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Environmental Stress Reduction Technologies Piloted by the GEF Pacific IWRM Project's National Demonstration Initiatives

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1. Introduction

Pacific Island Countries (PICs) vary considerably in their size, geomorphology, hydrology, economics and political approaches. Yet despite the different size, resources, and level of development across the Pacific region, PICS do share some common environmental features that can have a profound influence on their development. Pollution levels are generally higher in poorly-developed small islands as a result of lack of infrastructure and options for storage, as well as the frequently porous nature of soils and rocks. The water-related ecosystems and critical habitats associated with International Waters are integrated parts of island ecosystems. International Waters extend far inland and far out to sea. This is due to the nature of the global hydrological cycle linking watersheds, estuaries, and coastal and marine waters through transboundary movements of water, pollutants, air and living resources. The ability of SIDS to manage their resources and ecosystems in a sustainable manner while sustaining their livelihoods is crucial to their social and economic well being, and is clearly directly related to GEF's mandate for protection and sustainable management of biodiversity and international waters.

Water availability at both surface and ground level is generally unreliable unless suitable storage facilities and management regimes have been adopted. The relatively short length of access to surface water flows (compared to larger islands and continental countries) limits opportunities for abstraction and for storage methods. The strong dependence on agricultural production (for domestic demand and export) places a priority on expansion in this sector by any means available. This creates pressures on the relatively small areas of critical habitat available on these small islands which are in high demand for cultivation and livestock, and which are then heavily fertilised and dosed with pesticides resulting in chemical pollution throughout small island watershed systems.

In some cases, prioritisation and subsidisation of water for irrigation then exacerbates water shortages and problems related to environmental flows. In addition, there is frequently an absence of effective water storage and distribution, inappropriate allocation and abstraction, and an absence of long-term planning for water resource conservation. All of these concerns and many other closely related issues threaten water resources management and efficient use within the participating PICs. In acknowledgment of this vulnerability and the particular needs of small island countries, the Sustainable Integrated Water Resources and Wastewater Management (IWRM) programme has been formulated to addresses sustainable water management in Pacific Small Island Developing States.

Additional mounting evidence has suggested that pollution on land from inadequate wastewater disposal, increased sediment erosion and industrial discharges are detrimentally impacting coastal water quality and in turn damaging reef ecosystems and fishing stocks which sustain entire island populations. This has led to changing managing practices to not only consider the watersheds and groundwater, but also the receiving coastal waters. Within the Pacific this concept is referred to as water management from *Ridge to Reef*.

The project used country-driven and designed demonstration activities focusing on sustainable water management to utilize Ridge to Reef IWRM approaches to bring significant environmental stress reduction benefits. Demonstration projects will act as catalysts for replication and scaling-up approaches to improve national water resources management, and regionally to support the Pacific in reducing land based pollutants from entering the ocean.

2. Technologies Trialled in the GEF Pacific IWRM Demonstration Project

To address the various environmental stressors occurring across PICs a number of different environmental stress reduction technologies were trialled during the project. The technologies were chosen based on several criteria:

- Address environmental stress source/pollution source
- Locally appropriate
- Community preference

Choosing the right technology for the situation required knowledge of where the primary source of environmental stress is occurring. For water contamination this is usually identifying where the source of pollutants originate. For flooding this is identifying areas of watershed degradation. The following table highlights the origin of primary sources of degradation at each demonstration site.

Table 1: Primary sources of pollution and/or degradation at project demonstration sites

Demonstration Site	Island Type	Pollutant/Degradation Type	Primary Source
Muri Lagoon, Cook Islands	Low volcanic	– Ground and coastal water contamination from nutrients (NPK) and pathogens	– Poorly constructed/maintained and overloaded septic systems – Wash-down piggeries
Pohnpei, FSM	Low volcanic	– Ground and coastal water contamination from nutrients (NPK) and pathogens	– Deforested catchment – Poorly constructed/maintained and overloaded septic systems
Nadi Basin, Fiji	High volcanic	– Flooding – Sedimentation	– Deforested catchment – Poor erosion control – Loss of riparian buffers – Poor landuse practices
Nauru		– Ground and coastal water contamination from nutrients (N,P,K) and pathogens	– Poorly constructed/maintained and overloaded septic systems – Pit latrines – Wash-down piggeries
Niue	Raised coral atoll	– Non-household and hazardous waste pollution – Ground and coastal water contamination from nutrients (N,P,K) and pathogens	– Oil and fuel storage – Poorly constructed/maintained and overloaded septic systems – Water distribution leakage – Wash-down piggeries
Ngerikiil Watershed, Palau	Low volcanic	– Sedimentation – Solid waste pollution of waters	– Storm-water runoff – Poor erosion control – Loss of riparian buffers – Poor landuse practices
Laura Village, RMI	Low-lying atoll	– Ground and lagoon water contamination from nutrients (NPK) and pathogens	– Poorly constructed/maintained and overloaded septic systems – Pit latrines – Wash-down piggeries
Apia Catchment, Samoa	High volcanic	– Flooding – Sedimentation	– Deforested catchment – Poor erosion control – Loss of riparian buffers – Poor landuse practices
Honiara, Solomon Islands	High volcanic	– Poor water quality	– Water distribution leakage

			–
Vava'u, Tonga	Raised limestone	– Ground and lagoon water contamination from nutrients (NPK) and pathogens	– Poorly constructed/maintained and overloaded septic systems –
Tuvalu	Atoll	– Ground and lagoon water contamination from nutrients (NPK) and pathogens	– Poorly constructed/maintained and overloaded septic systems – Pit-latrines – Wash-down piggeries
Vanuatu	High volcanic	– Flooding – Sedimentation	– Deforested catchment – Poor erosion control – Loss of riparian buffers – Poor landuse practices

Nitrogen and phosphorous are nutrients of particular interest for their role in eutrophication, algal blooms and reef degradation. Additionally land application of waste is one option for waste utilisation, and nitrogen, phosphorous and potassium (NPK) are the principal components considered in development of a waste management plan. Septic effluent contains several nitrogen and phosphorous compounds which are detrimental to the health of water systems. Determining these and the oxygen demand of waste materials is a guide to their potential hazard in the environment. Table 2 contains definitions and characteristics of these.

Table 2: Definition and characteristics of nitrogen and phosphorous

Term	**Abbreviation**	**Definition**	**Remarks**
Ammonium Nitrogen	NH4-N	The positively ionized (cation) form of ammoniacal nitrogen	Can become attached to the soil or used by plants or microbes
Nitrate nitrogen	NO3-N	The negatively ionized (anion) form of ammoniacal nitrogen	Nitrogen in this form can be lost by denitrification, percolation, runoff and plant microbial utilization
Total nitrogen	TN;N	The summation of nitrogen form all the various nitrogen compounds	Macro-nutrient for plants
Phosphorous	TP SRP	Total phospohorous (TP) is a measure of all the forms of phosphorous, dissolved or particulate. Soluble reactive phosphorous is a measure of orthophosphate, the filterable (soluble, inorganic) fraction that is directly taken up by plant cells	Critical in water pollution control; may be a limiting nutrient in eutrophication and spreading wastes
5-day Biochemical oxygen demand	BOD5		Standard test for measuring pollution potential of waste
Chemical oxygen demand	COD	Measure of oxygen consuming capacity of organic and some inorganic components of waste materials	Estimate of total oxygen that could be consumed by oxidation of waste material

The types of technologies trialled in the Pacific IWRM Project can be separated into two categories; hardware and software. Hardware includes those activities typified by physical construction such as eco-sanitation toilets, household secondary treatment systems, treatment plant upgrades and drainage systems. Software includes those activities that have been undertaken that gather information critical to the restoration of degraded sites such as biophysical surveys and GIS. In the body of the document these are further broken down into Wastewater and Sanitation Management and Watershed Protection and Land Management. Table 3 presents a summary of the stress reduction technologies undertaken in the Pacific IWRM Project with reference to supporting documents. Each of these technologies is discussed in detail in the following sections.

Table 3: Summary of stress reduction technologies trialled in the GEF Pacific IWRM Demonstration Project

Stress Reduction Technology	Environmental Benefits	Applicability	Trial Countries	Document Links
Software				
Pollutant Source Survey	– Identify pollutant source, land use and water use – Identify potential hotspot areas – Develop management plans accordingly	– Pollutant sources are various but unknown – Data required to inform management decisions	Cook Islands, Palau, Niue	Annex x
Sanitary Survey	– Identify pollutant source – Identify potential hotspot areas – Develop management plans accordingly	– Pollutant sources are various but unknown (human and animal waste) – Sanitation is a known cause of catchment degradation – Data required to inform management decisions	Niue, Palau, RMI	Annex x
Biophysical Survey	– Identify land use areas – Identify land type	– Data required to inform management decisions – Current land use practices are unknown	Fiji, RMI	Annex x
Soil Type Classification	– Identify soil types – Informs decision based on infiltration characteristics – Identify hotspots prone to erosion or flooding	– Data required to inform management decisions – Soil types in catchment are unknown	Samoa	Annex x
GIS Mapping	– Collates data from surveys and collection – Useful management tool	– Multiple stressors need to be considered for appropriate management decisions.	Cook Islands, Fiji, RMI, Samoa, Tonga	Annex x
Leak Detection	– Identify areas of water leakage – Provide data for targeted management plans	– Reticulated water system – Aging infrastructure – Loss to water leakage is known but not quantified	Niue, Solomon Islands, Tonga	Annex x
Hardware				
Eco-Sanitation Toilets	– Reduced water use – Reduced pollutant load to the environment – Production of a nutrient rich soil conditioner that can lead to increased food production – Multiple health benefits from improved sanitation facilities	– High water table – Low water supply – Limited resources for off-site treatment – Poorly maintained existing sanitation systems	Nauru, RMI, Tonga, Tuvalu, Vanuatu	Annex x

Secondary Treatment Systems	– Reduced pollutant load to the environment – Treated wastewater for agricultural irrigation	– Poorly maintained existing sanitation systems – Existing septic systems	Cook Islands, Nauru, RMI, Tonga	Annex x
Treatment plant upgrade	– Reduced pollutant load to the environment	– Existing reticulated sewerage system	Samoa	Annex x
Dry-Litter Piggeries	– On-site waste treatment – Reduced nutrient load to the environment – Reduction in water use – Production of a nutrient rich soil conditioner that can lead to increased food production	– High water table – Low water supply – Poor existing maintenance of piggeries	FSM, RMI	Annex x
Drainage System	– Reduced storm water runoff – Reduced waterway contamination	– Existing or planned roadways – No stormwater management	Niue, Palau	Annex x
Riparian Restoration	– Revegetated riparian areas – Removal of invasive plant species – Reduces sedimentation of waterways	– Surface waters – High sedimentation in waterways	Fiji, Palau, Samoa,	
Buffer Zones	– Reduced sedimentation of waterways – Reduced direct pollutant discharge into waterways	– Surface waters – Poor land/agriculture management practice – Short pathways from pollutant source to waterway	Palau	
Catchment Revegetation	– Reduced catchment erosion – Reduced sedimentation of waterways – Potential to reduce impacts of high river levels – Improve water quality	– Poor land/agriculture management practice – High sedimentation in waterways	Fiji, Samoa, Vanuatu	

Section 1: Software

Survey and Information Management

In order to maintain or improve water quality and habitat conditions, these resources need to be assessed, managed, and protected. Prior to any rehabilitation efforts it is important to understand the source of pollutants, the number and type of sanitation systems in an area that are potential sources of pollutants, land use practices and agricultural activities that may contribute to waterway degradation. This information can be methodically collected using a variety of survey techniques. In the Pacific IWRM Project almost all projects undertook some form of survey to assess the local conditions of their demonstration areas.

It is useful to compile all of this information in a way that highlights priority areas for action and creates an efficient decision making environment. Geographical Information Systems (GIS) are the management system of choice for collating a variety of spatial data on a layered map. It is through systematic data collection that actions are developed for the mitigation and/or remediation of degraded sites.

The following sections discuss the various techniques used in the projects for survey and data management.

3. Pollutant Source Survey

A pollutant source survey identifies all potential and existing pollutant sources in a given catchment that may pose a threat to the health of surface and/or groundwaters. Pollutant sources can include:

- Wastewater
- Solid waste
- Non-household waste (oils, fuels, agro-chemicals)
- Hazardous waste (hospital, industrial)

A pollutant source survey is one of the preliminary activities undertaken when developing a catchment management plan or strategy. It will identify hotspots of pollutant sources, non-point pollution sources and areas that are consistently degraded. There are many different guidelines, manuals and methods for conducting this survey and choosing the most suitable one requires an understanding of what the most prevalent pollutant threats are and what are the general restoration aims.

In Palau the project conducted pollutant source surveys by trialling a method used in USA for conducting Watershed Assessments known as the Unified Stream Assessment. Fundamentally it is a method that uses visual observation of stream condition to assess the level of degradation. Though there was irrelevant information on the form the easy and visual style of the survey allowed for it to be easily adapted and accepted by the survey team. A sample of the form is provided in the accompanying annex.

4. Sanitation Survey

Similar to the pollutant source survey, the sanitary survey is used to identify existing or potential contaminants to a water body. This survey focus is usually on pathogenic organisms known to cause a variety of human diseases. It also identifies the source of nutrient loads associated with waste, contaminants that cause a variety of environmental issues. The sanitary survey provides information on the overall condition of the watershed and makes recommendations for improving water quality. This information can then be used to design site specific monitoring programs and initiate pollution source remediation efforts. Sanitary surveys can consist of three main components:

1. **Point Source Identification:** A site survey surrounding the area of concern. The survey should contain information on land usage, sewage disposal, and identify point sources of potential pollutants.

2. **Ambient Water Quality Monitoring:** The water quality of the area of concern is monitored by collecting water samples on a regular basis. Water samples are also collected from potential pollution sources to assess their impact on the area.

3. **Hydrographic, Meteorological and Other Studies:** After the pollution sources have been correctly identified, further studies are done to understand how the contaminants affect the surrounding area.

Niue, Palau, Tonga and Tuvalu conducted sanitation surveys to determine sources of pollutants and to generate maps of where sanitation systems need upgrading, including piggeries. Country managers often developed locally appropriate household surveys and questionnaires. An example from RMI is provided in the accompanying Annex.

5. Biophysical Survey

Biophysical surveys investigate the biological and physical conditions of a marine, riparian or freshwater environment when works are being planned for that area. After identifying the major problems of the watershed, detailed biophysical surveys should be designed on a problem-solving basis. Healthy parts of a watershed should be put on routine care while special attention and urgent treatment must be given to critical areas or problem sub-watersheds. A biophysical survey should be able to identify land use and water use practices, land capability, vegetation, erosion data, water resources and geology.

If the main purpose of the effort is to reduce sedimentation of a reservoir, the survey work should be concentrated on identifying erosion or sediment source areas. Survey of forest areas should be concentrated on identification of cut-over areas, bare areas, reforestation needs, as well as cover types, densities and hydrological conditions of the land, rather than on volume or value of timber. Detailed surveys will also need to be carried out on disturbed areas such as cultivated fields, road slopes, streambanks, mined-out areas and landslides. If the main objective is for watershed or rural development, then, the survey should for example concentrate on resources inventory, distribution, uses, establishment and land productivity.

Table 4: Country use of biophysical survey

Country	Use
Fiji	Agricultural land use, deforestation
RMI	Laura Village water and land use

6. Soil Type Classification

The type of soil that is present in a watershed has significant implications for runoff, erosion and groundwater. Converting natural land through agricultural or urban development can have serious consequences for the state of a watershed and downstream communities; increased sedimentation, water volume and flow, and pollutant load. Soil type classification tests are a standard method for determining the varying soil types in a catchment area from which land capability can be identified.

Land capability classification shows, in a general way, the suitability of soils for development as agricultural, pastoral, forestry, cropping, development or not suitable for any productive use.

In Apia catchment, Samoa soil characteristics that had been previously determined were validated by site visit and ground proofing. This data has been digitised into GIS layers by regions and is available for use by environmental managers to make decisions on areas that need protecting and those were development is acceptable.

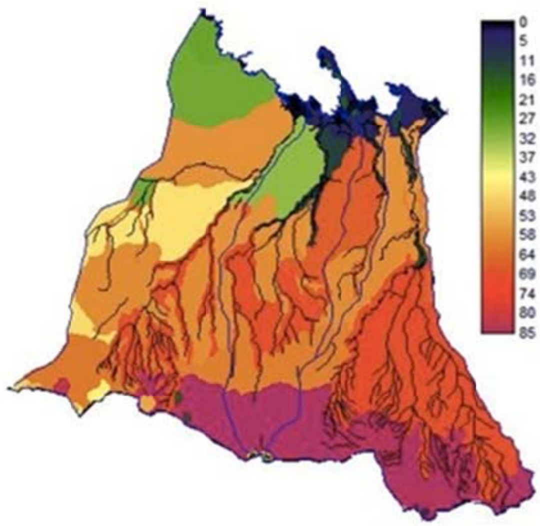


Figure 1: IDRISI Taiga Soil series raster map of the Apia Catchment. Where 0 describes peaty sand, 28 describes boulder clay loam, 44 describes high soils, 58 describes silty clay, 69 describes steepland soils very steep phase, and 85 describes hill soils.

7. GIS Mapping

A geographic information system (GIS) is a system designed to capture, store, analyse manipulate and manage all sorts of geographical datasets. With GIS technology, people can compare the locations of different things in order to discover how they relate to each other. For example, using GIS, the same map could include sites that produce pollution, such as piggeries, and sites that are sensitive to pollution, such as coastlines. Such a map would help people determine which coastlines are most at risk.

With all the information that is required to make decisions about appropriate interventions at the demonstration sites, GIS is becoming the preferred information system for managers (Table 5). It is a useful tool to present technical information to stakeholders and to graphically show the interrelated aspects of land and water issues.

Table 5: Country use of GIS

Country	**Use**
Cook Islands	Land use, pollutant source
Fiji	Riparian Zone, flood inundation, land use
RMI	Land use, pollutant source
Samoa	Land use, soil classification, water distribution system
Tonga	Land use, pollutant source

8. Leak Detection

Loss of water through leakage is a prevalent problem in developing countries where much of the water distribution systems are ageing and are often tapped into illegally. Water transmission and distribution networks deteriorate naturally with time and, subsequently, lose their initial water tightness. The deterioration results from corrosive environments, soil movement, poor construction standards, fluctuations in water pressure, and excessive traffic loads and vibration. Water is lost due to leakage in different components of the networks that include transmission, distribution and service connection pipes, joints, valves, fire hydrants, and storage tanks and reservoirs. In addition to the physical losses due to leakage, many networks suffer from apparent losses.

The recovery of water loss caused by distribution system leakage, through leak detection and repair programs is significant as a readily available water resource. In addition to helping meet water demand, the detection and repair of pipe leaks helps to minimize water quality breaches that may result from the entry of contaminants via leaks. They also help to reduce the high cost of energy wasted on the treatment and pumping of leaking water.

There are a variety of standard methods for leak detection can be hardware based; acoustic equipment, visual devices, gas sampling devices and pressure wave detectors or software based; flow/pressure change, mass/volume balance, dynamic model and pressure point analysis.

In the Solomon Islands, night flow step tests were conducted. Step testing is a proven method of localising water loss within a zoned distribution system. It works by measuring the flow of water into a zone as valves are shut off in sequence. Step testing is conducted at night, where water consumption is at a minimum. The targeted area is subdivided by the systematic closing of valves during this period of minimum night flow. The flow data is analysed to determine the areas of suspected leakage. Leak pinpointing is then carried out in the section of the zone that had high night flows.

Table 6: Country use of leak detection

Country	Type of method used
Niue	Acoustic assessment
Solomon Islands	Night flow step test
Tonga	Acoustic assessment

Section 2: Hardware

Sanitation and Wastewater Management

Many of the demonstration sites are faced with similar challenges of inappropriate, poorly constructed/maintained septic systems or no sanitation system at all. Septic systems are recognised as a major source of groundwater contamination and a significant source of nutrient loading in groundwater, coastal and lagoon waters. On small low-lying atolls with shallow groundwater lenses this can become a critical situation as populations become reliant on rainwater harvesting as their major source of freshwater. Regardless of island type, poor sanitation systems are associated with numerous health issues, algal blooms in lagoons and coral reef degradation. The primary contaminants of concern from inappropriate sanitation systems are nutrients and pathogens.

The composition of human excreta shows a wide range of variability from person to person and from country to country. "Typical" composition are based on an average of Western and African diets as there is no data on nutrient content relative to a typical Pacific diet. Diet can have a great effect on the composition of septic influent and so must be considered. Table 7 presents a summary of different parameters characterising human faeces and urine. These data will serve as reference for the chemical assays of the trialed sanitation systems.

Table 7: Composition and characterisation of human faeces and urine*

Parameter	Faeces	Urine
Quantity (wet) per person per day (g)	70-520	1000-1500
Quantity (dry) per person per day (g)	30-70	50-70
Moisture content (%/gwet sample)	66-85%	93-99%
Approximate composition (% of dry weight/matter)		
COD total (g/L)	46.2-78.3	12.8-15.3
TN	5.0-7.0	15-19
TP	0.69-2.5	1.08-2.2
K	0.80-2.1	1.5-3.7

*(E.N Chaggu, 2003)

The following table summarises typical nutrient loads for the current sanitation systems and for the sanitation options trialled at the demonstration sites. Nutrient loads to the groundwater from a pit latrine assume that all influent becomes effluent without accounting for uptake by vegetation. Data has been calculated using the USEPA reference for nutrient removal by on-site disposal systems (USEPA, 1993).

Table 8: With and without scenarios for typical nutrient loads from sanitation systems

Typical Nutrient Loads* (kg/HH/yr)							
Current system	**N**	**P**	**K**	**Trialed Technology**	**N**	**P**	**K**
Pit latrines	34.5	4.6	12	Eco-sanitation	2.4	0.6	
Septic system – with no treatment	29.8	3.6		Anaerobic Baffle Reactor	14.5	0.9	
				Sand Filter	15.5	0.9	

	Septic System – maintained	24.8	1.9

*10-person household;

9. Eco-Sanitation (Compost) Toilets

Application Level	Management Level	Inputs	Outputs
Household, (Community)	Household, Shared, (Public)	Faeces, urine, organic material	Compost, urine
Country Trialled			
Nauru, RMI, Tonga, Tuvalu, Vanuatu			

Eco-sanitation is a dry sanitation option that treats waste on-site and is also known as a composting toilet. All waste (liquid, solid and cleaning material) is collected in a chamber that sits above ground. Organic material (coconut husk, dried plant leaves, wood ash) is added after every use and the waste and organic material allowed to decompose for at least 12 months. This produces a benign soil conditioner suitable for use on gardens and food crops.

Eco-sanitation toilets are an appropriate choice of sanitation facility where there is risk of environmental contamination from misused traditional systems or no sanitation facility, where there is a recurrent lack of water and where groundwater levels are high. The compost toilet is best suited at the household level but with appropriate community involvement can be scaled for use in public areas and schools.

9.1. Design

Shown in the schematic below, the design of eco-sanitation toilets is quite simple. The whole toilet superstructure sits above ground over an enclosed waste collection chamber. The pedestal is rotated between the two chambers. When the first chamber is full the toilet pedestal is moved and the chamber locked off from further use. The toilet pedestal is then placed above the second neighbouring chamber, which is then used and the process starts again.

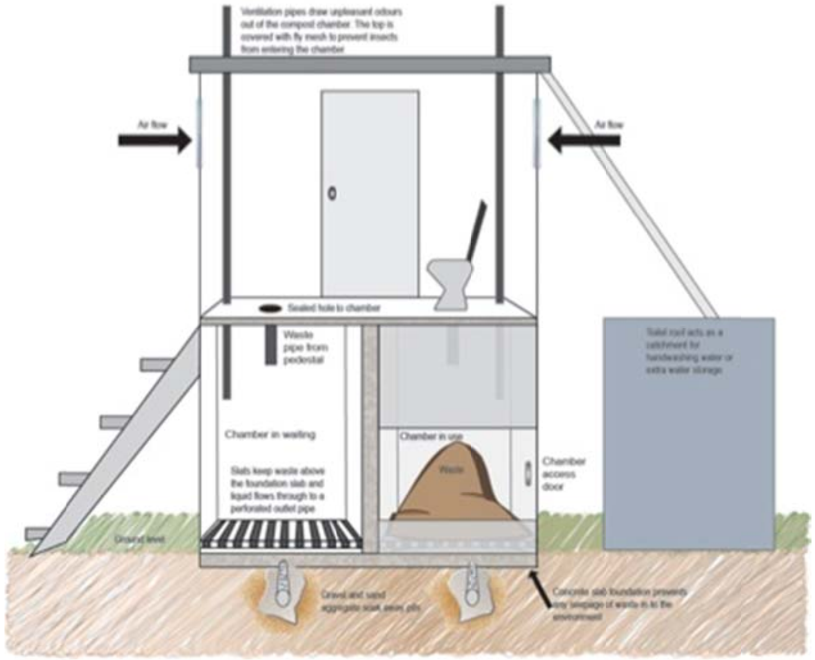
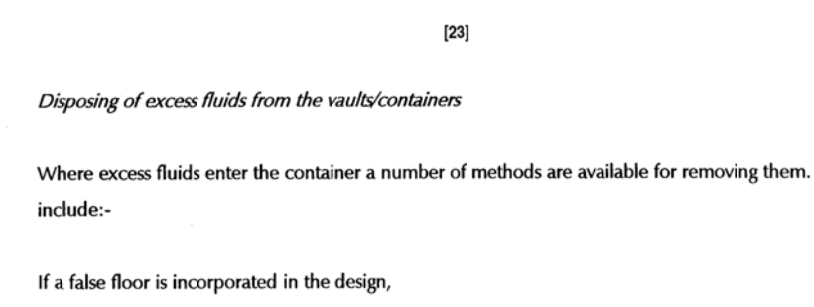


Figure 2: Eco-sanitation or composting toilet

Following each toilet visit, organic material is put into the composting chamber after it has been used. This prevents smell, soaks up any moisture and provides the necessary ingredients for decomposition to occur. By maintaining dry conditions inside the chamber and by enhancing air circulation through vent pipes provided to the chamber, composting of faecal matter is achieved. After 12 months (safe time stipulated by WHO) the pathogens in faeces are destroyed by the alkaline environment and a compost is generated. Human manure from the compost toilet can be mixed with other organic materials such as food scraps, garden waste, paper products and sawdust to produce a soil additive suitable for gardens or crops.

This standard compost toilet system collects urine is collected in the chamber. Liquids overflow into an evapotranspiration trench (soak-away pit) that is lined with a durable plastic liner and coral aggregate. It is backfilled with gravel and/or coral aggregate around the perforated pipe and filled in the top with sand. This allows for evapotranspiration and reduces the flow of urine. Indigenous species are planted overtop to absorb the nutrients from the liquid waste; this is particularly necessary in areas with a high water table.


[23]

Disposing of excess fluids from the vaults/containers

Where excess fluids enter the container a number of methods are available for removing them. include:-

If a false floor is incorporated in the design,

Figure 3: evapotranspiration trench or soak away pit

Designs used in the Pacific IWRM were adapted at each demonstration site to suit the particular needs of the community:

- Low staircase for easy access
- Soak away pits for removing liquid waste
- Water collection tanks
- Overhanging roof to protect users from weather
- Increased structural stability for regular use by large families
- Increased chamber size

A list of relevant documents is provided in the table below.

Table 9: Eco-Sanitation documents from the Pacific IWRM Project

Document Name	Location
Falevatie Construction Manual	Annex x
Composting Toilet Schematics	Annex x
Your Composting Toilet: A Maintenance Guide	Annex x
Photo Gallery	Annex x

9.2. Environmental Benefit

The eco-san treatment process closely mimics that found in nature, it is sustainable and uses no manufactured chemicals, and so has no negative impacts on the environment. This approach is essentially a "closed loop" sanitation system, treating human excreta as a resource. Recycling of faeces prevents direct pollution caused by sewage being discharged or seeping into water resources and ecosystems. Nutrients from urine are the only potential source of loading to the surrounding environment, and are minimised through evapotranspiration at the surface from reduced flow through aggregate and uptake through plants.

A secondary benefit is that of recycling nutrients to soil and plants, which reduces the need for chemical fertilisers. A human excretes almost the same amount of nutrients required to grow their yearly supply of food. Nutrients recovered from human excreta can be used to enhance the productivity of horticulture and agriculture in home gardens and farms, in urban as well as rural areas. As human waste is always readily available it can be a free source of nutrients and organic matter, particularly useful in areas where soil condition is poor, such as atolls and low-lying islands.

Nitrogen reductions from the introduction of eco-sanitation systems were estimated using typical daily nutrient loads per person, values for similar systems and the number of households with the installed technology. The only potential nutrient load will be from the urine waste through the evapotranspiration trench, this value has assumed to be 80% reduction.

Table 10: Typical nitrogen reductions at trial sites from eco-sanitation installation

Demonstration site	Total number of households	Number of trialled households	N volume reduction (kg/yr)	Current reduction (% all HH)
Funafuti, Tuvalu*	490	40	960	6

Laura Village, RMI	319	3	72	1
Vava'u, Tonga*	570	2	48	0.25
Ewa & Anetan, Nauru	134	2	48	1

*estimate based on population data

9.3. Health Benefits

Nearly all pathogens in excreta are found in faeces, while urine is sterile with few exceptions. An eco-sanitation toilet reduces the presence of faeces in the immediate environment and eliminates the potential pathways for infection assuming that good hygiene practices are observed. In principle most pathogens found in faeces are killed off upon excretion. *Ascaris* eggs are used as the pathogen indicator in faeces because they are the most resistant. The concentration of *Ascaris* eggs in excreta will depend upon the occurrence of infection among the community and various other factors. Temperature, dryness and UV light are the main factors influencing die-off. Where agricultural use of the waste is practiced, treatment must be designed in such a way as to reduce the helminth egg count to reach the WHO guidelines of <1egg/gTS. Raising the pH of the compost will increase pathogen inactivation; this can be achieved by adding a handful of wood ash after using the toilet.

There is wide variability in the literature about the potential sanitisation of *Ascaris* eggs through composting. The range can be from 54-100% reduction in occurrence depending on pH, moisture levels, storage time and temperature. This type of variability stemming from construction, operation and maintenance of eco-sanitation systems recommends that further research needs to be conducted to fully understand the process of pathogen inactivation particularly in Pacific climate conditions.

10. Secondary Treatment Systems

There are many options of secondary on-site treatment of effluent prior to its discharge, whether for irrigation or direct discharge to ground or surface waters. Most of these treat the wastewater and sludge underground either anaerobically or aerobically and improve the quality of the wastewater prior to discharge by reducing the total suspended solids (TSS), chemical oxygen demand (COD) and biological oxygen demand (BOD, a measure of organic material), nutrients and pathogens. Options trialled in the Pacific IWRM Project were the Anaerobic Baffle Reactor (ABR), Sand Filter and Soil Absorption Trenches.

ABR, sand filters and trenches are an appropriate sanitation choice in areas where septic systems have been chosen as the sanitation system of choice and where there is a dedicated vacuum pump-out truck available for regular septic maintenance. Singularly or in combination these systems can be efficient at reducing nutrient and pathogen loads and produce treated water for domestic or agricultural use. These systems can be used at both the household and community level, however all require regular pump-out service and fully functioning septic tanks to begin with.

10.1. Anaerobic Baffle Reactor

Application Level	**Management Level**	**Inputs**	**Outputs**
Household, Community	Household, Shared, Public	Blackwater, greywater	Faecal Sludge, effluent
Country Trialled			
Nauru			

ABR is an improved septic tank, which, after a primary settling chamber, uses a series of baffles to force the black water to flow under and over the baffles as it passes from the inlet to the outlet. The wastewater is introduced into the chamber at the bottom, leading to an enhanced contact with the active biomass which results in an increased retention and anaerobic degradation of suspended and dissolved organic pollutants. ABRs are robust and can treat a wide range of wastewater, but both remaining sludge and effluents still need further treatment in order to be reused or discharged properly.

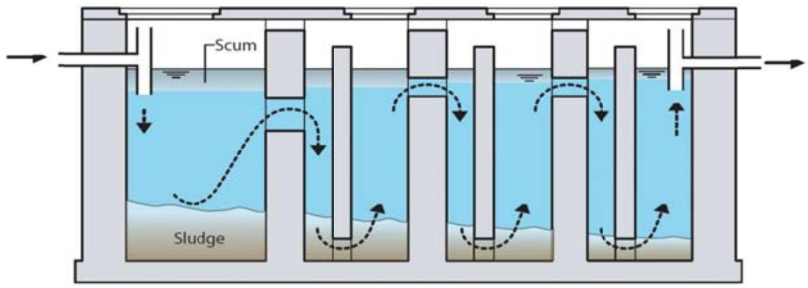


Figure 4: Anaerobic Baffle Reactor. Source (Morrell & Diener, 2006)

The reactor starts with a settling chamber for larger solids and impurities followed by a series of at least 2 more chambers. The wastewater enters the chambers at the bottom and needs to pass through the sludge to move to up and to the next compartment. Thereby particles settle against the up-stream. As the wastewater passes through the sludge, intensive contact between the active biomass in the resident sludge and newly incoming wastewater occurs. To retain any possible scum formed in the up-flow chamber, the outlets of each tank as well as the final outlet should be placed slightly below the liquid surface.

ABR tanks should be checked for water-tightness regularly. Also the scum and sludge levels should be monitored to ensure a well functioning tank. As for the septic tank system, sludge removal is important for ABRs and must be done every 1 to 3 years preferably by a vacuum truck or a gulper to avoid that humans get in contact with the sludge and are exposed to health risks. When emptying the tanks, it is vital that some active sludge is left in each of the compartments to maintain a stable treatment process.

10.1.1. Pollutant Reduction

The majority of the settleable solids are removed in the sedimentation chamber at the beginning of the ABR, which typically represents 50% of the total volume of TSS. The up-flow chambers provide additional removal and digestion of organic matter. Typical reductions for TN are up to 59% and BOD 62%. Table 11 presents typical TN reductions for the Nauru demonstration site where ABR has been trialled.

Table 11: Typical nitrogen reductions at trial sites from ABR installation

Demonstration site	Total number of households	Number of trialled households	TN volume reduction (kg/yr)	Current reduction (% all HH)
Ewa & Anetan, Nauru	134	40	3808	18

10.2. Sand Filter

Application Level	Management Level	Inputs	Outputs
Household, Community	Household, Shared, Public	Blackwater, greywater	Treated wastewater
Country Trialled			
Tonga,			

Wastewater is passed from the outlet of the septic system after treatment into a distribution box. Effluent passes through three slotted pipes leaving the distribution box that sit on top of 750mm of sand (but under some crushed rock, topsoil and grass). These pipes are almost level so that they can distribute the effluent from the septic tank evenly over the sandy area (Figure 5).

The effluent filters through the sand and is treated by organisms that grow on the sand particles. As the treated effluent reaches the bottom of the sand filter, it collects in a large slotted pipe located along the bottom of the sand filter. The bottom of the sand filter is in the shape of a 'V', so that treated effluent can be channeled towards the bottom pipe. Loading rates determine the amount of maintenance needed and how long the system will last.

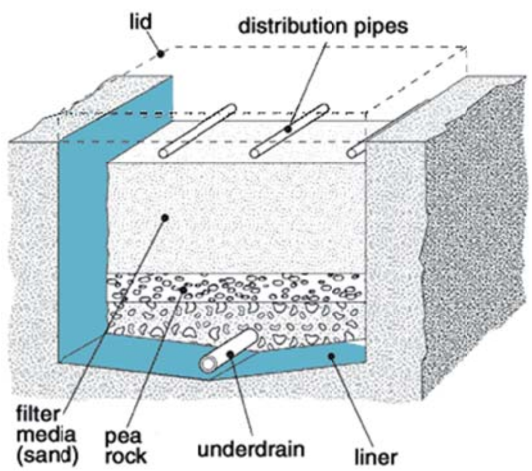


Figure 5: Sand filter for septic tank system. Source: (University of Minnesota)

10.2.1. Pollutant Reduction

In a sand filter the subsoil percolation area performs a straining and filtration function, in conjunction with sorption and ion exchange and acts as an attached growth medium for aerobic biodegradation due to the unsaturated nature of the soil. Physical, chemical, and biological processes treat the effluent. Suspended solids are removed by mechanical straining due to enhanced contact and sedimentation. Treatment occurs through the bacteria that colonise in the sand grains. Microorganisms use the organic matter and nutrients in the effluent for growth and reproduction.

A properly operating sand filter should produce high-quality effluent with less than 10 mg/liter BOD, less than 10 mg/liter TSS (total suspended solids), and less than 200 cfu/100 ml fecal coliform bacteria, an indicator of viruses and pathogens (USEPA, 1993). Nutrient removal from the sand filter can be as high as 55%TN and 80%TP.

Table 12: Typical nitrogen reductions from trialled sand filters

Demonstration Site	Total number of households	Number of trialled households	TN volume reduction (kg/yr)	Current reduction (% all HH)
Neiafu, Tonga	570	40	3808	18
Ewa & Anetan, Nauru	134	10	195	4

10.3. Soil Absorption

Application Level	Management Level	Inputs	Outputs
Household, Community,	Household, Shared,	Blackwater, greywater	Treated wastewater

Country Trialed
Tonga

Absorption trenches are the most common design option for soil absorption systems also known as a drainfield. Trenches are shallow, level excavations between 0.5-1.5m deep and up to 1m wide. The bottom is filled with at least 16cm of crushed rock or gravel over which a single line of perforated pipe is placed. Additional rock or gravel is placed around the pipe. A synthetic building fabric is placed over the gravel to prevent backfill from clogging the gravel and pipes. Some amount of anaerobic decay occurs to the sludge that collects at the bottom of the septic tank, the clarified effluent exits the tanks and enters the trench where a biological or clogging mat forms. This contributes to the even distribution of the waste into the trenches.

The size of a soil absorption is based on the size of the house and the soil characteristics of the area. Traditionally soil is evaluated using a 'percolation rate', that is a measure of the water migration rate through the local soil. This is particularly important to consider in Pacific Islands where soils are often porous and percolation rates to groundwater can be swift.

The character of wastewater flowing into the soil absorption area is a critical variable for proper functioning of septic systems. Soil absorption systems work most effectively when the influent wastewater does not contain significant levels of settleable solids, greases and fats which can accelerate clogging of the infiltrative soil.

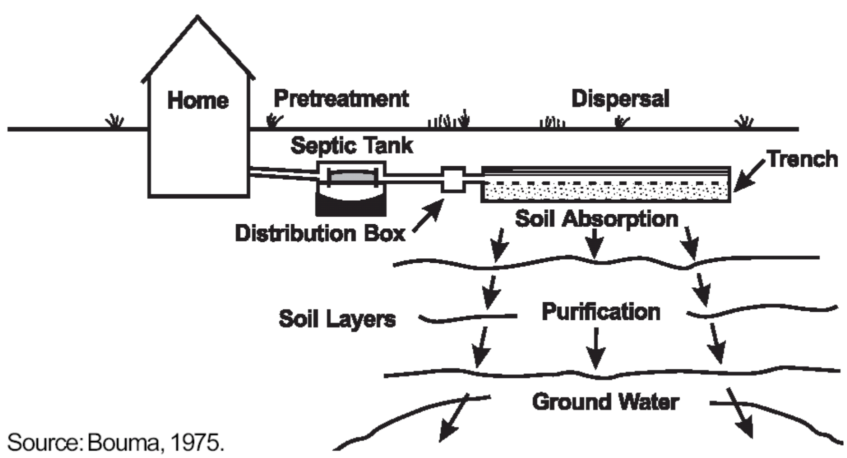


Figure 6: Soil absorption trench. Source (Bouma, 1975)

10.3.1. Pollutant Reduction

The soil absorption system relies solely on the natural biogeochemical processes that occur in soil to assimilate various effluent pollutants. The advantage that this method has over other on-site systems is its relative simplicity, low cost and, if designed and constructed properly, treatment capability. The limitations of soil absorption relate to the inherent variability and heterogeneity of soil and soil biogeochemical processes. Removal mechanisms in the biomat zone, primarily adsorption and filtering, are important processes in the overall purification abilities of a soil absorption. The primary nutrient reduction occurs at the biomat phase. Table 13 illustrates typical nitrogen reduction from the soil absorption trench. Nutrient removal from soil absorption can be as high as 44%TN.

Table 13: Typical nitrogen reduction from trialed soil absorption

Demonstration Site	Total number of households	Number of trialled households	TN volume reduction (kg/yr)	Current reduction (% all HH)
Neiafu, Tonga	570	2	31.2	0.2

11. Dry-Litter Piggeries

Application Level	Management Level	Inputs	Outputs
Household, Community, Commercial	Household, Shared, Public, Private	Organic material, pig waste	Compost/fertiliser
Country Trialled			
RMI			

Pacific Island communities generally raise numerous pigs either at the household level or at communal or commercial piggeries. Concentrated and poorly managed piggeries generate higher volumes of nutrients and pathogens than domestic sanitation systems and need to be addressed as a major source of water source contamination. Current practices require that pens be washed down twice daily with water to eliminate the build up of waste that is harmful to the pigs health and well-being. In some countries where piggeries are located near water sources this nutrient and pathogen rich wastewater is simply washed into the adjacent water source. Alternately wastewater flows out of the pen area often into overflowing septic tanks and is left to seep through into groundwater supplies and ultimately into lagoons or coastal waters.

11.1.1. Design

A livestock nutrient management system is designed to collect, transfer, store, treat and finally utilize nutrients generated from animal wastes, from the point of production to beneficial integration into a cropping system. The system is planned and designed to manage the nutrients and pathogens, normally associated with a livestock operation in a manner that would protect the natural resources of the area.

The dry-litter system employs a sloping pen floor covered with a thick layer of dry organic material such as leaves, coconut husk, mulch and garden residues (Figure 7). Through a pig's hoof action the litter material is propelled out of the pen and into a holding trench. The carbon-nutrient mix flows out of the pens, and the separate composting trench prevents pigs from exposure to pre-compost material, where diseases and parasites may develop. The schematic below shows the design for a commercial piggery, holding up to 100 pigs. The critical features of sloping floor and holding trench are the same whether at commercial or domestic scale.

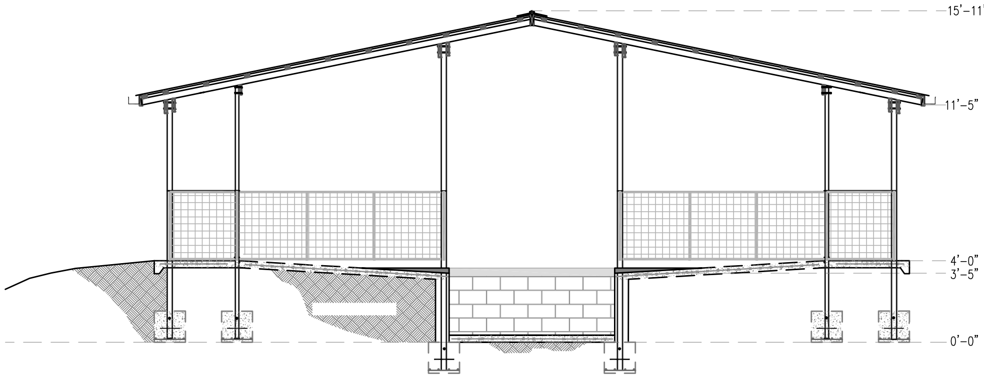


Figure 7: Commercial dry-litter piggery schematic Source: (American Samoa, EPA)

11.1.2. Pollutant Reduction

Using the manure generation data from the Agricultural Waste Management Field Handbook (USDA, 2008), annual manure production and annual N, P, K was calculated for the pig operations in RMI. Manure production and hence nutrients loads, will vary depending on the size of pigs being raised. For this assay data for “small” size pigs on a piggery with <10 animals. A small pig is class size 7.3 (G. K Fukumoto and J David, 2011).

Table 14: Annual nutrients produced (potential compost values) per “small” pig

Nitrogen (kg)	Phosphorous (kg)	Potassium (kg)
2.7	0.9	1.7

It assumed that through the generation of compost that all nutrients from current water-washed pig systems will be absorbed into the compost production therefore nutrient reduction is close to 100%. The following table provides an estimate of nutrient loads that haven been prevented from entering the water systems from household piggeries that have assumed to hold 6 pigs each. Three commercial piggeries have also been converted to dry-litter systems each holding 100 pigs.

Table 15: Typical nitrogen reduction from trialed dry-litter waste piggeries

Demonstration Site	Number of HH piggeries	Number of trialed households	TN volume reduction (kg/yr)	Current reduction (% HH piggeries)
Laura Village, RMI	106	30	486	28%

Watershed Protection and Land Management

12. Drainage System

Application Level	Management Level	Before	After
Household, Community,	Household, Public	High flow and volume	Reduce flow and volume, reduce potential sedimentation
Country Trialled			
Palau			

The conversion of vegetated areas to impervious surfaces such as paved roadways or cleared areas for development always result in greater volumes of runoff generated during rainfall events, and faster travel times for runoff to reach streams. The effect on stream flow is sharper increases in flow during rain events. This results in faster stream velocities that accelerate bank erosion causing greater sedimentation in potential water supply areas. Mitigation of these effects can be achieved through appropriate drainage system design implemented either concurrently with roadway development or retrofitted to existing roadways.

12.1.1. Design

In the Ngerikiil Watershed in Palau, the Compact Road is contributing to a significant proportion of soil erosion in the watershed. The two main sources of erosion are from road cuts and embankments and erosion caused by the discharge points of the concrete drainage channels. Recommended measures to reduce flow velocity and therefore reduce erosion is through the installation of stone check dams.

Stone check dams are the simplest and least expensive retrofit applicable to discharge points along the Compact Road. The function of check dams is to slow the velocity of the runoff discharging from the drains, and thereby prevent erosion. The stone checks are emplaced in the existing earth channels beyond the stone riprap aprons, at a minimum spacing of 15 feet. Placement can be completed by hand, at little expense and in a short time frame.

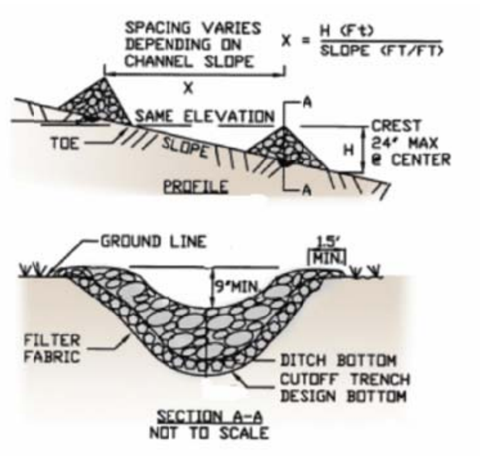


Figure 8: Stone check used in Compact Road, Palau

13. Riparian Restoration and Buffer Zones

Application Level	Management Level	Before	After
Household, Community	Household, Public, Private	Invasive species, bank erosion, grazing	Native revegetation, invasive species removal, bank stabalisation, fencing

Country Trialled
Samoa, Palau,

The riparian zone is the transition area between the aquatic environment and the terrestrial environment. Healthy riparian buffers with mature vegetation provide a wide range of critical ecological and water quality services. Many land management practices result in the degradation of the riparian zone as well as the introduction of invasive plant species. Such practices generally originate from encroaching agricultural or urban development. With the right techniques, stream channels and corridors can be restored and reconstructed to improve habitat for fish and to stabilize banks against erosion and incision.

Such efforts can serve to benefit water quality and can be used to remove or reduce nutrients that have detrimental effects on human health and aquatic life. Excess nitrogen enters streams from fertilizer runoff, animal wastes, sewer lines, and atmospheric deposition of nitrous oxides from fossil fuel combustion. Ecological restoration can be used to enhance the ability of a stream to naturally remove nitrogen through denitrification, a process performed naturally by microorganisms in the water and subsurface.

Riparian zone restoration attempts to restore the natural process necessary to maintain a high level of ecosystem function. In general, the larger the riparian buffer the more ecosystem functions it can provide. Creating a buffer zone provides a range of benefits to the surrounding ecosystem:

- Filters pollutants out of storm runoff before it reaches the waterway
- Limits erosion, protects creek banks and keeps sediment out of the waterway
- Provides shade and maintains moderate water temperatures
- Provides habitat for a diverse group of animals, both on land and in the water

Methods for restoring riparian zones are often determined by the cause of degradation. Two main approaches are used in riparian-zone restoration: restoring hydrologic processes and geomorphic features, and re-establishing native riparian vegetation. Restoring native vegetation was trialled at two sites in the Pacific IWRM Project.

Revegetation can be accomplished through active or passive means, or a combination of the two. Passive restoration assumes riparian vegetation may come back on its own if human-induced disturbances are stopped and/or hydrologic processes are restored Watershed Revegetation. It requires minimal management and is more cost effective than alternative methods. Activities include fencing areas to prevent cattle grazing in the riparian zone. Active restoration includes replanting of native species to assist with regrowth and the return of native animals.

Table 16: Country use of riparian restoration

Country	Use	Before
Samoa	Introduce and enforced 20m buffer	

	zones around water source and intake.	

14. Catchment Revegetation

Agricultural and urban development has resulted in widespread land use change which has caused increase of sediment loads to waterways. Increased suspended sediment in rivers and waterways reduces primary production by planktonic and benthic algae, reducing the food and oxygen available to fish and invertebrate river life. Transport of sediments brings nutrients that are bound to the soil, affecting both stream ecology and consumptive human use, such as those promoting algal blooms. The delivery of sediment to river beds and floodplains can also affect the riverine habitats of fish and macro-invertebrates, such as by in-filling pools and replacing stable and diverse substrates with mobile sand and gravels.

The dominant sources of the sediment in rivers are riverbank erosion, gully erosion, and surface sheetwash and rill erosion of hill slopes. Vegetation can play an important part in regulating sediment supply from each source. Re-vegetation (the planting of trees, shrubs, groundcovers and other plants) is a common practice used for habitat restoration. The other major strategy is natural regeneration. The aim of habitat restoration is to restore cleared or degraded areas to the condition they were in before disturbance, using nearby remnant cover areas as a guide to vegetation species and structure. Re-vegetation is appropriate where the site has been highly altered by clearing, farming or grazing. In such situations, there is generally little evidence of native vegetation and little possibility of natural regeneration occurring from seeds in the soil or nearby remnant native vegetation. Benefits of re-vegetation include:

- Prevention of erosion and protection of water quality in the watershed
- Enhanced bio-diversity of the site
- Restoration or expansion of buffer zones
- Restoration of wildlife corridors

Table 17: Country use of catchment revegetation

Country	**Use**
Fiji	Developed nurseries for native plants. Planted over 60 hectares of degraded land with fruit trees and staple varieties (coconut & breadfruit)
Samoa	Native tree planting around water source and intake
Vanuatu	Developed nurseries for native plants. Native plants have been established at 6 community demonstration sites.

Annex 1: List of Documents

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