COMPONENT 1A - Project 1A4

Integrated Coastal Managament
COWRIE Project

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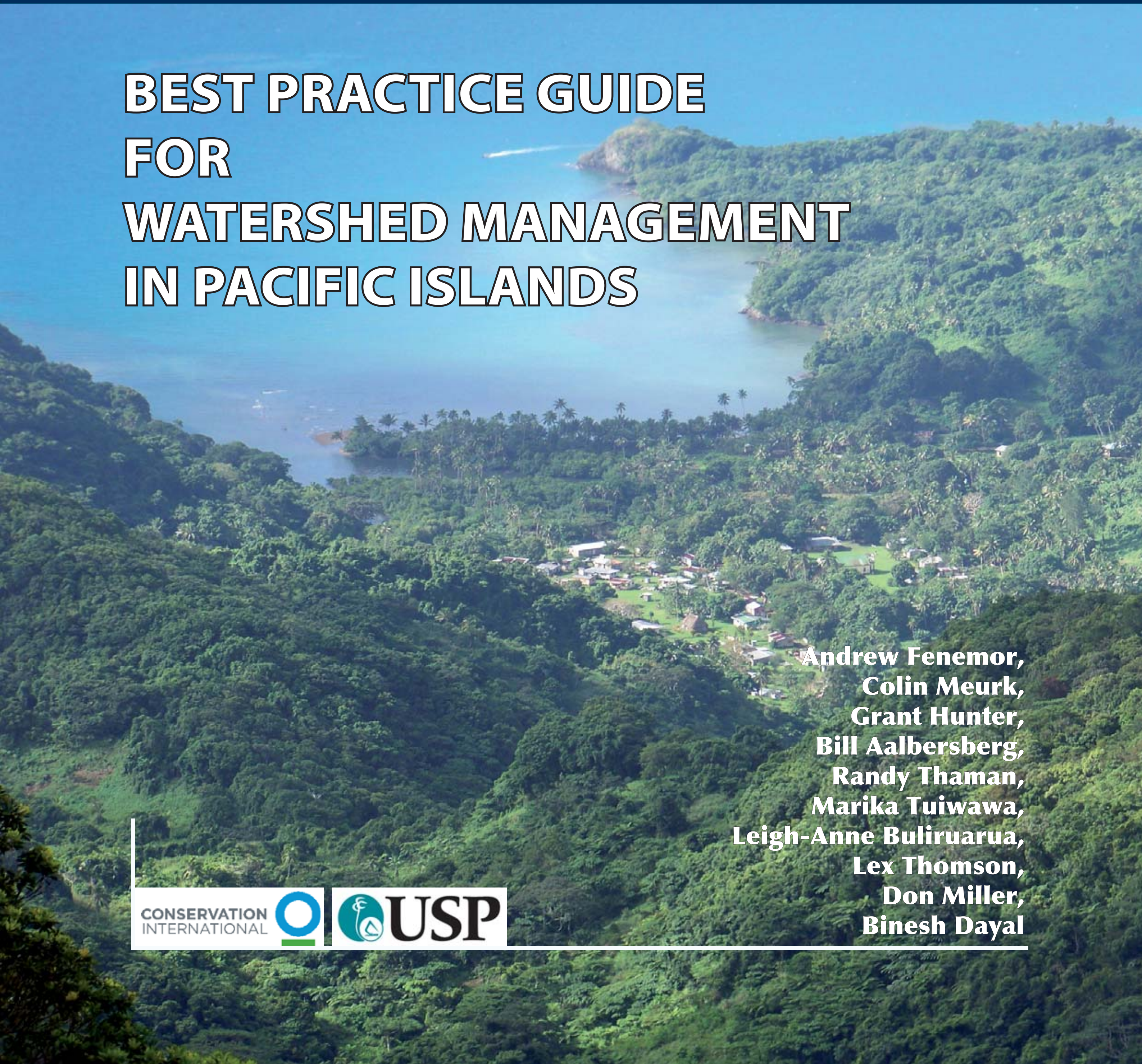
CRISP
Coral Reef InitiativeS for the Pacific
Initiatives Corail pour le Pacifique

GUIDE



BEST PRACTICE GUIDE FOR WATERSHED MANAGEMENT IN PACIFIC ISLANDS

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CONSERVATION INTERNATIONAL

USP

The CRISP Coordinating Unit was integrated into the Secretariat of the Pacific Community in April 2008 to insure maximum coordination and synergy in work relating to coral reef management in the region.

The CRISP programme is implemented as part of the policy developed by the Secretariat of the Pacific Regional Environment Programme for a contribution to conservation and sustainable development of coral reefs in the Pacific.

CRISP
Coral Reef InitiativeS for the Pacific
Initiatives Corail pour le Pacifique

The Initiative for the Protection and Management of Coral Reefs in the Pacific (CRISP), sponsored by France and prepared by the French Development Agency (AFD) as part of an inter-ministerial project from 2002 onwards, aims to develop a vision for the future of these unique ecosystems and the communities that depend on them and to introduce strategies and projects to conserve their biodiversity, while developing the economic and environmental services that they provide both locally and globally. Also, it is designed as a factor for integration between developed countries (Australia, New Zealand, Japan and USA), French overseas territories and Pacific Island developing countries.

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The CRISP Programme comprises three major components, which are:

Component 1A: Integrated Coastal Management and Watershed Management
- 1A1: Marine biodiversity conservation planning
- 1A2: Marine Protected Areas (MPAs)
- 1A3: Institutional strengthening and networking
- 1A4: Integrated coastal management

Component 2: Development of Coral Ecosystems
- 2A: Knowledge, monitoring and management of coral reef ecosytems
- 2B: Reef rehabilitation
- 2C: Development of active marine substances
- 2D: Development of regional data base (ReefBase Pacific)

Component 3: Programme Coordination and Development
- 3A: Capitalisation, value-adding and extension of CRISP activities
- 3B: Coordination, promotion and development of CRISP Programme

COMPONENT 1A – PROJECT 1A4

Integrated Coastal Reef Zone and Watershed Management

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The GERSA Project led by IRD – Space Unit 140 and the COWRIE Project, led by the Institute of Applied Sciences at the Universty of the South Pacific, both aim at developping methodologies and tools for the high Pacific islands, integrating interactions between watersheds and coral reefs, as well as local communities dynamics in the implementation of sustainable management system, for instance such as MPAs management plans.

The project 1A4 is composed of 5 main activities:

- *ACTIVITY 1: SPATIAL APPROACH (GERSA PROJECT)*
- *ACTIVITY 2: TERRITORIALITY AND SOCIO-ECONOMIC VALUES (GERSA PROJECT)*
- *ACTIVITY 3: ENVIRONMENTAL INFORMATION SYSTEMS AND MODELISATION (GERSA PROJECT)*
- *ACTIVITY 4: DYNAMICS AND MODELISATION OF WATERSHED (GERSA PROJECT)*
- *ACTIVITY 5: TOWARDS COASTAL AND WATERSHED RESTORATION FOR THE INTEGRITY OF ISLAND ENVIRONMENTS (COWRIE PROJECT)*

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EXECUTIVE SUMMARY

Accelerated erosion of soils associated with a growing population and demand for resources from the land, and disconnection from traditional, conservative land use practices, threatens land and water based livelihoods and communities in many hilly Pacific Island countries such as Fiji and Vanuatu.

This Best Practice Guide for community action and revegetation in Pacific Island hill lands applies Integrated Watershed Management (IWM) principles to promote management practices that reduce accelerated soil erosion, sediment loss and deposition in freshwater and nearshore marine waters and coral reefs. It seeks to support sustainable and productive land use, viable freshwater and marine fisheries, traditional cultural values, biodiversity and associated opportunities such as tourism.

There is a vast literature on IWM (also known as Integrated Catchment Management – ICM) which underpins this Guide. Fundamentally it is about understanding the cascading and linked effects of an event or action in a watershed or catchment, identifying problems or deterioration that affects natural processes, sustainable functioning, and ultimately human welfare, and conceiving measures that avoid, mitigate or remedy those effects throughout the catchment and its receiving waters.

Various case histories define effective measures that have been taken in and around the Pacific. In particular, coordinated community engagement and capacity building, modifying land use (eg timing and location of burning or land clearance and cropping, and avoiding earthworks in sensitive areas), and planting of grasses and trees known to grow fast on eroded ground, all seem to have worked.

This document collates information from the literature, previous discussions and forums held by COWRIE, and experience in Best Practice techniques employed elsewhere. Particular attention is given to use of revegetation and planting as a practical solution to long term catchment recovery. Smart planning, such as incorporating high value plant material that will motivate a more protective and nurturing attitude amongst land managers and communities, provides an incentive for community action.

The approach defines a series of steps: engaging communities and raising awareness, identifying problems and vision as part of a planning process, identifying erosion risk according to simple, easily applied field criteria, recognising where in the landscape these risk classes occur (based on land units on maps and oblique aerial photographs), ecologically characterising these land units, providing a palette of (safe) species suitable for each named land unit, providing choices among these palettes according to use value (timber, building, crafts, fibre, medicine, pasture, crop/food, and biodiversity), propagation process, applying planting and maintenance techniques that ensure best result for effort and resources, carrying out a monitoring regime and learning from the process through an adaptive management cycle.

Purpose of Best Practice Guide

This Best Practice Guide applies an Integrated Water Management (IWM) approach to reduce soil erosion and sediment loss in Pacific Island watersheds, through community and planting (revegetation) initiatives.

It seeks to reduce downstream sediment impacts on streams and marine resources, including lagoons and coral reefs, while maintaining sustainable and productive land use that protects or enhances local biodiversity, traditional cultural values and local economic activity.

The Guide provides a framework, planning process, technical advice, and planting checklists that contribute to these outcomes. Since time frames for achievement of goals will vary from years to decades, the sooner the principles are implemented, the sooner the benefits will be felt.

CONTENTS

PART 1 – PRINCIPLES FOR ACTION

1. Scale of the problem

In many Pacific Islands, increased population pressure, logging of indigenous forests and expansion of agriculture and grazing onto marginal lands has increased soil erosion and sedimentation (Figure 1). Some of the sediment from erosion is washed into streams and deposited in coastal marine areas. The increased sediment has negative impacts on the habitats of freshwater and near-shore marine ecosystems where it affects freshwater and marine fin fishes and other organisms, and chokes coral reefs (Figure 2). Both have a strongly negative impact on security of fisheries and food production.

Figure 1 – Example of eroded Pacific slopes, Vanuatu. Photo credit – Don Miller

Figure 2 – Sedimentation of corals. Photo credit – Don Miller

Sediment loss also results in loss of topsoil and agricultural production, loss of valued local plants, and reduced livelihood options such as cropping, grazing and tourism. We cannot afford to lose soil – our food production and the production of countless other goods and services depends on it. It is far more preferable to stop soil moving in the first place, because of the risk that sooner or later it will be washed into a stream and reach the coast.

With the economic constraints facing land users across the Pacific, it is desirable to have information on the economic costs of soil loss, not only to crop and animal production but also to freshwater and marine fisheries. These type of data are, however, rare. Morrison et al. (in Ziemer et al. 1990) summarise erosion assessments in Fiji (see Box 1). An average soil loss of 53 t/ha/year was estimated for the heavily forested Waimanu watershed. Widespread landsliding after heavy rains was attributed to shifting cultivation (Carpenter & Lawedrau 2002). Annual soil losses were reported to be as high as 24–79 t/ha/year, or up to 5.3 mm depth of soil lost each year. In areas converted from grassland or forest to sugar cane production, losses may be as high as 90–300 t/ha/year.

Box 1 – Case Study: FIJI

The Rural Land Use Policy Statement for Fiji (Leslie & Ratukalou 2002a) notes that increased population pressure, especially on land which is marginal for agriculture, has increased rates of soil erosion.

Fiji was once covered with forest. Open grassland, fernland, reed grass and savannah would gradually revert to forest if protected from fire and human use. However, the current areas of the very competitive introduced mission grass would require active reforestation.

Subsistence gardens are increasingly being forced onto steeper slopes. If traditional mulching is not practised, or fallow periods are too short, this may lead to soil loss. This leads to depletion of soil fertility, soil moisture deficits and decreasing productivity. Burning, especially of sugar cane residues and mission grass, worsens these effects.

Apart from commercial crops like sugar, ginger, yaqona and dalo, most farmers subsist on root crops, pulses and rice. A more diverse farming system with a mix of perennials, fruit and nut trees, as well as these subsistence crops, would increase income and self-reliance, as well as provide environmental benefits such as reducing soil loss.

Soil loss measurements show that the productive base especially in sugar cane and ginger growing areas is being run down faster than is economically acceptable. Estimates of annual soil loss in major catchments are 9.3 Mt in the Rewa River, 6.4 Mt in the Ba, 4.2 Mt in the Nadi and 1.1 Mt in the Sigatoka. The erosion index (EI) for Fiji's dry zones is 700 and for its wet zones 800; when EI exceeds 500, agricultural land requires careful management regardless of soil type.

Conservation and development go hand in hand. The *vanua*, the Fijian emotional attachment and duty of care for the land, must be reinvigorated. Both the Rural Land Use policy for Fiji and the Fiji Forest Policy Statement identify the need for an integrated, ecologically sustainable approach to reversing these trends; integrated natural resource management at the catchment (watershed) scale is essential.

Collective land ownership is likely to encourage communities in many Pacific countries to plant the most sensitive areas of watersheds – if they see a direct benefit. For example, in Fiji some 80% of land is native title under the custodianship of the Native Lands Trust Board, and much of this is leased out. In Vanuatu, all land belongs to the 'indigenous custom owners and their descendants'. Over 80% of Vanuatu's population and most of Fiji's rural Fijian population still depends on subsistence agriculture, which is done with shifting cultivation of forests, savannah or grassland areas and regrowth land. A community approach to planning watershed stabilisation and revegetation is recommended for these situations.

2. What can I control and what can't I?

In every watershed, the protection and planting of areas vulnerable to erosion, including riparian or riverside, mangrove and coastal vegetation, will help maintain productivity and prevent soil loss. Some watersheds or parts of watersheds (Figures 3 and 4), rivers and coastal areas are more sensitive to erosion because they have erodible soils, or are prone to heavy rainfall, or are naturally unstable in other respects. Human actions such as clearing of trees and forests, cultivation of steep lands, poorly sited tracks and other developments leading to concentration of runoff into channels worsen soil erosion and sedimentation.

Pacific communities can help protect sloping land, soil productivity, streams and rivers, and their lagoons and coral reefs by prioritising erosion control efforts into the most vulnerable areas, and the places where sediment is most likely to wash into streams and reach the coast. Although this guide focuses on replanting, it is stressed that the protection of existing forest and trees outside of forests is the most important first line of defence against increasing erosion and sedimentation, as well as against the loss of the diverse products and services that forests and trees provide.

While extreme events such as tropical cyclones cannot be prevented and cumulative erosion of slopes is a natural process, these processes are accelerated by deforestation and poor land management. These processes are naturally faster in higher rainfall and warmer climates. However, the negative impacts of extreme events can be reduced by taking an Integrated Watershed Management (IWM) approach so that negatively impacted environments, such as low country stream courses, coastal lagoons and reefs, have time to recover from periodic disturbances before they reoccur and become cumulative. The approach needed is to reduce the risk of soil loss, while recognising that, at times of exceptional rainfalls or on extremely erodible soils, revegetation alone may not be sufficient to prevent damage.

Watershed stabilisation is not simply a matter of planting or building erosion-control structures such as contour terracing, and leaving things to take care of themselves. Maintenance of plantings and structures is essential for them to hold the soil. Plantings that die for lack of weeding, protection, watering or other maintenance are a waste of the efforts made to raise and plant them in the first place. Plantings will not reduce erosion risk until they are well established, whereas erosion control structures are mostly effective from when first constructed.

Figure 3 – Deep-seated erosion unlikely to be prevented by planting. Photo credit – Marika Tuiwawa

Figure 4 – Typical watershed which would benefit from erosion control plantings. Photo credit – Binesh Dayal

3. Why a watershed approach?

A watershed or catchment is a basin within the landscape where all rain falling within its boundaries flows towards a single river outlet. Activities within a catchment affect the amount and quality of water and the amount of sediment downstream of any point in that catchment.

To improve the water quality and reduce sediment in a river or stream draining towards the coast, we must consider and manage all causes of erosion and poor water quality contributed by upstream events. This makes the whole, self-contained catchment (or watershed) a good basis for planning the management of processes, such as erosion and sediment loss, that lead to poor water quality and supply. This is because any negative activity in the watershed affects all downstream conditions.

Flows of water and the levels of nutrients, contaminants and sediments (contributing to pollution) in the water all start in the headwaters of the rivers or tributaries within the catchments/watersheds and then converge on, and may overload, the receiving waters, which include rivers, lakes/ponds, estuaries, mangroves, beaches, near-shore waters and coral reefs. This results in sediment deposition, nutrient enrichment and oxygen deprivation of the water, which may smother freshwater and marine aquatic life.

Impacts of water flows through watersheds accumulate over time and vary down the watershed and across receiving waters. These are called ‘cumulative effects’. For example, earthworks from building a road may wash gradually into a stream, and over a series of rainstorms gradually smother corals farther and farther offshore. Once the earthworks stabilise, some of the corals may recover, but if the sedimentation continues or increases, recovery is often not possible – reaching a point of no return.

Communities that manage these impacts at the watershed scale are well placed to achieve improvements because they address and prioritise sources of pollution – the effects of the pollution can be traced back to their causes, and therefore managed as a whole system. Communities and landowners within a watershed (or sub-watershed) take responsibility to work together. They are likely to be most effective if they target ‘hot spots’ such as localities where the risks of contaminant flows, like suspended sediment, are greatest.

4. Principles for Integrated Watershed Management

Integrated Watershed Management (IWM) is the process for guiding and organising land and water uses within a watershed, to provide desired goods and services without adversely affecting the land and water resources, and the values of those resources to the people of that watershed now or in the future. Because land and water use affect coastal waters, we need to think of the watershed as extending offshore (e.g. Gillespie 2008) – IWM must include coastal management. This is particularly true on high Pacific islands, where there is very close ‘connectivity’ between the upper parts of a watershed and coastal and marine ecosystems.

Research on IWM shows that (1) having a planning and monitoring process, (2) building capacity and support from communities within the watershed, and (3) using good scientific and local knowledge, are critical for success. These are shown in Figure 5.

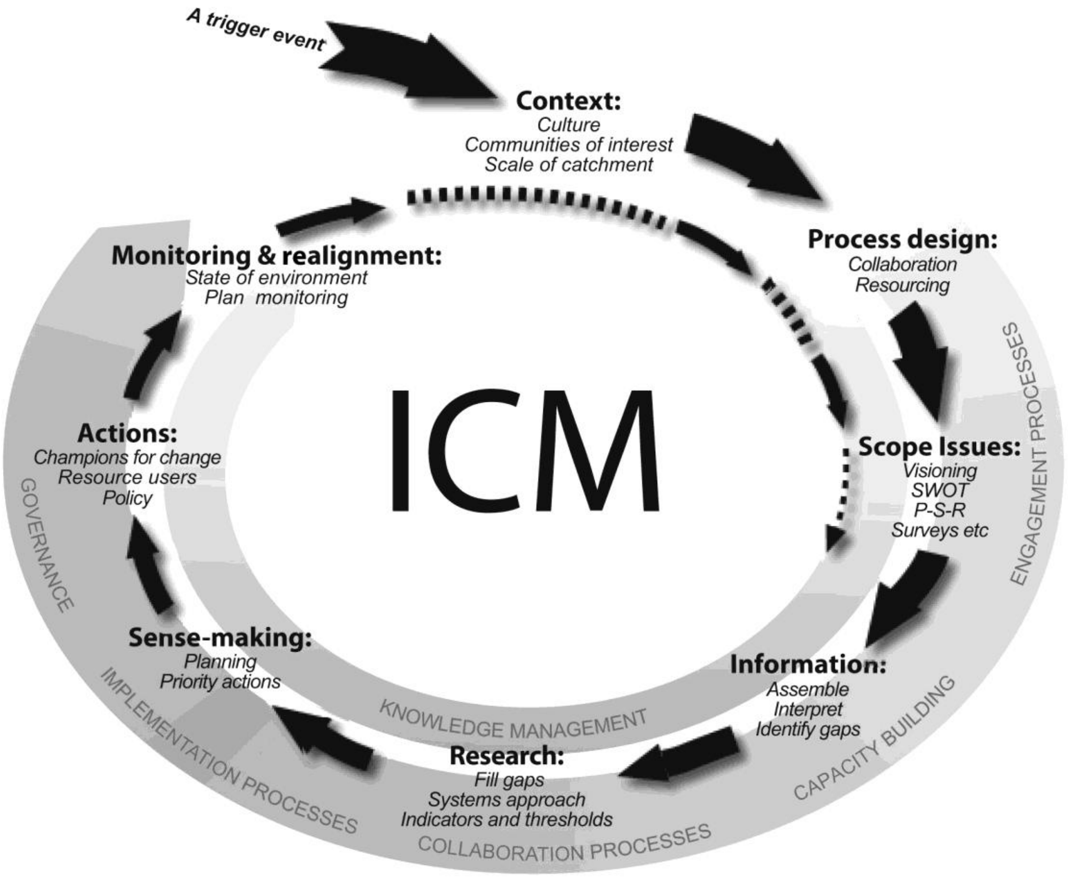


Figure 5 – Integrated Watershed/Catchment Management as a planning process. In some countries Integrated Catchment Management (ICM) is used to mean IWM. (from Fenemor et al. 2008)

This guide provides advice on strategies for watershed stabilisation to prevent or reduce sediment being washed off into river systems and being carried into the marine environment where it may damage coral reefs and other marine habitats and organisms. A principle for managing coral reefs is to manage ‘connectivity’, that is, to recognise and protect the connections between watersheds or catchments, river systems and diverse marine and reef habitat ‘patches’ (Sale et al. 2010). Principles for doing this include:

- Setting clear goals, for both the marine area and the catchment
- Applying a systems approach, understanding flows of water and sediment, and their causes, and the connectivity from upstream to coastal areas and reefs
- Targeted research to fill information gaps
- Managing ‘hot spot’ source areas of sediment, and land–water buffer zones, such as riparian or riverbank vegetation, agro-forests, mangroves and coastal forest and vegetation
- Educate, enforce and monitor over short to long timescales, to support good practices
- Adapt management, depending on how the ridge-to-reef system is responding

IWM in Fiji and Vanuatu requires community-led approaches to soil conservation, revegetation and land restoration. This guardianship ethic is not new to Pacific communities, with most high islands having some form of ridge-to-reef land management philosophy.

While this guide concentrates on preventing sediment reaching the lower reaches of river systems and near-shore marine areas and coral reefs, through revegetation, there are a range of other issues needing consideration. Not the least is the imperative for families and communities to continue to make a living from the land and their freshwater and marine aquatic resources (see Box 2). A central principle of the IWM approach is that all matters are considered in a holistic fashion and managed sustainably – such as subsistence agriculture and livelihoods, wildland-use activities, and freshwater and marine fisheries, alongside erosion control.

Box 2 – Elements of a successful IWM strategy in the Pacific

- Needs a programme, not a project approach – projects finish, maintenance is ignored, people lose faith. In contrast, programmes are designed to ensure these vital components are ongoing.
- Needs continuity of funding, and long-term commitment: allocate a proportion of project funds for longer-term continuity
- Needs involvement of upstream and downstream communities (including both land and freshwater and marine aquatic resource users, and noting that catchment and administrative (e.g. Fiji's tikina) boundaries often don't coincide): joint planning coupled with local implementation
- Requires striking a balance between catchment protection, restoration and production – people have to live
- Needs a plan for plantings and land use that are sustainable in the long term: a land capability or land suitability classification can help
- Needs to set priorities for management and follow-through as a long-term plan
- Only tackle what can realistically be achieved within available resources
- Needs coordination rather than competition among agencies for mutual benefits
- Requires planning and ongoing facilitation: respect each party's rights, responsibilities, jurisdiction
- Monitor progress to learn what is working and what is not. Make adjustments as you learn
- Local participation requires establishment of a local organisation which includes upstream and downstream people – examples are Panchayats in India, Forest Villages in Thailand, and Tree Farmers in the Philippines. These associations or groups are supported by NGOs (Sheng, in APO 2000)
- Local families and communities must see the actions as benefiting them, not just working for the government or funder
- Planned solutions need to have been proven effective in similar situations or pilots

In summary, an IWM approach builds ecological resilience founded on community resilience (Figure 6). This means that a combination of community-led action and good knowledge – both scientific and traditional – is required for successful watershed-to-coast management.

Figure 6 – IWM as a combination of community resilience and ecosystem resilience (from Fenemor et al. 2008).

The next sections provide guidance on the community component, and the basics of the science for avoiding sediment loss to coral reefs.

5. Mobilising commitment

IWM requires a participatory approach. The Locally Managed Marine Areas (LMMA) process applied through the University of the South Pacific and other agencies in many Pacific countries (Govan et al. 2008) provides an ideal IWM model for collaborative, locally-led management of watershed-to-coast natural resources.

Collaboration requires negotiation and empowerment of local people. Their needs and wants must be linked with desired ecosystem conservation outcomes, such as reduced sediment loss to waterways and the coast. Erosion is often insidious and cumulative, so may not be seen as a priority for farmers. Erosion prevention is not an end in itself; instead ideally communities will learn that sensitive watershed management relates to the effect erosion has on agricultural production and labour requirements for damage repair, as well as on their coastal resources.

Other issues such as land tenure may also need addressing. The collaborative approach will be most important where land is in communal ownership (e.g. under management of the Native Lands Trust Board as in Fiji, or in customary ownership as in Vanuatu), as commons land can be a barrier to good management (Tacconi 1997, Elder 2007, Murti & Boydell 2008). Lack of long-term tenure can also be a disincentive to commitment while external private ownership may also lead to short-term exploitation. If commitment to long-term actions for watershed management carried the ‘reward’ of a long-term lease or ‘right of use’ of land, that may encourage improved environmental practice (APO 2000). Incentives for participation need not be just financial – they might include help with marketing production, research or extension, or helping land users to understand the direct benefit of IWM to their quality of life and its dependence on a mountains-to-sea perspective. Having a technical adviser to continue to show interest in what the group is achieving can be a powerful motivator (Fenemor et al. 2010). Involving women, youth and the less privileged can also help motivate the group.

While partnerships between communities, non-governmental organisations (NGOs), corporations and governments are important, it is essential that the aspirations of communities are treated as the main driving force for this type of management, and that their legal or de facto rights over resources are respected (Govan et al. 2006).

There has been a move back towards traditional land use practices, including the stewardship concept of *vanua* in Fiji (Mohamed & Clark 1996). The more the management approach incorporates such traditional practices, the more motivation there is for uptake (Regenvanu et al. 1997). With the expiry of many NLTB leases in Fiji and sugar cane cultivation being taken on in some cases by indigenous Fijians, extension training needs to be targeted towards these new land users (Asafu-Adjaye 2008).

Expanding the LMMA approach from the ocean back upstream into the entire watershed requires multi-scale planning. This can start at the sub-watershed level, where (as shown in Figure 5) villages, officials and resource users:

1. Discuss current land and water use
2. Identify causes of watershed sediment loss
3. Develop an achievable vision, taking account of wider livelihoods and issues affecting the group's willingness to act
4. Harness indigenous and expert knowledge to explore options to tackle the issues
5. Translate this into action plans (e.g. protection and production planting plans), then
6. Implement and monitor outcomes at the most effective scales.

Figure 7 is an example of the type of diagram which could be generated at a community meeting summarising agreed causes of erosion and their interconnections.

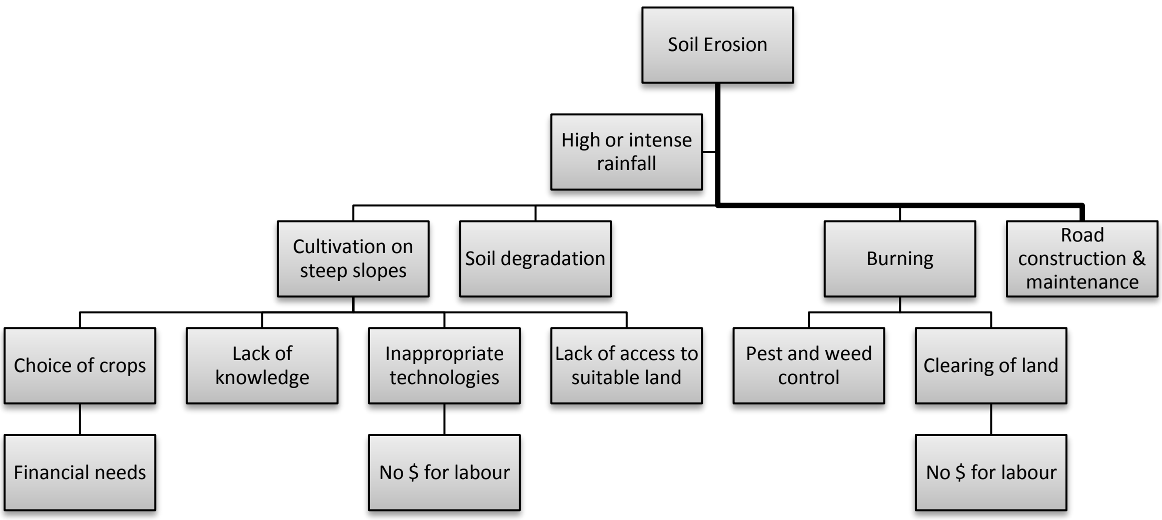


Figure 7 – Causal diagram for soil erosion.

Commitment to the action plan developed at step 5 comes from participants being aware of the benefits arising from implementing the plan (see Box 3). These considerations are likely to be more than just *environmental* (e.g. the land remains productive, the reefs continue to provide fish) but also *economic* (e.g. new products from plantings, or attracting tourism), *social* (e.g. community cohesion and pride developed), and *cultural* (e.g. customary uses of traditional plants rediscovered). This is basically the old Triple (now Quadruple) Bottom Line approach (TBL).

Table 1 is an example of a typical community action plan that is usually derived following consultations with the relevant communities through the management planning process discussed in Figure 5.

Table 1 – A typical community action plan

Threat	**Root-cause of threat**	**Location of threat**	**Solution**	**Stakeholders**		**Timeline for completion**
				Internal	**External**	
Indiscriminate burning in upper catchment areas	Lack of awareness on burning impacts Demand for cash, clearing of land to extend agriculture	Totogo (local area name)	Replant identified threatened location with native tree species	Village headman to lead	Department of Forestry Department of Agriculture	Six months
Uncontrolled grazing of livestock	Owners not aware of impacts of livestock grazing in upper catchment areas	Magiti (local area name)	Issue to be brought up at next village meeting – propose to confine livestock within fenced area Replant grazed areas	Village headman to lead	Agriculture Department	One month
Lack of freshwater fishery (prawns)	Use of duva *(Derris)*as bait Excessive chemical fertilisers in agricultural areas	Daveta (local area name)	Village meeting to instill ‘taboo’ on use of duva More awareness on proper use of chemical fertilisers	Village headman	Department of Agriculture	One month

Tools for identifying and resolving conflict may be needed: conciliation, negotiation, mediation. In the Pacific this may arise particularly because of disputes over control or ownership of land. Tamla (2002) identified for Vanuatu the role of small group meetings, separate meetings with men and women, and pre-meeting kava sessions to draw out the issues to be resolved.

Ongoing commitment to the project and maintenance of community knowledge or memory are also important. This can be done in a socially enjoyable context, preferably led from community level. It is better for funders to spread resources to match the community’s ability to act (e.g. staged plantings) than rushing in with resources then leaving.

Box 3 – Pointers for successful community implementation of a catchment revegetation plan

☺ **Awareness**
→ **Interest**
→ **Evaluation**
→ **Trial**
→ **Adoption**

Be realistic; discuss threats to the project with communities, so they can be avoided. Plantings may fail, for example because of poor soil fertility or erosion, but other threats such as burning, drought or grazing damage can be avoided with good planning and maintenance after planting.

Done well, the 6-step IWM process described above will help develop a sense of ownership and commitment from participants (Atkinson et al. 2009). People are at the centre of such an approach, and the participatory design must include those who are influential, such as local chiefs, teachers, business people, religious leaders and government officials.

In summary, two often-quoted principles can help to guide IWM planning:

- Tell people what to do and they forget; involve people and they will understand; collaborate with local communities and they will value the work being done.
- A healthy ecosystem can sustain itself without costly intervention; plan to mimic natural systems because they reduce erosion, improve water quality and support habitats and production.

6. Reducing soil erosion and sediment delivery to the coast

Soil erosion has two main components that affect sustainable use of land and water. Soil erosion leads to the loss of productive soils from an area. It also often leads to the accumulation of sediment that washes downstream from the eroded land. Where this sediment washes out to sea and builds up near the coast it may it smother coral reefs and lead to ciguatera (fish poisoning).

This section of the guide outlines how loss of soil and sedimentation affect agricultural and grazing systems as well as freshwater and marine ecosystems and coral reefs. It covers proven methods for preventing or stabilising erosion. Having described these principles, we then propose a method to help communities prioritise their response to soil erosion and the threat it poses to coral reefs. The method is a terrain mapping and plant selection approach based on the community's own knowledge of the landscape they live in, where possible in conjunction with scientific knowledge provided through support and funding agencies.

How sediment affects coral reefs

Sedimentation affects coral reefs (Figures 2, 8) in two primary ways: soil deposited on corals impedes their respiration, and reduced visibility reduces photosynthesis. If the sediment is nutrient laden, this encourages phytoplankton and algal growth which competes with corals, reducing coral vigour and cover (Hashimoto 2006). Research by Hoffmann (2002) on coral reef health in the Cook Islands and Fiji concluded that reefs with traditional systems of resource management are healthier. Agriculture, rather than population pressure *per se*, is the main cause of degradation of reefs in these South Pacific Islands (Box 4).

Figure 8: Sediment impacts offshore. Photo credit: P Dumas, IRD

Box 4 – Commentary from COWRIE Steering Group meeting, USP June 2010 on catchment impacts at Rakiraki, Fiji

- The condition of the Penang River mouth in Rakiraki was particularly poor, with coral dying and fewer fish present than expected. As well as sediment wash from the catchment, causes may include sediment re-suspension and possibly discharge from the Penang sugar mill.
- Sediment from storms fills the bay, and then fans out. Corals located on headlands that were less affected by this pattern were in better condition than those in the bays within the sediment fan.
- Roading was seen as a likely direct source of sedimentation, and furthermore, roads would open up more agriculture, burning and human impacts.
- Once sediment is reduced, coral can recover – as long as the substrate is suitable for coral polyps to settle.

Soil erosion and control methods

Observations show that big storms move the most sediment. Our objectives should be to minimise soil erosion, and if it does occur during these big storms, to minimise the amount of sediment able to wash to waterways and the coast.

Box 5 – Types of erosion

- Mass movement – whole slopes slump or slide, Erosion features may be deep or shallow. Includes landslides, slips and slumps.
- Fluvial erosion – running water erodes gullies or channels.
- Surface erosion – soil particles detach and are washed (sheet & rill erosion) or blown by wind.

Principles of erosion and sediment control

- Plan ahead to minimise erosion (e.g. roading, cultivation, forest harvesting)
- Minimise bare ground
- Minimise soil disturbance
- Protect streamside areas and don't let soil or debris reach watercourses
- Don't allow stormwater runoff to concentrate (i.e. spread it out)

Source: NZ Ministry for the Environment (MfE 2001)

Box 5 summarises three types of erosion found throughout the volcanic Pacific countries, and the high-level principles for avoiding or controlling such erosion.

To implement these principles, there are two basic techniques for keeping sediment on slopes: **structural-mechanical** (engineering works) and **(re)vegetation**. Alongside these interventions, **improved management of current land uses** will also reduce erosion potential (e.g. better management of cultivation, burning, crop harvest cycles, forestry, timing of actions, and risk management).

Methods suitable for controlling soil erosion in Pacific landscapes are based on either (1) the vegetation cover directly protecting the underlying soil, or (2) a vegetative or physical barrier contributing to stopping or reducing runoff. They include the following (Table 2).

Table 2 – Alternative approaches for erosion control in Pacific islands (from Young 1989)

COVER APPROACH		BARRIER APPROACH
Mulching (vegetative litter on the ground)		Terraces
Cropping/cover selection		Rock walls
Reforestation		Contour ditches and/or banks (bund)
Intercropping		Vegetative barriers
Fallowing		Contour cultivation
Fertility maintenance		Strip cropping
Maintain trees in agro-forestry systems		
Maintain/establish riparian buffer zone		
Crop rotation		Any physical barrier

Barrier approaches may use a mix of vegetation and built physical structures. Such approaches generally are more costly and require more maintenance. For example, Miller (1999) reports that the use of contour bunds and ditches in Myanmar created more problems than they solved because they concentrated flows which caused soil erosion elsewhere. He preferred contour hedging, as long as plantings were protected from grazing during establishment.

This guide focuses on (re)vegetation as a relatively low cost, multi-value and accessible option for Pacific watersheds. Vegetation to control erosion is particularly suited to preventing surface erosion and shallow mass movement.

Between 65 and 80% of shallow landslides in the tropics are 1–2 m deep (JRA 1984). One way of preventing such landslides is to have roots 'anchor' the soil. Except in vetiver grass, grass roots rarely exceed 1 m in depth and thus are not useful for this purpose; however, some bamboo species are sometimes useful for erosion control. Trees and bushes are needed to achieve some stability. Deeper landslides and gullying may require structural works such as terracing, debris dams, check dams, retaining walls, re-contouring or runoff diversion work, with vegetation planted into and around such structures. Vegetation will make little difference to very deep seated, rotational mass movement erosion such as slumps, or deep gullying.

In a cover approach, herbaceous plants reduce erosion because foliage intercepts raindrops, roots bind the soil, plant residues and foliage retard runoff to slow it down, roots and plant residues improve infiltration, and plants transpire (breathe) to reduce soil moisture. Woody plants that are larger and deeper rooted also help control shallow sliding on slopes (Marden 1991) through:

- Root reinforcement
- Reducing soil moisture
- Buttressing and arching to counteract sliding forces

But they can also contribute to landslides as they:

- Add weight to the slope
- Have roots which invade cracks and channels to loosen rocks
- Create potential for windthrow (blowing over).

Revegetation is the obvious low cost measure for stabilising hill slopes and gullies. However, for it to be successful the following matters must be dealt with:

- Priority areas in landscape for planting need to be identified, based on experience and knowledge, to achieve best results for investment of time and resources
- Ecologically and culturally appropriate species should be chosen that will be most sustainable, according to a robust classification of land units and erosion condition
- Good planting technique and post-planting care must be applied and monitored at least until the vegetation has become self-sustaining.

Thaman et al. (2000) identified the following threats to integrity of plantings for erosion control, which must be managed in any watershed stabilisation plan:

- Failure to replant (lack of materials, motivation)
- Natural disturbances (cyclones, coastal erosion, sedimentation)
- Over-logging

- Over-use
- Grazing
- Wild animals (pigs, goats etc.)
- Soil acidification (under pines)
- Fire
- Slow growth rates
- Wrong habitat
- Earthworks.

Deciding where to plant – using terrain mapping to prioritise

Integrated watershed management addressing erosion issues will usually require planting or replanting of previously cleared lands. Planting into secondary woody vegetation, acting as a nursery, is also a viable technique. We need to decide priority areas for planting and what species to plant. Mapping the watershed into zones is a useful tool for prioritising where and what to plant. Each zone is an area where the landscape characteristics are relatively uniform compared with other zones. Of course, other factors such as land ownership may mean that those priorities are modified in reality.

One very simple form of zonation for Pacific countries would be into areas where plantings are designated for Production versus areas for Protection (e.g. streamside areas). The Protection areas would never be cleared.

An erosion terrain zoning of moderate complexity could use the Universal Soil Loss Equation (USLE) parameters as in the GERSA project (Guete 2008) and can be generated from a GIS system as a map (Figure 9).

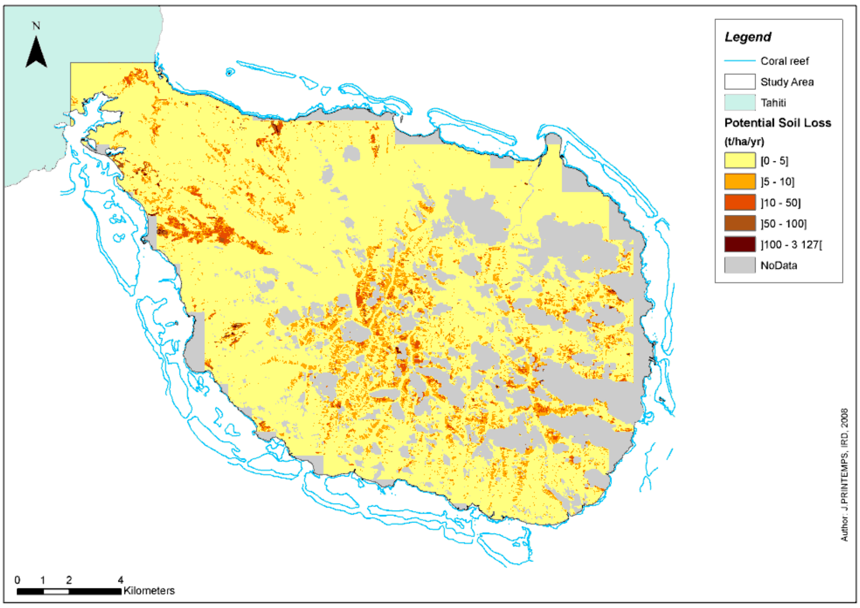


Figure 9: GIS based potential soil loss map, Taiarapu, Tahiti (J Printemps, IRD)

However, we consider a zoning that allows local people to have input into mapping vulnerability and other factors important to their own decision-making – and to then select suitable plants for each zone – is more likely to achieve an acceptable outcome. This type of zoning is based largely on visual and walkover inspection of the watershed with or by local people, supplemented by whatever geology, soil and climate data are available. Existing resource maps or aerial photographs are also useful tools for visualising and creating special-purpose maps.

We suggest for this purpose the concept of Erosion Hazard groups proposed and trialled in Ecuador by Harden (in Ziemer et al 1990). Key erosion-related parameters for deciding on the map units are:

- Rainfall (intensity and duration, particularly the occurrence of heavy rainfalls)
- Slope angle (>25, 15–25, <15 degrees)
- Soil erodibility subjectively estimated (based on general knowledge of topography, geology, soil types, seepage zones, microclimate, land use)
- Existing vegetation protection (trees, shrubs, grasses, bare land)
- Land management factors through the year (e.g. vulnerable times after cultivation, harvesting or burning, cultivated/garden areas, roads as sediment sources)
- Protection of trees, tree groves and forest remnants within the main areas of agricultural land use.

Community members have the long-term experience of the landscape to be able to integrate their knowledge across the cycle of a year. This will help ensure the terrain map does not just represent what is seen 'today', but accounts for changes in land use over a longer period. For example, in the short term, cultivated crops may cover up evidence of high rates of soil loss.

Table 3 suggests a way of experientially scoring erosion hazard factors.

Table 3 – Erosion Hazard Factor scoring (modified from Harden, in Ziemer et al. 1990)

FACTOR Score	1	2	3
Rainfall	Dry/lower intensities	Moderate rain	Wet/higher intensities
Slope angle	<15 degrees	15–25 degrees	>25 degrees
Soil erodibility	Lower	Moderate	High
Vegetation protection	Forested	Shrubs	Grasses/cultivated/bare
Land management	Forested Planted streamsides Little human activity	Lightly grazed traditional Kastom gardens away from streams	Cultivated steep-lands; Sometimes burned; Roading cuts; Channels to streams/coast

An example of how the erosion terrain mapping can be applied is given in Figure 10. Each factor score is summed to give a total score ranging from 5 (lowest erosion potential) to 15 (severest erosion potential).

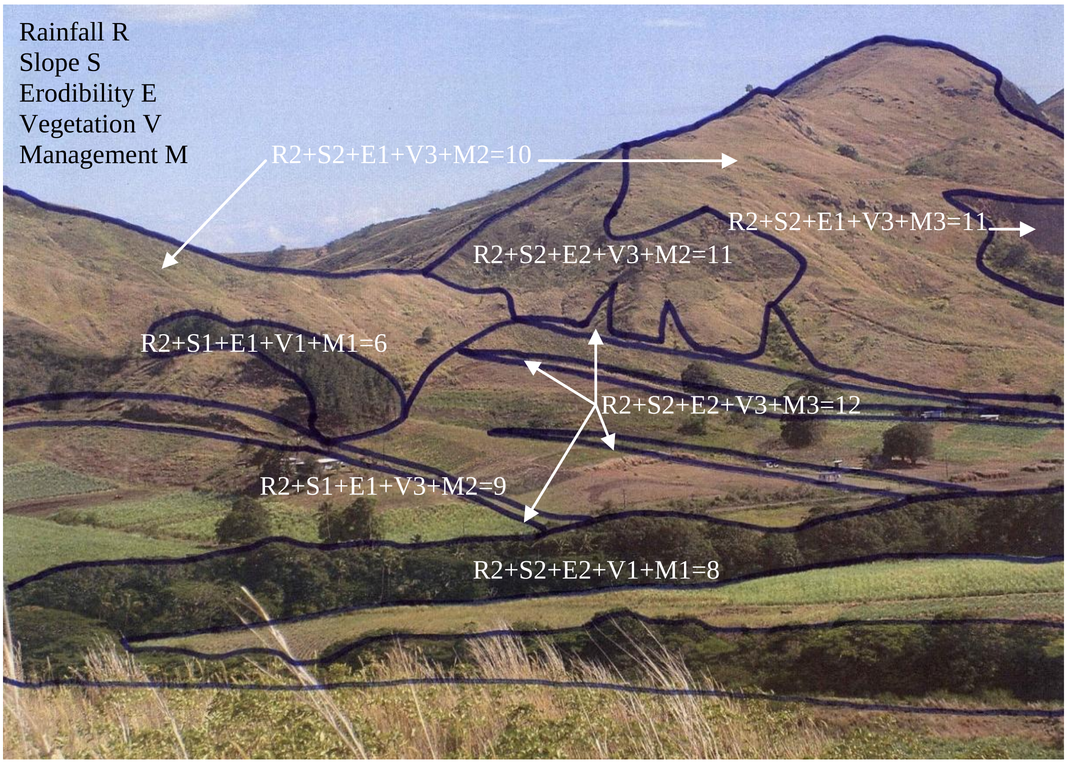


Figure 10 – Example of terrain mapping for a Fiji landscape, Ra province (highest ratings are priority planting areas).

Selection of erosion control measures

Having completed a terrain map, decisions are made on the erosion control measures, including species for planting. Table 4 offers a list of techniques to select from. Section 7 of this guide then outlines how to select suitable species and provides advice on planting and maintenance to ensure survival of the plantings.

Table 4 – Low cost erosion control ('bioengineering') techniques (adapted from Dhakal et al., in Barker et al. 2004). This assumes appropriate fast-growing or cutting material is available, either indigenous or 'safe' exotic species that pose no biosecurity risk and minimal environmental weed risk

TECHNIQUE	DESIGN & FUNCTION
Planted contour lines of grass	Rooted cuttings or grown from seed, provide surface cover, catch sediment, drain surface waters, reinforce the slope
Grass seeding	Revegetate bare ground rapidly
Shrub and tree planting or seeding	Reinforce and anchor the slope
Planting of agro-forests/erosion control strategies within shifting agricultural systems	Minimise soil runoff and provide alternative sources of income (wood, non-wood forest products)
Brush layering	Lay lines of woody or hardwood cuttings across the slope to trap sediment*
Palisades	Plant lines of woody or hardwood cuttings along the contour to trap sediment and reinforce slopes
Live check dams	Plant lines of woody or hardwood cuttings across a gully** to trap sediment and reinforce gullies

Fascines (live contour wattling)	Lay bundles of live branches in shallow trenches to root and grow, catching sediment and reinforcing the slope
Vegetated stone walls	Plant vegetation within stone walls, to armour slopes
Jute netting	Laying netting on the slope protects against erosion, provides a seedbed, improves microclimate and acts as a mulch as it rots

*1 Some species with dry fruits can be collected as brush after seed set, laid and pinned on slope; seed then falls through to protected and partially shaded soil where it germinates and establishes through the decomposing branches.

**2 Gully planting should be carried out at end of wet season, once water discharge has ceased, while soil is still moist, but before it has become dry.

In Australia and Japan, techniques to prevent soil erosion impacting rivers and coral reefs include cultivation of green manure crops, crop rotation (minimising bare ground), riparian buffer zones in agricultural, grazing and logging areas, and surrounding fields by permanent green belts (Hashimoto 2006).

Primary factors affecting performance of grass filter strips include the rate of upslope erosion, vegetation density and structure in the buffer, water flow rate through the buffer, and the fineness of the sediment (CRC for Catchment Hydrology 1997).

Pole planting of willows and poplars is widely used in New Zealand to reduce slope creep and mass movement erosion. Different species will be needed in the Pacific, but examples could include mangrove poles, which are used in Malaysia, and *Casuarina*, which has been used in the Seychelles. In the Pacific this could include *Hibiscus tiliaceus*, *Pterocarpus indicus*, *Gliricidia*, and other live fencing plants.

Effectiveness of erosion control measures

Measuring rates of soil loss is useful for understanding the severity of erosion, but the lack of data should not be an excuse for delaying action such as plantings to stabilise watersheds. There is limited information on the effectiveness of revegetation measures in Pacific environments, but community observations of what works should be used alongside scientific data which will continue to accumulate and become more useful over time.

There is certainly enough evidence (Box 6) to project tangible benefits of IWM practices and to justify their more widespread use.

Box 6 – Examples of measured soil loss rates

Ferrandon et al. (in Barker et al. 2004) reported 8 times as much soil loss from Vanuatu traditional garden practices compared with contour hedging and mulch, caused mainly by a 2-year-return-period cyclone.

Planting sugarcane across the slope, conserving trash mulch, and keeping a vetiver hedgerow were found by Ram et al. (2007) to reduce soil erosion in Fiji. These types of measures are needed to control soil loss which otherwise is reducing returns from sugar cane production.

The extensive gully erosion seen in the red soils of Aneityum, Vanuatu, are caused by the interaction of soil characteristics, indiscriminate burning, frequent cyclones, and susceptibility of indigenous vegetation to fire but Miller and Lambrechtson (2004) report the success of *Vetiveria zizanioides* (*Chrysopogon zizanioides)* and *Acacia spirorbis* in controlling this soil loss. Refer Appendix 2 for more detail on the use of vetiver.

Role of scientific knowledge

Reliable and objective information on land and water resources is needed by all contributors, from families on the land to government departments, to make the most robust, sustainable land use and conservation decisions. There is considerable information and knowledge available on soils, climate, vegetation and topography for most Pacific countries – the challenge is to find, share and apply it.

For example, in Fiji soil series have been mapped nationwide as Soil Taxonomic Unit Descriptions (STUDs) at 1:50000 scale and these describe physical, chemical, mineralogical properties plus climatic and topographic aspects (Leslie & Seru 1998). Fiji's land capability mapping system would assist in assessing sediment loss risk for each of these STUDs.

Leslie and Ratukalou (2002b) conclude that sustainable farming systems, trees, agro-forestry and forests can all play an integral role in soil and water conservation in Fiji, and this applies throughout the Pacific. For Fiji, they particularly identify soil loss from sugar cane and ginger on sloping areas as excessive and unsustainable; the practice of burning cane trash results in serious depletion of soil fertility and soil loss.

We have suggested a community-led approach to prioritising where and what to plant for erosion control. However, if science knowledge about soils, climate, vegetation and topography is available (e.g. through extension services), that information can be applied alongside the community assessment to provide a more robust IWM plan for plantings.

Research trials, informed by village and ecological experience, can identify the range of species that can grow, and management methods that support sustainable watershed and conservation goals. Village communities can then determine which of the potential mix of species and methods best meet their immediate and long-term needs and utility. Together these sources of knowledge can be applied in an agro-forestry or improved custom gardening approach to fit the economic and conservation objectives of Pacific hill-country management.

In the end, for IWM to be effective, communities have to recognise its benefit, and make a commitment. Mahadevan (2008) reports for Fiji that, based on surveys of cane farmers, only 54% believed the benefits of soil conservation outweighed the costs. Whereas vegetative erosion barriers need to be seen as integral to production-conservation systems, uptake has been patchy because of cost, loss of space, fertility gradients, and inadequate payback to farmers. Yet vegetative barriers are cheaper and less damaging than cut-and-fill terracing (Critchley et al., in Barker et al. 2004). On balance, farmers felt that visits by extension staff would make the biggest difference in encouraging implementation of erosion control practices. A great deal of attention needs to be given to 'capacity building', which in this context will involve using traditional networks, achieving trust, presenting information in locally legible and attractive formats, providing incentives, and linking valid science and management concepts to traditional knowledge of best practice and 'guardianship'.

Monitoring and evaluation of effectiveness of erosion control measures

Monitoring and evaluation (M & E) is a series of processes and actions to assess the effectiveness of implementing the project plan. Each IWM stabilisation project requires an M & E process. This should include monitoring of what was planned versus what was done, whether the longer term outcomes are being achieved (e.g. less sediment reaching coral reefs), and ongoing monitoring of community commitment to the objectives of the work and recognition of the benefits arising from it.

M & E thus has two components: progress with the biological or environmental initiatives (e.g. what is the success rate of plant establishment? Is the area planted on target? Are tending regimes effective? Is erosion control becoming effective? What is happening downstream?). Secondly, progress with the social and economic outcomes (e.g. What is happening to the social and economic well-being of the community arising from the project? Are people coping and keeping up with demands? Seeing the benefits?). Both aspects need to progress satisfactorily for a successful project in the longer term. Monitoring in each case involves selecting suitable indicators for measuring progress, and applying those indicators at suitable intervals over the project lifespan and even beyond. Evaluation involves considering the messages arising from the monitoring data and information assessing progress. A common and healthy outcome from M & E is to modify the project plan according to lessons learned.

Stages in an effective M & E plan include:

- Keep in mind the outcome (e.g. maintaining healthy coral reefs and fisheries)
- Identify measurable goals or targets and the trajectories from the base line to the end point (e.g. sediment load in rivers is within the natural range; or sustainable production of fruit and timber contributes to viable local economies).
- Specify milestones or achievements at a stated time (e.g. weed-free crop is established at a particular site or land unit by 2012; or riparian planting is forming a dense cover in eroded gullies by 2011; or sediment reduced to 90% of baseline by 2015).
- Identify and define physical, biological and social indicators of success (e.g. weeding achieved through the year; bare ground reduced; height of trees; fruiting, regeneration, etc. See section 7).
- Establish baselines –based on historical records, photographs or maps, etc.
- Record and archive data in a secure place (note the very simplest form of technical monitoring is repeated photographs (preferably digital images)), but these must be stored and backed up somewhere safe.
- Analyse changes or trends in successive evaluations.
- Based on trends towards or away from goals and milestones, modify actions and management practices accordingly (adaptive management).

The nature of the monitoring questions and indicators may change over time as the project matures. For example over a 10–20-year period they may change from being about the success of planting, through to the effectiveness of plantings on controlling erosion, and then to the downstream effects on fresh water and then the near-shore zone.

Social and economic monitoring may include methods such as: community surveys (families, groups, and individuals), interviews, focus groups, and direct observations.

7. Best practice revegetation

In this section we provide guidance on the species to select for planting, and how to establish and maintain plantings.

The revegetation plan requires consideration of a range of factors, not just the erosion prevention benefits of the planting. Positive attributes of (re)vegetation include:

- The shade provided by trees
- The protection provided from wind and salt spray
- Carbon sequestration
- The improvements in soil organic matter from leaf litter, and
- Creation of habitats, breeding sites and nurseries for plants, birds, fish and other animals.

Plantings also provide economic and social benefits, which include a diversity of products, greater self-reliance of communities, and reduced pressure on natural forests (Elevitch & Wilkinson 2000). Traditional species within agro-forestry systems, when applied to appropriate land zones or units, are likely to lead to better maintenance of plantings and more effective erosion control as there is a recognised and visible value being produced.

Table 5 summarises the desirable characteristics for selecting species for watershed stabilisation, tailored towards use in Pacific countries.

Table 5 – Desirable characteristics for selecting plant species (adapted from Barker, in Barker et al. 2004)

	ATTRIBUTE	PURPOSE
√	Rapid stem and leaf growth	Erosion control
√	Rapid root growth	Erosion control
√	Rapid and dense deep root growth	Shallow slope stabilisation
√	High root strength and surface roughness	Soil reinforcement
√	Vegetative propagation preferred	Cuttings for brush layering and pole planting
√	Incapable of becoming a weed	Avoid seed dispersal and biosecurity risk
√	Tolerant to climate, soil conditions, burial	Plant survival
√	Preference for multi-value perennial plants	Maintains vegetation cover
√	Preference for N-fixing species	Replenish lost nutrients
√	Species diversity	Biodiversity, economic returns, combined stabilisation functions, resilience, seasonal continuity of production and supply
√	Readily available plant materials, local species preferred	Affordability, applies traditional knowledge, timely planting, indigenous biodiversity
√	Has multiple cultural usage/multipurpose species	
√	Economic value as well as stabilisation attributes	Community incentive to establish, maintain and protect plantings

Table 5 identified the primary planting options as vegetative strips for soil retention, and planting of shrubs and trees to provide vegetative cover on erodible slopes. Optimal vertical spacing of natural vegetative strips for soil retention was found to be 2–4 m (Garrity et al., in Barker et al. 2004) which means closer surface spacing on steeper slopes.

Mangroves play a particular role as the buffer between the land and marine areas, and provide a nursery for fish, and so should be protected. In light of predicted sea level rise, particular attention should be given in the planting plan to protection and re-establishment of *coastal forest* and to anticipate inland migration of this zone. Balanced against this will be coastal extension as a result of sedimentation from accelerated erosion in the hinterland and the colonisation of this shallowed water by mangroves. IWM is aimed at reducing this erosion but realistically it is likely to continue above natural levels for some time to come.

Among the most versatile vegetative barriers is vetiver grass, which is discussed in more detail in Appendix 2. Previously widely promoted and used in sugar cane plantings, its use has dropped off with the reduction in extension work with cane farmers. It deserves to be more widely reintroduced. The attributes of vetiver grass *Vetiveria zizanioides* are (Truong et al. in Barker et al. 2004, NRC 1993):

- Deep fine root system which reaches 2–3 m deep in year 1
- Stiff erect stems withstand flood flows up to 0.8 m deep
- Line planting reduces water velocities and traps sediment
- It shoots from the base so can withstand traffic and grazing
- It grows to form terraces over time
- Tolerant of drought, flood, submergence, temperature (−14° to 55°C), salinity and heavy metals in soils
- It is a low-cost stabilisation measure
- It can enhance adjacent crop productivity as it retains soil and its roots grow straight down
- Its use in Fiji over 50 years has not seen it become a biosecurity problem – strains presently in Fiji appear to be non-seeding clones with limited potential to spread; however, Miller (Appendix 2) alludes to other fertile strains that need to be carefully screened before allowing them into countries where they are not currently present
- In Indonesia, it was found to be more effective and resilient to drought than elephant grass (*Pennisetum*), lemongrass (*Cymbopogon*), *Gliricidia*, *Flemingia*, *Leucaena*, or *Calliandra* (Suyamto, in Barker et al. 2004).

However, we note that:

- Vetiver dislikes shade, and may need weed control when first established.
- Successful establishment also requires good plant materials, adequate moisture and avoidance of grazing but after that requires minimal maintenance.
- In Vanuatu, on eroded highly acid and nutrient-depleted soils, additional plant materials stimulated vetiver growth; and *Acacia spirorbis* seemed to promote symbiotic growth.

Direct seeding for erosion control may be cheap but requires good planning to be successful:

- Viable seed needs to be collected in large quantities close to the time of sowing (unless the species has hard-seed in which case manual scarification or hot water pretreatment may be required).
- Seeding should be timed to have the best chance of good weather conditions to ensure germination.
- Coating seed with slow-release fertiliser and, if appropriate, mycorrhizal inocula will greatly enhance survival.
- Predation by insects, birds and rodents needs to be controlled.
- Grass competition stifles germination so seed beds with bare soils for as long as possible are essential.

Generally, quality of plants resulting from direct seeding are poor or at least variable in form. Experience in temperate zones with direct seeding has been mixed, especially for erosion control. The Landcare Movement and Gondwana Project in Australia have successfully used large-seeded woodland species in landscape scale revegetation seeding trials. McCracken (1969) observed that the only promising technique was from seeding a herbaceous ground cover into which plantings of woody species could later be made. However, the greatest success in New Zealand has been with layering seed-bearing branches of manuka (*Leptospermum scoparium* – Myrtaceae) onto bared ground (see note in Table 4).

Agro-forestry

Thaman (in Bule et al. 1996) recommends that agro-forestry (including agro-forestry for erosion control) be based on evolution of traditional Pacific agro-forestry approaches (refer pp. 90–94 in Bule et al. 1996). He provides a checklist of 100 important agro-forestry species to consider, many of which are itemised in Appendix 1.

Agro-forestry will be a mosaic of integrated land uses appropriate to the resources and erodibility of particular land units or zones. This will include carefully integrated uses of erosion control technologies (see section 6) in the worst cases, soil conservation / biodiversity planting, continuous-canopy selectively harvested forest, open woodland with inter-cropping with staple food plants, open woodland with controlled extensive grazing, perennial cropping and annual crop-rotation – well away and buffered from stream channels.

Agro-forestry, first and foremost, incorporates a wide range of tree conservation and enrichment techniques, including deliberate tree planting along with ground crops, pollarding, coppicing, selective weeding of gardens to protect tree seedlings, and deliberate protection of trees and inland, riparian, coastal vegetation and mangroves as an integral component of the land use philosophy (Thaman & Clarke 1990, 1993; Thaman et al 1995, 2004).

Information required

Questions that need to be addressed in designing an IWM system include:

- What are the current dynamics of watersheds and vegetation?
- What are the natural dynamics of vegetation?
- Are there pest animals in the watershed?
- Are novel ecosystems being dominated by exotic invaders?
- Are tree-crop-species nurseries available for an indigenous/endemic understorey?
- Is there a succession to indigenous dominance?
- Which of the plants are harvestable for productive or cultural purposes?
- Can harvesting be carried out in a continuous-canopy regime?
- What indigenous species are useful as commercial crops?
- What are rotation length and management requirements?
- What is the right combination of species to optimise those used for multiple needs of IWM, biodiversity & utility (e.g. framework planting)?
- What is the effect of cultural practices, such as burning in relation to dry and rainy seasons, on sediment yield?
- What are the capacity (resources) and opportunity for capacity building? This may include building knowledge of indigenous species and ecosystems and awareness of interrelationships of watershed elements to provide the basis for local ecotourism business.

Box 7 – Commentary on community plantings in COWRIE pilot catchments (Buliruarua & Fenemor (eds) 2010; pers. comm.)

- Community feedback identified common threats across the sub-district as indiscriminate burning, agriculture moving up-catchment, pesticides and 'duva' (or *Derris*) being used in fresh waters for harvest, uncontrolled grazing.
- They identified the following as actions: replanting; use of vetiver grass to trap sediment; implementation of village rules to control burning, tree cutting and use of pesticides in water. The women had requested replanting of mulberry and kuta, which were also diminishing from village surroundings, for crafts. Kuta may be suitable for stabilising gullies, also Nassau grass.
- Shade-house construction – main local bamboo, *Bambusa vulgaris*, was not durable unless appropriately treated; several imported species such as *Bambusa oldhamii*, *Dendrocalamus asper* and *Gigantochloa* species were much more durable but there was limited planting material available in Fiji
- Sandalwood (yasi) may grow well in Ra but was not suitable in wet humid areas.
- In Naroko, the Dept of Forestry supervised the plantings using their recommended methods, e.g. 6 × 6 m spacings. However the 6 × 6 m spacings were queried in terms of time to canopy closure or enmeshed root structure, with 3 × 3 m spacings noted as more common for plantations.
- Species planted in Naroko were mainly based on whatever was available, with teak purchased from Future Forests in Ra Province. Species planted included three exotics (mahogany, teak and *Calliandra*), 14 natives (damanu, vesi, dakua, vesiwai, velau, kuasi, laubu, mavota, yaka, tadalo, tavola, makosoi, dakua salusalu, yasi) and 4 fruit trees (moli, vutu, kavika, dawa) (Appendix 1.1). A 5-m-wide firebreak covered the plot boundaries. Plantings were either E–W to follow the sun, N–S, or following the contour, the aim being to compare them.
- *Flueggea flexuosa* could be interplanted with high value timbers for production of durable poles on short rotation (6–7 years), because villagers would be reluctant otherwise to thin a tree crop. Coppice teak and cocoa were also suggested.
- May need to weed more than once in the dry season. June–November dry season would be the biggest test for these plants; watering of these plots may be needed in dry conditions.
- Planting coconut, cassava and pineapple in the firebreaks meant villagers would keep weeding these areas. Discussions on alternatives included thick-canopy economically valuable trees to act as 'green' firebreaks: such species would include mango, jackfruit and cocoa if not too dry. A suggestion was to dig V-trenches downhill towards the planted tree with a ridge on the downhill side to channel and capture more rainfall.
- There is a lack of native plants or seedlings available for revegetation, therefore pre-planning and nurseries are needed
- Suggested grass and reed species for stabilisation included *Chrysopogon/Vetiver zizanioides* (vetiver grass), *Pandanus tectorius* (for wetter sites), *Saccarum edule* (duruka) for slopes, *Eleocharis* species (kuta) for swamps, all of which have economic value. *Arundo donax* was also suggested though this was noted as introduced and weedy. *Bambula textilis* was also considered as a potential.
- SPC reports on uses of various species will be a useful resource base for communities.

Box 8 – Anecdotal information to guide catchment plantings in the Pacific

- Planting of native trees should be considered in an agro-forestry context with biodiversity values – traditional hardwood interplanted with production hardwoods such as teak and mahogany.
- Production projects can act as buffer zones for high biodiversity and watershed protection areas.
- Payments to landowners help create ongoing commitment but are expensive.
- Utilise retired civil service staff where available for their technical expertise.
- Women's views are important because they involve the whole community, keep people fed, and bring in family and children's health perspectives (in Vanuatu, women decide where the next garden for the family will be); Listening to youth views builds commitment into the future.
- Community projects should be at least 10 years – short-term projects often cannot show results in 3 years; need to build communication channels beyond end of project. e.g. the Drawa SPC/GTZ project was successful because of community-based commitment, champions, empowerment through training, and long-term commitment by a major donor.
- Lack of follow-up and enforcement of codes of practice (e.g. for logging) is a problem – ensure the same laws apply to all; Companies and State must lead by example.
- Biodiversity protection schemes need to be accompanied by sustainable livelihood development.
- Alongside the existing Red List of endemic threatened species, at some point villages should develop a Green List of species that they want protected.
- Planting species with a range of harvest dates avoids clear-felling impacts.
- Planting of valuable species like teak discourages burning, as they're susceptible while young.
- Cyclone resistance should also be a consideration, e.g. *Terminalia richii* as evidenced after the category five cyclones in Samoa in the early 1990s. Tavola and tivi are coastal plants that tend to be drought tolerant. Regarding fire risk, teak, mahogany and sandalwood are not resistant the first few years after planting, but mango and jackfruit could be used in a 'green firebreak'.
- Consider merits of planting down-slope from any remnant upland forest or planting upwards from the garden areas where villagers would see the plantings and be reminded more often about weeding.
- Training and capacity building is vital for continuity, e.g. sustainable forest management projects provided portable sawmills but not the financial support for continuing the business.
- Power politics – creating a forum for discussion allows other issues to be discussed and aired.
- Payments for ecosystem services could create tensions within communities unless care is taken to ensure equity in disseminating payments.
- Improved genetic material is important, e.g. faster growing, tropical-cyclone-proof species; increased dependence on indigenous rather than on introduced species.
- Increased commitment is needed to formal training in relevant forestry and conservation-oriented fields; work through effective local government authorities.

Matching plants to place

Each species of plant has particular requirements of temperature, water and humidity, soil fertility, and mycorrhizas, and tolerances of frost, heat, drought, water-logging, desiccation, soil acidity, salinity and mobility, exposure/wind, browsing and competition. Grime (1979) described the niche or strategy of plants in terms of a matrix of these different types of stress and disturbance.

To match plants to locations, sites and associated conditions, we have to first characterise the land into convenient and easily identified units which can then be defined in terms of the above physical and biological factors. These may be termed the ecological factors or 'bottom lines'. The units also have to be recognisable on the ground.

Desired plants are likely to thrive only where there is motivation in the community to plant them well and look after them. Motivation relates to community engagement and technique, discussed earlier in section 5.

In developing a typology of land units, the highest level is the **bioclimatic zone,** here applied specifically to Fiji, but equally relevant to other South Pacific high islands – those with volcanic and/or sedimentary geologies:

- Coastal
    - Marine/lagoon
    - Salt marsh
    - Mangrove
    - Coastal forest
    - Beach
- Dry zone (prolonged dry season with <1500 mm annual rainfall)
    - Dry forest/woodland
    - Scrub
    - Grassland (induced)
- Intermediate zone (short dry season with <2500 mm annual rainfall)
    - Moist forest
    - Grassland, shrubland and woodland (induced)
- Wet zone (wet all year with >2500 mm rainfall)
    - Rain forest (lowland)
    - Cloud forest (upland/summit)
- Riparian zones/Wetlands
    - Ponds/lakes and margins
    - Wetlands
    - River margins
    - Floodplains
    - Ephemeral stream margins
- Disturbed environments
    - Fallow garden areas
    - Slips with soil debris

- Slips/slides to bedrock
- Slips/slides to gravel, sand, loam or clay
- Riverbeds
- Bare soil (perhaps topsoil eroded)
- Gullies

Most of the land being considered in the current revegetation context falls within the Dry zone grassland, scrub and woodland, Intermediate zone grassland, shrubland and woodland, and Ephemeral stream margins and Bare soil/Gullies. Some of these conditions represent young, seral or pioneering vegetation; others are mature or climax vegetation. Included in this zone are extensive areas of active shifting agricultural and associated fallow forest, woodland or grassland-savannah.

So, we sub-classify the landscape into homogeneous land units for which different plant species will be needed. Landscape factors include hydrology/drainage, parent material, fertility and geomorphology. Figure 11 shows this zoning for the same terrain which was zoned for erosion hazard in Figure 10. Effectively we have first prioritised zones most in need of planting then we have further classified those priority areas to be able to select appropriate plants which will survive and fulfil that erosion control function.

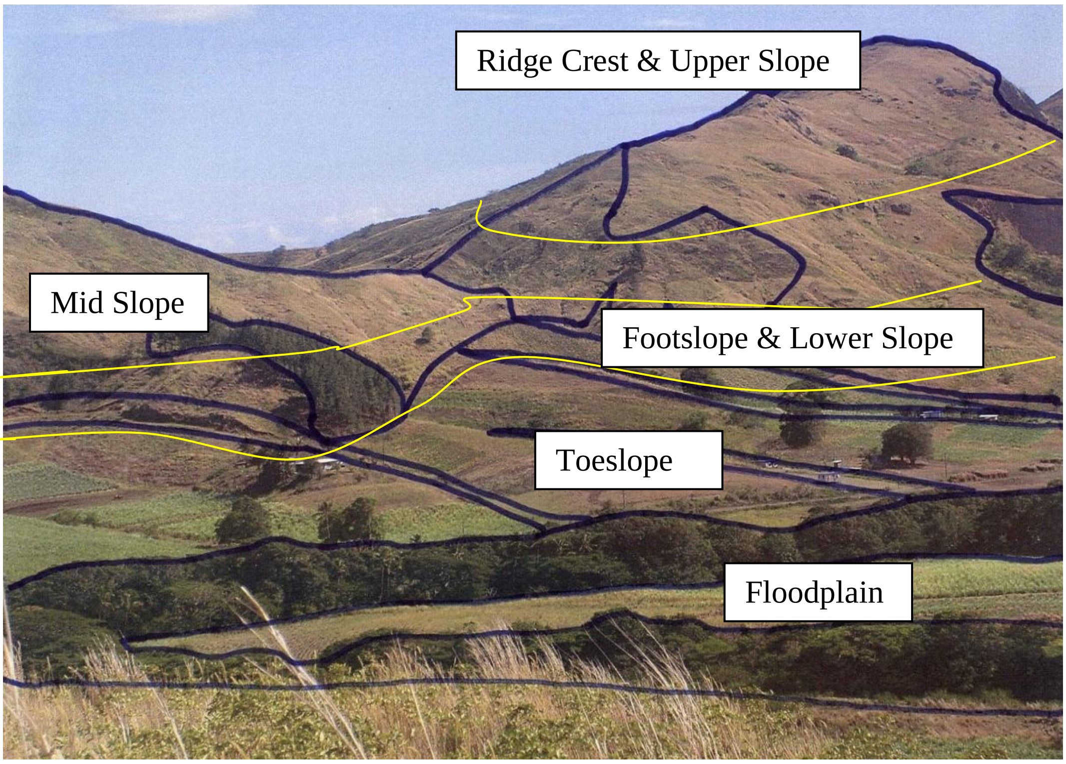


Figure 11 – Schematic representation of Land Unit types in a typical low elevation landscape. These integrate with the erosion hazard classes of Figure 10.

Combining bioclimatic zones, developmental stages, land units and erosion hazard classes creates a matrix as in Table 6. Once a suitable classification of land units has been developed (encompassing capabilities and limitations), the next task is to prepare a comprehensive list of species suitable for revegetating any one of these combinations. This requires all the cells in the table to be filled with suitable species according to the collective wisdom of expert ecologists and villagers. This then establishes their ecological suitability for the task of growing on and stabilising the sites designated. These species' lists can be further refined and selected on the basis of economic and cultural priorities. This provides the choices for the communities – species that will thrive in the conditions, and of these, those that provide particular economic or cultural values or needs. Within this framework, some species are early colonising plants (often annual crops, 'weeds' or legumes) whereas others are longer term, often slower growing, mature forest species – that may flourish only once an initial cover has been established.

Table 6– Matrix of bioclimatic zones and developmental status (sequence of planting) with some broad species groups appropriate to the various combinations.

BIOCLIMATIC ZONE	DEVELOPMENTAL STATUS			
	Disturbed/Seral/ Primary/Pioneer	Established/ Secondary/ Mid succession	Mature Climax	Riparian (Zonation) – continual disturbance
Rain Forest	*Macaranga, Homolanthus*	*Endospermum, Cananga odorata, Gymonostoma*	*Agathis, Dacrydium, Decussocarpus, Calophyllum, Canarium, Syzygium*	
'Summer' Dry	*Acacia, Dodonaea viscosa*	*Acacia, Casuarina equisetifolia*		Bank erosion
Floodplain	Flood zone spp	*Inocarpus fagifer,*		*Dacrycarpus?*
Coastal Forest	Coconut	*Pongamia pinnata, Terminalia catappa, Cordia subcordata, Scaevola*	*Calophyllum inophyllum, Barringtonia asiatica, Pandanus tectorius*	
Mangrove	Storm surge site species	*Lumnitzera littorea*		
Lagoon/Marine				

Hill country example

Some typical land units that fall within the above bioclimatic zones are: Plateaux, Ridges, Side slopes, Foot slopes, Toe slopes, Basins, Valley floors and Floodplains. Qualifiers include convex, concave, planar, nose, upper, mid, lower, fans, screes, cliffs, and gullies.

Table 7 is an example of a typical table for matching and selecting species according to site classes and erosion control needs. Tables provided in Appendix 1 provide more detailed species lists for hill slopes and broad land units (Appendix 1.1) and riparian zones or gully erosion control (Appendix 1.2).

Table 7 – A possible table format for easily accessing species names suitable for a particular land unit, characterised according to appropriate planting stage and community value or threat (identified by various bracket styles; e.g. # … # identifies species posing a biosecurity threat)

LAND UNIT	SPECIES			
	Pioneer	Mid	Climax	Riparian

Rain Forest zone, concave, steep mid slope	Vetiver grass			
		(Cultural Value)		
			[Commercial Value]	[Cultural and Commercial Value]
	Conservation Value	#Biosecurity risk#		

Some broad land units are illustrated in Figures 11–14.

Figure 11 – Mangrove running back into coastal grassland.

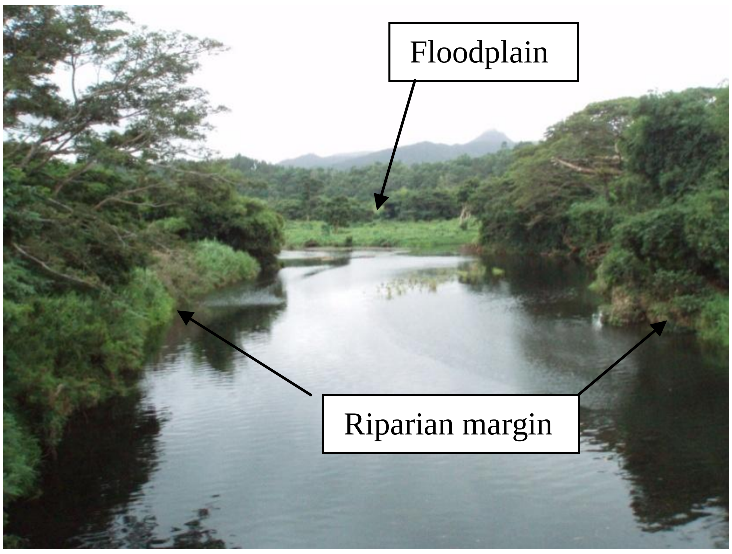


Figure 12 – Riparian margin and floodplain.

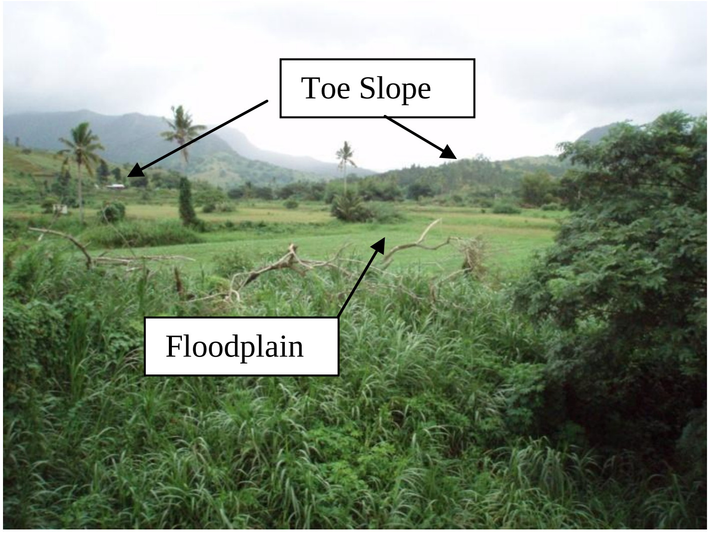


Figure 13 – Floodplain, toe slope and foot slopes in distance.

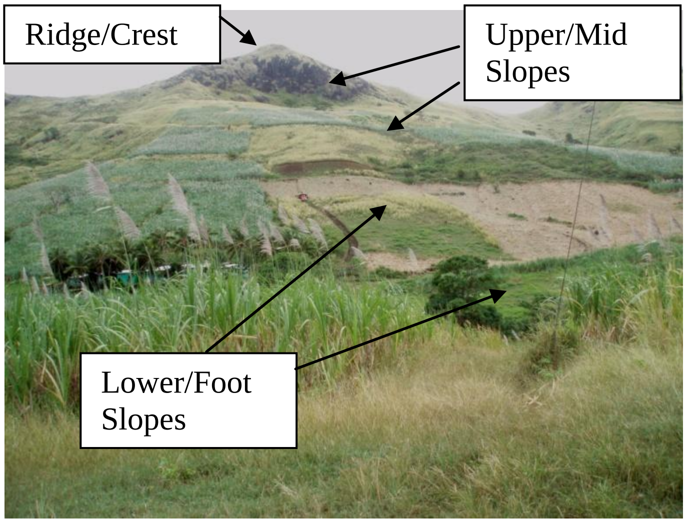


Figure 14 – Rolling hills with Ridge/Crest, Upper Slope, Mid Slope, Lower Slope and Foot Slope.

Riparian zones

Riparian zones include: Water's Edge, Bank, Levee, Backswamp, Terrace Scarp and Terrace Tread with qualifiers upper, mid and lower (Figures 15–18).

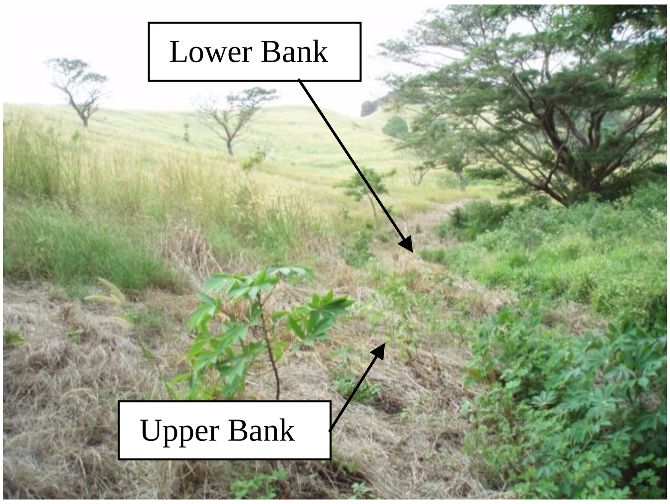


Figure 15 – Ephemeral stream with lower and upper banks.

Riparian planting zones for permanent rivers to ephemeral streams are shown in Figures 15–17. Species for all riparian zones are indicated in Appendix 1.2.

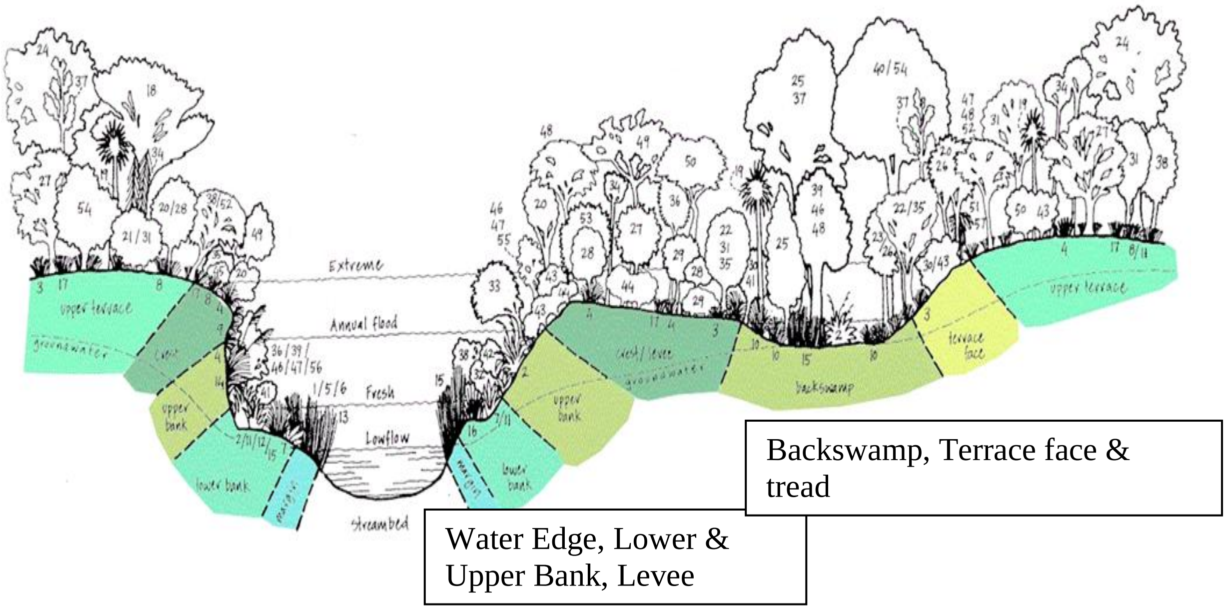


Figure 16 – Profile of major river showing a sequence of riparian and floodplain zones on the inside (steep bank) and outside (broad floodplain) of a meander. The zones from the water line are: margin, lower bank, upper bank, levee, backswamp, terrace face/scarp, upper terrace. Not all zones are always present.

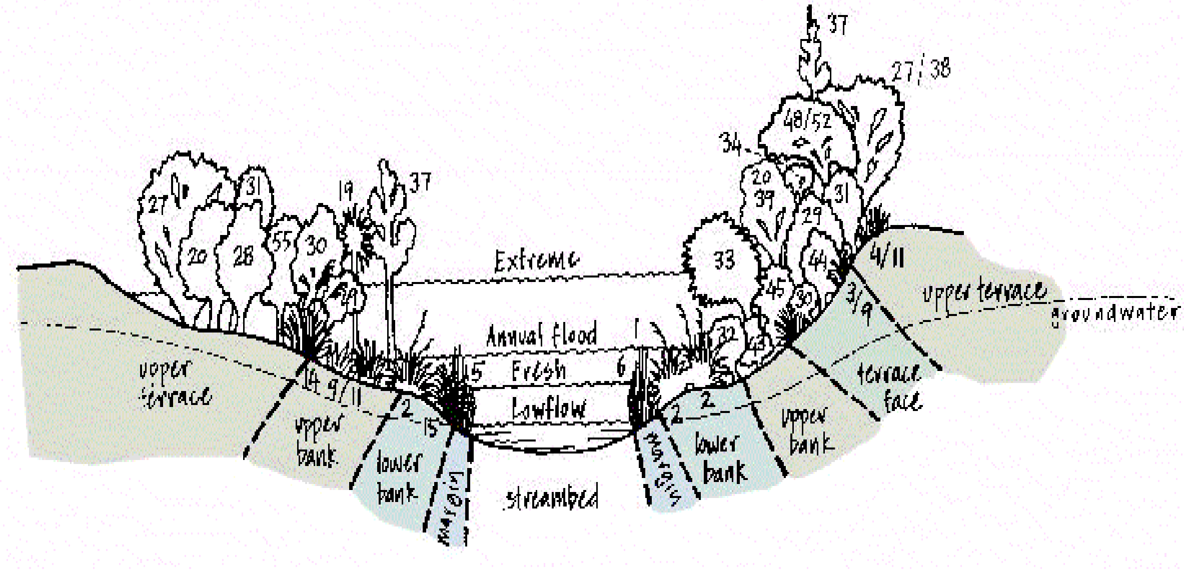


Figure 17 – Profile of small permanent stream showing the reduced number of potential riparian zones and flood levels.

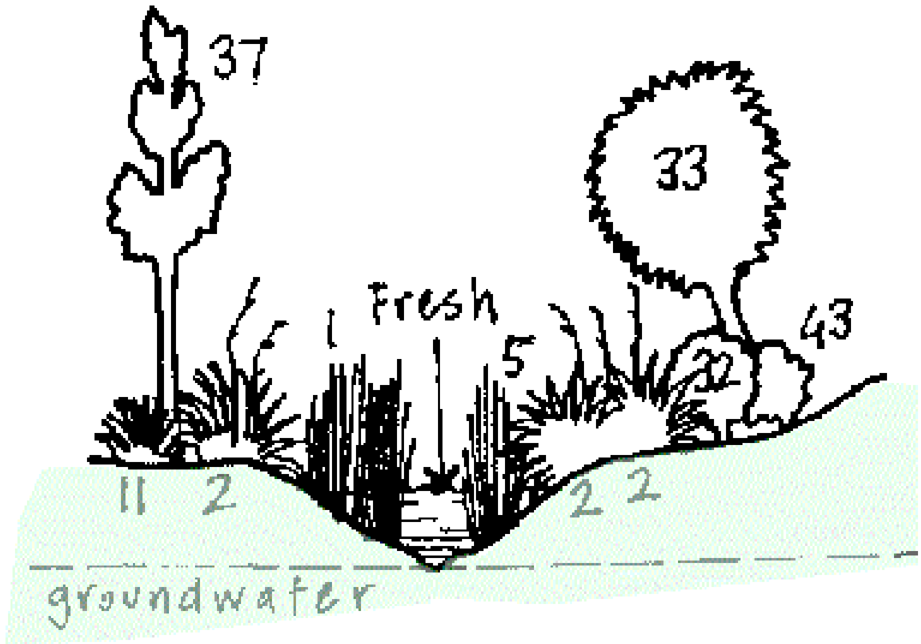


Figure 18 – An ephemeral stream profile with only the equivalent of a lower or upper bank zone present.

PART 2 – A PROCESS FOR IMPLEMENTATION

There are several discrete stages or phases in the revegetation process for an IWM project. These are Planning (arriving at a concept, evaluating it, design, formulating goals, objectives and actions or milestones, work plan & budget), Propagation, Site Preparation, Planting, Maintenance, and Monitoring. These establish a cycle of planning, action, monitoring, evaluation and adaptation that should achieve the stated purposes and are sustainable. These apparently rigid rules of engagement are theoretical constructs around or descriptions of what people actually do. Often these steps are retrospective – people do things, look at what they have done and then propose something more carefully thought out and which perhaps is able to attract funding or other support. For these reasons, even a rough statement of what a project is about and how it is performing will stand the community and project in good stead. It can also be a useful training exercise in itself for younger members of the community – even though all should 'get their hands dirty' in order to better comprehend the effort required to build a more sustainable livelihood from the land.

8. Planning

- Establish community/village engagement (at all levels) through consultation, discussion, prioritising of project areas – according to need for erosion control, cash crop (and speed of return) and achieving long-term multi-value ecosystems.
    - Identify tenure, ownership, stakeholders and engage with them
    - Part of achieving community outcomes involves 'capacity building' or increasing knowledge levels and technical or practical skills – often rediscovering lost knowledge
    - Other factors to be considered include productive or commercial objectives; cultural values; natural heritage values (e.g. use of indigenous species mixes); avoiding invasive plants
    - Visioning exercise.
- Identify watershed boundaries appropriate to the communities of interest. Criteria include threat posed by existing land uses, level of risk from sedimentation, receptiveness of local communities, tractability (likelihood of success)
    - Identify any watershed 'hot spots' for planting (linked to watershed impacts on the coast)
    - Identify type of planting – forestry, horticulture, conservation (water, soil, biodiversity, biosecurity) that supports the vision
    - Identify inhibitors to successful planting (fertility, water, topsoil loss, pest plants, pest animals, community knowledge or activities – review current practices, successes and failures) (SWOT analysis – see Box 9).
- Agree on broad goals for the project among project and community leaders
    - e.g. 'Minimise sediment reaching streams and the coast, through watershed re-vegetation'
    - Agree on actions appropriate to erosion hazard and landscape unit
    - Design and agree Prioritised Actions with time frames (Objectives or Milestones).

Box 9 – Some basic principles

- An IWM approach accommodates multiple issues
- Protecting existing vegetation should take priority over restoration planting (it is in the long term much cheaper to defend what you have rather than rebuild something we only vaguely understand)
- Apply LMMA-type process with land uses considered alongside marine systems
- Principles of ICM/IWM and CBAM (Community Based Adaptive Management) are applied from grass-roots
- A SWOT type analysis helps to focus thinking – Strengths, Weaknesses, Opportunities, Threats
- The steps in the process are best generated collaboratively from within the community – to ensure buy-in all the way along.
- 'Problem trees' trace issues or effects back to their fundamental causes (see Figure 7, for example)

- Compile background information
  - Situation analysis includes current land use, state of marine receiving areas, trends in land and marine uses and drivers of those trends
  - Relevant scientific and traditional knowledge summarised
  - Community perceptions of issues, risks and need for action using techniques like problem trees (see Box 9)
  - Research knowledge needed for project design and implementation
  - To fill knowledge gaps, plan and implement a short-term research project if needed (this should not be an excuse to delay implementation, but well-informed planning pays dividends and avoids heading off in the wrong direction and investing in areas that are not critical)
    - Examples include: Plant propagation trials, gathering weather records, and setting up baseline surveys of sediment reaching marine areas.
- Define priority zones for revegetation, according to erosion hazard based on factors such as rainfall, erodibility, slope, current vegetation cover and land management. Subclassify planting site according to elevation, hydrology/drainage, parent material, fertility, geomorphic zone including riparian or coastal zone (see Figures 10–18, Tables 6 and 7 for indicative land units and Appendix 1 for species selection).
  - Draw up list of plants for each watershed component (land unit) according to purpose and priority with a mix of species that contributes land stability, cultural value and biodiversity (indigenous species)
  - Some species may be desired for nitrogen fixing to facilitate vegetation development
  - Match species with land units for particular stages of succession
  - Avoid species with high biosecurity (weed) risk – increased local knowledge about such risks from recently arrived species may be a prerequisite.
- Detailed design plan includes:
  - Prioritised planting areas depending on erosion risk

- Species and numbers/proportions matched to sites
- Propagation and sourcing of plant materials – in plenty of time
- Planting plan (it is probably necessary to stage some of the planting, especially if there are species with precise requirements in terms of initial shelter or avoidance of competition)
- Tools, equipment, supplies and labour
- Maintenance routines including weeding, spraying, watering and any replanting (see later section)
- Document collective agreement of prioritised actions with time frames, responsibilities and resourcing agreed (milestones)
- Include an action map (work plan) with year-by-year checklist (e.g. a wall map with areas annotated with progress as a reminder of commitment and achievements)
- Develop a medium- and long-term work plan with indicative 'budget'
- Ensure there are resources for planning, site preparation, planting AND maintenance for at least 3 years (don't bite off more than you can chew).

9. Implementation in the field (project management and plant preparation)

- Project leadership and management by respected and experienced members of the community is important – to ensure someone (or some small group) is responsible for keeping the project going, identifying and correcting problems.
- Train villagers in the operation and techniques of plant nurseries and seed propagation of native tree and fruit species, maximising the use of existing local resources that require minimal external assistance (Figure 19).
- Source plants of appropriate type, quantity and quality (including provenance) at least 9 months in advance of planting (see Box 10).

Box 10 – Planting standards required

- If taking seedlings from wild – keep some soil around roots; ensure they don't overheat or dehydrate.
- If growing from seed – add some natural soil/litter/duff to potting mix to give best chance of incorporating beneficial or essential fungi.
- Plant stock, at time of planting, should be at least 50 cm tall, with >1-cm-diameter basal stem (collar) (a good indicator of plant performance), and be in good health with well-developed root system, appropriate mycorrhizal infection, and, for plants subject to transplant stress or dehydration, cut back foliage to reduce transpiration surface and restore a more favourable root–shoot balance.
- Special care must be taken to avoid root damage or kinking of root–shoot junction during propagation – this will distort roots and affect future plant performance.

- Spacing should be 6 m for larger commercial trees with intermediate spacings (3 m) for smaller or short-lived (companion) trees.

- Planting density in riparian or more erosion-prone areas should be at about 1 metre spacing. In stream systems spacing can be down to 1 metre to ensure rapid cover and root networking.
- Elsewhere, nursery species should be considered at close spacings.
- Optimise the timing of planting – such as planting dry sites in rainy season and riparian sites immediately following rainy season (Table 8).
- High rainfall areas may need to be planted in low rainfall season whereas in climates with marked dry season, planting should be carried out during or at end of the wet season with time to establish a root system before drought sets in. Very wet areas such as swamps or lake margins or more or less permanently flowing stream margins should be planted at the driest time of year.

Figure 19 – Village plant nursery.

10. Site preparation

- Cultivation should only be carried out where there is no threat from erosion.
- Cleared planting lines should be along contours rather than up and down slopes.
- Prepare site by burning on gentle slopes, slashing weeds or herbicides – just in the site to be planted (say a 1-metre diameter clearance for each tree).
- Top-dressing if required – where there are known to be nutrient deficiencies.
- Pest control (weeds and animal pests) – if there are browsing mammals these need to be kept away by physical barriers, eradication, deterrents, or repellents.
- Fire-breaks – use green leathery-leaved species or natural retardants such as citrus and mango and other species especially those that have multiple values.

11. Planting

Planting is a very critical step in the success of the 'crop' and it is even more important to get it right in a semi-natural or wild situation where plants will have to fend for themselves to some extent, compared with a garden situation where plants can be constantly tended, weeded or watered.

- Organise logistics, planters, plants, maintenance regime and all associated equipment and supplies – as well as food and water for workers.
- Establishment – appropriate timing, planting technique according to site and drainage is essential (see Table 8, Figures 16, 17)
- Avoid leaving bare-rooted or potted plants out in sun or roots will 'cook' and survival will be poor.
- Planters can be issued with a dozen or 20 plants in a heavy white plastic bag – to reflect heat and reduce heat stress.
- Keep water on hand to maintain plants in prime condition during this transition from nursery to field.
- Or if holes are pre-dug, plants can be allocated according to a predetermined pattern/arrangement and placed in holes on shady side

Table 8 – Example of a table that can be used to demonstrate optimum planting times (X) for different parts of the country – in the case of Fiji – in relation to dry or wetter climates and wet/riparian or dry sites

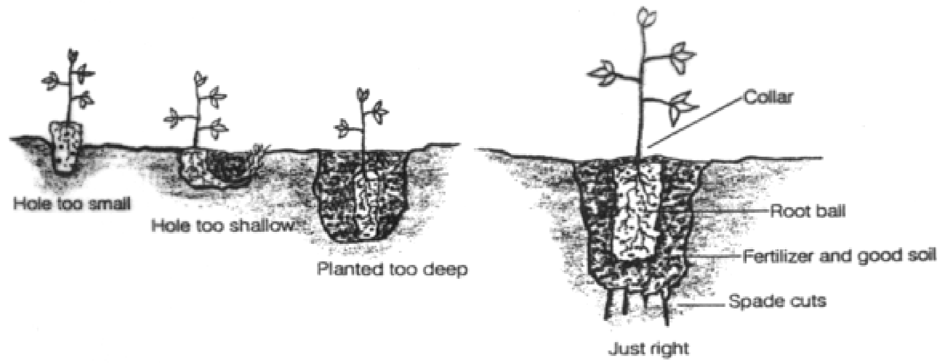
			Wet season	**Transition**	**Dry season**
	Climate	**Site**			
Hills	High rainfall	Wet + Riparian	0	0	X
		Dry	0	X	X
	Low rainfall	Wet + Riparian	X	X	0
		Dry	X	0	0

- Plant deep and if site is drought prone create a dish, cut into slope if necessary, so water will gravitate to desired plant (Box 11, Figure 20).
- Pack soil firmly around roots – from bottom up so there are no air gaps that can dry out around the roots.
- Plant as per diagram (Box 11, Figure 20), depending on slope and position – ensure the hole is large enough to accommodate the root ball without squashing or deforming the roots.
- Plant should be deep and firm enough to ensure tree doesn't fall over or spin in the wind.
- If available, place slow-release fertiliser tablet (or compost) in bottom of hole, cover with 2 cm of soil (to avoid burning the roots), bed-in the plant, pack soil in around the tree from base up, and put another 2–5 cm of soil on top of potting mix to avoid a

wicking effect. Firm soil all around the young tree seedling so that when you give a gentle tug there is no hint that the plant will pull out of the ground. The profile of the hole should be as per diagram – a dish or hollow, even on slopes, enough to allow any rain or watering to preferentially run towards the planted tree.

Planting steps

- Soak plants before planting, but leave to drain and keep out of direct sunlight.
- Skim any grass regrowth off the soil surface using a spade or grubber (screefing). Do not damage other plant roots or remove too much topsoil.
- Turn over the cleared patch (Porteous 1993), or use the removed grass as a mulch.
- Dig a hole twice the size of the plant container, score the sides and loosen soil in the bottom of the hole.
- Add water to the hole in dry areas, if it is available.
- Remove plant from the container carefully, retaining as much soil around the roots as possible.
- Untangle or prune roots if necessary.
- Trim the bottom 2–3 cm off the root plug of root–trainer plants to encourage root growth (Porteous 1993).
- Place plant in hole so the base of its stem is the correct depth below the adjacent soil surface.
- Gradually add soil around the roots, firming each layer.



- Firm the soil well after planting, leaving a slight depression (in unsaturated soils) to catch any rain or water run–off.
- In droughty situations, thoroughly water the plants and do not water again for at least 2 weeks.
- Apply animal repellents immediately before, or at planting time (see section

Box 11 – Tips for proper planting technique on a site with good moisture levels, not too wet or dry. See Figure 20 for variations according to profile position. (From Davis & Meurk 2001)

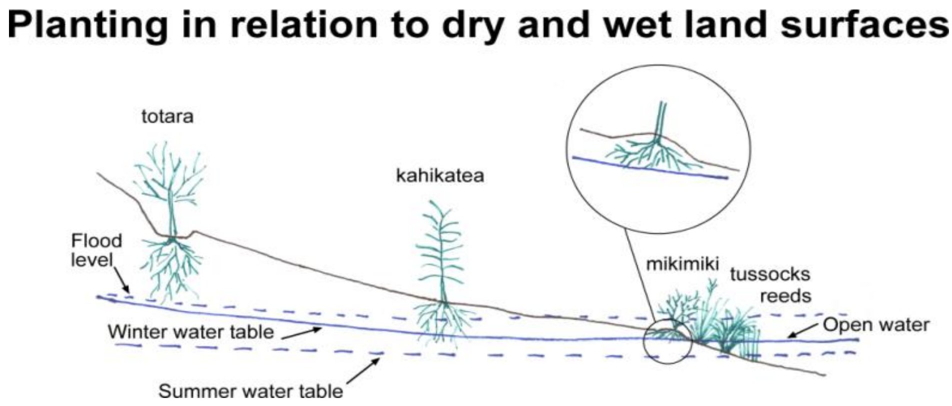


Figure 20 – Planting depth at varying positions along a river or lake edge. On slopes prone to drying out planting depth should be greater with a dish around the base of the plant (which still must have its root ball and potting mix well covered with local soil and/or mulch). Such sites should be planted during or towards the end of the wet season. Sites that are saturated most of the time should be planted during the dry season and woody plants may need to be mounded above the general ground level so that roots can establish properly.

- If appropriate, provide plant protection, e.g. 'combi-guard' system (Figure 21) which comprises a mulch mat, a plastic sleeve or guard and stakes to support and tension it. This will protect against low level browsing, weed competition, spray drift, weed-eater damage (see Figures 22, 23), and ensure plants can easily be located for subsequent attention if grass grows up around plants between visits. Make sure sleeves are wide enough so that scorching, from lack of air movement, doesn't occur – and they should be light in colour rather than dark – to avoid absorption of heat. It will be possible to design this kind of protection using local materials.

Figure 21 – Use of 'combi-guards' like these provides protection against immediate weed competition, small mammal browsing, spray drift, mechanical weed eaters, etc. Diameter needs to be large enough to prevent scorching or over-heating of plants while they are small. Alternatively use heavy mulch and/or frequent manual weeding.

- Repeat the planting instructions several times during a planting day – planting in the hills is quite different from planting in a garden where one can keep a constant eye on performance and take immediate action if plants are getting dry or starved of nutrients. Experienced people will be able to mentor the younger planters.

- Mulch – as required or as available. The ‘guards’ will work for up to a year or so while establishment is occurring, and they provide a means of ensuring plants are not lost in the grass! Use any organic waste material available, but leave a 5–10 cm square around stem of plant to allow any rain that falls to penetrate into soil around roots rather than evaporate off mulch surface.
- Animal pest repellent may be required for additional protection; this can be sprayed onto foliage.
- In second or third year interplant additional species that need or prefer initial shelter.

12. Maintenance (follow-up establishment and tending)

It is essential to have a plan or maintenance calendar in place for the vital post-planting follow-up. This is part of the ongoing work plan and budget.

- When watering don’t broadcast water over foliage and around all competing plants – water topically (i.e. half a bucket once a week applied directly to plant) and do this thoroughly but infrequently in order to train roots to seek moisture at depth.
- Avoid herbicides around plants except perhaps grass-specific sprays growing around the desirable broad-leaved plants! (Figure 22).

Figure 22 – Effects of spray herbicide drift on sensitive plants. Extreme care on the part of well-trained and supervised workers is required to prevent losses of planting investment.

- Avoid using mechanical ‘weed-eaters’ or ‘strimmers’ unless plants have been hand-weeded first (Figure 23); always do initial weeding by hand with trained workers.
- Ensure there is plenty of positive reinforcement for planters; ‘cheering along’ the team and celebrating successes is important – providing food and refreshments, and protection against the elements is desirable.

Figure 23 – Ring barking of well-established tree by careless use of a mechanical 'weed-eater'. Extreme care on the part of well-trained and supervised workers is required to prevent losses of planting investment.

13. Monitoring – evaluation and adaptation to ensure successful and enduring outcomes

- Establish indicators of plant performance, weed levels, vegetative cover, wildlife, fungi, seedlings, fruiting, erosion and sedimentation, and social factors.
- Implement a monitoring plan for:
  - Plants
  - Wildlife
  - Sediment
  - Water quality in streams
  - Water quality and sedimentation on reefs
  - Social capacity building
  - Knowledge levels and understanding
  - Buy-in
  - Contribution and actions/behaviour
  - Longer term watershed responses
- Monitor and note which species do best and use this knowledge to inform future plantings.
- In first year – overseer/project manager must visit planting sites every month with community, discuss any emerging problems, and necessary actions that can be 'contracted' for the following month. This will also maintain connection, continuity and trust.
- If pests appear – take action immediately (repellents, fencing, control, etc.)
- If weeds begin to restrict growth then clear immediately (using hand-weeding immediately around plants).
- If drought appears put resources into watering – it will be bad for morale and trust if planting effort is wasted through not taking timely action.

- Adapt when things go wrong; learn from successes – this is the well-known concept of Adaptive Management – completing the cycle of planning–implementation–monitoring–adjusting the plan and actions.
- Establish a regular review at appropriate intervals – to reassess progress towards goals and that communities remain engaged and committed.

Table 9 – An example of species selection in practice. Naroko watersheds, NE Viti Levu. Distribution of tree species for three sites

Species	Seedling no. required	Rewasa			Narara		Vatukacevaceva				
		1 ha	4 ha	5 ha	5 ha	5 ha	2 ha	2 ha	2 ha	2 ha	2 ha
Teak	5,000 (1,500 per site)	300	500	700	750	750	300	300	300	300	300
Mahogany * Bare root * Potted * Seeds	1,000 (300 per site) 1,000 (300 per site) 1,000 (300 per site)		150 150 150	150 150 150	150 150 150	150 150 150	60 60 60	60 60 60	60 60 60	60 60 60	60 60 60
Calliandra calothyrsus	1,000 (330 per site)										
Dakua makadre (*Agathis macrophylla*)	90 (30 per site)		10	20	15	15	6	6	6	6	6
Dakua salusalu (*Decussocarpus vitiensis*)	11 (11 for 1 site)				11						
Damanu (*Calophyllum*)	300 (100 per site)		50	50	50	50	20	20	20	20	20
Laubu (*Garcinia pseudogutiferra*)	150 (50 per site)		20	30	25	25	10	10	10	10	10
Tavola (*Terminalia .catappa*)	50 (15 per site)		5	10	7	7	3	3	3	3	3
Velau (*Gymnostoma vitiensis*)	60 (20 per site)		10	10	10	10	4	4	4	4	4
Vesi (*Intsia bijuga*)	90 (30 per site)		15	15	15	15	4	4	4	4	4
Yaka (*Dacrydium nidulum*)	100 (30 per site)		15	15	15	15	6	6	6	6	6
Yasi-sandalwood (*Santalum ysai*)	600 (200 per site)	10	95	95	50	50	40	40	40	40	40
Total		310	1,170	1,348	1.398	1.387	573	573	573	573	573

Final words

These steps for effective revegetation within an IWM framework are comprehensive and based on sometimes bitter experience of past failures and observations of what works. Many of these items will already be well known to communities and their leaders; so it is really a checklist and guide. Not all the steps will necessarily be relevant to all situations and all people; each project needs to develop its own objectives, plan and design, but hopefully this information, approach and the associated species tables will provide useful information to support those local decisions.

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APPENDIX 1 – RECOMMENDED SPECIES FOR RESTORATION

Appendix 1.1 Recommended Tree species for Hills, Flood plains and Coasts

This table lists species suitable in Fiji. A local assessment will be required to provide a more definitive list appropriate to each island nation.

Scientific Name	Name	Mature Size Range (m)	Habit/ Form	Growth Rate S – Slow M – Med F - Fast	Land Unit Types										Uses/Purpose				
					Ridge Crest & Upper slope	Mid slope	Lower slope & Foot slope	Flood plains	Dry Forest	Flat Plains	Coastal Forest	Mangrove	Riparian/ Stream	Grassland	Timber tree species	Erosion control	Traditional	Soil Improvement	Water Management/ Ecosystem/ Biodiversity
Acacia richii	Qumu	20	Tree	M	√	√	√								√		D	√	√
Acacia auriculiformis	Northern black wattle	30	Tree	F		√	√	√	√	√	√		√	√	√	√		√	
Agathis macrophyllum	Dakua makadre	30	Tree	M	√	√	√			√					√		√		√
Aleurites moluccana	Lauci	15	Tree	F	√	√	√		√		√		√				I		√
Alphitonia franguloides	Doi damu	15	Tree	S	√				√								√		√

Alphitonia zizyphoides	Doi	25	Tree	F		√	√			√	√				√		FW		√
Alstonia costata	Sorua	10	Tree	F	√	√					√								√
Alstonia vitiensis	Sorua draulevu	15	Tree	F	√	√													√
Amaroria soulameoides	Vasa ni veikau	25	Tree	M	√	√	√	√									M		√
Artocarpus altilis	Breadfruit	20	Tree	F		√	√			√	√						F, M		
Artocarpus heterophylla	Uto-ni-dia	20	Tree	F	√	√	√	√					√	√			F, FB		
Atuna racemosa	Makita	15	Tree	M			√			√							T, D, M		√
Barringtonia asiatica	Vuturakaraka	20	Tree	M							√	√				√	O		√
Barringtonia edulis	Vutu	20	Tree	F			√			√	√						F		√
Barringtonia racemosa	vutu wai	10	Tree	F								√	√				Fencing		
Bischofia javanica	Koka	25	Tree	F	√	√	√			√						√	FW, D	SS	√
Bruguiera gymnorrhiza	Dogo	25	Tree	M							√	√				√	D, FW, P, M, G		√
Buchanania attenuata	Damanu ni yaqaqa	18	Tee	M		√	√			√	√				√				
Burckella parviflora	Baumika	30	Tree	F	√	√					√				√				√
Calophyllum inophyllum	Dilo	20	Tree	M							√				√		M		√
Calophyllum neo-ebudicum	Damanu	25	Tree	M	√	√	√			√					√				√

Calophyllum vitiense	Damanu	25	Tree	M	√	√	√			√					√				√
Canaga odorata	Makosoi	20	Tree	F		√	√			√	√							G	√
Canarium spp.	Kaunicina	24	Tree	M	√	√				√	√				√				√
Casuarina equisetifolia	Nokonoko	20	Tree	F					√		√				√	√	M	SS, CP	√
Cerbera manghas	Vasa	20	Tree	M	√	√	√				√						M		√
Cocos nucifera	Coconut	30	Tree	M			√				√				√		F, M, G		√
Commersonia bartramia	Sama	10	Tree	F	√	√	√	√		√			√	√					√
Cordia subcordata	Nawanawa	15	Tree	M							√						C, G		√
Cordyline fruticosa	Vasili	5	Tree	F		√	√			√	√						F, O,G		
Crossostylis seemannnii	Tirivanua	15	Tree	M		√	√	√								√	M		√
Cyathea spp.	Balabala	10	Tree	F		√	√			√			√		√	√	M, B		√
Cynometra insularis	Moivi/Cibicibi	20	Tree	M	√	√	√			√	√							NF	√
Dacrycarpus imbricatus	Amunu	24	Tree	M		√									√				√
Decaspermum vitiense	Nuqanuqa	10	Tree	F		√	√			√				√			FW, M		√
Dacrydium nidulum	Yaka	25	Tree	S	√	√									√			NF	√
Decussocarpus retrophyllum vitiensis	Dakua salusalu	43	Tree	M	√	√	√			√					√				√
Degeneria	Masiratu	30	Tree	S							√				√				

vitiensis																			
Dillenia biflora	Kuluva	20	Tree	M	√	√	√	√		√			√		√		LF, M	LF	√
Dysoxylum richii	Tarawaukeirakarak a	25	Tree	M		√	√			√	√				√		M		√
Elaeocarpus spp.	Kabi	27	Tree	M	√	√								√	√				
Elattostachys falcata	Marasa- I	25	Tree	M	√	√	√		√	√	√			√	√		FW		√
Emmenosperma micropetalum	Tomanu	25		M	√						√						HD		
Endospermum macrophyllum	Kauvula	35	Tree	F		√	√			√	√				√				
Endospermum robbieannum	Vanua Levu kauvula	25	Tree	F		√	√			√	√				√				
Erythrina variegata	Drala	15	Tree	F				√	√	√	√						LF	NF	√
Excoecaria agallocha	sinu gaga	15	Tree	M							√	√					M		√
Fagarea berteroana	bua ni Viti	12	tree	S			√	√					√				M,G		
Fragraea gracillipes	Buabua	25	Tree	S		√	√		√	√	√				√		P, M		√
Flueggea flexuosa	Baumuri	15	Tree	F			√				√		√		√		LF		
Ficus baraclayana	Losilosi	10	Shrub	M			√			√			√						√
Ficus fulvo-pilosa	Ai-masi	12	Tree	M		√	√	√			√		√				M		√
Ficus obliqua	Baka	30	Tree	M							√						√		√
Ficus prolixa	Baka ni Viti	30	Tree	M	√	√	√												√
Ficus smithii	Nunu	10	Tree	M		√	√												√
Ficus vitiensis	Lolo	10	Tree	M	√	√	√		√					√			M		√

				F - Fast	Ridge Crest & Upper	Mid slope	Lower slope & Foot slope	Flood plains	Dry Forest	Flat Plains	Coastal Forest	Mangrove	Riparian/ Stream	Grassland	Timber tree species	Erosion control	Traditional	Soil Improvement	Water Management/ Ecosystem/ Biodiversity
Garcinia myrtifolia	Laubu	28	Tree	S	√	√	√							√	√				
Geissois ternata	Vure	15	Tree	M	√										√				√
Glochidion seemannii	Molau	10	Tree	M		√	√			√	√			√			M		√
Gmelina vitiensis	Rosawa	27	Tree	M	√	√									√				√
Gnetum gnemon	Sukau	15	Tree	F	√	√	√		√	√	√						F		√
Gonystylus punctatus	Mavota	22	Tree	M		√	√				√				√				
Gymnostoma vitiense	Velau	27	Tree	M	√						√				√		FW, FR		
Gyrocarpus americanus	Wiriwiri	25	Tree	F			√		√		√						M		√
Haplolobus floribundus	Kaunigai	25	Tree	M	√	√	√			√					√		F		√
Hermandia olivacea	Dalovoci	25	Tree	M	√	√	√				√				√				√
Heritiera littoralis	kendra ivi yalewa kalou	10	Tree	M								√				√	FW		√
Heritiera ornithocephala	Rosarosa	35	Tree	M	√	√									√	√	C		√
Hibiscus tiliaceus	Vau	8	Shrub	F			√		√		√	√					M, G		
Inocarpus fagifer	Ivi	25	Tree	M			√	√		√	√					√	M, F	NF	√
Instia bijuga	Vesi	30	Tree	S	√	√	√	√	√	√	√	√	√	√	√	√	M, BF	NF	√
Jatropha curcas	Banidakai	8	Tree	F			√			√	√								

Kingiodendron platycarpum	Moivi	35	Tree	M	√				√		√				√				
Lumnitzera littorea	Sagale	12	Tree	M								√	√		√		M, G		√
Macaranga graffeana	Gadoa	15	Tree	F		√	√			√						√	√		√
Macaranga harveyana	Gadoa	15	Tree	F		√	√			√						√	√		√
Mangifera indica	Mango	25	Tree	M			√		√	√	√			√			F		
Mastixiodendron robustum	Duvula	15	Tree	F	√	√	√	√	√						√				√
Metrosideros collina	Vuga	20	Tree	S	√										√	√	P		√
Myristica spp.	Kaudamu	30	Tree	M	√	√	√				√				√				
Neonauclea forsteri	Vacea	25	Tree	M		√	√		√				√				M		√
Pagiantha thurstonii	Vuetinaitasiri	20	Tree	M	√	√	√			√				√	√		M, C		√
Palaquium hornei	Sacau	25	Tree	S	√	√									√				√
Palaquium porphyreum	Bauvudi	25	Tree	F	√	√	√								√				√
Palaquium vitilevuensis	Bau	24	Tree	M	√	√	√								√				√
				F - Fast	Ridge Crest & Upper	Mid slope	Lower slope & Foot slope	Flood plains	Dry Forest	Flat Plains	Coastal Forest	Mangrove	Riparian/ Stream	Grassland	Timber tree species	Erosion control	Traditional	Soil Improvement	Water Management/ Ecosystem/ Biodiversity
Parinari insularum	Sa	30	Tree	S	√	√	√				√				√		M, P		√

Phalaria disperma	sinu ni baravi	4	Shrub	M							√						S, G		
Pittosporum spp.	Tuvakalou	20	Tree	M	√			√			√						M		
Planchonella vitiensis	Sarosaro	25	Tree	M	√				√						√		CM		√
Pleiogynium timoriense	Manawi	25	Tree	f	√			√									D		√
Plerandra spp,	Sole	15	Tree	F	√														√
Podocarpus affinis	Kuasi	15	tree	S	√		√	√											√
Podocarpu neriifolius	Kuasi	25	Tree	S	√		√	√			√			√	√		P, S		√
Pometia pinnata	Dawa	27	Tree	M			√			√	√				√		F		√
Pongamia/Milletti a pinnata	Vesi wai	25	Tree	M			√	√		√	√				√		M	NF	√
Premna serratifolia	Yaro	15	Tree	S		√	√		√	√	√		√	√			P, M, FW		√
Pterocymbium oceanicum	Ma	30	Tree	M		√									√				√
Rhizophora mangle	Tiriwai	10	Tree Shrub	M								√				√	FW, M, D	SS	√
Rhizophora stylosa	tiritabua	15	tree									√					FW, M, D, G		
Samanea saman	vaivai-ni-vavalagi	25	Tree	F		√	√	√			√		√		√	√	M	NF	
Santalum yasi	Yasi dina	12	Shrub	S					√						√		S		
Semecarpus vitiense	Kaukaro	30	Tree	M	√	√				√					√				√
Serianthes spp.	Vaivai-ni-veikau	21	Tree	M	√	√									√		FW, C	NF	√
Spondias dulcis	Wi	25	Tree	F		√	√			√	√						F, M		√

Sterculia vitiensis	Waciwaci	30	Tree	F			√								√		F		√
Storckiella vitiensis	Marasa	20	Tree	M	√	√									√	√	FW	NF	√
Syzygium decussatum	Yasimoli	15	Tree	S	√	√									√				
Syzygium malaccense	kavika	15	tree	M			√										F, M		
Syzygium spp.	Yasiyasi	20	Tree	S	√										√				
Terminalia catappa	Tavola	25	Tree	F															
Terminalia littoralis	Tavola Leka	10	Tree	M															
Terminalia pterocarpa	Tivi	25	Tree	M	√	√									√				√
Trichospermum calyculata	Makoloa	25	Tree	M		√	√	√										O	√
Trichospermum richii	Mako	20	Tree	M		√	√	√											√
Turrillia vitiensis	Kauceuti	25	Tree	M	√	√	√								√				√
Xylocarpus granatum	dabi	20	tree	M							√	√					FW, M		√
Xylocarpus moluccensis	dabi	20	tree	M								√					FW, M		√

Key: M – Medicinal, FW – Firewood, D – Dyes, I – Ink, T – Thatching, S – Scenting, NF – Nitrogen fixing, SS – Soil stabilisation, CP – Coastal protection, WB – Windbreak, FR – Fishing rod, C – Carving, HD – Hand tools, LF – Living fence, P – Posts,

F – Food, CM – Combmaking, S – Spears, BF – Biofuel, O – Ornamental, FB – Fire break, O – Others (Stupify, Fishing net floaters, totem, etc.)

Appendix 1.2 Species for Riparian Zone Planting

This table is an indicative approach to assigning species suitable to riparian restoration. It lists species suitable in Fiji. A local assessment will be required to provide a more definitive list appropriate to each island nation

		Riparian/Gully								Use/Purpose			
Species	Name	Water Margin	Gully Floor	Lower Bank	Upper Bank	Levee	Backswamp	Scarp	Terrace	Commer-cial	Erosion	Cult-ural	Biodi-versity
Alpinia boia													
Balaka sp.	palm												
Bambula textilis					considered as potential								
Bambusa vulgaris	bitu ni/common bamboo				1	1		1		B	x		
Carex dietrichiae	sedge												
Carex graeffeana	sedge												
*Chrysopogon/Vetiveria zizanioides**	vetiver		1	1	1			1			S		
*Cyperus papyrus**	sedge												
Dianella intermedia	lily			1									
Eleocharis dulcis	kuta†	1	*										
Erianthus maximus	grass												
Geanthus cevuga													
Heliconia paka													
Joinvillea plicata	sedge												
Lepironia articulate													
Mariscus javanicus													

Metroxylon vitiense	palm												
Miscanthus floridulus													
Neovietchia storckii													
Pandanus tectorius							for wetter sites				x		
Rhynchospora corymbosa											x		
Saccarum edule	duruka							for slopes					
Schizostachyum glaucifolium	bamboo												
Scirpodendron ghaeri													
Scleria lithosperma													
Tacca maculata													
Typha domingensis	bulrush												
Veitchia pedionoma	palm												
Veitchia vitiensis	palm												
	natapoa										M		
	nassau grass		1										
Vetiveria zizanioides *(Chrysopogon zizanioides)*	Vetiver grass												
T – timber, C – Carbon, V – Vanuatu, F – Fiji, N – N-fixing													
1 – Pioneer planting; 2 – Secondary planting; 3 – Planting only under shelter/shade													
**Arundo donax* was also suggested though this was noted as introduced and weedy													
†Kuta may be suitable for stabilising gullies also													

APPENDIX 2 – VETIVER GRASS FOR EROSION CONTROL AND IMPROVED PRODUCTION: A TRAINING GUIDE

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Introduction

This training manual has been prepared to support fieldworkers who are faced with the challenge of controlling soil erosion on sloping agricultural lands, re-establishing vegetation on bare eroding gullies and generally reducing sediment movement to coastal zones and coral reefs. While it has been written specifically for situations found in Fiji and Vanuatu, it has application to many other locations in the tropical Pacific which have similar erosion problems to control. The Atiu and Mangaia in the Cook Islands, Guam, Palau, and Molokai and Kaho-o-lawe in Hawai'i, have similar instances of extremely severe erosion as that found on Aneityum Island in Vanuatu, while most high Pacific islands, such as Upolu in Samoa, have potential soil erosion and soil fertility loss problems on sloping land.

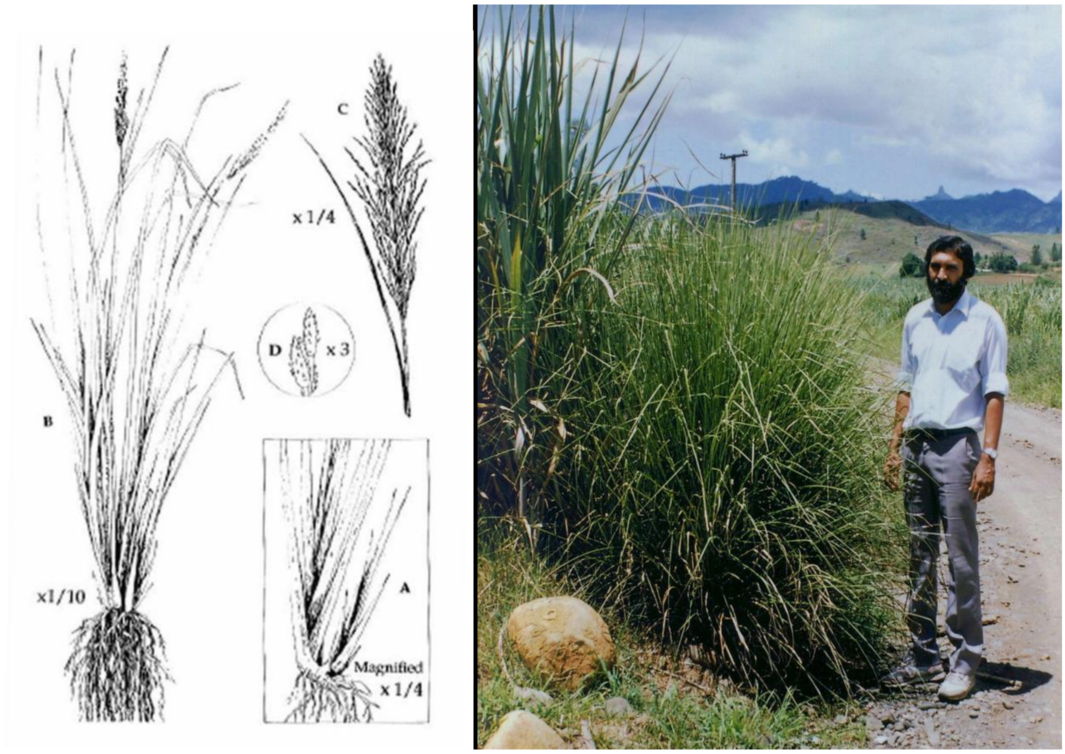
When applied correctly, vegetative systems of soil and moisture conservation – particularly the system of hedges of vetiver grass described in this handbook – have proved cheaper and more effective at controlling soil erosion on cropping land than engineered systems. The vetiver system has proved to be the most effective of these vegetative systems in many tropical countries. Since 1987 the technology has been tested in the field in many countries – India, China, the Philippines, Indonesia, Nigeria, Madagascar, Brazil, Vietnam, Thailand and Australia, to name a few. Soils and climate vary tremendously within this group. For example, in China vetiver is being grown as hedges on 60% slopes to protect tea and citrus crops on low pH (4.1) red soils.

In India vetiver is being used successfully on severely cracking soils on slopes of 2% or less. In other countries, such as Trinidad, it has been used for years to stabilise rock-based roadsides. In every case this unique grass has displayed the same extraordinary characteristics that make it an ideal low-cost, non-site-specific system for controlling soil loss and improving soil moisture.

An early Pacific application of vetiver was its very successful use on sloping sugar cane fields in Fiji from the 1950s to 1970s. Here it controlled soil loss, improved soil moisture and raised the productivity of sugar cane. This application was studied in 1990 by the author of this guide and trials of its use on the red acid soils of the Cook Islands followed, which showed that there was potential for its use in extremely severe erosion situations.

What is vetiver grass?

Ten species of coarse perennial grasses found in the tropics of Europe, Africa and Asia belong to the family Andropogoneae, but only one of these, *Chrysopogon zizanioides* (formerly known as *Vetiveria zizanioides*), has proven to be ideal for soil and moisture conservation.



Vetiver

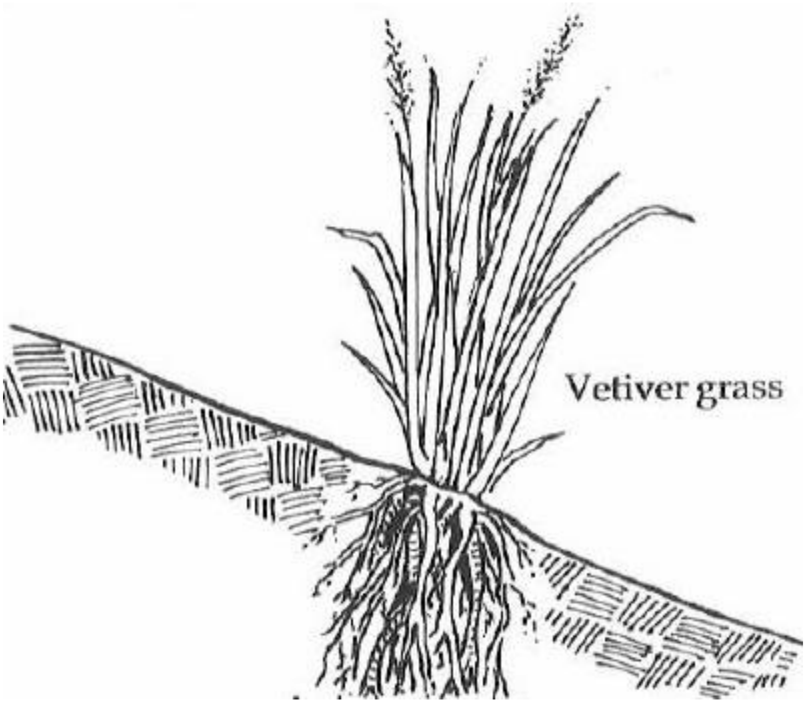
The following are some of its positive properties:

- It has a strong fibrous root system that penetrates and binds the soil to a depth of up to 3 m and can withstand the effects of tunnelling and cracking.

Roots of a one-year-old vetiver plant.

- Its crown (growing points) is below the surface, which protects the plant against fire and overgrazing. When all surrounding plants have been destroyed by drought, flood or fire, vetiver will remain to protect the ground from the onslaught of the next rains.
- Its sharp leaves and aromatic roots repel rodents, snakes, and similar pests.
- Its leaves and roots have demonstrated a resistance to most diseases.
- Once established, it is generally unpalatable to livestock. The young leaves, however, are palatable and can be used for fodder.
- It is both a xerophyte and a hydrophyte, and once established it can withstand drought, flood, and long periods of waterlogging.
- It will not compete with the crop plants it is used to protect. Vetiver grass hedges have been shown to have no negative effect on – and may in fact boost – the yield of neighbouring food crops. Its roots are a host to beneficial mycorrhiza, which may be of benefit to adjacent crops.
- It is cheap and easy to establish as a hedge and to maintain – as well as to remove if it is no longer wanted.
- It will grow in almost all types of soil, regardless of pH, or salinity. This includes sands, shales, gravels, and even soils of relatively high aluminium toxicity.
- It will grow in a wide range of climates. It is known to grow in areas with average annual rainfall between 200 and 6000 mm and with temperatures ranging from −9° to 45°C, although hot-season conditions are needed for part of each year to ensure long-term survival.

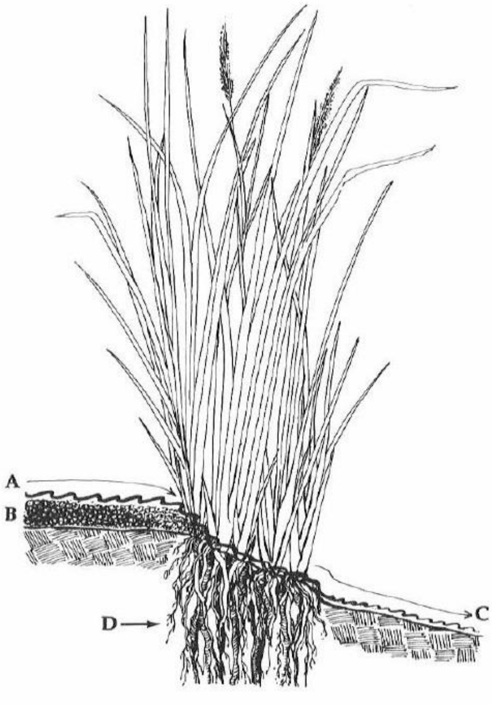
What is vetiver's value to agriculture?



Vetiver is planted as a contour hedge (on a level, although not necessarily straight line) across cultivated slopes. The stems grow so close that runoff water flowing down the slope is slowed and spread evenly.

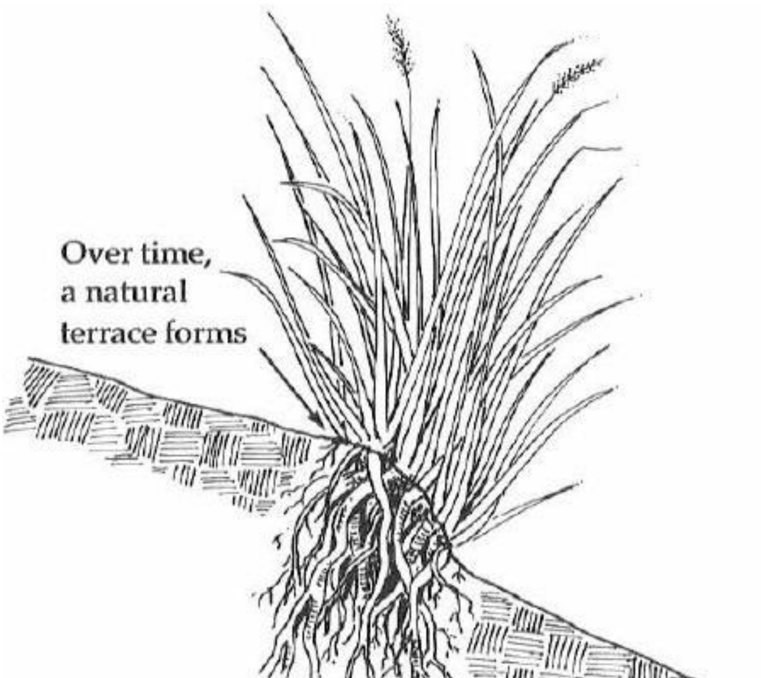
The dense barrier of vetiver stems formed by a young hedge. The stems are strong enough to stand up against flowing water 300 mm deep.

When runoff is slowed its ability to carry sediment is reduced, the sediment is deposited and is retained by the vetiver hedge.



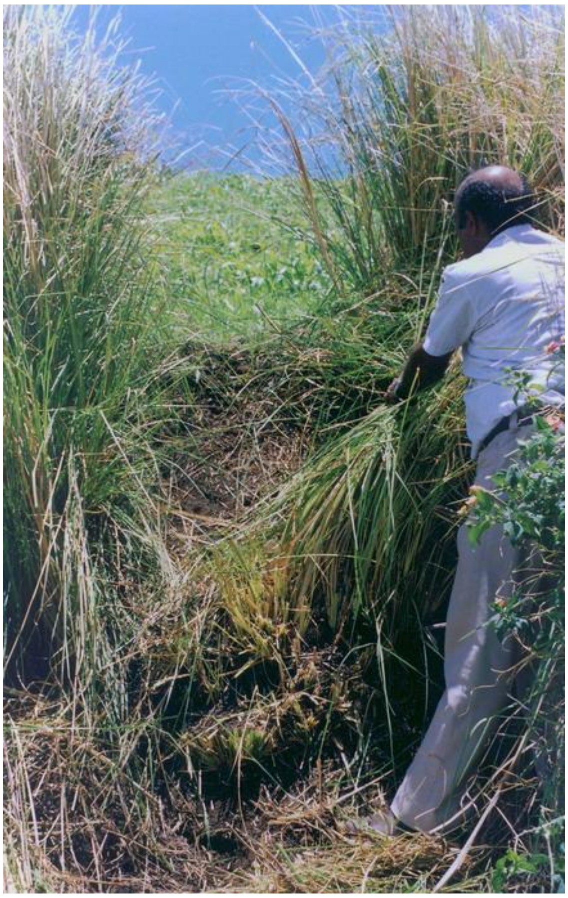
A. Runoff water being slowed and spread; B. Sediment being dropped from suspension and retained; C. Slow and even flow of runoff water below the vetiver hedge; D. Thick mat of roots which have beneficial mycorrhizal fungi living in them.

A vetiver hedge showing sediment being deposited by slowed runoff and then trapped to form a terrace.



Over time a terrace of trapped soil, which has high fertility, is formed. As the water flowing down the slope during rainfall is slowed by the hedge, and the level terrace above it, it has an increased opportunity to infiltrate into the terrace.

Vetiver stems will grow up through the sediment retained on the terrace thus providing protection to the front of the terrace as well. Terraces of substantial height can be formed over long periods of cultivation, as seen in the photo below.



The late Jonathon Subramanium, a former CSR extension worker, planted this contour vetiver hedge near Rakiraki about 25 years before this 1990 photograph was taken. The terrace is about 1.2 m in height – all of it soil that was trapped and retained by the hedge, instead of being washed away into the sea. The contour grass hedge was originally planted at the level of Jonathon's feet and the grass has grown up to keep pace with the increasing height of the retained soil.

Two examples of the practical use of vetiver that highlight the adaptability of this vegetative approach to environmental protection will be described here. This may help potential users develop their own responses to the problems they encounter.

Example A – Fiji's sloping sugar cane fields

This is a highly relevant example of erosion control with vetiver grass as it illustrates the advantages and disadvantages of a highly effective system that was later abandoned, with disastrous long-term consequences. Some of the positive effects are visible in the photograph above.

Around 1955 the Colonial Sugar Refinery was expanding its production and needed more land. The only option was to cultivate slopes that had been unused for cane before, but heavy rains showed that the soils would quickly be destroyed by erosion. Experiments were tried using a range of local grasses and it was observed by John Greenfield, the agronomist at that time, that vetiver grass, which appeared to have been introduced from South India, was very effective at trapping moving soil.

It was made mandatory by CSR that all slopes steeper than 13 degrees had to be planted with contour hedges of vetiver at 2-m vertical intervals. No cane was accepted at the mills if this was not done. A team of extension workers instructed the farmers on how to install the hedges and provided initial supplies of vetiver.

A Colonial Sugar Refinery extension worker, Ram Pratap. on the right, assisted by the farmer's son, planting vetiver clumps on a contour across a sloping cane field. Note cultivation by the farmer using a draft animal, which was almost standard practice during the 1950s and 60s. Photo reprinted courtesy of Padma Lal

An additional benefit was that cane production increased by as much as 10% after the contour hedges were planted and so farmers were keen to use it.

A 1990 photograph of sugar cane in Fiji protected by a vetiver hedge. Note the height of soil captured by the contour hedge and the rocks showing through the unprotected field down-slope, where soil has been lost.

Despite all of the benefits resulting from the use of vetiver hedges the system was progressively abandoned after CSR left Fiji, although the cultivation of sloping cane fields continued. Recent inspection of the Rakiraki area shows a few surviving contour vetiver hedges and the physical remains of terraces from which the vetiver plants have been removed.

Remnant terraces near Rakiraki with no sign of vetiver plants surviving.

Discussions with John Greenfield and with Sugar Research Institute staff since 1990 have yielded some clues as to why this has happened.

The use of draft animals for cultivation was compatible with contour farming but the introduction of tractors meant that sections of terrace were removed to allow the machines to move up- and down-slope and this eventually led to entire terraces being lost. The need for erosion control was not passed on to subsequent generations and only a few farmers now use it.

It should be noted that in only very few countries is the voluntary use of soil erosion control ever successful. The immediate requirement of farmers to survive understandably becomes dominant. Where there is an ongoing and severe problem to be controlled, legislation is normally used. Even in New Zealand, a law has been recently passed that makes farmers legally responsible for planting conservation trees on certain classes of land.

There is still time to save at least some of the soil of the sloping sugar cane fields and there is planting material available to start new vetiver nurseries. Work in Vanuatu has shown that even previously eroding gullies in very infertile soil can be producing food crops 12 years later. The physical problem of rehabilitating the degraded Rakiraki lands can be overcome by using vetiver combined with nitrogen-fixing trees, but a similar extension effort to that formerly provided by the sugar mills will be needed.

Example B - Extreme gully erosion in Vanuatu

The small island of Aneityum, the southernmost in the Vanuatu chain, has been affected by very severe erosion for many years. Sediment from the eroding gullies has had a significant negative impact on the coastal zone and on fringing coral reefs, with red mud lying several centimetres thick on some beaches.

A footprint in thick sediment deposits on an Aneityum fringing reef – 1995.

From 1965 *Pinus caribaea* forest was planted on 900 ha of moderately eroded land but even this hardy tree would not survive on the depleted red acid soils of Aneityum, which are affected by seasonal drought and occasional uncontrolled fires. An early trial of a range of grasses by the Forestry Department was abandoned but examination of those field sites in 1995 showed that a number of vetiver plants had actually survived, although they had not grown and looked unhealthy. They were not retaining any sediment as they had been planted too far apart.

Further trials and field plantings over the next eight years developed a vetiver planting regime that either allowed indigenous trees to be established on the eroding walls of the active gullies or in the floors of the gullies where the moving sediment could be extracted from runoff and retained.

One example of many is the Chalk Hill catchment, which was a major source of red sediment that affected the coastal zone. The total catchment area was several hectares and initial attempts to trap sediment in the valley floor were not successful, particularly after Cyclone Yali in 1998 dumped 350 mm of rain on the area.

It was decided to attempt to establish trees on the gully walls, despite their steep and infertile soils, by first establishing contour rows of vetiver across the 30-degree slopes. The fine particles of weathered rock trapped by the vetiver made it possible for the indigenous *Acacia spirorbis* to grow rapidly and protect the soft rock from further erosion.

The plantings at Chalk Hill have proved so effective that there is no longer red mud on the reef, where before it was a great nuisance and obviously damaging the marine environment. The reduced runoff from the catchment due to the terracing and new forest cover has allowed the valley floor plantings to survive and these are now able to trap any sediment that does still escape from the gully walls.

Elsewhere on Aneityum gully floor plantings have trapped so much sediment that the level of retained soil has risen by over a metre and large, formerly exposed, rocks are now being buried again.

Much work remains to be done on Aneityum but now that the techniques have been developed it may be possible for the custom landowners, village people and the Vanuatu government to carry on the work, with outside financial input possibly limited to the costs of essential plant nutrients.

Chalk Hill gully in 1997 before planting started on the gully walls.

Initial contour rows of vetiver established on the gully walls in 2001.

The same area of gully wall at Chalk Hill showing vetiver hedges and well established indigenous *Acacia spirorbis* 7 years after the previous photograph.

The same area of reef 15 years later, with no red mud visible.

Establishing vetiver nurseries

Sources of vetiver plants

The great advantage of the South Indian strain of vetiver found in the South Pacific (also known as Monto in Australia and Sunshine in the US) is that it does not have fertile seeds and so cannot become a weed. There are other strains of vetiver in Asia and Australia which may have fertile seeds but these have not been found in the South Pacific and so will not be a problem. No signs of weediness in vetiver has been observed by the author in the Pacific Island countries in which he has studied it and 100-year-old plantings have remained just where they were planted with no spreading.

As it cannot be grown from seed vetiver is multiplied by vegetative methods and the easiest of these is by splitting up existing large plants and growing these on in a nursery as mother plants, until they are large enough to be split into smaller plants again – either to plant out in the field or back in a nursery.

With a multiplication factor of up to 20 being possible in a well-managed nursery per year, a large number of plants can be produced in even 2 years. One hundred small nursery plants can produce up to 40 000 plants after 2 years – enough for 4 km of vetiver hedge on agricultural land and a shorter length on severely eroding infertile soils. Getting a good nursery started early is the key to a soil conservation programme based around vetiver.

It is very important that vetiver plants for a nursery are sourced from within the country where they are to be used, if they can be found. It is known that the appropriate strain of vetiver is available in the Cook Islands, New Caledonia, Fiji and Vanuatu. Plentiful supplies should be available from the Rakiraki area of Fiji as there are still remnants of old cane field plantings there. In Vanuatu there are nurseries in Anelghowhat and Port Patrick, established by the two phases of the Aneityum erosion project over the last 16 years, and plants have been observed on other islands.

Preparing nursery material

Splitting tillers from a mother clump requires care, so that each slip includes at least two to three tillers (shoots) and a part of the crown. After separation, the slips should be cut back to 20 cm (8’’) length. For faster growth the slips should be kept in wet and sunny conditions until planting out. In Vanuatu, direct planting of the slip into the nursery has been very successful although being kept in damp sacks for over a week has not harmed the planting material.

A. Vetiver plant ready for splitting

To remove a clump of vetiver grass from the ground, dig it out with a spade or fork. The root system is too massive and strong for the grass to be pulled out by hand. Only a short length of root is needed so don't bother digging too deep – 100 mm is enough. Next tear a handful of the grass, roots and all, from the clump (B). The resulting piece, the slip, is what gets planted in the nursery or field (C).

B. Splitting the plant and roots

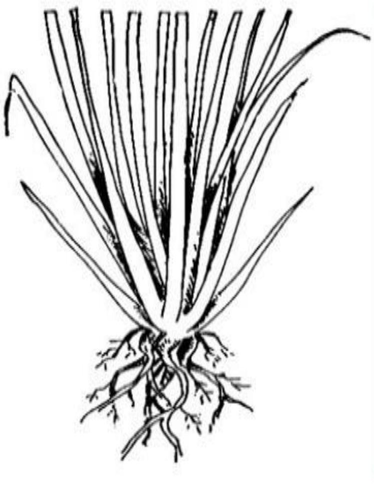
C. Slips of about 3 tillers each after being pulled apart

The slips must consist of about three tillers, including the crown and the associated roots. In very old source plants sections of root and crown that do not have shoots or roots may be planted as they will probably grow. If in doubt place such pieces in water for a week and see if they grow roots. If roots grow, the piece of crown will survive in the nursery.

It can be difficult to split a large plant. To help break it apart swing the base of the plant down on to the ground while holding the leaves, as this will loosen the intertwined roots and shake out the soil. If this isn't enough to loosen the roots, try cutting the plant in halves or quarters with a cane knife or sharp spade. Some slips will be lost but it may be the only option.

If there is a shortage of planting material, small pieces of crown and single tillers can be grown on in bowls of soil (about 30 in a plastic washing bowl) until they are large enough to plant in the nursery.

A medium-sized vetiver plant that will yield about 10 slips when split.



A vetiver slip with a suitable number of tillers and roots.

There is no point in leaving long roots on each slip as the roots only serve to hold the plant in the soil while new roots grow. Likewise too much leaf will just allow the slip to dry out and reduce its chance of survival.

Nursery size

Nursery size will depend on area available, but for planting on agricultural land a 20 × 20 m area would be able to provide about 24 000 slips suitable for field planting each year, enough for 2400 m of contour vetiver hedge. On extremely eroded slopes in infertile soils, as on Aneityum, a higher field planting density is required and so a nursery of that size would allow the planting of only about 500 m of contour hedge.

A number of smaller nurseries will be just as suitable as long as essential maintenance such as weeding and trimming is carried out on fragmented plots. The nurseries should be in full sunlight as shade slows vetiver growth, although survival may not be affected once plants are well established.

To allow easy tending and digging use a mother-plant spacing in the nursery of 500 × 500 mm. Weeding is important particularly if creeping vines may be a problem. Care must be taken when weeding to avoid damaging new tillers, which form just below ground on the outside of the mother plants.

The essential ingredients: a growing nursery (ready for trimming), a good taro spade, sacks to transport plants out to the field site, a pole to sling the sacks from and a very determined and dedicated village leader (who has persisted with vetiver planting in difficult conditions for over 10 years).

The rate of new tiller production can be increased by trimming the plants to about 200 mm height roughly every 3 months, or whenever flower stalks grow. (Note that while flowers may form they do not produce fertile seed.) While the trimming may slow plant growth for a while, the increased rate of tiller production more than compensates with more planting material being available after a year.

It has not been found necessary to fertilise plant nurseries, even on Aneityum, as if they are located on soils that would, for example, grow pineapple without fertiliser, the vetiver will thrive. It is also possible that a better mycorrhizal fungi population will form on the roots of vetiver grown without artificial fertiliser (soluble phosphate fertilisers inhibit mycorrhizal fungi) and this will allow more immediate beneficial mycorrhizal action when the vetiver is field planted.

Vetiver plants can be produced in plastic potting bags in the nursery but this is much more expensive and time consuming. It is not necessary for agricultural land as bare-rooted slips perform well enough. Potted plants might perform better on severely eroding lands but on Aneityum the additional effort of carrying the bags of soil to the planting site greatly outweighs any advantage (there are no roads or vehicles on Aneityum and no horse in the area affected).

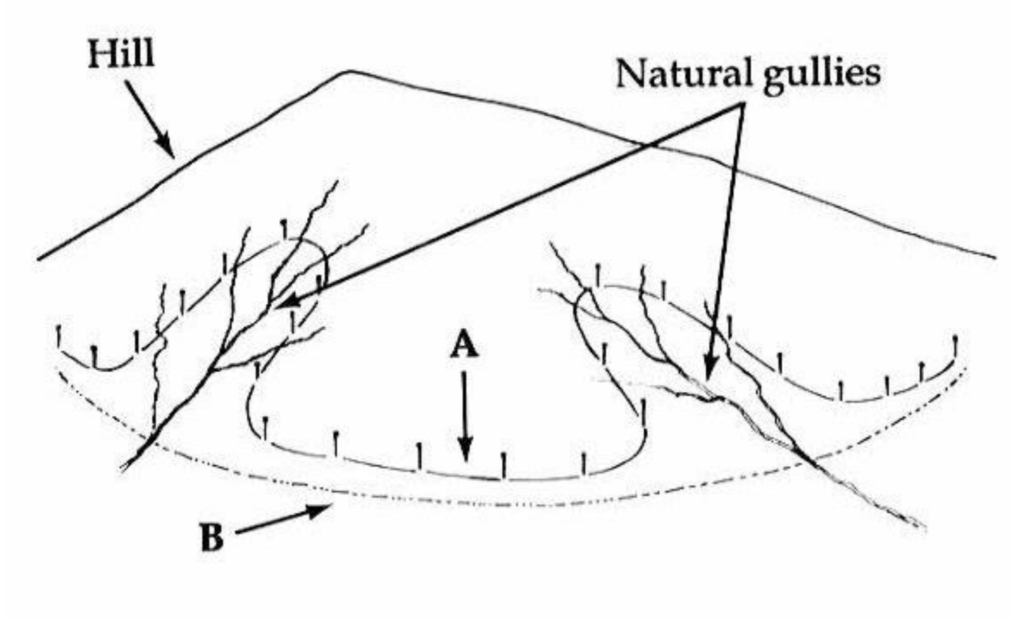
Where roadside slopes are being planted and very rapid growth is required, the use of potted plants may be justified as transport will be available and the additional costs will be minor compared with the cost of the road works being protected.

Field planting of Contour Vetiver Hedges on Agricultural Land

This section will cover the two main aspects of agricultural planting of contour vetiver hedges – plant establishment within the contour rows and the location of the contour rows down the slope.

1. Planting a contour vetiver hedge

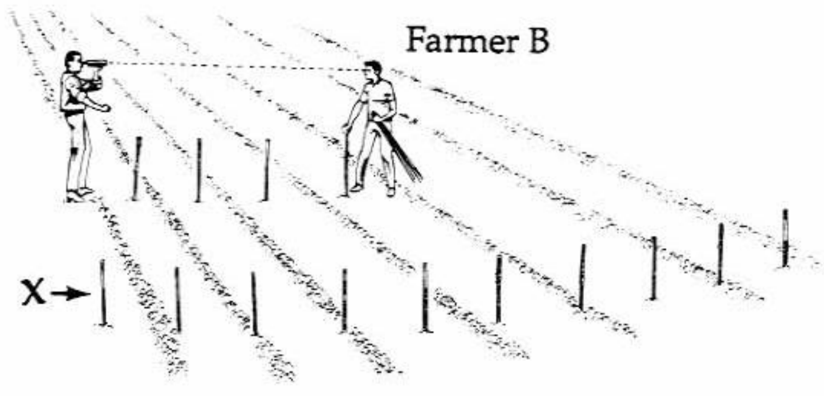
A true contour line (A) will weave in and out along a slope while maintaining a perfectly horizontal line. This can make subsequent land use difficult and so a slightly modified and straighter ‘contour’ (B) may be used for planting the hedge. This will mean that where a small gully is crossed there will be a low spot on the line of the hedge, but this need not be a problem, as long as the line does not have an overall slope in either direction.



A valuable property of the vetiver hedge is that when there are low spots in the 'contour' line those spots will fill with sediment faster until a true contour is formed. The reasoning is that as more water will flow in those low spots more sediment will be carried there initially too. As that sediment is deposited, the line automatically levels itself.

Note, however, that if the low spot is too long or too deep, too much water may flow there and the vetiver plants may be washed away before they are properly established. It is recommended that the low spot should not be more than about 200–300 mm below the true contour and that a higher density of plants be established along the low section. Experimentation in each situation will determine just how far from the true contour a farmer can vary his hedge line.

A contour line can be laid out by using a simple bubble level (Abney or Suunto) or by using an A-frame level in which a pendulum weight provides the reference from which the level is determined.



Laying out contour lines using a bubble level.

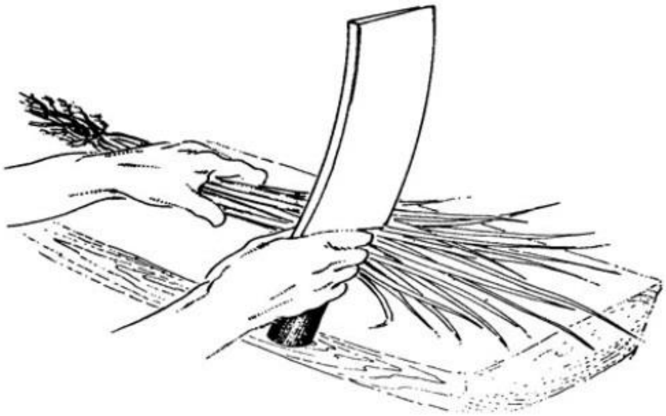
The diagram above shows one method of laying out a contour line but this could result in an overall slope if one person is taller than the other. Resting the level on a pole and having a white rag tied at the same height to another pole is better and less tiring.

A simple level can be made from three pieces of round-wood bound with string or even bark and using a rock on a string as a pendulum. The horizontal stick is marked to show when the ends of the two long pieces of wood are at the same level. After that is done, the level is used by ‘walking’ it across the slope and marking the contour with small sticks. This technique, if used carefully, is quite accurate enough for most purposes.

Building an A-frame level.

Planting material

As discussed in the section on nursery establishment, it is best to use slips with a minimum of three tillers, which have been cut to a length of no more than about 200 mm. This is easiest done with a cane knife and a block of wood.



After a trench has been dug along the previously marked contour line, slips can be laid out and planted.

Planting the vetiver slips

Digging a contour planting trench.

Planting in the trench where the contour crosses a major waterway. Note the upper contour row 2 m higher in the background.

Spacing between slips is approximately 100 mm and they are planted deep as this cannot harm them and improves their soil moisture environment.

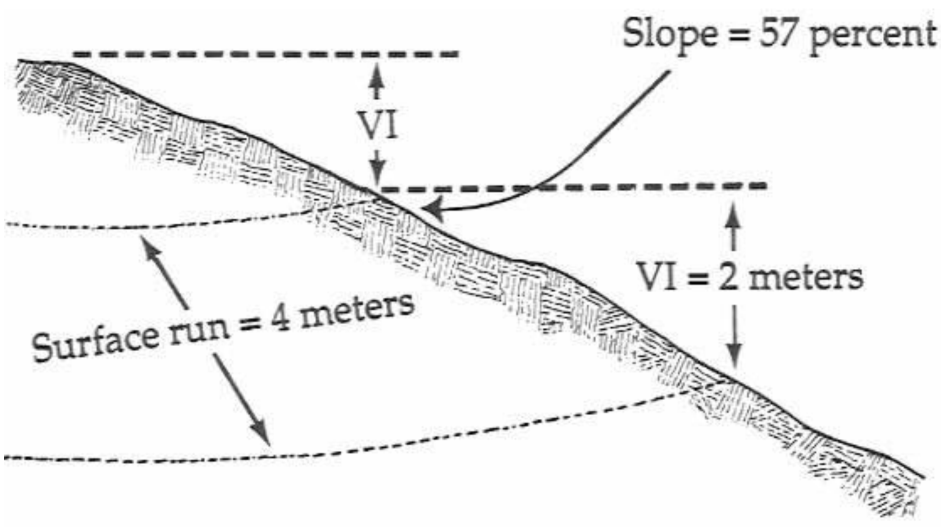
A well-planted contour hedge can start trapping light plant debris and soil very quickly, as seen in this 5-week-old hedge in the next photograph. Note that the slips were planted closely at this point in the contour hedge because it was known to be a waterway during heavy rain.

The collection of plant litter and animal droppings (which float easily and are the first material to be washed off a slope in heavy rain) increase the fertility of the trapped soil and also increase infiltration.

Debris and soil trapped by a 5-week-old vetiver hedge during a 220-mm rainstorm that caused severe erosion on unplanted fields close by.

2. Locating the contour rows on the slope

Experience from much earlier vetiver hedge plantings in Fiji, and confirmed later in a number of other tropical countries, has shown that a 2-m vertical spacing is a good balance between erosion control and possible inconvenience to cultivation.



This diagram illustrates the relationship between vertical interval and surface run on a 30-degree slope. This slope would be the upper limit of most agricultural activity unless cultivation is by hand and not draft animals. On a more gentle slope of 13 degrees, a recognised upper steepness limit to safe tractor cultivation, there will be a 9-m surface run.

The following chart gives the relationship between slope and surface run for a 1-m vertical interval.

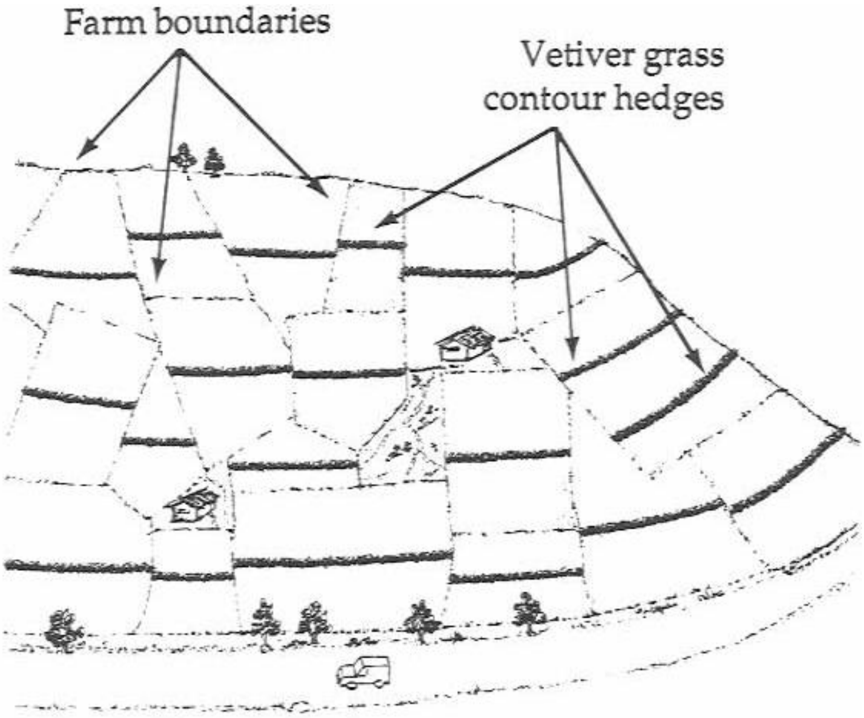
Table 1. Slope, Surface Run, and Vertical Interval

Slope degrees	Slope percent	Gradient	Surface Run (a) meters
1	1.7	1 in 57.3	57.3
2	3.5	1 " 28.6	28.7
3	5.3	1 " 19.1	19.1
4	7.0	1 " 14.3	14.3
5	8.8	1 " 11.4	11.5
6	10.5	1 " 9.5	9.6
7	12.3	1 " 8.1	8.2
8	14.0	1 " 7.1	7.2
9	16.0	1 " 6.3	6.4
10	17.6	1 " 5.7	5.8
11	19.4	1 " 5.1	5.2
12	21.3	1 " 4.7	4.8
13	23.1	1 " 4.3	4.5
14	25.0	1 " 4.0	4.1
15	27.0	1 " 3.7	4.0
16	28.7	1 " 3.5	3.6
17	30.6	1 " 3.3	3.4
18	32.5	1 " 3.1	3.2
19	34.4	1 " 3.0	3.1
20	36.4	1 " 2.8	3.0
21	38.4	1 " 2.6	2.8
22	40.4	1 " 2.5	2.7
23	42.5	1 " 2.4	2.6
24	44.5	1 " 2.3	2.5
25	46.6	1 " 2.1	2.4
26	48.8	1 " 2.0	2.3
27	51.0	1 " 2.0	2.2
28	53.2	1 " 1.9	2.1
29	55.4	1 " 1.8	2.1
30	57.7	1 " 1.7	2.0
31	60.1	1 " 1.7	2.0
32	62.5	1 " 1.6	1.9
33	65.0	1 " 1.5	1.8
34	67.5	1 " 1.5	1.8
35	70.0	1 " 1.4	1.7
36	72.7	1 " 1.4	1.7
37	75.4	1 " 1.3	1.7
38	78.1	1 " 1.3	1.6
39	80.1	1 " 1.2	1.6
40	84.0	1 " 1.2	1.6
41	87.0	1 " 1.2	1.5
42	90.0	1 " 1.1	1.5
43	93.0	1 " 1.1	1.5
44	96.6	1 " 1.0	1.4
45	100.0	1 " 1.0	1.4

a. The figures for the surface run are based on a vertical interval (VI) of 1 meter. To use this table, multiply the surface run by the VI: for example, with a VI of 2 meters on a 70 percent slope, the surface distance between vegetative barriers = 2 x 1.7 = 3.4 m

If the dimensions of a field do not fit multiples of 2 m easily, it may be better to adjust the vertical interval so that a contour row exists near the top and the bottom of the field.

Vetiver hedges do not need to be aligned with structures on neighbouring land and this simplifies a district approach to erosion control.



Vetiver hedge maintenance

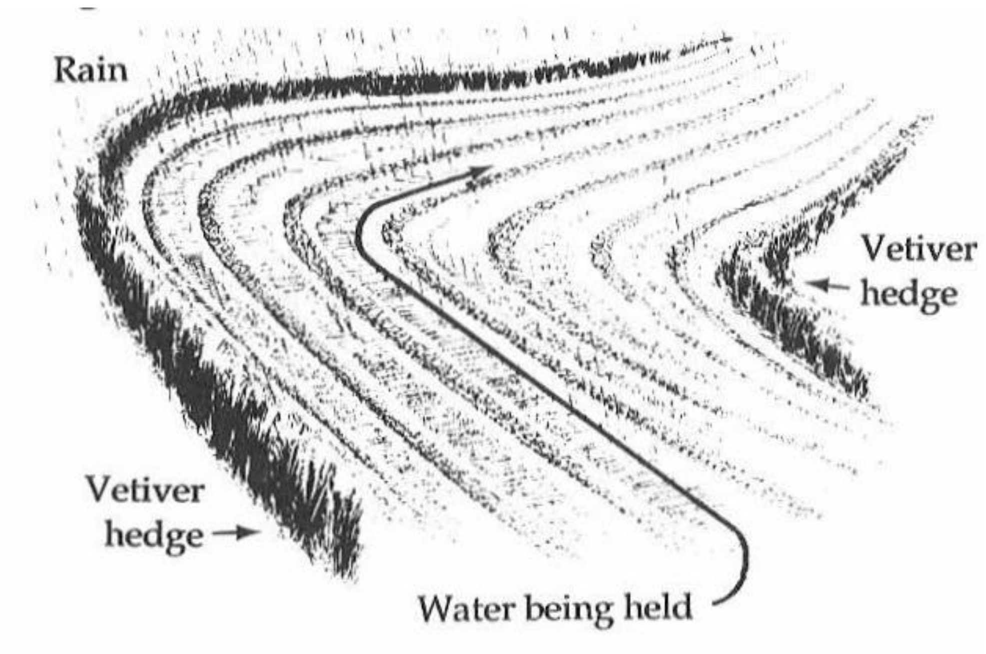
Once the hedges have been established in the farm field, the only care they will need is annual trimming to a height of about 30–50 cm to encourage tillering and prevent shading of the food crops. Ploughing along the edges of the hedgerows will remove any tillers that encroach upon the field and will thus prevent the hedges from getting too wide. If this ploughing is done in damp soil conditions, any large sections of vetiver can be collected and used for further planting. They should not be left on the ground as they may take root and become a nuisance later.

After the vetiver hedges have properly established, the vetiver grass can be cut down to ground level when the dry season sets in and its leaves used as a mulch at the base of the fruit trees to help retain stored moisture. The advantage of using vetiver for this purpose is that its leaves harbour few insects and last well as a mulch. Vetiver hedges also protect the young trees in the hot summer months by providing some indirect shade and in the colder winter months by acting as windbreaks.

Soil and moisture conservation

The next two diagrams illustrate what happens when contour and non-contour farming systems are exposed to heavy rainfall.

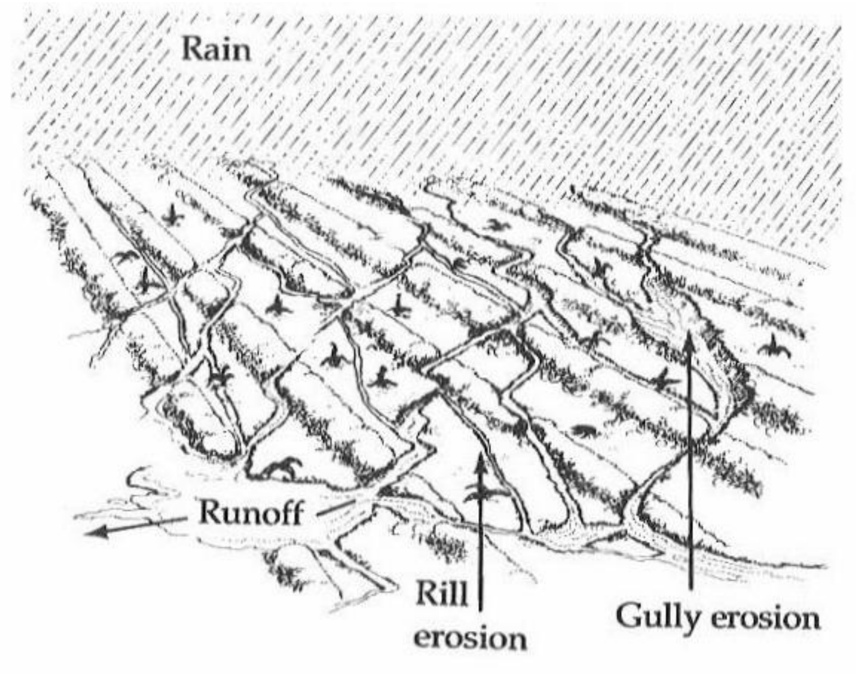
A contour-farmed field is protected by the vegetative hedges, and there is no loss of soil. The contour furrows store all the rainwater they can hold. Any surplus rainfall runs off, but the vetiver hedges control the flow – slowing it down, spreading the water about – and cause the silt to be deposited. As a result the runoff is conducted down the slope in a safe, non-erosive manner. Without vetiver hedges the furrows will overflow and create erosion further down the slope.



On unprotected land, the rainfall runs off at great speed, taking along soil, fertiliser and organic matter as it runs off the land.

Measures to retain natural moisture in the soil are essential to all rainfed farming systems. There is no such thing as flat land; water runs off all land. No matter how flat it may seem, all land must be contoured if it is rainfed or too much water will be lost during heavy rainfall. Periods of very heavy rainfall are expected to increase with global warming as are long periods of drought. Evidence is growing that proves vegetative terracing with vetiver is a useful strategy to cope with climate change.

As explained in the first section of this appendix the terraces created under the vetiver system of erosion control have enhanced infiltration. This has been proven on a large scale in Ethiopia where large areas of land have had improved production and decreased soil loss in the 20 years since planting started. In addition the wetlands at the foot of the slopes have improved and wells have become usable again.



Where flooding is a problem during heavy rainfall any technique that will enhance infiltration will also create a reduction in runoff and so also a reduced flood peak in the lower catchment. While establishing forest will have a similar effect in the long term it is possible to increase catchment infiltration characteristics more rapidly by using vetiver contour terracing on a large scale.

Field planting on severely eroded land – Aneityum as an example

In the severe gullying situation an early triage decision needs to be made as some land may not be worth wasting time on. Frequently there are large differences in the physical and chemical properties of the various volcanic strata and these mean that some may erode more than others and some have more chemicals toxic to plants than others.

While some areas are steep and bare, there may not actually be much sediment leaving those slopes and the soil may be too physically hard to allow any vegetation to establish. Those slopes should be ignored.

Some slopes are steep and highly infertile but still discharge large volumes of sediment as they may lose as much as 50 mm from over the entire slope surface. These areas must be handled by trapping sediment in the gully floor and eventually establishing forest on that trapped sediment.

Other slopes may be rapidly eroding and discharging great quantities of sediment, but are relatively fertile and on these a high rate of slope planting success may be achieved.

1. Gulley-floor planting

The smaller the sub-catchment being treated, the higher the rate of success. Very large volumes of runoff will destroy the valley-floor plantings before they can establish and small sub-catchments have smaller peak flows. If small sub-catchments are treated, the lower part of the catchment will be easier to treat in the future as so much water will be absorbed and retained by the vetiver terraces during heavy rain that peak flows will be substantially reduced.

Start by planting contour rows of vetiver across the widest part of the gulley floor. A wide cross-section will have the lowest depth of water flow. If there is no flat cross-section in the gully floor, it may be necessary to use rock walls or timber walls to trap initial quantities of sediment in which to establish the vetiver hedges.

If flows of water are too high and plants are being washed out, a supporting framework of stakes may be needed. If the stakes are blu wota *(Pterocarpus indicus)* they will take root and contribute to the fertility status of the catchment.

A danger is that so much sediment may be trapped by the combination of vetiver and support frame that the vetiver plants will be totally buried. This problem can be avoided if catchment size is kept small – less than 1 ha.

The photograph below shows an early stage in gully-floor planting and 10 years later the sediment level at this location is over a metre higher. A significant volume of sediment has been prevented from entering the ocean and the large trees now growing in the sediment are spreading and also providing shade to the gully walls – a factor that will reduce breakdown of the soft rock of those walls. Planting of vetiver on the walls is now taking place.

Gully-floor plantings 3 years after establishment. The supporting structures are growing well and already the rows of vetiver need to be extended as the width of the gully floor is increasing as sediment levels rise.

In this example the catchment is quite large and the gully floor is too narrow. Too much sediment was retained and there was difficulty maintaining this structure.

Gully-floor plantings will be more successful when they are paired with gully-wall planting and afforestation, as peak runoff will be reduced.

2. Gully-wall revegetation

Where the material is soft and non-toxic enough to allow plants to survive, contour vetiver hedges can be planted at close vertical intervals across the slope.

The Chalk Hill plantings were the first attempt on this particular situation with a single trial hedge being established in 1999. When the next season's rows were one year old, seedlings of the indigenous *Acacia spirorbis* were planted in the soil trapped above each contour hedge.

The successful slope plantings on a section of Chalk Hill, Aneityum, in 2001.

There are some key differences between plantings on agricultural land and on these eroding infertile soils which have a very low pH and high amounts of available aluminium:

a. Vetiver slip spacing

As there is effectively no soil on these soft-rock slopes (it is washed off by every heavy rainfall, exposing more soft rock to be broken down by drying) it is essential to create a soil immediately for the roots of the vetiver. This is achieved by using the planting pattern developed by the island workers themselves, as seen in the above photograph.

Rain begins to be trapped by the terraces soon after they are planted and this greatly enhances their chances of survival.

b. Plant nutrients

No plant can survive for long or grow well if it is starved of nutrients. There are effectively no available nutrients in this weathered soft rock and so techniques must be developed for each situation to allow success while preserving the environment.

The properties of the ‘soil’ are such that soluble nutrients are quickly made unavailable and so cannot escape into the environment. The soil pH is modified slightly to maximise plant nutrient uptake in the root zone of the vetiver only. Insoluble plant nutrients, which will be only accessible by the mycorrhizal fungi on the plant roots, are added along with very small quantities of more conventional plant nutrients to allow initial growth of the vetiver.

Once the vetiver plants are established they are able to access the insoluble nutrients and, once growing, the nitrogen-fixing indigenous *Acacia* fixes and supplies adequate nitrogen to maintain all plants in the re-established ecosystem.

The need for plant nutrient additions was established by early trials which showed outstanding responses to very small additions of soluble nutrients.

This early trial showed the absolute need to supplement plant nutrient supplies in the early stage of establishing vetiver. The dead-looking vetiver plants on the left have had no supplements.

While it is fashionable to decry the use of any fertiliser at all, as it could be a risk to the coral reef, it should be understand that burning releases large amounts of soluble nutrients from plant material. In addition the natural fixation of atmospheric nitrogen by nitrogen-fixing plants, plants that every tropical ecosystem must have for survival, can be as high as 500 kg nitrogen per hectare per year. To date only a fraction of 500 kg has been used on the entire island over a period of 10 years.