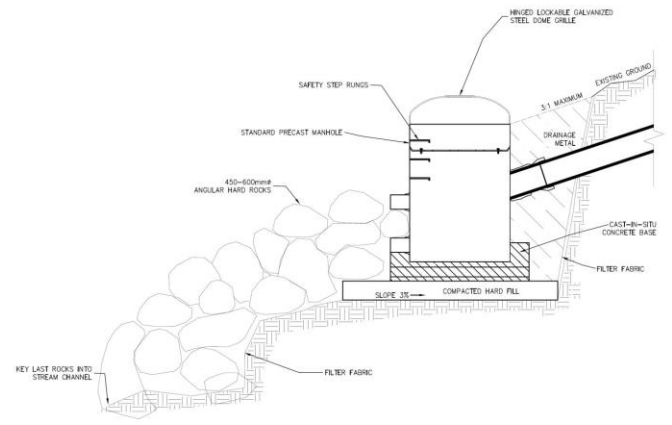
Sizing is based on the specific design volume from the contributing catchment. Where there is area or depth constraints on capacity, consider incorporating a stabilised spillway discharging to a constructed overflow path

Energy dissipation to be assessed, in particular where discharge is to beach sands (or other erodible material)</td><td>

Reference: Auckland Council GD01</td></tr>
<tr><td>Storage tanks/chambers</td><td>One or more tanks or chambers that collect and store rainfall and/or storm water runoff. May</td><td>Primary systems: Reduces total runoff volumes by providing storage (detention). Stored water is then available for reuse or can be attenuated by infiltrating to ground</td><td>Discharge to ground is suitable only where the underlying soils are free draining
Consider applying minimum 200mm freeboard above normal groundwater levels</td><td>A range of proprietary systems are available with a range of designs, intended purpose and performance. Details vary and specific systems should be selected or designed to address site and climate specific factors</td></tr>
</table>

	Item	Purpose	Design guidance		
			Relevance to Muri Outcomes	***Design considerations***	***Typical detail***
		be buried or above ground			
Sediment treatment	Bioretention devices	Stormwater is conveyed or collected into an sunken area which consists of a grass buffer strip, sand bed, ponding area, planting soil, and plants	**Primary systems:** Constructed areas adjacent to the road corridor, driveways or parking lots **Treatment:** Traps soil. Plants filter and remove pollutants (heavy metals, nutrients)	Bioretension devices a suitable for stream protection. They are not suitable for overflow or flood management Early planning of space for bioretention devices creates an opportunity for enhanced streetscape for road corridor improvements	 Reference: Auckland Council GD01
	Wetlands	Natural/enhanced or newly constructed basins or depressions that are planted. Typically allows for dead water storage (e.g. stays wet)	**Primary and/or secondary systems:** Slows down flows by storing large volumes of storm water runoff, and releasing in a controlled manner (attenuation) **Treatment:** Traps soil. Plants filter and remove pollutants (heavy metals, nutrients)	Energy dissipation to be assessed, in particular where discharge is to beach sands (or other erodible material) Sizing is based on the specific design volume from the contributing catchment. Where there is area or depth constraints on capacity, consider incorporating a stabilised spillway discharging to a constructed overflow path Consider local plants resilient to inundation, and suitable for filtration and heavy metal uptake Consider a maintenance bypass in the design (e.g. a weir to isolate the wetland for maintenance)	 *Reference: Auckland Council GD01*
	Riparian planting	Planting of 5m buffer either side of the stream	**Treatment:** Filters and removes pollutants (soil and metals) Protects against stream bank erosion	Consider in combination with other storm water management devices Consider local plants resilient to inundation, and suitable for filtration and heavy metal uptake	 Figure 15: Riprap Channel Obscured by Riparian Planting *Reference: Auckland Council, Technical report 2013/018*

	Item	Purpose	Design guidance		
			Relevance to Muri Outcomes	***Design considerations***	***Typical detail***
Inlet & Outlet control	Inlet debris control	Heavy rainfall can carry with it floating as well as submerged debris. Counter measures to protect culverts from blockage and damage include: Debris racks and/or fins in the stream channel, upstream of the culvert; Online dams or basins; Culvert inlet grates; and Or a combination of devices.	**To be considered for primary and secondary systems**	Specific design required. Consider classifying debris by floating/submerged/size/ shape, to determine the device (or combination of devices Assess potential impacts of the debris control structure to recreational use of the streams (e.g. swimming, fishing) Consider frequency of maintenance of culverts with debris control vs. increasing the capacity of culverts to pass select debris matter	 Figure 44: Debris Grille  Figure 45: Effective Debris Fencing Upstream of Critical Inlet *Reference: Auckland Council, Technical report 2013/018*
	Decant outlet	An outlet dewatering device designed to remove water within the upper water column without removing any of the settled sediment	**Primary and/or secondary systems:** Wetland and detention basin outlets	Refer typical detail	 *Reference: Auckland Council GD01*
	Flow spreading devices	Reduces scouring velocity by uniformly spreading flows across the inflow or outflow of storm water management devices	**Primary and/or secondary systems:** Wetland and detention basin inlets and/or outlets	Consider multistage discharge, using low and high discharge weirs	 FLOW SPREADER DETAIL 

	Item	Purpose	Design guidance		
			Relevance to Muri Outcomes	***Design considerations***	***Typical detail***
					Reference: Auckland Council, Technical report 2013/018
	Scour protection	Energy dissipation at the start or end of pipe	**Primary and/or secondary systems:** Allows stepped discharge where grades are steep; and Wetland and detention basin inlets and/or outlets.	Consider: Baffle blocks; Inlet/outlet aprons; Riprap (or alternatives e.g. hessian bags filled with weak concrete); Bubble up chambers.	 *Reference: Auckland Council, Technical report 2013/018*

5.1 Key considerations

There are a number of key factors that require consideration in selecting the appropriate mix of options in a specific location or catchment. These are outlined below:

- Managing storm water runoff and sediment at its source ("point source control") is likely to result in immediate improvements to storm water quality in the receiving environment during normal rainfall. Integrating point source control with the storm water management solution would also assist in meeting the other two project objectives. This is a result of the cumulative reduction of storm water run-off, which in turn reduces the potential for sediment and flood flows to be generated;
- All of the potential options presented above require varying extents of private land to be made available for public use. This includes storm water management associated with the road corridor improvements.

  We understand the 2019 Infrastructure Act allows for temporary access to land during construction of infrastructure along with maintenance of infrastructure, and provides a process to acquire land for infrastructure where this is required;

  Negotiated agreements could possibly be made with the landowners for existing drainage features within private land to be enhanced and improved by ICI. The benefits of improved flood resilience would be used to support these negotiations;
- Through environmental studies completed for the Mei Te Vai Ki Te Vai Project, there is understanding of marine habitats and potential impacts to marine ecology and biodiversity. However, there is limited information on the existing freshwater habitats, therefore limited understanding of potential impacts to modifying freshwater environments for managing storm water before discharging to the marine environment. Potential impacts could include:
  - **Short term construction impacts:** Typically can be managed through best practise fish removal exercises and sediment control during construction; and
  - **Long term sedimentation and inundation impacts:** Historically, natural depression areas were used for food crops and would also attenuate flood flows. Hence, it is likely that the aquatic ecology of these areas are tolerant to sedimentation and inundation of flood flows. We recommend an ecology survey to assess this;
- Good performance of any storm water management system is reliant on routine and reactive operations and maintenance activities. Where possible, engineering solutions should consider building in redundant capacity, however this needs balancing with land availability constraints. We recommend long term operations and maintenance budgets are prepared to support funding applications for storm water capital expenditure;
- Uncertainty on Maximum Probable Development (MPD). MPD refers to a design development scenario that considers future storm water flows by allowing for development within a catchment assuming the maximum impervious surface limits for the catchments. We understand MPD is not defined for the Cook Islands. We recommend further work be completed on defining this important design parameter for the Cook Islands;
- Further potential increase in flood risk due to:
  - Catchment wide increases in impervious area continue (with no legislative control on maximum values), contribute to potential increased of flood size and frequency;
  - Development continues in the flood plains (Coastal beach ridge area), which increases potential for damage from a flood; and
  - Uncertainty on the MPD, combined with changing flood risk make it difficult to assess if future resilience of storm water management systems are feasible; and

- Climate change impacts, in particular more frequently occurring extreme rainfall events.

6 Options assessment

An assessment of three concept options for the Muri catchment has been undertaken using a high level multi criteria assessment (MCA) process. The purpose of the MCA was to identify an appropriate mix of 'tools' to implement in the Muri catchment.

The MCA process is essentially a decision matrix which sets out each option and assesses the impacts or costs/benefits of different options by scoring each option from a range of different perspectives ("assessment criteria"). Typically, this includes environmental, social, cultural and economic (and other) impacts. MCAs are a useful collaborative tool, allowing for input from a number of stakeholders and a clear process which shows how different options perform when measured against each criteria.

6.1 Outline of methodology

The methodology for the MCA process is summarised as follows:

- **Development of assessment criteria**: Eight assessment criteria were developed for the options workshop. These criteria were developed in conjunction with ICI and workshop participants. Criteria were developed considering opportunities and challenges on similar scale projects, the local context, likely risk areas, and a review of other existing information;
- **Pre-workshop briefing:** Workshop participants were invited to attend a pre-workshop briefing on Tuesday 21 May 2019 which set out the intent and content of the workshop, including a description of the MCA process. An additional briefing was held with the facilitator and group leaders on Wednesday 22 May 2019, to further discuss the workshop process. Information sent to workshop participants prior to the main workshop is attached in **Appendix C1**;
- **Options workshop:** An options workshop was held on Thursday 23 May 2019 at Muri Beach Club Hotel. The workshop opened with a prayer and introductions. ICI and T+TI gave a presentation outlining the project context, the problem definition, and the integrated catchment management approach which underpins the three options which were assessed at the workshop. Workshop participants were then split into eight groups to discuss each of the eight assessment criteria. Findings were presented back to the whole group. Workshop minutes, including the presentation, are attached in **Appendix C2**;
- **Analysis:** additional analysis has been applied to the final scoring, including weighting/sensitivity analysis; and
- **Presentation of MCA results:** This report presents the results of the MCA, which informs the overall recommendation.

6.2 Concept options

Three concept options were developed by selecting a range of devices from those set out in **Table 5.1** above. The options are outlined briefly below:

- Option A assumes treatment and slowing down of water are the primary functions. Key opportunities explored by this option are:
  - The enhancement of multiple existing areas to provide flood attenuation and sediment treatment; and
  - Provision of up to 5 m buffer on the road corridor margin for enhanced biofiltration and infiltration;

- Option B assumes treatment and slowing down of water are primary functions, however this would be constrained by land availability. This option assumes reduced opportunity to enhance existing areas for flood attenuation and sediment treatment (compared to Option A), and allows for up to 2 m buffer on the road corridor margin for enhanced biofiltration and infiltration; and
- Option C assumes dedicated areas for treatment and slowing down of water will not be available, and the primary function is conveyance. Sediment treatment opportunities would be limited to stream riparian planting. Attenuation Outlet Energy dissipation structures are likely to require more heavy engineering.

Sketches illustrating Options A, B and C are attached in **Appendix C2.**

6.3 Development of assessment criteria

The assessment criteria used to assess the options are set out in **Table 6.1** below.

Table 6.1: Assessment criteria

Criteria	Description
Ease of construction	The difficulty of constructing the option within reasonable and known construction and capability constraints This has been identified due to terrain and ownership challenges, and the feasibility of constructing certain solutions on Rarotonga (e.g. importation of certain materials or equipment)
Ease of operation / maintenance	Ongoing operation / maintenance within reasonable and known operational and capability constraints Building on challenges from other infrastructure projects in the Cook Islands, this has been identified as a criteria to minimise maintenance issues which might lead to poor outcomes
Water Quality (lagoon)	Impacts on water quality entering Muri Lagoon from the Muri catchment. Qualitative assessment to consider overland flow and types of treatment The impact of sediment flows into the Muri Lagoon has been identified as a key issue for this catchment
Water Quantity (land based flooding)	Impact of immediate and short-term flooding and stormwater inundation. Assessment includes whether the design enables/supports a low impact design approach Flooding has been identified by stakeholders as a key concern
Resilience and adaptability	Capacity of the option to adapt to changing needs and to provide resilient solutions over time. Includes the ability of the option to integrate required / potential future works, including response to climate change over the life of the design For the purpose of this assessment, resilience is defined as "what enables people to survive, adapt and thrive in the face of shocks and chronic stresses."[1] This criteria provides for a longer term view, taking into account changes over time including climate change

[1] Based on 100 Resilient Cities, http://100resilientcities.org/resources/#section-1

Criteria	Description
Community impacts	The change that could be experienced by the Muri community as a consequence of the options. Could include consideration of:[2] • Way of life; • Cohesion, stability, character, services and facilities in the community; • Biophysical environment and resources (e.g. seafood, taro); • Quality of the living environment and amenity; • Family, community, and social networks; and • Health and wellbeing. Community considerations are central to a high level assessment of social impacts
Cultural acceptability	Impacts on culture and identity associated with the land or types of options being assessed Cultural values have been identified as critical to a holistic assessment of the impacts of each option
Property	The extent and nature of property that would need to be used for each option, and the effects on landowners

6.4 Options workshop and results

6.4.1 Scoring instructions

As set out in **Section 6.1** above, workshop participants were split into eight groups to discuss each of the eight assessment criteria. The groups also identified priority criteria, which assisted in weighting the raw scores (refer **Section 6.4.3** below). Workshop participants were given the following scoring instructions:

- Each workshop table focussed on one criteria ("perspective") only;
- For each criteria, the process for undertaking the assessment was:

  1 Identify the top three criteria;

  2 Discuss and record the positive and negative aspects of the three options; and

  3 Agree a score which reflects the overall balance for each option, as follows:

Scoring	Description
-1	Negative impact e.g. construction is difficult and materials/skills are not readily available
0	Neutral (minimal to no impact) e.g. operation and maintenance is "business as usual"
+1	Positive impact e.g. option helps improve water quality in the lagoon

- Additional matters that groups felt the project team should know about e.g. opportunities, technical matters, other projects, were recorded on a separate piece of paper. These are summarised in the minutes attached in **Appendix C2**.

[2] New Zealand Transport Agency, *Social Impact Guide 2016* defines social impact as: *A social impact is a (positive or negative) change that can include aspects of people's: way of life; cohesion, stability, character, services and facilities in a community; biophysical environment and resources; quality of the living environment and amenity; family, community, and social networks; health and wellbeing; material wellbeing, personal and property rights; fears and aspirations; culture and identity; political system*.

Figure 6.1: Group scoring process at options workshop.

6.4.2 Raw scores

Raw scoring is presented in **Table 6.2** below. This shows the scores for each of the three concept options, for each of the eight criteria. The total provided for each score at the bottom of the table shows that, for the raw scores, Option A was generally the most preferred option and Option C was generally the least preferred option. Option B was the middle ground however, it was did not score significantly less than Option A (particularly when compared to Option C). The reasons behind this scoring are discussed in **Section 6.5** below.

Table 6.2: Raw scores for the three options

	Option A Assumes treatment and slowing down of water are the primary functions	**Option B** Assumes treatment and slowing down of water are primary functions, however this would be constrained by land availability	**Option C** Assumes dedicated areas for treatment and slowing down of water will not be available, and the primary function is conveyance
Construction	-1	0 (+)	0
Operation	0	0 (+)	0
Water quality	+1	0	-1
Water quantity	+1	0	-1
Resilience and adaptability	+1	0	-1
Community	+1	0	-1
Cultural	+1	+1	-1
Property	+1(+1)	+1	0
Total	**+5**	**+2**	**-5**

NB: The water quantity group initially scored water quality. After reviewing their scores in relation to water quantity, they advised that these would not change.

6.4.3 Weighted scores

Each group identified three (or four) top criteria out of the eight in total. The top criteria for each group are summarised below (refer **Table 6.3**). The table shows each group down the left hand side, with an 'x' in the box against the criteria that particular group prioritised. This process provided a simple basis for weighting the criteria.

Priorities identified by the groups were:

- Water quality and water quantity were joint top priorities (based on written records); and
- Community and then resilience and adaptability were the next two priorities.

Table 6.3: Priority criteria

Priority criteria	Ease of construction	Ease of operation / maintenance	Water Quality (lagoon)	Water Quantity (land based flooding)	Resilience and adaptability	Community impacts	Cultural acceptability	Property
Group								
Ease of construction			X	X	X			
Ease of operation / maintenance			X		X	X		
Water Quality (lagoon)*			X		X	X	X	
Water Quantity (land based flooding)*		X	X	X				X
Resilience and adaptability			X	X		X		
Community impacts*			X	X		X	X	
Cultural acceptability			X	X		X		X
Property				X	X			X
TOTAL	**-**	**1**	**6** (7)	**6**	**4**	**5**	**2**	**3**

Groups marked by * presented four top criteria.

Grey text denotes that the group looking at cultural acceptability nominated water quality in their verbal presentation at the workshop, but the scoring sheet records that the top priorities identified were water quantity, community impacts and property.

In order to weight the criteria, the scores were converted as shown below (as weighting a neutral score of 0 has no effect on the overall scores).

Original scoring	Converted scoring	Description
-1	1	Negative impact e.g. construction is difficult and materials/skills are not readily available
0	2	Neutral (minimal to no impact) e.g. operation and maintenance is "business as usual"
+1	3	Positive impact e.g. option helps improve water quality in the lagoon

The converted scores are shown in **Table 6.4** below.

Table 6.4: Converted scores for the three options

	Option A Assumes treatment and slowing down of water are the primary functions.	**Option B** Assumes treatment and slowing down of water are primary functions, however this would be constrained by land availability.	**Option C** Assumes dedicated areas for treatment and slowing down of water will not be available, and the primary function is conveyance.
Construction	1	2	2
Operation	2	2	1
Water quality	3	2	1
Water quantity	3	2	1
Resilience and adaptability	3	2	1
Community	3	2	1
Cultural	3	3	1
Property	3	3	2
Total	**21**	**18**	**11**

Weighting has been applied to the converted scores, based on the overall total number of times each criteria was identified. As shown in **Table 6.5** below, applying weighting based on the identified priority criteria made no difference to the overall ranking however, it did distinguished further between Option A and Option B, with Option A clearly the preferred option based on the weighted scores.

Table 6.5: Weighted scores for the three options

	Weighting	Option A Assumes treatment and slowing down of water are the primary functions.	Option B Assumes treatment and slowing down of water are primary functions, however this would be constrained by land availability.	Option C Assumes dedicated areas for treatment and slowing down of water will not be available, and the primary function is conveyance.
Construction	0*	0	0	0
Operation	1	2	2	2
Water quality	6	18	12	6
Water quantity	6	18	12	6
Resilience and adaptability	4	12	8	4
Community	5	15	10	5
Cultural	2	6	6	2
Property	3	9	9	6
Total		**80**	**59**	**30**

*Construction was not identified as a priority criteria by any group. Note that if construction was given a weighting of 1, there is little difference to the overall result.

6.4.4 Sensitivity analysis

Further to the weighting based on the priorities identified through the workshop process, all criteria were individually weighted progressively from 1-10 to gain an understanding of how the ranking moved when one particular criteria was preferred over all others.

This is particularly important with regard to criteria which were not necessarily identified as priorities, but will nonetheless be critical to implementation of the preferred option, for example construction and property. **Figure 6.2** shows rankings when a weighting of ten is applied to each criteria.

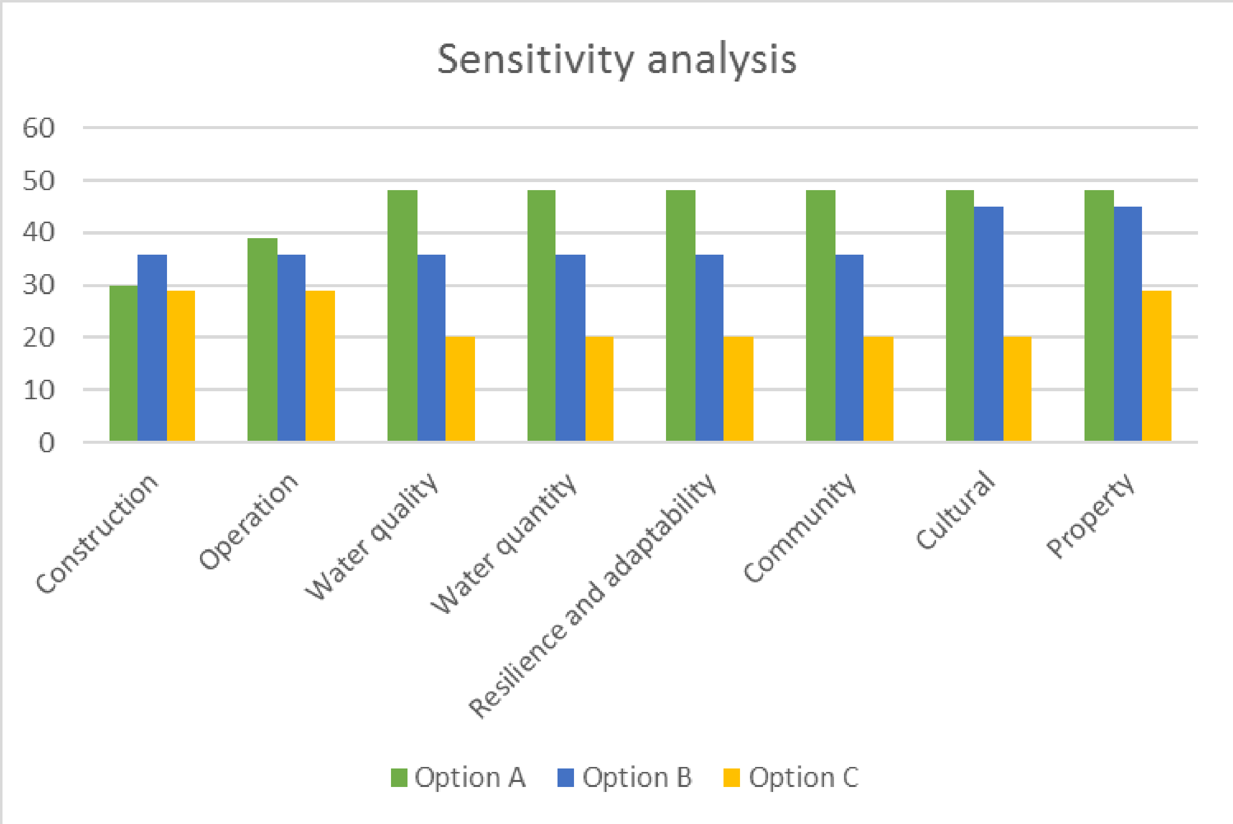


Figure 6.2: Graph showing scores for each option (x axis) when a factor of ten is applied to individual criteria (y axis).

The following observations can be made in relation to the rankings in **Figure 6.2** above:

- For most criteria, the rankings are not particularly sensitive. Even with a weighting of 10 applied to this criteria the overall ranking of the three options remains the same;
- For the water quality, water quantity, resilience and adaptability and community criteria, a weighting of 10 further distinguishes between Option A and Option B i.e. Option A is clearly preferred;
- However, for the operational, cultural and property criteria, the overall difference between Option A and Option B remains reasonably close when a weighting of 10 is applied;
- For the construction criteria, Option B becomes the preferred option with a weighting of 10 applied. This is because the construction group scored Option A negatively (and the other two options neutral), the only group to do so;

6.5 Scoring analysis

This section provides further analysis of the results and weighting/sensitivity analysis set out above, drawing on the reasons for scoring and verbal presentations at the workshop (see the minutes attached in **Appendix C2**).

6.5.1 Ease of construction

From a construction perspective, Option A was scored negatively. There are temporary construction effects associated with all works (e.g. closing part of the road, accessing land to construct devices). Because of this staging, including funding, resources and design / construction becomes a key issue. However, Option A has a lot more construction work “fronts” than other areas (e.g. two wetlands, two dry detention ponds) and therefore could be more difficult to construct. Staging could assist in this respect e.g. the emergency outfalls could be built first, but the project team would need to consider the mitigating the risk of temporarily worsening water quality within the lagoon (if appropriate treatment is not provided in a timely manner). However, while on the face of it, Option C is easier to construct than Option A, it may be challenging to build due to site constraints, as it is more substantial and could involve relocating houses/businesses (i.e. with further investigation, it may be that Option C is fatally flawed).

If construction is weighted heavily (i.e. at 10 x the other criteria), Option B becomes the top ranked option, although this approach would essentially minimise all other criteria which consider long-term issues in favour of construction issues which, although critical, are temporary/short-term in nature.

6.5.2 Ease of operation

From an operational perspective, the options all scored neutral, although the group indicated that Option B was slightly better than Options A and C. There is local knowledge in drainage so capability to undertake maintenance was not seen as an issue however, the ability to maintain and operate all options is funding dependent. Other negative aspects identified for all options included negotiation with landowners, time requirements for establishment of riparian planting and ongoing requirements for labour for maintenance/operational aspects.

6.5.3 Water quality and water quantity

As the water quantity group initially scored water quality, the comments from the water quality and water quantity groups are discussed together. These groups saw Option A as positive, Option B as neutral and Option C as negative.

Riparian planting and enhancement of natural wetlands are key opportunities identified by these groups. During the discussion on water quality, the workshop participants discussed riparian planting being started by the community rather than waiting for Government, with guidance from ICI as necessary. ICI noted that riparian planting needs to ensure appropriate plants (beneficial plants) are used rather than aesthetic plants. Source control (i.e. managing storm water quality and quantity at source) was identified as a key water quality issue, which was not addressed at this workshop.

6.5.4 Resilience and adaptability

The ‘resilience and adaptability’ groups also saw Option A as positive, Option B as neutral and Option C as negative. However, land requirements are a negative aspect. The 5 m additional road width proposed for Option A was identified as a particular issue, and this group thought this was unlikely to be achievable. This group noted that Option A relies on the community buying into it, as it is more land intensive than other options and will require everyone to work together to make it happen. Option C was seen as the most expensive and short-term option, which did not address water quality, although being able to do something immediate to address the problems was seen as a positive aspect.

6.5.5 Community

The group scoring ‘community’ scored Option A as positive, Option B as neutral and Option C as negative.

This group noted that the dry detention ponds proposed near the Avana Stream and on the rugby field as part of Option A were both located on protected areas (subject to a ra’ui notice). The Avana mudflats are an important spawning area for fish and the rugby field is located on a graveyard site. However, there was also a potential opportunity identified in relation to the rugby field detention structure, which could become stadium seating (note we have not investigated the feasibility of this proposal).

Implications for land owners are also an important part of community considerations. The community group also stated, in relation to the group discussion on riparian planting, that the community should clean out the stream in an environmentally friendly way before planting.

6.5.6 Cultural acceptability

In terms of cultural acceptability, the group scoring this noted that cultural acceptability should inherently be in all criteria, as culture plays an important part in everyday life. There are key linkages to the tourism industry and the way of life for the local community. Aesthetics and naturalness were identified as key reasons why Option A was preferable to Option C. Ongoing community engagement and research into historical knowledge/cultural values in the area is also seen as important – the group suggested that if any of the options generate research about cultural/historical background, then this would be a positive outcome for Muri and Rarotonga.

6.5.7 Property

The property group scored Option A as a 'high positive', Option B as 'positive' and Option C as 'neutral'.

Positive aspects of Option A included that it was less intrusive and more environmentally friendly, would lead to less sediment in the lagoon, less scouring, and would be better long-term. This option was seen as potentially being more 'doable'. However, negative aspects were the extent of land (and compensation) required, high maintenance requirements and a potentially high erosion risk, and the impact of the option on 'private streams'. Option B was seen as being less costly and quicker to build with better aesthetics and less maintenance (both planting and engineering), but would restrict land development, may not last as long and solve the problem and may introduce more problems, with associated cost. Option C was seen as being efficient and would last longer, with less maintenance and less property damage, but with a high cost, negative aesthetics and more intrusive (and may not resolve the problem).

From a property perspective, compensation for any land required would need to be investigated.

6.5.8 Overall options assessment

Option A scored best for all criteria except from a construction and operational perspective. Option B was generally seen as the middle ground of the three options, with Option C being the most "hard" engineered solution, with large scale culverts/channels. In terms of aesthetics and the ability to treat stormwater, Option C was seen as the most negative option, and the construction group noted that it may be 'fatally flawed' due to site constraints, as it is more substantial and could involve relocating houses/businesses.

While Option A consistently scores the best, there are some significant constraints on this option identified by the groups, particularly in relation to:

- The 5 m wide road reserve proposed as part of this option;
- The scale of land required to successfully implement this option;
- Cultural and ecological constraints relating to the dry detention areas in the ra'ui locations; and
- Construction staging.

Any option to be progressed to detailed design will need to take into account these constraints. Resolving land access arrangements (for construction and operations) is likely to take some time. This means that fully implementing Option A could take an extended period of time and there may be merit in considering a "staged construction" to implement aspects of Option A that do not impact on or require significant additional land (refer **Section 7**).

7 Staging and cost implications

Table 7.1 below sets out a summary of the options, their functions, performance, assessment and cost (on a Low-Medium-High scale for each option). Based on this, we recommend that Option A be progressed in 2 stages:

- Stage 1 focusses on aspects that can be progressed with minimal land requirements (conveyance and inlet/outlet controls); and
- Stage 2 adds additional conveyance (including opportunity to expand the road reserve from 2 m to 5m at key locations), and implementing treatment and attenuation devices.

Cultural values and property matters (such as obtaining landowner agreements for stormwater management purposes) will also be a key constraint on the project regardless of the preferred option. Accordingly, defining the extent of the works and adopting 'tool box' options to limit associated intrusions will be a critical part of the detailed design process.

The staged approach is consistent with feedback that adopting short-term actions, particularly in relation to water quantity (flooding), would be seen positively. This would need to be carefully managed to avoid impacting water quality in the lagoon unnecessarily. We also note that, as set out in section 2 above, there is also some additional information that will be required in relation to this option particularly on the impacts of this option on freshwater ecology and natural wetlands. Finally, based on key themes from the options workshop, the following aspects should be incorporated in the final option where possible:

- Ensuring that opportunities to enhance natural systems and features are included, e.g. associated enhancement of biodiversity;
- Consideration of aesthetically pleasing options is important to stakeholders; and
- Involvement of the community is important e.g. through riparian planting programmes, subject to funding.

Table 7.1: Summary of options

Storm water Management Option	Function				Performance[1]		MCA conclusions	Capital and operational costs[2]		
	Conveyance	Attenuation	Treatment	Inlet/Outlet Control	.Treatment	Discharge Control		Short term 5 year	Medium term 10 year	Long term 50 year (50 years +)
Option A	√	√	√	√	Improvement	Improvement	Most preferred option Constraints include: The 5 m wide road reserve proposed as part of this option High demand of private property required to successfully implement this option Cultural and ecological constraints relating to the dry detention areas in the ra'ui locations Construction staging Any option to be progressed to detailed design will need to take into account these constraints	Low Stage 1 works only	Medium Stage 2 works, and operational costs	Low operational costs only
Option B	√	√ Reduced compared to A	√ Reduced compared to A	√	Some improvement	Improvement	Seen as the 'middle ground'	Medium capital costs	Low operational costs only	Low operational costs only
Option C	√ Increased compared to A & B	×	×	√ Increased compared to A & B	No change	Improvement	The most "hard" engineered solution, where large scale culverts/channels are considered likely. In terms of aesthetics and the ability to treat stormwater, Option C was seen as the most negative option, and the construction group noted that it may be 'fatally flawed' due to site constraints, as it is more substantial and could involve relocating houses/businesses	High capital costs	Low operational costs only	Low operational costs only

Notes:

1. Performance has been assessed against current conditions/issues.

2. Further work is required to quantify dollar values for low, medium and high.

8 Conclusions and recommendations

[to be expanded following ICI review]

Analysis has concluded that:

- Option A is the preferred option; and
- Staged implementation is appropriate given uncertainty about land access.

We recommend that:

- Further work is carried out to assess the benefits of point source control devices to meet the storm water management objectives. This could include simulation modelling of a test catchment accounting for these devices and/or a pilot study to test their effectiveness in a Cook Island context;
- Collect additional data required to inform detailed design e.g. refer **Figure 2.1**, further work on MPD;
- Progress to detailed design of Stage 1 for Option A;
- Further work is required to quantify cost implications for the preferred option (i.e. define dollar bands for low, medium, high); and
- Commence discussion with potentially impact landowners for Stage 2 drawing on the anticipated framework under the Infrastructure Bill.

9 References

1 Hydrodynamic Investigation of Muri Lagoon and Avana Harbour, Rarotonga, Cook Islands, UNSW School of Civil and Environmental Engineering (ref: WRL TR 2018/21), dated October 2018.

2 Muri Lagoon Ecological Assessment, Ministry of Marine Resources, Government of the Cook Islands, dated September 2018

3 Mei Te Vai Ki Te Vai Environmental Investigation Report DRAFT, GDD (ref: 51/34601/30), dated November 2018

4 NZ Soil Survey Report 49: Soils of Rarotonga Cook Islands, NZ Soil Bureau, dated 1980

5 Current and future climate of the Cook Islands, Pacific Climate Change Science Programme, dated 2013

6 Land use map of Rarotonga, Geography Department Massey University, September 1965

10 Applicability

This report has been prepared for the exclusive use of our client Infrastructure Cook Islands , with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor International Ltd

Report prepared by:

....	....
Sharon Parackal	Sarah McCarter
Environmental Engineer	Senior Planner

Authorised for Tonkin & Taylor Ltd by:

....

Chris Purchas

Project Director

Review by: Manea Sweeny (Principal Planner), Chris Freer (Senior Engineer)

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Appendix A: Muri Catchment information

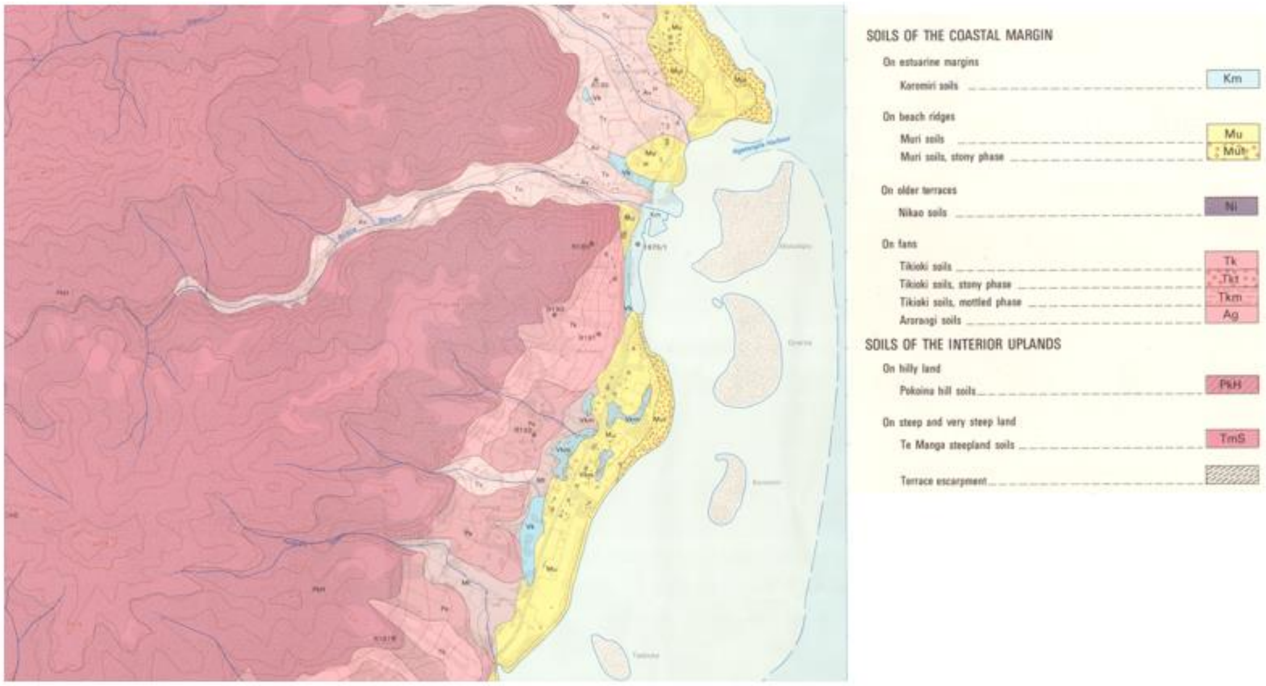
A1 Flood photographs

	
Muri Ngatangiia Floods – 6/12/14	Muri Ngatangiia Floods – 6/12/14
	
Koka & Muri Floods; Land damage at Pacific resort – 10/4/18	Koka & Muri Floods; Land damage – 10/4/18

A2 Historic maps

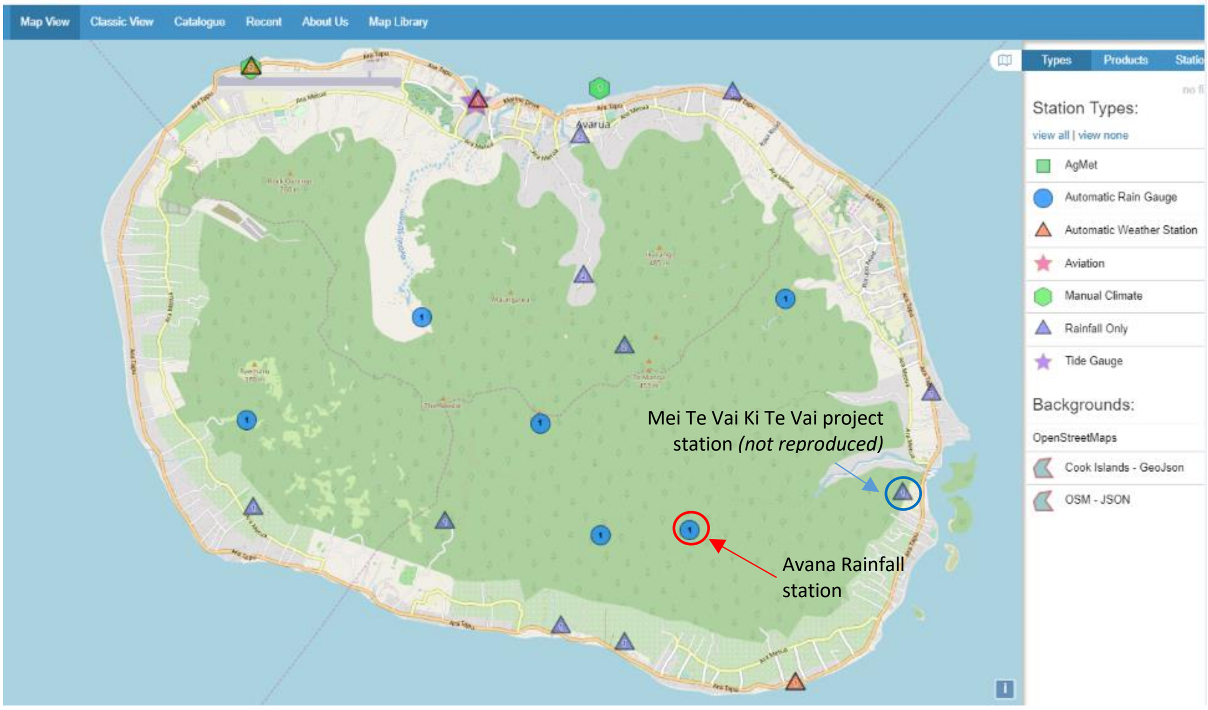
1965 Land use map (Muri catchment)

1980 Soils of Rarotonga map (Muri Catchment)



A3 Rainfall

Weather monitoring locations map



Avana Automatic rainfall station summary, from 2008 onwards (raw data provided by ICI):

	Median values (mm)													
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Max**	**Max date**
2008	?	?	?	6	2	0.5	0	2	2.5	2	2	2	240	3/12/2008
2009	4	0.5	8	2	0	0.5	0	3	1.5	0	0	0	150	3/10/2008
2010	2	1	0	1.5	0	1	2	1	1.5	2	3.5	5	150	20/04/2010
2011	4	10	1	1	2	2	0	0	1	0	1	5	189	28/12/2011
2012	3	2	1	2	3	0.5	1	0	1	0	0	2	141	22/03/2012
2013	5	0	1	0	1	1.5	1	1	0	1	1	0	188	16/01/2013
2014	1	0	1	0.5	3	1.5	2	1	0	0	1	2	234	25/11/2014
2015	4	1.5	11	1.5	1	1	0	0	0.5	0	0.5	1	239	3/01/2015
2016	0	0	1	0	1	1	1	0	0.5	0	2	4	253	26/11/2016
2017	2	5.5	?	?	0	1	0	1	0	0	4.5	2	144	18/12/2017
2018	1	2	1	0	1	1	1	1	0	0	0	0	**210**	9/04/2018
2019	0	2.5	2										86?	8/02/2019
												Overall Max	*253*	*26/11/2016*

NIWI ARI analysis (provisional draft)

ARIs of rainfall depths at Avana ARG (mm)

ARI	10min (error)	20min (error)	30min (error)	60min (error)	2h (error)	4h (error)	6h (error)	12h (error)	24h (error)	48h (error)	72h (error)	144h (error)
2	18.1 (0.9)	31.2 (2.2)	38.3 (2.5)	63.3 (5.1)	91.3 (6.5)	110.5 (6.4)	122.2 (6.8)	156.3 (8.4)	220.9 (14.4)	293 (20.1)	316.4 (18.7)	385 (22.3)
5	20.7 (1.6)	36.1 (2)	45.9 (4.4)	77.2 (7.4)	106.1 (6.2)	124.5 (5.6)	141.2 (10.2)	184.6 (19.4)	253.2 (13.4)	337.3 (17.7)	357.5 (16.4)	452.8 (40.2)
10	22.7 (2.5)	38.1 (1.7)	51.7 (7)	86.3 (10.2)	112.7 (5.9)	130.3 (5)	154.1 (14.5)	210.5 (38)	267.2 (12.5)	355.5 (15.7)	374.3 (14.5)	506.1 (65)
50	28.4 (7.1)	40.5 (1.2)	67.1 (18.8)	106.4 (22)	121.7 (5.4)	137.4 (3.3)	183.6 (32.9)	298.8 (142.4)	285.9 (10.6)	377.9 (10.5)	395.2 (9.7)	653.1 (183.7)
100	31.4 (10.5)	41.1 (0.9)	75 (27.3)	114.9 (29.5)	124 (5.5)	139 (2.7)	196.5 (44.8)	354.7 (230.6)	290.5 (10.4)	383.1 (8.5)	399.9 (7.9)	730 (270.2)

ARIs of rainfall intensities at Avana ARG (mm/hr)

ARI (year)	10min (error)	20min (error)	30min (error)	60min (error)	2h (error)	4h (error)	6h (error)	12h (error)	24h (error)	48h (error)	72h (error)	144h (error)
2	108.3 (5.2)	93.5 (6.7)	76.6 (5.1)	63.3 (5.1)	45.7 (3.3)	27.6 (1.6)	20.4 (1.1)	13 (0.7)	9.2 (0.6)	6.1 (0.4)	4.4 (0.3)	2.7 (0.2)
5	124 (9.3)	108.2 (5.9)	91.8 (8.8)	77.2 (7.4)	53.1 (3.1)	31.1 (1.4)	23.5 (1.7)	15.4 (1.6)	10.5 (0.6)	7 (0.4)	5 (0.2)	3.1 (0.3)
10	136.4 (15.1)	114.2 (5.2)	103.4 (13.9)	86.3 (10.2)	56.3 (3)	32.6 (1.2)	25.7 (2.4)	17.5 (3.2)	11.1 (0.5)	7.4 (0.3)	5.2 (0.2)	3.5 (0.5)
50	170.6 (42.8)	121.6 (3.5)	134.3 (37.7)	106.4 (22)	60.8 (2.7)	34.3 (0.8)	30.6 (5.5)	24.9 (11.9)	11.9 (0.4)	7.9 (0.2)	5.5 (0.1)	4.5 (1.3)
100	188.5 (63)	123.3 (2.8)	150 (54.6)	114.9 (29.5)	62 (2.8)	34.8 (0.7)	32.7 (7.5)	29.6 (19.2)	12.1 (0.4)	8 (0.2)	5.6 (0.1)	5.1 (1.9)

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Appendix B: Existing infrastructure information

B1 Maintenance photographs

	
14/4/18 – Pau Arthur Culvert	11/4/18 – Uncontrolled overflows at Ngatangiia Rugby Field site
	
2014 – Flooding along Muri Main Road	2014 – Road culvert blocked, private access road inundated
	
2015 – Clearing blocked drain	2014 – Blocked Muri-Aroko drain

B2 Problem “Hot Spots”, recorded by ICI

Appendix C: Options assessment information