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Tagabe Riverbank Restoration and Stabilisation Plan through EBA Options

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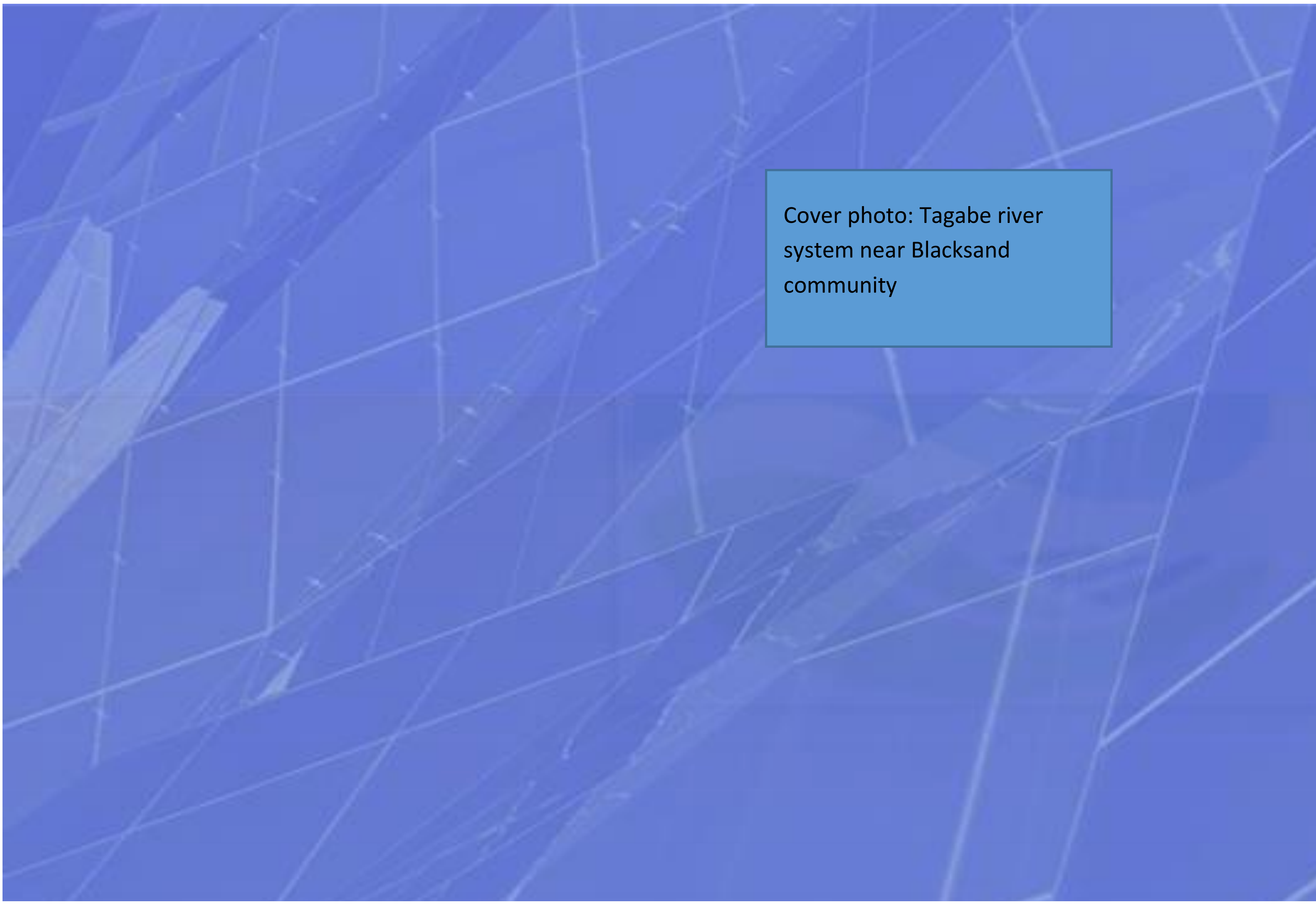

Cover photo: Tagabe river system near Blacksand community

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Acronyms

ASL	Above Sea Level
CRU	Climatic Research Unit
EbA	ecosystem-based adaptation
NbA/NbS	Soft Engineering, Nature Based Adaptation/Solutions
NDVI	Normalized Difference Vegetation Index’
PACRES	Pacific Adaptation to Climate Change and Resilience Building
PEBACC	Pacific Ecosystems-based Adaptation to Climate Change
R2R	ridge to reef
SPREP	Secretariat of the Pacific Regional Environment Programme
SRTM	Shuttle Radar Topography Mission
TRCA	Tagabe River Catchment Area
WWN	Working with Nature

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1. Introduction

This report was undertaken to support the work to explore local eco-friendly technology, materials and alternatives for riverbank stabilization and riparian zone rehabilitation and implement the most viable option to restore Tagabe riverbank and riparian zones, Vanuatu. The work is part of the Pacific Adaptation to Climate Change and Resilience Building (PACRES) project, coordinated by the Secretariat of the Pacific Regional Environment Programme (SPREP). It is a component of an assignment within the project to explore local eco-friendly technology, materials and alternatives for riverbank stabilization and riparian zone rehabilitation and implement the most viable option to restore Tagabe riverbank and riparian zones.

The Tagabe River watershed suffers from the removal of trees for firewood and topsoil disturbances from the establishment of gardens along the riverbank that have contributed to the degradation of the riverbank including through erosion and landslides. These impacts are compounded by increasing extreme weather events that amplify the vulnerability of the river to siltation.

The Pacific Ecosystems-based Adaptation to Climate Change (PEBACC) project and Pacific Regional Ridge to Reef (R2R) projects amongst others have initiated the planting of trees along the Tagabe catchment to protect water resource and stabilize the riverbank, providing shade to the river and safeguarding important habitats. Interventions from previous and existing projects have also revegetated riparian areas to some extent and due to human activities related to the development and human settlement, there is still more work needed for riparian restoration and riverbank stabilisation along the Tagabe River catchment. It is important to note that these previous projects were focussed on the upper catchment of the Tagabe and towards the lower Tagabe river. PACRES will scale up and continue riverbank stabilisation and riparian zone restoration through innovative ecosystem-based adaptation approaches within the mid-section of the Tagabe river, constituting the majority of the main river system.

This document presents the results of catchment and field assessment analysis to support the selection of target riparian zone rehabilitation zones and presents a range of eco-friendly technology, materials and alternative stabilisation approaches for the catchment.

2. Background

Vanuatu's main economic hub and the greatest concentration of people and businesses are located in the capital city, Port Vila. The Tagabe River Catchment Area (TRCA) is currently the only source of potable water in Port Vila. The TRCA provides water for residents, businesses, agriculture, manufacturing and industries. The rapid urbanisation and increase in Port Vila's population, the drive to increase tourism, and the proliferation of infrastructure that will increase the connectivity of Port Vila to international and domestic markets, will increase per capita use of fresh water and subsequently intensify pressures on Port Vila's water source.

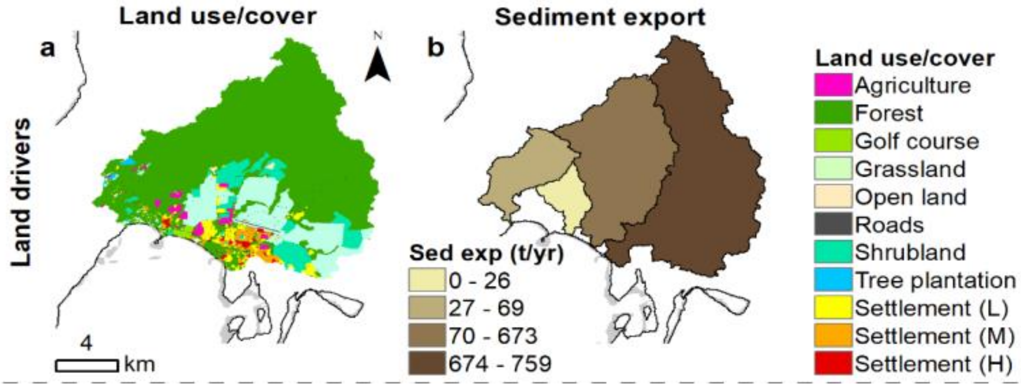

Figure 1: (a) Present land use/cover, (b) InVEST SDR results – sediment export (t/yr) summarized by watershed.

Currently, the majority of land use/cover across the watersheds discharging in Mele Bay consists of forest (69.1%), grassland (14.8%), shrubland (7.3%), and human settlement and infrastructure (8.2%) (e.g., agriculture, golf course, roads, and plantations) (Fig 1a. The sediment export model under existing land-use resulted in a total sediment export of 1,258 t/yr (or 9.7 t/km-2), with Tagabe watershed discharging approximate 759 t/yr and therefore contributing 50% of the sediment load (Fig 1b).

Climate change will additionally escalate the vulnerability of Port Vila and Vanuatu's ability to support existing and future TRCA users.

The project will increase the resilience of the Tagabe River through the integration of ecosystem-based adaptation (EbA). This moves away from traditional 'hard' engineering approaches and towards a more balanced approach combining hard and soft methods. This work builds on recent work which has integrated Nature-Based Adaptation, Building With Nature and Ecosystem Services that show the many benefits of catchment restoration and natural rehabilitation including significantly lower cost than hard defences and a higher-cost benefit ratio for flood and drainage management.

Following the field assessment on the Tagabe river system, other goals related to the implementation of projects are:

- To present to Tagabe catchment stakeholders prioritized local eco-friendly technology, materials and alternatives for riverbank stabilization and riparian zone rehabilitation of the Tagabe riverbank and riparian zones.
- To pursue partnership opportunities with government agencies and local communities in the delivery of riverbank stabilization and riparian restoration activities.

3. Field assessment results

For the period 26 July 2021 to 14 August 2021, a field assessment as part of this project was conducted along the Tagabe river. The objectives of the field assessment were:

- To assess the current health of the riparian area and riverbank status along the Tagabe river
- To use the results from the assessment to identify high priority areas where the riparian areas and riverbanks need restoration and stabilization activities

The survey consisted of a visual assessment of the riverbanks and riparian zones along the Tagabe river. The assessment was focused on areas of deteriorated vegetation, especially on catchment areas that were heavily devastated by anthropogenic effects and riparian zone deforestation.

Riverbanks that were unstable and damaged riparian areas were marked on a printed satellite map. A geographical location was also taken using Global Positioning System (GPS). Disturbance sites were identified as sites that were impacted by riverbank erosion and human activities (i.e. unstable banks caused by grazing, logging, poor bridge crossings, lawns, etc.). Photos of the most disturbing sites were taken, and the reason for the disturbance was also recorded.

The four different categories of riverbank and riparian stability were stable, slightly unstable, moderately unstable, and highly unstable. These different categories were defined by the following 2:

1. Stable: riverbanks and riparian well-vegetated or such that they are not susceptible to erosion or removal
2. Slightly Unstable: >50% of riverbanks and riparian are stable, the limited indication of silt contribution and vegetation removal
3. Moderately Unstable: <50% of riverbanks and riparian are stable, some indications of silt and vegetation removal
4. Highly Unstable: massive riverbank erosion and removal of riparian, large deposits and bare riparian zone

From this field assessment, seven sites were identified that require riverbank stabilization or riparian enhancement work (Figure 2). These areas are mainly situated in the segment of the Tagabe river with thriving industries or established communities.

Figure 2: Priority areas identified for riverbank stabilisation and riparian restoration.

4. Assessment of riparian eco-friendly technology and approaches

4.1. Background

Ecosystem-based mitigation strategies are rapidly gaining interest to mitigate the adverse effects of habitat degradation, flooding, erosion and future climate change. Throughout typical coastal, estuarine, riparian and catchment-zones they include a range of approaches, including Working With Nature (WWN), Soft Engineering, Nature-Based Adaptation/Solutions (NbA/NbS) and bio-engineering, as shown in **Error! Reference source not found.** 3. Specific approaches can then include revegetation, integrated basin management, channel restoration using techniques such as log jams, and targeted riparian restoration. The suitability of these approaches will vary in relation to the purpose of the hazard mitigation or protection required.

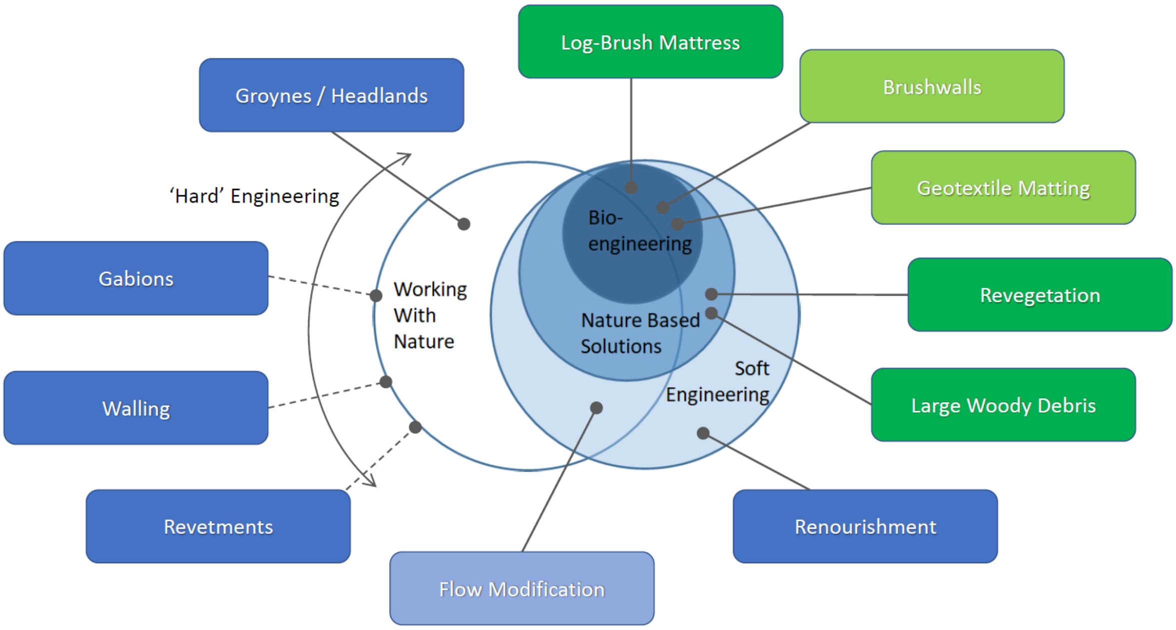

Figure 3: Nature-based adaptation approaches (Courtesy of Matt Eliot, Damara)

4.2. Type of protection required

The Port Vila water supply was reviewed based on available descriptions given in the study by the South Pacific Applied Geoscience Commission (Nath et al., 2006). Water supply falls under several authorities in Vanuatu, with the private company Union Electrique du Vanuatu Limited (UNELCO) the producer and distributor of drinking water in the urban centre of Port-Vila and the suburbs. At the time of the South Pacific Applied Geoscience Commission (SOPAC), one of its reports stated that the water supply involved water being abstracted from six boreholes, which pump water to two buffer tanks for chemical processing, with treated water then pumped into four storage sites. Known problems with the supply network are published within the

Integrated Water Resources Management programme's Diagnostic Reports (Nath et al., 2006):

- Quality and quantity
    - Information on the chemical composition of ground and surface water quality is limited however generally believed to be good with only calcium hardness to note. Contamination of ground and surface water in the Tagabe River Catchment is noted in areas of high-density living, septic tank use and cattle grazing.
    - Suspended solids and turbidity increase towards the lower catchment, at approximately the eastern end of the Airport Road.
- Pollution
    - Improper waste disposal through residents directly disposes of solid waste along the Tagabe River that ends up clogging the river system. Poor drainage and waste management provide pools of water that are favourable breeding sites for malaria mosquitoes. Unmanaged and uncontrolled sanitation and wastewater are also major concerns

The Tagabe catchment has been identified as a sensitive area and a pollution hotspot within the Integrated Water Resource Management Hotspot Analysis Report (Nath et al., 2006), with priority issues watershed degradation and pollution (microbiological and chemical). The threats to the catchment are listed as:

- Human-related threats: Toilet and septic systems, cattle grazing, subdivisions, logging (impacts on sedimentation and lower water level), agriculture – fertilizer runoff, industrial waste, brewery effluent, and stormwater runoff.
- Natural threats: Flooding, landslides, sedimentation, and drought

A range of concerns was presented for the catchment, which included catchment water shortages (specifically a reduction in streamflow of quality and pollution of existing supplies), pollution, and habitat modification through the loss of ecosystems or ecotones.

Based on the descriptions above, of importance to this project are the impacts due to continued catchment degradation and riparian erosion, which can lead to poor water quality.

5. Ecosystem-based adaptation being implemented within Vanuatu and the Pacific

A range of nature-based, EbA options and catchment management approaches have been reviewed based on available implementation plans or summary documents. These have been reviewed and any actions involving the riparian zone are presented below.

Options considered within the Tagabe Riparian Corridor Regeneration Project are detailed in Section 6, and include:

- Riparian revegetation
- Sustainable land management
- Pollution protection

Options considered within the Tagabe River Catchment Management Plan 2017- 2030.

- Tree planting at various locations within the catchment (Activity 4.2, 4.3, 4.4, 4.5)
- Revegetation of riparian areas along the lower Tagabe river (Activity 4.6)
- Improved knowledge of management of water catchments based on best practice (Activity 8.6)

Options considered within the Tagabe Integrated Water Resource Management Plan and associated documents (Department of Geology, Mines and Water Resources (DGMWR), for all streams, creeks and rivers:

- No land-use activities are permitted within 20 meters of the waterway (In accordance with Water Resources Management Act No. 9 of 2002).
- Riparian land replanting
- No damming of any stream, creek or river, no matter how small.

Options assessed within the Vanuatu (Tanna Island) Ecosystem and Socio-economic Resilience Analysis and Mapping (ESRAM). Establishment of diverse agricultural systems, where using indigenous knowledge of specific crop and livestock varieties, maintaining the genetic diversity of crops and livestock, and conserving diverse agricultural landscapes secures food provision in changing local climatic conditions.

- Establishing and effectively managing protected area systems to ensure the continued delivery of ecosystem services that increase resilience to climate change
- Sustainable water management where river basins, aquifers, flood plains and their associated vegetation provide water storage and flood regulation
- Sustainable management of grasslands and rangelands to enhance pastoral livelihoods

Options considered within the Pacific Ecosystems-based Adaptation to Climate Change (PEBACC):

- EbA interventions are recommended to occur over a longer time than conventional projects; preferably 5−10 years
- Tagabe catchment, Vanuatu: Planting of 3,000 native trees, fruit trees and vetiver grass along the Blacksands coastline to reduce erosion and provide shade along the river, reducing sunlight, which will curb the growth of invasive aquatic plants.

Options assessed within the Lami Town ecosystem-based adaptation study by SPREP in 2012:

- Conservation of mangroves, seagrasses/mudflats, coral reefs, forests, and river buffer areas.
- A range of techniques to reduce riverbank erosion, however these specifically identified 'hard engineering'\approaches including rock-filled wire 'gabion' baskets.

Table 1, below illustrates some of the EbA projects that have been implemented in the region and their applicability to the Tagabe catchment.

Table 1: Issues and lessons learnt on implementing EBA in the region

Country	Alignment	Success	Lessons learnt	Applicability to Tagabe Catchment
Kiribati	Forms part of adaptation priorities in major climate change policies and plans Kiribati 20-Year Vision 2016–2036 and Kiribati Development Plan 2016–2019, both identifies "environment" as one of six priority areas with an associated goal to "facilitate sustainable development through approaches that protect biodiversity and support the reduction of environmental degradation as well as adapting to and mitigating the effects of climate change"	A review of the Kiribati Adaptation Project (KAPI and KAPII) highlighted that while both projects focused on hard infrastructure (especially the construction of seawalls), it was ecosystem-based aspects, notably mangrove rehabilitation and planting, that were the more successful elements of both projects (as assessed informal project evaluations)(Webber, 2015).	Local contextual factors such as social norms, environmental, or local governance and decision-making mechanisms must be identified and meaningfully incorporated into the design and implementation of CbA /EbA initiatives (Webber, 2015). Ensure communities participate in the co-design of adaptation interventions(Cauchi et al., 2021).	Applicable towards the lower parts of the Tagabe catchment. Implementation can incorporate lessons learnt through the incorporation of local contextual factors and being community-centric.

Samoa	Strategy for the Development of Samoa 2016–2020 (SDS) premised four priority areas including “environment” (including the key outcome areas of “environmental resilience improved” and “climate and disaster resilience increased”)	“EbA is well integrated within five of the nine priority projects identified in the NAPA [National Adaptation Programme of Action], which makes explicit the value of ecosystem services to building the adaptive capacity of communities”. Within the urban context, the most significant adaptation project incorporating NbS/EbA elements is the US$65 million Global Environment Facility (GEF)-funded and United Nations Development Programme (UNDP) implemented Vaisigano Catchment Project (VCP)(Chong, 2014). To date, about 20 EbA projects have been implemented with a further 319 projects approved; cash for work schemes are underway for ecological rehabilitation programmes at three reserve sites and fencing for watershed protection at one further site, and the PES component continues through feasibility stages (Latai-Niusulu, 2017)	To understand climate change resilience in island society, careful assessment of islanders’ perceptions and actions in the context of their physical locales and socio-cultural systems is required (Latai-Niusulu, 2017).	Applicable towards the entire Tagabe catchment. Institutional mechanisms can be replicated for Tagabe catchment, with a long-term plan for a large GCF funded project.

Vanuatu	The 2016–2030 Climate Change and Disaster Risk Reduction Policy identifies targeted EbA actions including “ridge to reef” solutions, prioritizing “soft” interventions such as coastal revegetation (compared to “hard” engineered infrastructure such as seawalls), advocacy and awareness programmes, and activities that build on existing local “taboos, conservation areas, heritage sites, locally managed areas and vulnerable habitats and ecosystems and carbon sinks”	The Vanuatu Climate Change and Disaster Risk Reduction Policy 2016–2030 provides more specificity on priority actions, bringing focus on the areas of disaster risk reduction (DRR), community-based adaptation (CbA), and ecosystem-based approaches. Riparian corridor regeneration; restoration and protection of coastal vegetation; intensification of home gardens; urban tree planting; and the use of traditional are some of the strategies that have been successfully implemented.	Review of 15 CbA/EbA projects in Vanuatu indicate these projects invariably fell short of success, longevity, and sustainability, often because such projects are typically led by external “experts” working temporarily in local communities in the sporadic design and implementation stages, “fitting” efforts to funding requirements and failing to view local communities as best placed to define and shape resiliency agendas. Localized adaptation efforts must be locally led and implemented across different entry points, and not just necessarily related to individual specific “communities” (Westoby et al., 2020).	Necessary institutional mechanisms in place.

Fiji	Fiji's Updated Nationally Determined Contribution, 2020, Adaptation Target 7: Develop simplified and standardized early warning and monitoring systems and priorities nature-based solutions to mitigate the impact of flooding and cyclones. Fiji will take measures to ensure that public infrastructure is resilient to cyclones and floods, prioritizing nature-based economically viable solutions, and developing future infrastructure and building projects while keeping in mind the effects of climate change.	Ridge-2-Reef programme. Fiji Ridge-to-reef management of priority water catchments on the two main islands of Fiji to preserve biodiversity, ecosystem services, sequester carbon, improve climate resilience and sustain livelihoods. Preservation of cloud forest and coastal habitat using ecosystem-based management, participatory approaches and integrated resource management. Water and Nature Initiative. Fiji and Samoa. Projects focused on good governance, payments for ecosystem services and learning leadership, to improve the quality and sustainability of water resources in the region. Kai Project. Fiji. Improving livelihoods through increasing economic benefits from kai fishery by addressing food safety issues.	EbA project should incorporate entirety, i.e., ridge-to-reef approach, acknowledging that the terrestrial, freshwater, and coastal ecosystems of small islands are highly interconnected. EbA should be well integrated within the national climate change, national sustainable and development policy and plans.	Applicable to Tagabe catchment provides options for better national institutional mechanisms around integrating EbA into national plans and policies.

6. Options for the Tagabe riverbank stabilisation and riparia restoration

6.1. Rationale for EBA in Tagabe

The most recent study by (Delevaux & Stamoulis, 2020), illustrate that the restoration scenario, which entails restoring 1,330 ha of shrubland, grassland, open land, and human settlement with native forests, indicate a considerable reduction in erosion (135 t.yr-1 of sediment) of the topsoil, and the corresponding reduction in Total Suspended Sediment (TSS). However, under the urbanization scenario, loss of native forests indicate a drastic increase of an additional 5,188 t.yr-1 of sediment discharging at the shoreline resulting in an increase of TSS in the southern and eastern sides of the bay (Fig 4f).

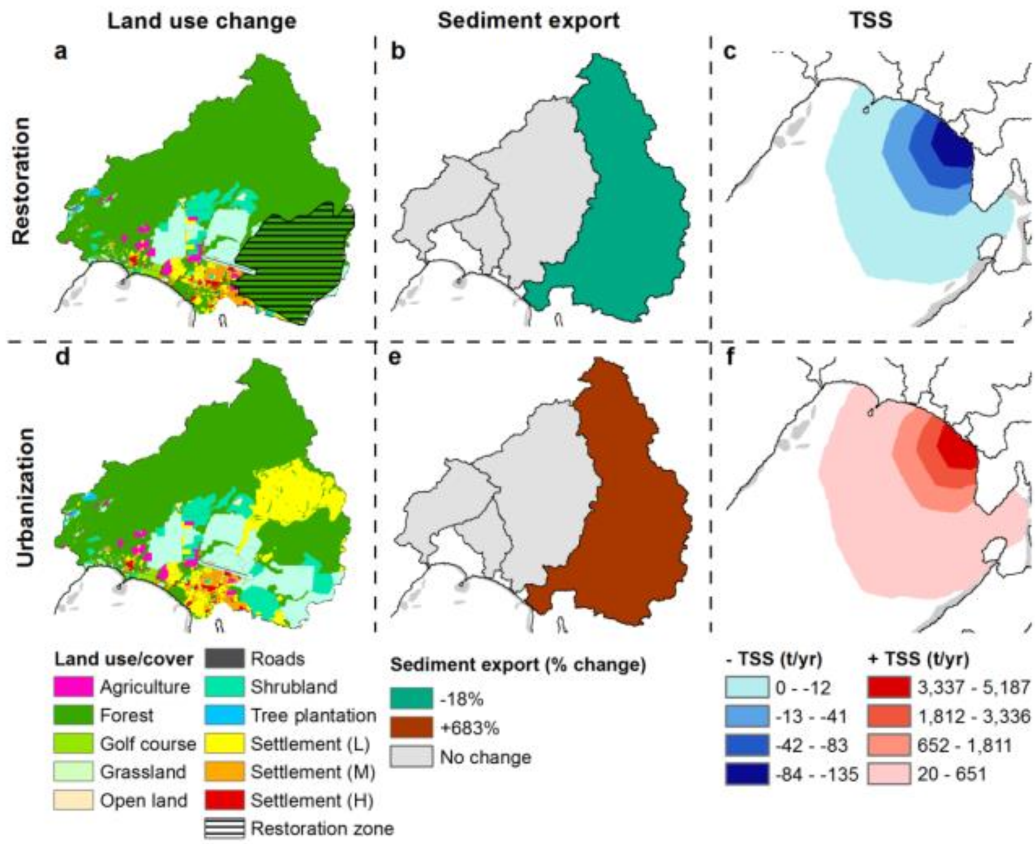

Figure 4: Mele Bay land-use scenarios: change in land cover, sediment export, and TSS. (a-c) restoration and (j-l) urbanization

Many different habitats are associated with rivers and streams (Figure 5). They include areas defined by flow type (e.g. rapids and pools), morphological features (e.g. gravel bars, riverbanks), or dominant plant species (e.g. bankside woodland or beds of aquatic plants). Habitats intimately connected to rivers include associated wetland areas, swamps, floodplains and woodland.

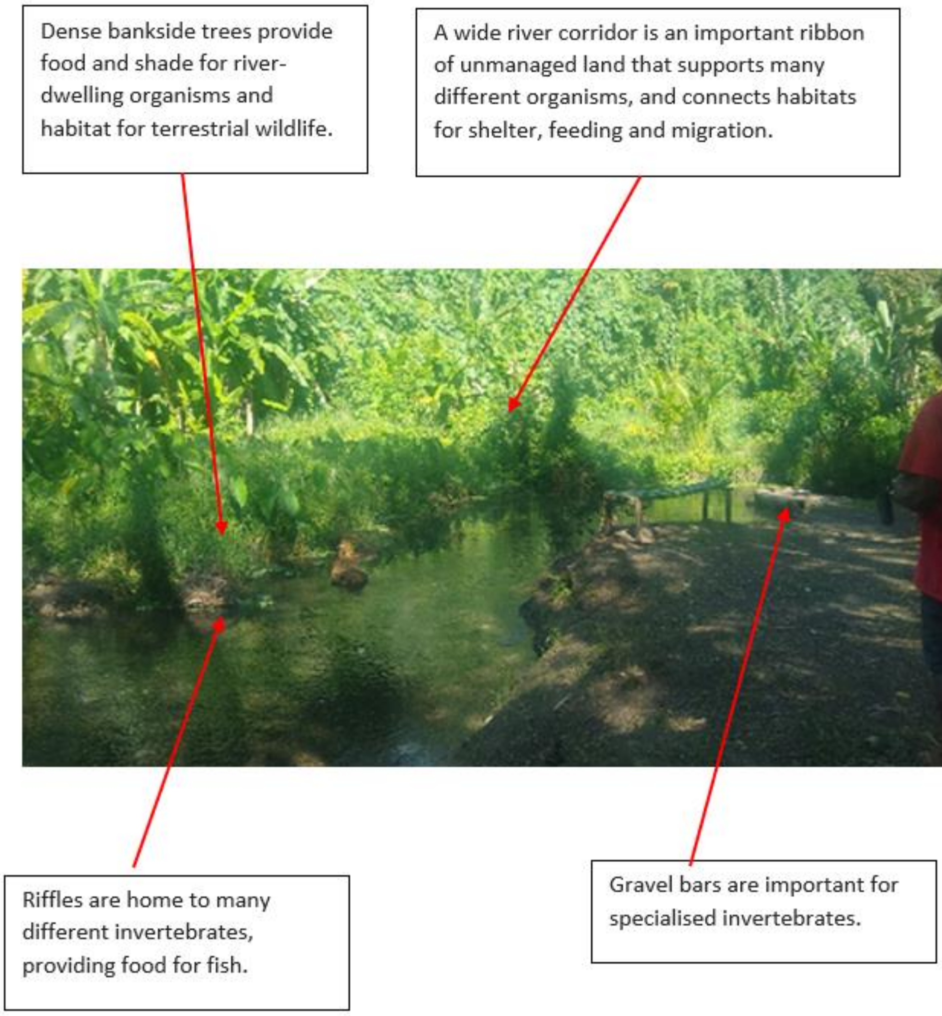

Figure 5: Tagabe river habitat along the Area 3.

The Tagabe Riparian Corridor Regeneration Project is currently in its implementation phase[1], which focuses on the riparian margins of mid to lower catchment streams throughout the catchment. Its purpose is to build resilience within the riparian system, which will reduce risks and impacts associated with floods, droughts and cyclones, and will improve water quality for human consumption and the habitat for freshwater and inshore marine fish stocks. This project encompasses three activity types: a) riparian revegetation and stream bank protection using vetiver grass – primary intervention;

b) sustainable land management of adjacent farmlands; and c) point source pollution prevention and remediation.

Riparian management options and five-year performance targets have been presented within a Project Implementation Plan. These include:

1. Riparian revegetation
    - Implement a 20% increase in riparian woody vegetation against the baseline values
    - Implement a 20% increase in agroforestry plantations against baseline values
2. Sustainable land management
    - 20% reduction in fertiliser use across 80% of the riparian areas
    - 40% reduction in cattle with direct access to the waterway
3. Pollution protection
    - 30% reduction in untreated point source pollution

This study recommends EbA approach using vetiver grass as the primary activity for restoration and protection of vulnerable riverbanks in Area 1 (Figure 6) and used complementary with other no regret measures for Area 2 and Area 3. Additional NbA measures could include the following actions, which include additional stock fencing which will support target Area 1. No regret measures (riparian buffer of 20 m etc, waterway clean up) can be implemented in Area 1 and 2, to stop any further encroachment.

Table 2: Classification of vulnerable catchment zones

Area	Characteristics
1	High-risk area, urgent need of riverbank rehabilitation. Most of the area along the river is highly populated.
2	Requires rehabilitation in the medium term. Not as highly populated as Area 1. Through the project, EbA riverbank protection approaches are to be replicated in Area 2.
3	Requires rehabilitation in the medium term. Not as highly populated as Area 1. Through the project, EbA riverbank protection approaches can be scaled up to vulnerable riverbanks in Area 3.

Also discussed are other options that offer advanced stabilisation techniques, such as using large woody debris or snags that can help control the grade of channel beds, contribute to pool formation, and armour both bed and banks against erosion.

Other NbS activities like encouraging greater storage in the streambed, can also help to increase the rate of replenishment of groundwater aquifers also presented.

Figure 6: waterway clean-up in Tagabe river

Woody debris also provides important habitat for fish, algae and macro-invertebrates.

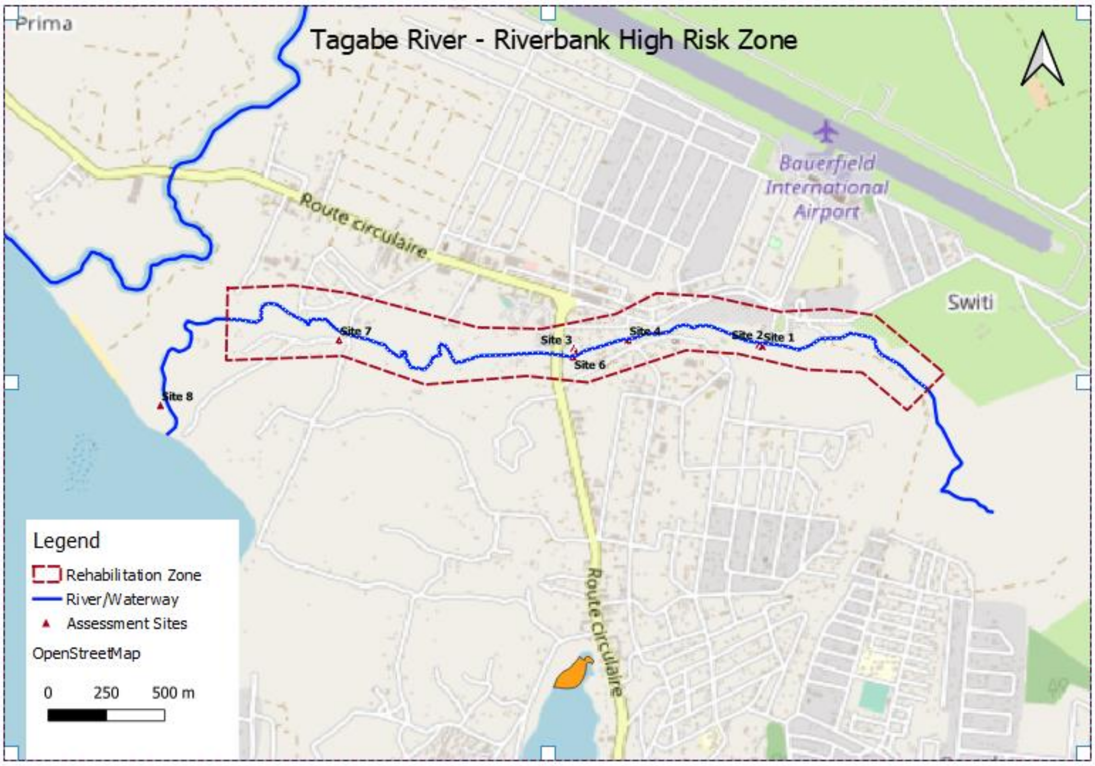

Figure 7: High priority areas for EbA interventions

Table 3 below illustrates the vulnerable zones along the Tagabe river system, focusing solely on areas provided in Figure 7. It also illustrates the least cost and no regret options for rehabilitating vulnerable riverbanks in these areas.

Table 3: Characterisation of vulnerable riverbank zones of Tagabe river system

Site	Current Status	Urgency	No regret option	Recommended Action
Site 1		Most of the vegetation currently forms part of the stream and active flow channel. There are minimum high slope areas, that would be vegetated with vetiver. This can be vegetated in the medium term.	1. 20 m buffer of either bank over of the river – stop any encroachment (farming, dwelling, clearing etc).	1. Rehabilitate grassland areas with vetiver for bank protection and fruit trees and native forest species for food security and economic wellbeing.
Site 2		The unvegetated area is an active part of the stream, hence any attempts to rehabilitate should consider potential scenarios during high flow events.	1. 20 m buffer of either bank over of the river – stop any encroachment (farming, dwelling, clearing etc). 2. Protection of shallow rapids (aquatic biodiversity)	3. Rehabilitate bare stream areas with vetiver for bank protection and fruit trees and native forest species for food security and economic wellbeing.

Site 3		Both banks are sloped and could be rehabilitated with the vetiver grass. Site for immediate rehabilitation.	1. 20 m buffer of either bank over of the river – stop any encroachment (farming, dwelling, clearing etc).	1. Riverbank protection using vetiver grass and bamboo where applicable
Site 4		The site is in immediate need of rehabilitation. Steep banks and instances of bank erosion are evident.	1. 20 m buffer of the bank over of the river – stop any encroachment (farming, dwelling, clearing etc).	1. Rehabilitate riverbank using vetiver.

Site 5		This site also requires immediate riverbank protection.	1. 20 m buffer around the riverbank for any encroachment activity	1. Rehabilitate riverbank using vetiver.
Site 6		This site also requires immediate riverbank protection works. Evidence of bank erosion	1. 20 m buffer around the riverbank for any encroachment activity	1. Rehabilitate riverbank using vetiver.

Site 7		Riparian vegetation cleared by the community, urgently requires riverbank protection.	1. 20 m buffer around the riverbank for any encroachment activity	1. Rehabilitate riverbank using vetiver.

6.2 Site Details

Site 1 and 2

Figure 8: Sites details 1 and 2.

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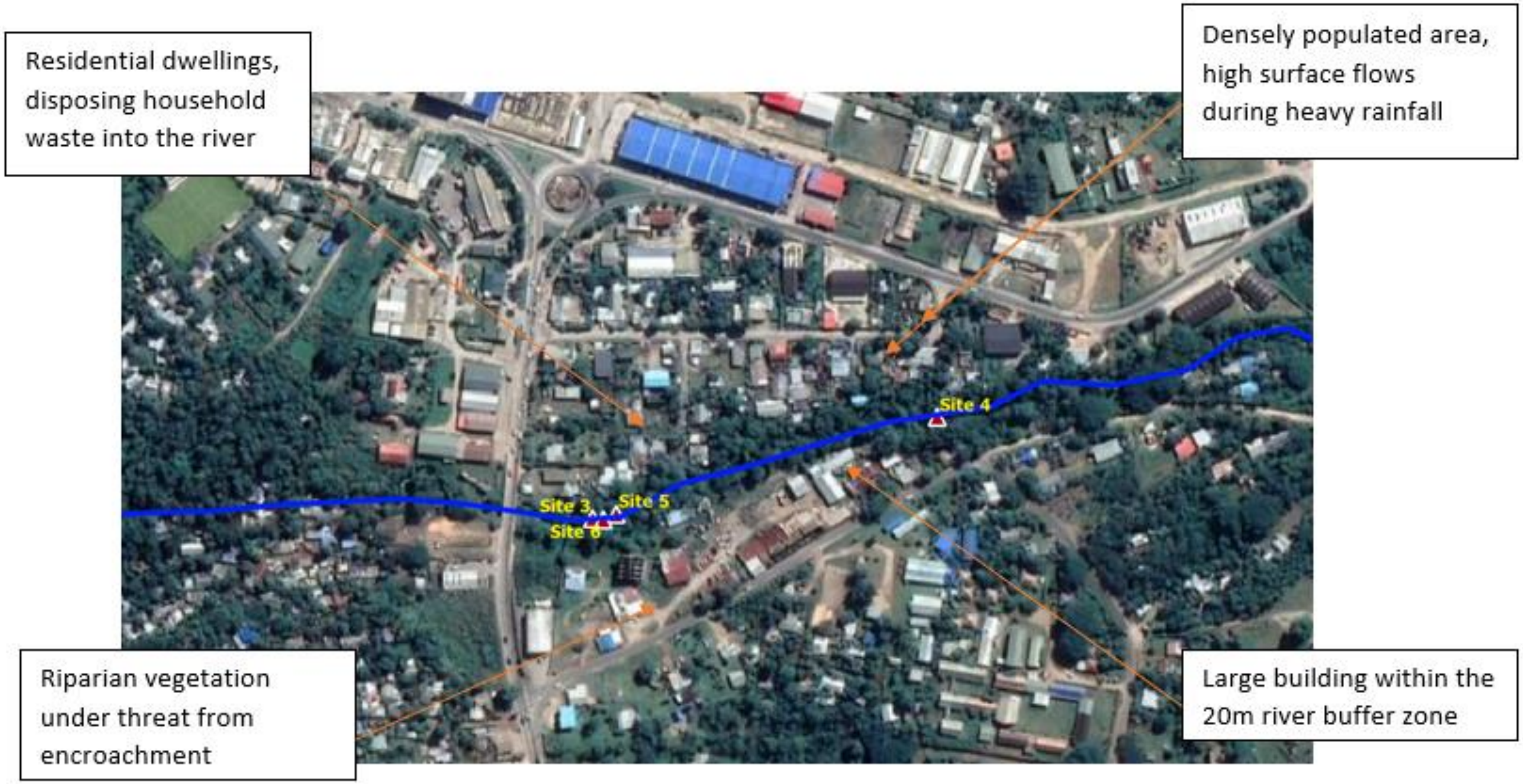

Figure 9:Site details 3 to 6

Site 7

Figure 10: Site details 7

As indicated above, this study recommends community-centric riverbank stabilisation using vetiver grass as the primary intervention for the restoration of vulnerable riverbanks in the Tagabe catchment. Other interventions that are applicable for the area is illustrated below are based on its bio-engineering prospects, costs and effectiveness.

Figure 12 below illustrates the riverbank slope and the suitability of vetiver grass for riverbank stabilisation. The riverbank slopes in Area 1 in of the Tagabe catchment are consistent with slopes given below and hence suitability for the use of vetiver grass to riverbank restoration.

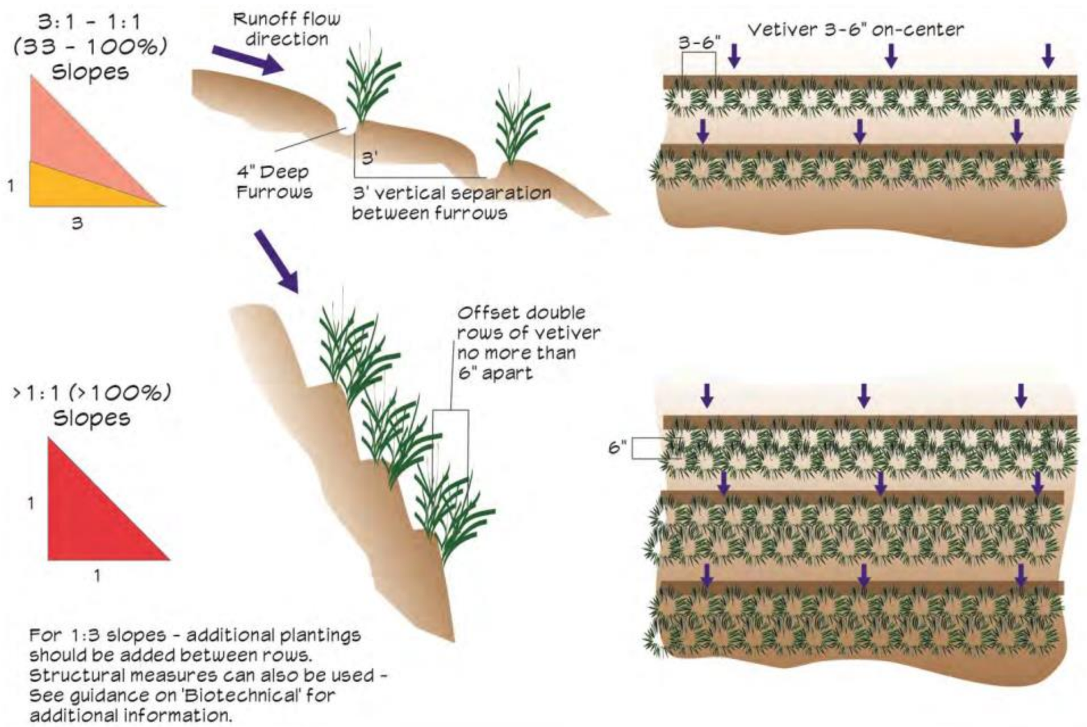

Figure 11: Riverbank stabilisation based on the slope (similar to certain bank slope in Area 1)

6.2. Riverbank stabilisation through Vetiver Grass

It is highly recommended that EbA using vetiver grass for riverbank restoration be upscaled in disturbed sites within the Tagabe river, high-risk zone (Figure 8-10) to address current riverbank degradation and soil erosion and promote the widespread use and utilization of vetiver for stabilization of all its vulnerable riverbanks within the catchment. Riverbank erosion is becoming more prevalent, it is becoming a threat to communities and livelihoods of people depending on the land along these streams.

When planted in a row in close space, the vetiver plant will form a hedge, a living porous barrier that slows and spreads runoff water and traps sediment. As the water flow is slowed down, its erosive power is reduced and at the same time allows more time for water to infiltrate the soil, and any eroded material is trapped by the hedges. Therefore, an effective hedge will reduce soil erosion, conserve soil moisture, and trap sediment on site. This is in sharp contrast with the contour terrace/waterway system which runoff water is collected by the terraces and diverted as quickly as possible from the field to reduce its erosive potential. All this runoff water is collected and concentrated in the waterways where most erosion occurs, particularly on sloping lands where this water is lost from the field.

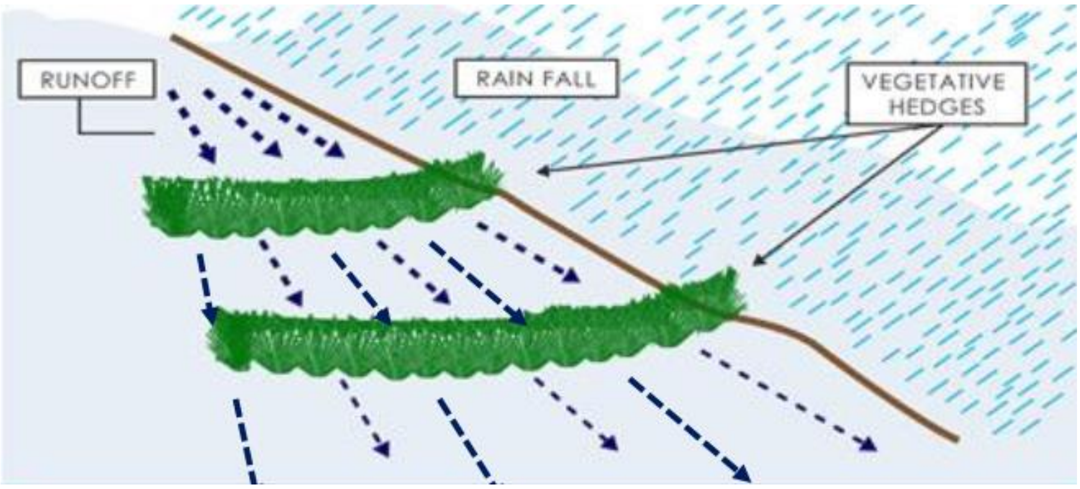

Figure 12:Vetiver system for soil and water conservation

With its extensive fibrous root system which penetrates deep down into the soil at great depth (2m in the initial year then 5+ as the soil builds up). Its roots were found to break through hardpan as thick as 15cm. They were also found to have 'innate' power to penetrate a fairly thick layer of asphaltic concrete. On slopes underlain with weathered rock, boulders or relatively hard layers, its penetrating roots will provide anchorage by root tendon action. Its action is comparable to a nail which could penetrate deep layers of soils whose texture may be quite hard, and at the same time it can hold soil particles together through its extensive fibrous roots, thus avoiding soil erosion due to wind and water, making it well known among road engineers as the 'Living Nail'.

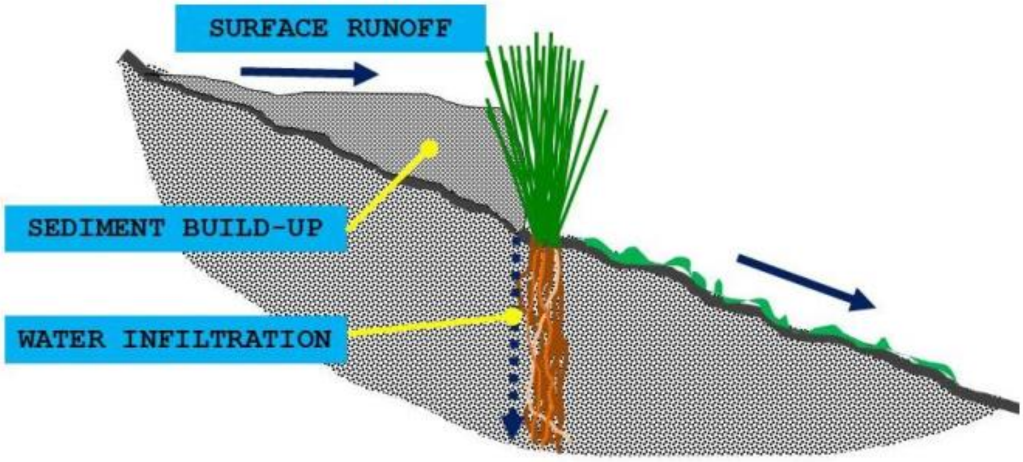

Figure 13: Illustrations of vetiver system for riverbank stabilisation

Further details on this are given in Annex 1.

6.3. Vetiver Project Costing

Table 4: Vetiver project budget

NO	EXPENDITURES CATEGORIES	TOTAL (US$)
1	1.1 Scoping and establishment of planting material Storage 1.1.1 Land Acquisition 1.1.2 Land Preparation 1.1.3 Fencing	 300 500 500
2	2.1 Planting 2.1.1 Vetiver slips for planting in the agreed nursery 2.1.2 Plant (Labor Cost for project duration)	 500 500
3	3.1 Planting material Storage Facility 3.2 Facility Implements 3.2.1 Irrigation equipment's 3.2.2 Fertilizer 3.2.3 Weeding 3.2.4 Trimming 3.2.5 Facility maintenance	 200 100 200 500 200 300
4	4.1 Uprooting and replanting 4.1.1 Uprooting 4.1.2 Site identification and labor cost for transplanting	 200 1,000
5	5.1 Community awareness and capacity building 5.1.1 Identify and clarify stakeholders 5.1.2 Revisit project design with stakeholders 5.1.3 Capacity Building and Stakeholder Consultation 5.1.4 Community training 5.1.5 Establishment of community-based nurseries 5.1.6 Catchment planting (3000m of vulnerable riverbank)	 200 200 300 300 200 9,000
6	6.1 Contingency	1,000
7	7.1 Total Budget	16,200

The budget in Table 4, above outlines the budget for rehabilitating 3,000 m of vulnerable riverbank in Area 1 and 2, where intervention is required at the earliest. The budget also includes the provision of setting up of vetiver nursery that should ensure supply of high-quality vetiver slips for replanting. It also entails budgetary requirements for community awareness, community vetiver nursery and training on the use of vetiver technology for riverbank stabilisation, to mobilise communities to identify and start rehabilitating vulnerable riverbanks. Such actions aim to transform the current way of building resilience and adapting to climate change where much is dependent on the government and gives communities opportunities to lead their adaptation efforts.

Further details on the use of vetiver for riverbank stabilisation is given in Annex 1. Other details on implementing the vetiver project are given in Annex 2 to 3.

Other options are listed below. These options may not be as cost-effective as using vetiver grass for bank rehabilitation, how are presented to provide options that may be considered given the availability of financial and technical resources.

6.4. Other Options

The following presents other approaches that could be implemented to address riverbank stabilisation requirements at the study sites. These interventions may have additional socio-environmental safeguards requirements and are presented for information.

6.5.1 Timber piling

Piled groynes use timber driven vertically into the riverbank to deflect flows and encourage accretion of sediment in the resulting low-energy areas adjacent to the. The piles are installed shore-normal or at an angle (typically 30º- 45º/N) to the bank facing in a downstream direction.

Timber piles are considered an example of a soft engineering approach to riverbank stabilisation; however, they tend to have a limited design life unless treated (nominally 10 years) (Bruce & Geosystems, 2000). During the design life, it is expected revegetation allows the surrounding area to stabilise, which will continue to function after the slow degradation of the wooden piles. Design considerations include the driveability of the piles and whether they have sufficient strength to be pressed through the underlying material. Typical pile spacing would be between 0.3m to 1.0m intervals, where one run of the pile would overlap with the start of the next run to ensure the bank is protected.

Figure 14: Example timber piles in Australia – Top: South Pine River, QLD, Bottom: Mossman, QLD

Some of the limitations of timber piles include:

1. Timber piles have small bearing capacity.
2. Untreated timber piles above groundwater may last more than 25 years but are not permanent.
3. Timber piles are prone to damage by hard driving.
4. Timber piles cannot be driven through hard stratum or boulders.
5. Piles of longer length may not always be available.

6.5.2 Log jams

A log jam is a nature-based groyne structure consisting of logs fixed along the riverbank and interlocked together, designed primarily as an erosion control structure. It is inspired by natural log jams, which are observed to be stable in a dynamic alluvial environment and prevent bank erosion through altering flow path and deflecting flow away from eroding banks. Log jams also provide complex cover and scour pools to create fish habitats, potentially increases the sequestration of nutrients, and can improve water quality. During construction placement of the structure will need to consider the waterway currents and potential erosion caused by altering the local flows. Designs would need to consider the jam geometry, including individual log dimensions, number of logs per layer, number of layers etc.

Whilst a potential NbA option for the river, given the Tagabe Integrated Water Resource Management Plan (DGMWR (2007) states the catchment requirement for *"no damming of any stream, creek or river, no matter how small"*, it is unlikely this option would be permitted.

Figure 15: Example log jam (Damian Leeding Park, QLD, Aus)

Some of the limitations of log jam include:

1. Lifetime is not temporary, depending on the type of log used
2. More resources is needed since large size logs are needed

6.5.3 Rock fillets – fish-friendly seawalls

If a suitable rock source is available, rock fillets could be used to support bank stabilisation, reducing erosion rates and encouraging the natural recovery and germination of riparian vegetation. A rock fillet involves the placement of rock just out from the toe of the waterway banks, which will absorb any wind-wave and current action and create an area of still water between the fillet and the bank. This still water area encourages the accumulation of sediment and provides a habitat that is suitable for the natural regeneration of riparian species. Their construction within the river would be dependent on available materials, ideally using rock with a diameter around 300mm. A typical fillet length could extend u to 5m long, 1.2m wide and 0.5m tall, which would require around $3m^3$ of rock each. Rock fillets are generally keyed into the riverbank at the upstream end and laid parallel to the bank, overlapping each other at the downstream end. When installed correctly, they maintain tidal flushing regime, fish passage and natural recruitment of mangrove seedlings into areas behind the structure. Examples of successful mangrove restoration behind a rock fillet is shown in Figure 19.

Figure 16: Typical rock fillet after construction and following mangrove establishment ((Jenkins & Russell, 2017)*)*

The limitations for rock fillet include:

1. Cannot withstand strong force of water such as flooding and stormwaters
2. Needs a lot of resources such as rocks and manpower

6.5.4 Riparian stock fencing

Introducing new fencing to restrict livestock accessing a waterway is a simple and relatively cost-effective approach to improve bank stability and river health, and to allow natural revegetation to occur. Fences should be at least 5 metres from the top of the bank, and ideally further (e.g. 20m or greater) where possible, or in areas where the bank is higher and erosion is actively occurring. Along freshwater reaches of a watercourse, fencing should be coupled with revegetation activities, including active weed control and periodic monitoring.

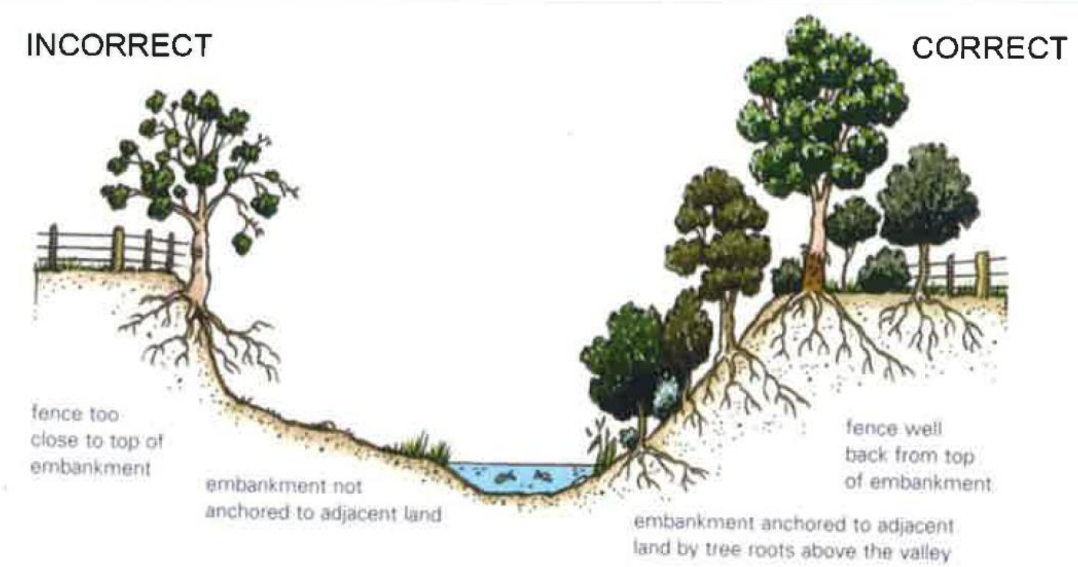

Figure 17: Schematic of stock fencing and revegetation (Source: Bellinger Landcare)

Riparian stock fencing would require a lot of consultations in residential areas and might also need more resources such as fencing material and manpower.

7. Next steps

The seven sites have been identified from the field assessment and are targeted to address riverbank erosion and rehabilitate particular zones contributing to streambed erosion:

- Areas experiencing bank erosion
- Areas where the stream has been straightened
- Areas that have been modified, e.g. for the extraction of sand and gravel
- Areas with excessive bed control measures such as weeds

Riverbank stabilisation using vetiver grass is the preferred intervention for vulnerable sites identified in this report and given Table 3 and Figures 9 to 11, especially for the sites where riverbank erosion is prevalent, where gravel extraction has modified geomorphological features of the river.

In each occurrence, the main aim is to address the erosion of riverbank and to stabilise riverbanks through EbA approach through additional root mass and cover. The secondary consideration is given for addressing dissipation of the stream energy through the introduction of increased friction and/or turbulence, and to capture additional debris through the introduction of woody structures.

This study further recommends the following for increasing awareness on EbA/NbA approaches for riverbanks stabilisation.

- Promote understanding of the scope and application of nature-based solutions (NBS) at the national level for riverbank stabilisation and restoration and its linkages with ecosystem services.
- Explore specific NBS opportunities and promote current options for promoting community-centric EbA approaches for riverbank stabilisation.
- Assess processes and causes of degradation at the catchment scale to inform the implementation of the right restoration measures in the right places and at the right scale that tackle the root causes of degradation.
- Engaging local communities and governments for the implementation of EbA projects such as vetiver: The community should be engaged in

planting and the monitoring of the vetiver, its survival rates and maintenance. This has implications for the project's success.

- Streamline regulations and permission processes to aid the implementation of small-scale, low-risk restoration projects.
- Consider innovative approaches to compensating communities for engagement in EbA activities.
- Communicate the principles and benefits of river restoration using vetiver grass to raise its profile, overcome barriers, and help inform future projects. In particular, tailor the messages depending on the audience, promote the long-term and catchment-scale benefits and share knowledge with others.
- Promote river restoration as an activity that overlaps with other conservation, landscape restoration and policy drivers to reinforce its added value.

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Annex 1: Planting guideline for Riverbank Stabilisation

To Reduce Sheet and Rill Erosion

While the best way to prevent soil erosion is to reduce soil disturbances and increase cover, vetiver can be used to reduce sheet and rill erosion. Vetiver rows planted at intervals can reduce slope length and, to a degree, reduce the slope. Interval planting is effective when the alignment results in cross slope or contour farming. To be effective, no gaps between plants must exist. Gaps created by dead plants must be quickly re-planted. Erosion reduction is achieved when the vetiver interrupts runoff flow. Barriers can be planted on contour lines, if fast drainage is needed, the gradient along the barrier should not exceed 0.2 and 1.0 percent, except where the vegetative barrier crosses concentrated flow areas. In concentrated flow areas best to plant two rows of vetiver close together. The vertical interval for bioengineering applications, the spacing between rows (i.e. horizontal, not vertical, interval) can be

1m to 2 meters, with the 1m spacing used on more erodible soil, and 1.5- 2.0m on more stable soil. For on-farm soil conservation, a VI of 2.0m is generally adequate.

A single line of vetiver, sometimes called a hedgerow, is often not sufficient to adequately prevent soil erosion. The number needed and distance between hedgerows will depend on the slope, soil conditions, and the severity of the problem. As a general rule of thumb, the vertical interval, or elevation change, between two hedgerows should not exceed 1m VI (vertical interval) when used to reduce sheet and rill erosion.

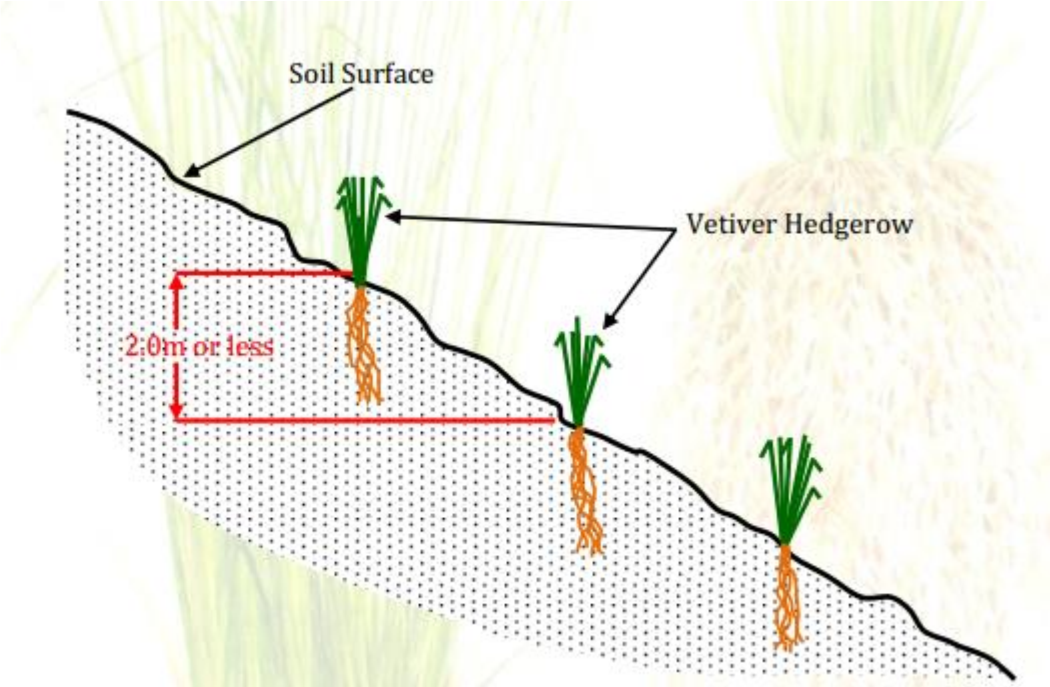

Figure 18: Vertical interval (elevation change) between vegetative barrier hedgerows is generally set at 1m (highly erodible soil), and should not exceed 2.0m when used to reduce sheet and rill erosion

Vetiver hedgerow will stay where it is planted and the sediment that is spread out behind the hedgerow will gradually accumulate to form a long-lasting terrace with vetiver protection as illustrated below.

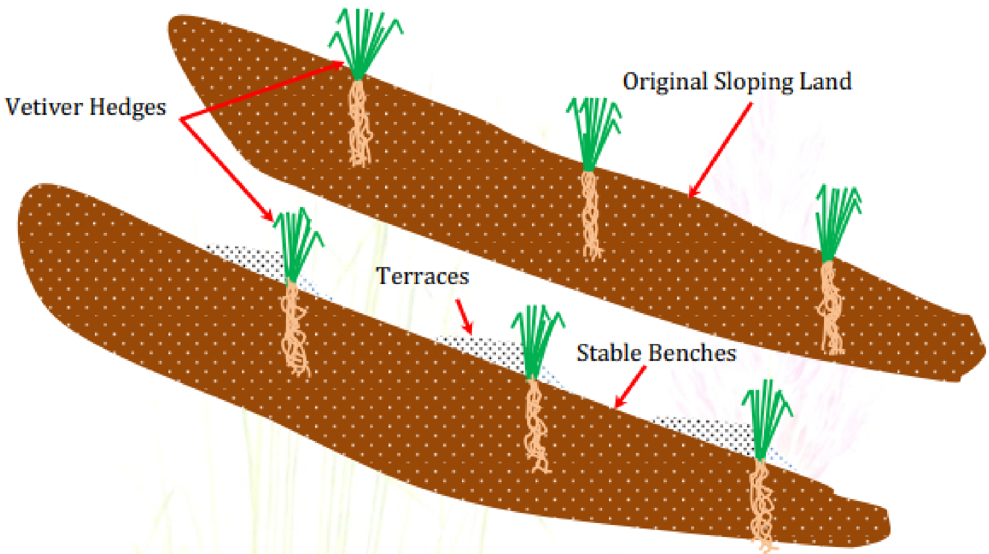

Figure 19: Overtime, soil deposits up-slope of the vetiver hedges form terraces and stable, less sloping benches. The vetiver helps to support and protect terraces

To Reduce Gully Erosion & provide grade Stabilization

In concentrated flow, areas plant vegetative barriers perpendicular to the direction of water flow. Higher plant densities are needed to withstand hydrologic forces in concentrated flow areas; therefore it is recommended to plant vetiver slips in double rows with 15cm between slips and 15cm between rows.

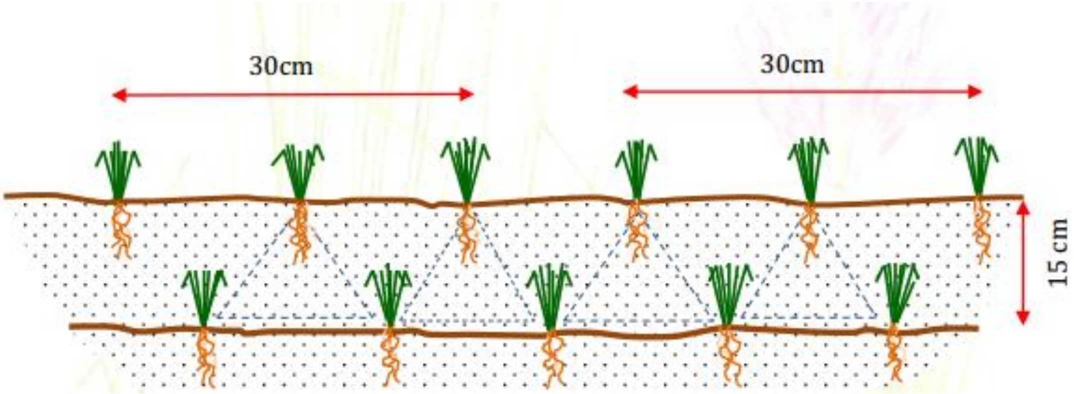

Figure 20: Vetiver barriers perpendicular to the direction of water flow

Single rows of vetiver are adequate for basic applications. For areas with the concentrated flow, or those warranting extra protection, vetiver slips are planted in two rows with 15cm between the rows and 15cm between plants within the row. Rows are slightly offset, resulting in plants per linear meter.

Spacing between multiple vegetative barriers in a gully will be based on a vertical interval of 50cm for conditions where no-tillage is performed between the barriers and 1m for all other conditions where sediment deposition and bench development is anticipated.

When water ponds between the barriers, it dissipates the energy of water flowing over them. Sediment deposits out of the ponded water provide a flatter, more stable channel. Start planting vetiver at a stable downstream location—at the bottom of a gully where the slope of the flow line flattens out, or above a hardened point in a channel. Continue planting to upslope of the top of the gully or section of the channel to be stabilized.

Each strip should extend far enough to provide at least 50cm of elevation from the centre of the flow area to the end of the vegetative barrier. Because vetiver will grow on accumulated sediment, the overflow level at the center will rise over time. Extending the vetiver to greater than 50cm above the center elevation will increase the life of the barrier and ensure that water will not flow around the sides of the barrier.

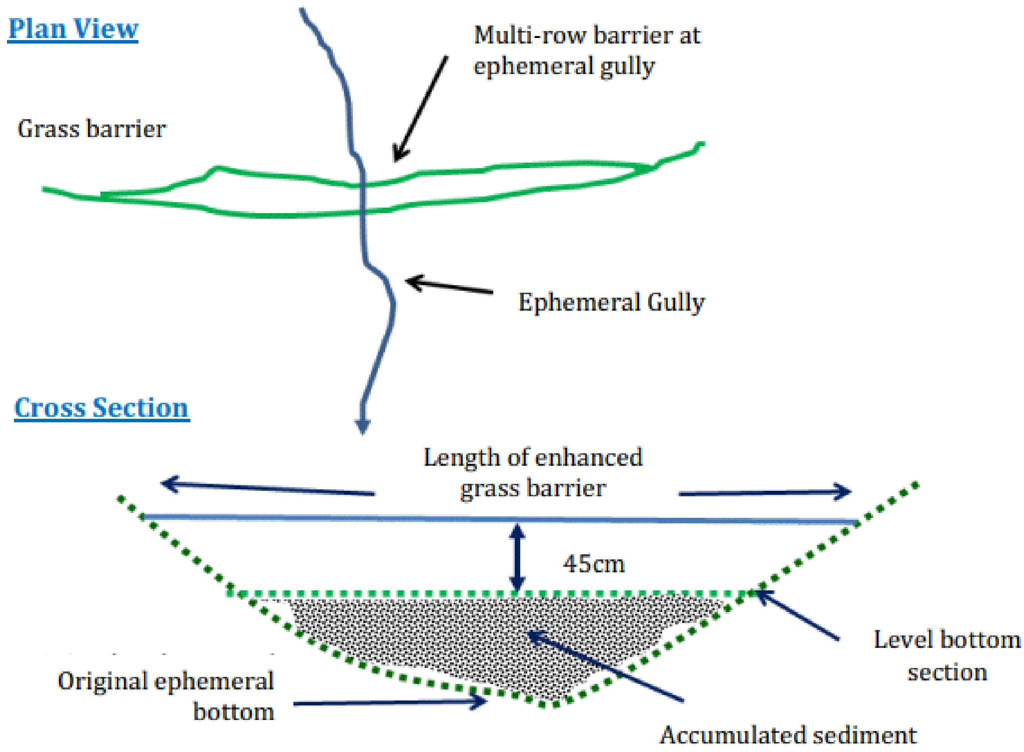

Figure 21: Vegetative barrier in concentrated flow areas must extend at least 45cm in elevation to avoid bypass around the ends at high flow.

Grade stabilization is often needed in steep forming channels to establish a non-erosive channel grade. The most common sign that grade stabilization is needed in a channel is the presence of head cutting.

Components of grade stabilization include structures that pond water in the flow channel, each with a controlled overflow and energy dissipation. Structures provide vertical intervals of 50cm, and are placed to create a stable channel slope. Structures in steep channels, while placed closer together than ones in flatter channels, will have backwater from one structure extending up to the base of the next structure which will help to dissipate energy and reduce the requirements for energy dissipation. Without backwater, it will be necessary to install an energy dissipating basin. Typically, this involves the shaping of a basin and installation of geotextile, gravel bedding and rock riprap.

In channels that are wide and that have gradually sloping banks; vetiver can be used as a grade stabilization structure. Higher plant densities, and care to ensure no gaps occur in the planting, will be needed for the vetiver to pond water and withstand concentrated flows over the planting. Plantings will need to extend up the sides of the channel to ensure that flows go over and not around the vetiver. To increase the weir length, angle the arms of the vetiver up the bank in a downstream direction to the required design depth, then outward perpendicular to the channel 2m more in vertical height.

To Stabilize Steep Slopes and Riverbanks

Vetiver can be used to stabilize steep slopes like roadsides and riverbanks, keeping in mind the difficulty of establishing vegetation on slopes that are steeper than 2 horizontal:1 vertical (50% slope). It is recommended to use vetiver in combination with critical area plantings, tree/shrub establishment, riparian forest buffers, filter strips, and conservation cover to maximize effectiveness. Where possible, eliminate concentrated flow channels by installing diversions or terraces to remove runoff from the upslope of the site and periodically along the slope.

The barriers should be installed on the contour, at a horizontal spacing between barriers resulting in a vertical interval of 1m. If the overland flow is expected down the slope face, however, the barrier alignment may deviate from the contour up to a grade of 2% to divert water if the spacing is adjusted so the vertical interval between barriers is no greater than 1m. VI on steep slopes should be 1m, and in extreme cases, VI of 0.8m is recommended.

As a general rule of thumb, banks with slopes steeper than 2:1 cannot be stabilized just with vegetation. It may be necessary to decrease the slope by cutting back the banks to achieve a 2:1 slope. In the case of streams, this may increase the top width significantly. If stream conditions allow, vetiver can be planted at the bottom of the slope, whereby subsequent deposition causes a reduction in the bank slope

Figure 22:Planning riverbank stabilisation with vetiver in Fiji

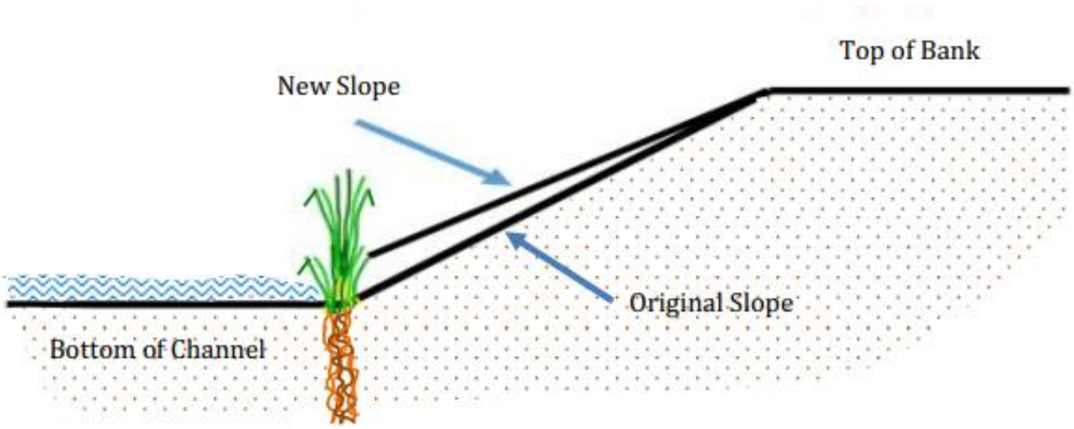

Figure 23: Vetiver can be planted at the bottom end of the slope and capture deposition, resulting in reduced slopes due to the build-up of sedimentation

Principles of the Vetiver System for River Bank Stabilization

In flood erosion control and riverbank stabilization, the VS uses the deep and high tensile root system to reinforce the bank slopes and its dense and stiff stems to spread and reduce flow velocity.

To stabilize the bank steep gradients, horizontal rows are planted on approximate contour lines.

- To reduce the flow velocity of the strong current, therefore, preventing scouring from the strong flow, planting of cross rows is needed.
- For maximum effect, the cross rows are orientated at the right angle to the flow direction.
- The spacing of both horizontal and cross rows varies with slope gradient and length, soil type, flow velocity and depth.
- Where the river bank has year round running water at its base (particularly on the outside bend) it is likely to undercut (eroded) by water current and

may collapse – in such instances, “hard” measures need to be taken to prevent such undercutting.

Planting Procedure

Planting Distance

- For poly-pots a minimum of 6 pots per meter is required.
- For strips the distance is already fixed, which avoids the problem of wrong planting distances.
- For bare-root slips one needs 7-8 slips/meter, but in semi-arid areas, this number may be up to 10 (Vetiver is a social plant, doing better with other Vetiver plants close-by).

Figure 24: Illustration of how to space vetiver planting

Preparing Furrows

Dig furrows deep and wide, in semi-arid areas the furrows depth may exceed 10 cm. This is very important, to ensure that the crown of the plant develops under the soil, that enough water is infiltrating, and to prevent washout by heavy rains in early stages.

If the furrows are deep enough, watering frequency can be reduced to three times or twice weekly (as long as enough water is indeed applied), also depending on the circumstances, and keeping in mind that water has to assure root growth but too frequent watering will not give the plant enough stress to speed up its rooting downwards in search of water.

Especially in semi-arid areas the dugout soil needs to be improved; some good soil may be brought to the furrow if the soil is hard clayish. Most other soil types (sand, loam, stone), if furrows are well prepared, will accept plant growth during long hot days. Improve the soil further with manure/fertilizer, and put it back leaving a 4-5 cm deep trough to allow water infiltration.

Figure 25: Preparation of furrow and planting for bank slope stabilization (Vunimoli villageLabasa, Fiji)

Field Planting

- As long as the vetiver is planted when the ground is wet, or watered at the end of the day, it can survive a long period of drought after planting.
- On very small farms and fields where land is scarce and where farmers are reluctant to plant across their fields, vetiver should be planted on the field boundaries or along the footpaths.
- On non-arable lands that are heavily eroded, vetiver should be planted first across the gullies and around the gully heads. The excess material from the gullies can then be used for planting across the slopes in subsequent years.
- Gap filling is essential and should be done at the beginning of the wet season. The possibility of “layering” live culms across the gaps should be tried as a gap-filling measure.
- To encourage tillering and hedge thickening, the grass should be cut back to 30 to 50 centimetres after the first year. Cutting in the first year does have incremental impact on tillering.
- Termite infestation (attacking dead material) can be controlled by applying 1 kilogram of benzene hexachloride (BHC) for every 150 meters of hedge line.
- Once the vetiver has established (one month after planting), ploughing a small furrow immediately behind the vetiver hedge line helps to capture runoff and results in better growth of the plant.

Figure 26: Bank slope where the first planting was done in 2019 (yellow dotted lines) and the community doing the planting

Figure 27:Site clearing before planting

Figure 28: Vetiver propagation at a vulberbale riverbank

Annex 2: Site completion report template after planting

COMPLETION REPORT

1.0 SITE LOCATION DETAILS:

1.1 Name of site:
1.2 Name of contact person:
1.3 Phone contact:

1.4 Number of households:

[No. of houses/families]

1.5 Population:

2.0 WORKSHOP/TRAINING DETAILS:

2.1 Date of workshop/training:
2.2 No. attended:
[state how many men, women and children attended]

3.0 VETIVER PLANTING DETAILS:

3.1 Date of planting:
3.2 How many kg of vetiver used:
3.3 Length of river bank covered:
3.4 Width of river bank:

4.0 Financial Details:

4.1 Vetiver seedling cost:
4.2 Workshop/training cost:
4.3 Sevusevu cost:
4.4 Allowance's cost:
4.5 Any other costs:
4.6 Total cost:

5.0 LESSONS LEARNT/IMPROVEMENTS:

5.1 Any lessons learnt:
5.2 Any improvements to be made:

GENERAL COMMENTS:

Annex 3 : Scope of Works / Description of activities

The scope of work includes;

i. Formation of a technical working group to identify sites for nursery and land acquisition.
ii. Land preparation including bush clearance, where required.
iii. Establishing vetiver nurseries in all divisions to ensure sufficient high-quality planting stock is available and to allow for replicating in other areas.
iv. Design of pilot projects in selective steep basins where slope stabilization is critical and in need of such intervention.
v. Develop a long term plan for extensive use of vetiver inappropriate key areas in Tagabe Catchment in conjunction with stakeholder groups, local NGO and other government agencies.
vi. Monitoring of pilot projects after 1 month, 3 months and 6 months.
vii. Pilot results determination would be expected within 6 months of the start on site of actual vetiver planting.
viii. Introduce the concept of community-based sustainable land and water resource management using vetiver systems.
ix. Participation of local communities in National activities to share experiences in Vetiver systems for environmental protection and disaster mitigation.
x. Follow up monitoring and coordinating the development of potential new vetiver project sites around the country to eventually protect vulnerable river banks in Tagabe Catchment.