Kingdom of Cambodia

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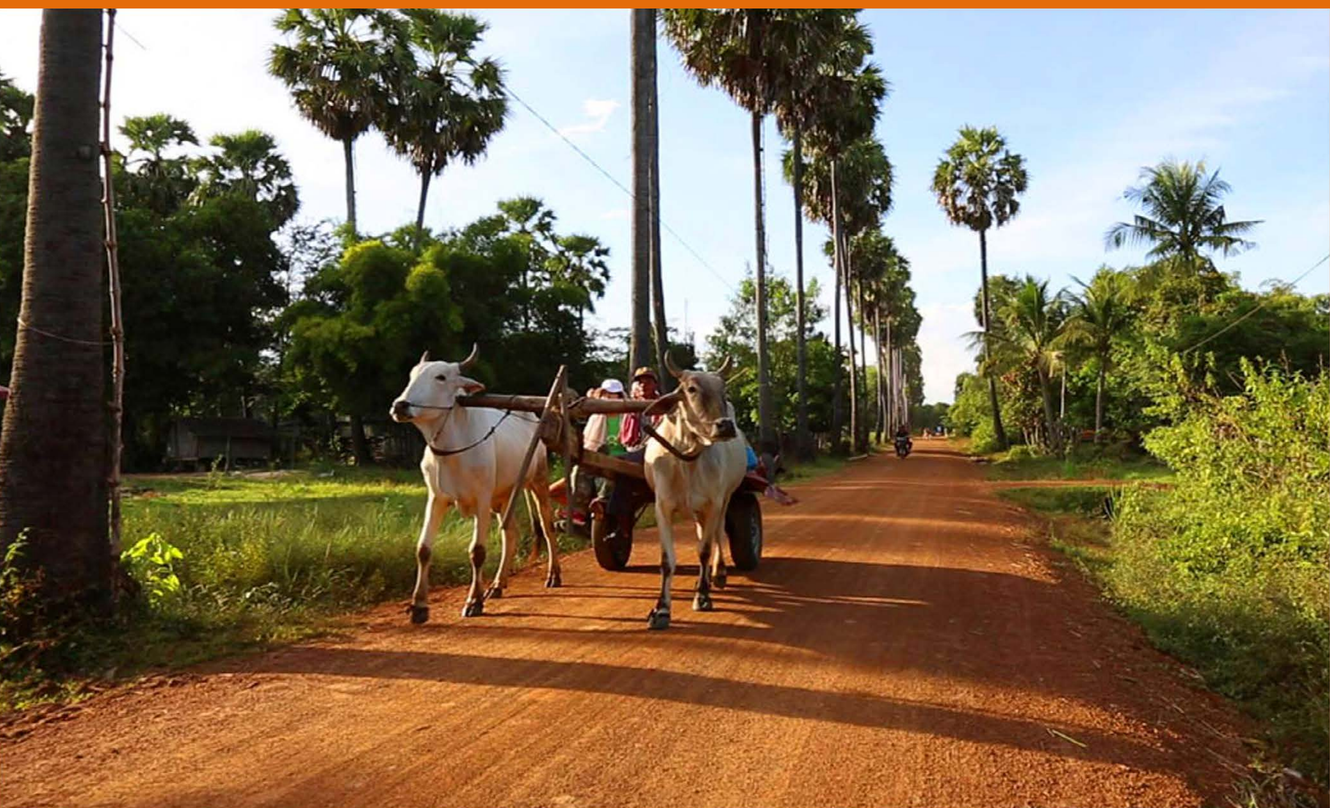
Ministry of Rural Development

National Council for Sustainable Development
Ministry of Environment

Green Rural Infrastructure Guide



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Green Rural Infrastructure Guide

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Foreword

The Royal Government of Cambodia (RGC) has put great effort into the development of physical infrastructure, highlighted as the backbone for development for Cambodia. The National Strategic Development Plan (NSDP, 2014-18) identifies development priorities for Cambodia, and serves as the roadmap for the implementation of the Rectangular Strategy, the government's development framework. The current Rectangular Strategy phase III, 2014-18, contains of four development pillars. Pillar #2 focuses on physical infrastructure development. The NSDP (2014-18) highlights the need for sustainable development and disaster risk reduction through improved infrastructure by developing appropriate adaptation technologies and strengthening capacity to implement sound adaptation practice. The Ministry of Rural Development (MRD) currently has a National Strategy for Rural Water Supply, Sanitation and Hygiene 2011-2025 and rural road improvement and maintenance that responds to climate change impacts and seeks poverty reduction.

Cambodia is considered one of the countries most vulnerable to the impacts of climate change in Asia. Current climate threats and long-term climate change impacts have been identified as significant environmental and developmental issues for Cambodia. Climate variability and frequency of extreme climate events such as extreme floods, droughts, intense rainfall, and storms are projected to increase. Increasing temperatures and changes in rainfall patterns cause high risk, sensitivity, and exposure to the infrastructure sector, especially rural infrastructure.

To respond to future impacts and trend of climate change and to supporting the NSDP, the Cambodia Climate Change Strategic Plan (CCCSP, 2013-2023) has been developed. The CCCSP is the national policy document in response to climate change. It reflects the political will, commitment and readiness for reducing climate change impacts on national development. For effective implementation of CCSP, concerned ministries, including MRD, have developed their respective Climate Change Action Plan (CCAP, 2014-2018). CCAP of MRD contains 10 action fiches (high priority actions) for rural development.

This MRD Green Rural Infrastructure Guide (an adaptation guide for the rural infrastructure sector) will support effective, on-the-ground implementation of CCAP. It provides guiding principles and insights for policy makers, planners and practitioners on how to apply climate resilience to their planning and project implementation. The guide is divided into three parts and comprises of 30 adaption technologies/measures and 12 case studies. Part A provides the introduction to the guide and the roles and responsibilities of MRD and matrix table of adaptation technologies/measures for rural infrastructure development.

Part B describes some appropriate adaptation technologies/measures for sustainable development of road, canal, reservoir, embankments slopes and stream banks, and sustainable rural water supply and management systems, and capacity building. Part C contains case studies of where the respective adaptation technologies have been applied in Cambodia and other countries.

On behalf of the Ministry of Environment (MOE), National Council for Sustainable Development (NCSD) and Ministry of Rural Development (MRD), we would like to take this opportunity to express our sincere gratitude to all stakeholders for their support and cooperation in developing this Green Rural Infrastructure Guide.

Ministry of Environment (MOE), National Council for Sustainable Development (NCSD) and Ministry of Rural Development (MRD) believe that all relevant agencies and partners will continue to work together to adopt this Green Rural Infrastructure Guide to combat the impacts of climate change and address poverty reduction and sustainable development.

Phnom Penh, 22 March, 2019

Minister of Rural Development

Dr. Ouk Rabun

Phnom Penh, 22 March, 2019

Chair of National Council for Sustainable Development and Minister of Environment

Say Samal

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Phnom Penh, 22 March, 2019

Secretary of State of Ministry of Environment

and SPCR Program Coordinator

H.E Prof. Dr. Sabo Ojano

Acronyms

ADB	Asian Development Bank
CCAMM	Climate Change Adaptation and Mitigation Methodology
CCAP	Climate Change Action Plan
CCCSP	Cambodia Climate Change Strategic Plan
CIF	Climate Investment Fund
CMDG	Cambodia Millennium Development Goals
FWUC	Famer Water User Communities
GDP	Gross Domestic Product
ICEM	International Centre for Environmental Management
MAFF	Ministry of Agriculture, Forestry and Fisheries
MCRDP	Mainstreaming Climate Resilience into Development Planning
MOE	Ministry of Environment
MOWRAM	Ministry of Water Resources and Meteorology
MPWT	Ministry of Public Work and Transport
MRD	Ministry of Rural Development
NCCC	National Climate Change Committee
NCDM	National Committee for Disaster Management
NCSD	National Council for Sustainable Development
NSDP	National Strategic Development Plan
PDoWRAM	Provincial Departments of Water Resources and Meteorology
PDRD	Provincial Department of Rural development
RGC	Royal Government of Cambodia
SEDP	Socioeconomic Development Plan
SPCR	Strategic Program for Climate Resilience
TA	Technical Assistance
WUA	Water User Associations

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A INTRODUCTION

1. INTRODUCTION

The World Bank reports that, following more than two decades of strong economic growth, Cambodia has attained lower middle-income status with gross national income (GNI) per capita reaching US$1,230 in 2017. Between 1995-2017, driven by garment exports and tourism, Cambodia sustained an average growth rate of 7.7% the sixth fastest-growing economy in the world. In 2018, economic growth is expected to reach 7%, compared to 6.9% in 2017 (World Bank 2018). Agriculture continues to be the backbone of Cambodia's economy, but garments, tourism, and construction have also contributed to this GDP growth.

Poverty continues to fall in Cambodia, albeit more slowly than in the past. In 2007, the poverty was 47.8%, 3.5% in 2014 and at a similar level in 2018 with the rural population making up the majority. About 90% of the poor live in the countryside. Around 4.5 million people remain near-poor, vulnerable to falling back into poverty when exposed to economic and other external shocks (World Bank 2018).

One of the primary constraints to rural development and poverty reduction in Cambodia is the underdeveloped nature of rural roads and irrigation infrastructure, and unequal access to it. Investment in rural roads yields high returns to poverty reduction in developing countries. Improving rural roads will help rural populations gain access to key services, including education and health, promote connectivity for isolated areas, and improve opportunities for income-generating activities other than farming. Furthermore, investments in irrigation and drainage infrastructure will reduce climatic risk, reduce yield volatility, and provide food and income security to agriculture-based households (ADB, 2012). However, only when the fiscal situation sufficiently improves will the government be able to allocate more resources to infrastructure investment.

In addition, the impacts of frequent and unpredictable extreme weather events due to climate change put the infrastructure, agricultural systems and livelihoods of rural people at risk (Thevongsa, 2012). As the sea level rises and the number of floods increase, typhoons and heavy rainfall will occur more frequently. Shorter and more intense rainy seasons, combined with longer and drier seasons, are expected to significantly alter the country's agricultural landscape. Since agriculture forms the foundation of Cambodia's economic growth, supports the livelihoods of a great majority of its population, and contributes significantly to rural development, the increasing impacts of climate change will continue to disrupt and slow down rural development process. Rural communities in Cambodia are already experiencing reduced agricultural productivity as a changing climate leads to more dramatic fluctuations in precipitation rainfall and more intense periods of floods and droughts (NCCC, 2013). In addition to threatening crop yields, the increasingly severe weather is resulting in roadside slope erosion, streambank and shoreline erosion and soil loss, damaging the roads and other infrastructure used by farmers to support agriculture and transport their goods to urban markets. In response, many rural Cambodians are increasingly relying on forest ecosystems for food and income, but the resulting degradation of Cambodian forests is actually reducing the ability of these agricultural communities to adapt by speeding the erosion of the very soil needed to grow crops (Adaptation Fund, 2013).

2. RURAL DEVELOPMENT ADAPTATION TOOLKIT

Climate change is a threat to Cambodia, where more frequent and intense extreme climate events such as floods, droughts and increased storm surges (such as the Typhoon Ketsana in 2009 and the devastating floods of 2011 and 2013) are already being witnessed. Such events result in significant physical and monetary damage to the country's economy and livelihoods (NCCC, 2013). Cambodia is consistently ranked among the top ten countries most vulnerable to climate change, and among the three most vulnerable in Asia. This is due in large part to a relatively low adaptive capacity. Building local resilience will prove key to better addressing the effects of climate change in Cambodia. Local actions and local solutions are needed to make the most difference (IRIN, 2011). This Rural Development Adaptation Toolkit, prepared under the TA 8179 - CAM mainstreaming climate resilience into Development Planning project, provides a systematic analysis of the most relevant information available on these local climate change adaptation approaches.

Ministry of Rural Development (MRD), along with Ministry of Water Resources and Meteorology (MOWRAM), has been tasked with provisioning key rural infrastructures, but they lack appropriate funding to invest in these infrastructures (ADB, 2012). The low-cost, locally available technologies and approaches presented in this toolkit can help overcome the problems financing infrastructure.

Retaining Cambodia's robust growth performance under a changing climate will be a challenge in the years to come, yet response efforts to address climate change cannot be separated from economic development and poverty alleviation, which are vital in a transition towards a green economy and low-carbon, climate-resilient development. This adaptation toolkit offers alternative choices not only to help increase climate resilience of Cambodia rural areas but also to contribute to the country's overall economic development.

This guide provides a set of technologies and approaches for climate change adaptation in rural development. These measures are divided into four sections:

- Streambank and coastline erosion prevention;
- Rural roadside slope protection;
- Sustainable water use and management; and
- Capacity building and stakeholder organisation.

The outline of the toolkit is as follows: Part A gives an introduction to the toolkit; Part B presents the adaptation technologies suitable for rural development in Cambodia; and Part C provides some case studies of where these technologies have been applied in Cambodia and other countries.

It is important to note that since rural development overlaps with many other sectors such as agriculture, transportation, water, and forestry, there are some similarities between this toolkit and other guidelines and toolkits prepared for other ministries. The technologies and approaches have been selected to be appropriate for rural development settings without affecting their relevance and usefulness in other sectors.

Information provided for each technology is presented as follows: (1) application – which describes the part of infrastructure can apply; (2) description – which describes the measure and its purpose/objectives; (3) contribute to climate resilience; (4) strengths – what are the strengths and benefits of the technology/approach; (5) limitations – limitations in use of the measure; and (6) sources – sources of further information on the measure. Further information is also provided on the application of the measure specific to location and context.

3. MINISTRY OF RURAL DEVELOPMENT

3.1 MANDATE

The RGC established MRD in 1993 to demonstrate the government's dedication to improving living standards and alleviating the poverty of rural people in Cambodia. The MRD has the following missions and core activities:

- Respond to the urgent short-term needs of the Cambodian rural population which may result from natural or man-made disasters, and then ensure that such suffering in the rural areas is answered promptly, met effectively and alleviated quickly;
- Establish long-term sustainable development in all rural areas by encouraging self-sufficiency, so that the rural community is able to make an increasing contribution to the national economy;
- Represent the hopes and aspirations yet to be achieved in rural Cambodia through peace, and progress toward prosperity. These are the basic building blocks that can provide and guarantee the essential quality of life for all rural people;
- Be responsible for integrating all rural development, at family, village and commune levels throughout the Kingdom;
- Raise the standard of living and the quality of life of the rural people by alleviating poverty through rural infrastructure improvement such as roads, water supply and primary health care promotion, agricultural development, rural credit provision, small business/industry promotion and provision of rural marketing facilities; and
- Promote human resource development for rural communities (and MRD staff) by organizing, publicising and making possible local training programmes, seminars and workshops that relate to identified relevant and specific rural training needs, to develop individual talents and skills that collectively enhance community independence through employment opportunities.

3.2 POLICIES

The RGC emphasises that the backbone of any sustainable development is physical infrastructure. The SEDP II notes that infrastructure is a key area that needs to be developed as it can have cascading positive effects on pro-poor, rural-based growth sectors, through supply-side adaptation (transport, electricity, telecommunication, water supply, and others). Infrastructure is one of RGC's Rectangular Strategy's Growth Rectangles (2003-2008). The rectangle covers: (a) further construction of transport infrastructure; (b) management of water resources and irrigation; (c) development of energy sector and electricity network; and (d) development of information and communications technology.

In June 2006, the government adopted the NSDP for 2006-2010. The plan was updated for 2009-2013 and 2014-2018. It aims to reduce poverty and serves as the guiding document for implementing the Rectangular Strategy, allowing Cambodia to achieve its Millennium Development Goals (CMDGs) and other socio-economic goals. The plan is a combination of earlier plans: Socioeconomic Development Plan (SEDP) I and SEDP II, National Poverty Reduction Strategy, National Population Policy, and other sector policies and strategies.

Among other things, the NSDP prioritises the provision and enhancement of rural infrastructure, particularly rural transportation, water supply and sanitation. Specific actions are:

- Accord priority to yet unreached communes or villages;
- Expand the rural road networks to ensure that all communes have easy access to district headquarters and to national primary and secondary road network;
- Use labour-intensive measures to increase rural incomes as much as possible, especially for rural roads construction and maintenance;
- Rehabilitate and reconstruct the existing irrigation and drainage systems particularly in high poverty incidence areas and along the border areas;
- Develop and apply measures on flood and drought mitigation and management;
- Expand surface water storage capacity and promote water harvesting technologies;
- Promote effective and sustainable development of groundwater resources in areas with scarce surface water availability; and
- Promote appropriate and effective river basin management and water allocation systems.

The MRD currently has National Strategy for Rural Water Supply, Sanitation and Hygiene 2011-2025 that both responds to climate change impacts and seeks poverty reduction. The vision of the strategy is that “every person in a rural community will have sustained access to safe water supply and sanitation services and will live in a hygienic environment by 2025” (MRD, 2011). In addition, the MRD is in the process of establishing a strong road maintenance policy linked to climate change resilience.

In 2013, MRD adopted Climate Change Strategic Plan for Rural Infrastructure to address four strategic priorities to help rural poor who are restrained by the impacts of climate change (MRD, 2013). This strategic plan was updated for period 2014-2018 in 2014 (MRD, 2014). Those strategic priorities are:

- Strategic Priority 1: development of policies and regulations to make rural infrastructure (roads, irrigation schemes, wells, ponds and bridges) resilient to climate change (policy design for quality-based rural infrastructures against climate extreme events);
- Strategic Priority 2: creation of rural business opportunities that focus on micro-credit provision for savings and improved rural livelihoods. The increase of families' income from local businesses will create preparedness to compensate for the loss of income during flood and drought periods (policy design and project implementation);
- Strategic Priority 3: Provision of upgraded rural infrastructure projects (roads, irrigation, wells and culverts) to be resilient to flood and drought as demonstrated in some areas (pilot project implementation); and
- Strategic Priority 4: Increase of awareness of rural communities about the concepts of climate change and response options, and provision of capacity development to village development committee members on climate change adaptation and mitigation options and on using other scientific knowledge which can be adapted for use by local people (primary health care, water, sanitation, research results dissemination and community development).

4. ADAPTATION TECHNOLOGY MATRIX

To help policy makers and practitioners begin implementing green infrastructure options, the below matrix illustrates how different measures may pair and interact with other complementary technologies.

Each column represents a development need that may be encountered within the MRD’s mandate. For each green infrastructure measure, a coloured box indicates its potential use for that particular development need.

	Bridges	Bridge abutments	Buildings	Canals	Capacity building	Coastline	Culverts and drains	Drainage	Dykes	Farms	Farmer community	Farmer group	Floodgates	Houses	Markets	River embankments	Road embankments	Roads and footpaths	Seawalls	Stakeholder organisation	Storm water outfall
Biological geotextiles	■	■		■		■	■	■	■				■			■	■		■		■
Brush mattress	■			■			■		■				■			■					■
Community-based agriculture extension											■	■									
Constructed wetlands								■							■			■			■
Farmer field school											■	■									
Field trenches				■			■	■	■	■											
Grey water recycling			■							■				■	■						
Hygienic pit latrine			■							■				■	■						
Live crib wall	■			■				■	■								■	■			
Live fascines	■			■				■	■								■	■			
Live staking	■			■				■	■								■	■			
Log terracing	■			■				■	■								■	■			
Mangrove forest planting						■			■										■		
Palisades	■			■				■	■								■	■			
Planting pit										■											
Plastic liner for ponds and reservoirs			■							■				■	■						
Protected springs			■							■				■	■						

Rainwater harvesting			■							■				■	■						
Rainwater harvesting pond			■							■				■	■						
Recharge pit										■											
Soak pit										■											
Solar power water pump			■							■				■	■						
Solar tube well			■							■				■	■						
Vegetated check dam							■	■	■	■											
Vegetated gabions		■		■			■		■				■			■	■				■
Vegetated geotextiles	■			■			■		■				■			■	■	■			■
Vegetated revetment				■			■		■				■			■					■
Vegetated riprap				■			■		■				■			■					■
Vetiver grass	■			■			■	■					■			■	■				■
Water user association											■	■									

B ADAPTATION TECHNOLOGIES

5. INTRODUCTION

The adaptation measures in this toolkit can be promoted and built into sector policies and design standards, delivering the key objectives of the MRD mandate. They are multi-use and can be applied in numerous rural contexts. Often their applications overlap across sectors. It is also important to recognise these measures often work best when used in combination.

6. STREAMBANK AND COASTAL EROSION PREVENTION

Due to climate change, many areas of Cambodia are expected to experience heavier rainfall, and more intense riverine and flash floods. This will lead to greater erosion of stream banks, riverbanks and coastlines, with consequent damage to nearby infrastructure and roads. Measures described below seek to reduce this erosion via various stabilizing techniques, with emphasis on bioengineering techniques. The key benefit of bioengineering is that it increases self-reliance of communities: because infrastructure is constructed using local labour and locally available materials, local communities can repair the structures quicker and more easily than for traditional civil engineering works. As with green infrastructure on the whole, streambank and coastline erosion prevention measures are often most effective when used in combination to maximise benefits. The described measures can also be applied to rural road infrastructure presented in Section 3.

6.1 BIOLOGICAL GEOTEXTILES

Application	Bridges, bridge abutments, canals, culverts and drains, coastlines, dykes, drainage, embankments, floodgates, seawalls, storm water outfall
Description	Biological geotextiles are a biodegradable material that controls soil erosion. Natural fibres are developed into woven geotextiles. Abundant supplies of cheap, local and renewable materials such as jute, sisal, coir, flax, coconut, bamboo, and water hyacinth allow for wide application of biological geotextiles. The presence of vegetation helps stabilise slopes and prevent erosion by providing root strength and absorbing effective stress, by acting as a drain providing permanent mechanical and hydraulic filter stability, and by building hedges. It can be used in protection of riverbanks, embankments and coastlines, and consolidation of soft soil.
Contribution to climate resilience	Biological geotextiles reduce erosion by increasing slope protection, acting as a drain for water and consolidating soft soil (thereby increasing slope stability). By these means they increase the resilience of streambanks to extreme climatic events. Because they are constructed with local labour and materials, they require less energy to produce, are far more sustainable, and can often be applied in a quicker timeframe than traditional civil engineering works.

Geojute product

Biological geotextile using jute

Strengths	Limitations
➢ Cost-effective, uses locally available materials and low-cost labour in comparison to more elaborate civil engineering works. ➢ Can be used to deal with slope erosion. ➢ Provide high initial tensile strength that can be maintained for a long time. ➢ The high moisture retention rates of water hyacinth can help the growth of vegetation. ➢ Easy to install as they are laid on the ground, not buried like synthetic geotextiles.	➢ Whilst a simple method, it can be labour intensive, and knowledge of how to undertake it correctly (the appropriate opening sizes, installation, channelling of surface water and accompanying vegetation) is critical or can result in further erosion and failure. ➢ There is currently a lack of experience and wide application of biological geotextiles.

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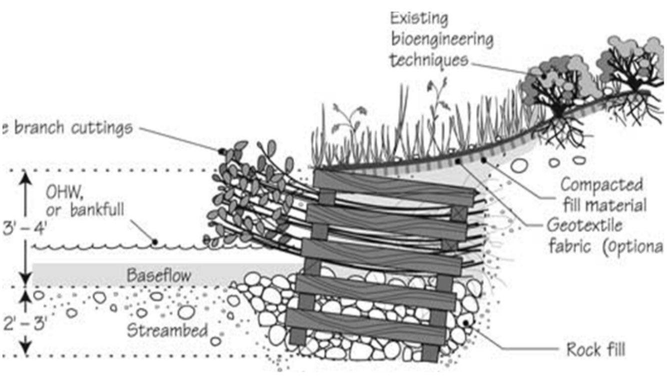
6.2 LIVE CRIB WALL

Application	Bridges, canals, dykes, drainage, road embankments, roads and footpaths
Description	A live cribwall is a three dimensional structure created from untreated timbers, fill, and live cuttings. Layers of logs are interlocked with long branches protruding out between them. The logs are spiked together and anchored into the bank with earthfill behind them to create a wall. The live cuttings help tie the logs together and extend into the slope. They will sprout and develop a root mass that, in conjunction with the log structure, will armour the streambank and protect it from erosion. The roots will eventually take over the structural purpose of the timbers. A live cribwall acts as a retaining wall and is effective at reducing erosion and streambank instability, especially on the outside bend of a stream where the strongest currents are, and at reconstruction of the streambank where extreme erosion has occurred. It can also be used to reduce the steepness of a slope by building a low wall to protect the toe and grading the soil above it back at a gentler grade.
Contribution to climate resilience	Live cribwalls prevent erosion, and can reconstruct eroded banks by acting as a retaining wall and developing a root mass that reinforces the banks. By these means they increase the resilience of streambanks to extreme climatic events. Because they are developed with local labour and materials, they require less energy to produce, are far more sustainable, and can often be applied in a quicker timeframe than traditional civil engineering works.



Design of live crib wall

Gully treatment using live crib wall

Strengths	Limitations
➢ Requires minimal space. ➢ Provides stability above and below water level. ➢ Stabilises the toe of the slope and protects it against undercutting. ➢ The submerged rocks and logs can provide excellent aquatic habitat. ➢ Provides immediate slope protection and stabilisation. ➢ Can be used instead of a structural treatment such as gabions or concrete blocks.	➢ Not intended to be used where the integrity of a road or structure is dependent on the crib wall, as it is not designed to resist large lateral earth pressures. ➢ Should not be placed in areas that experience large, lateral earth stresses or mass wasting for protecting stream banks. ➢ Large amount of material and labour is required. ➢ Can be costly to construct.

Sources

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6.3 LIVE STAKING

Application	Bridges, canals, dykes, drainage, road embankments, roads and footpaths
Description	Live staking is the placement of woody plant and tree cuttings (e.g. willow and cottonwood) on a graded streambank to grow, stabilize the streambank and control minor or shallow erosion by the formation of a root network and aboveground brush. It is also used as a means of securing other soil bioengineered structures or erosion control measures such as fascines and brush mattresses to the ground. The added advantage of using a live stake to secure a treatment lies in the extra plant growth that the stake itself will provide.
Contribution to climate resilience	Live stakes reduce erosion by stabilizing the streambank through physical reinforcement and formation of a root network. By these means, they increase the resilience of streambanks to extreme climatic events. Because they are developed using local labour and materials, they require less energy to produce, are far more sustainable, and can be applied quickly. If planned properly and planted at the right time, live staking can be valuable in preparing for likely changes in climate.

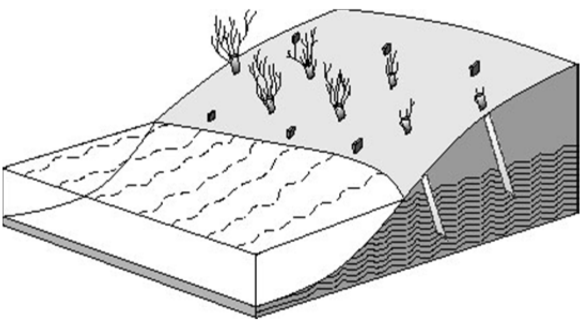

Illustration of live staking on slope

Live staking to control erosion in New Zealand

Strengths	Limitations
➢ Stakes can improve aesthetics and provide wildlife habitat. ➢ Low cost where materials are available. ➢ Can be easily installed and maintained on a wide variety of sites. ➢ Can enhance the performance of surface erosion control materials. ➢ Creates favourable conditions for natural colonisation of vegetation from the surrounding plant community. ➢ Stabilises intervening areas between other soil bioengineering techniques.	➢ Live staking must be carried out during their dormancy (late fall to early spring). ➢ Should be employed before severe erosion problems occur. ➢ Must be handled properly to avoid drying or exposure to heat. ➢ Not applicable for slopes greater than 2:1. ➢ Should not be used if immediate stabilization is required.

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6.4 PALISADE

Application	Bridges, canals, dykes, drainage, road embankments, roads and footpaths
Description	A palisade is a wall consisting of living uniform stakes of live material driven into the ground (one third of their length), close to each other to form a palisade. Palisades reduce slope in gullies and tributaries, encourages deposition of sediments especially in fine soils, and form a strong barrier to reinforce the slope especially once cuttings developed the root. Palisades are used to promote deposition in rills, V-shaped gullies and rehabilitation in fine soils (clay, sand, loess, loam).
Contribution to climate resilience	Palisades reduce erosion in gullies and tributaries by reducing their slope, encouraging deposition of sediments and providing slope reinforcement. By these means they increase the resilience of streambanks to extreme climatic events. Because they are developed using local labour and materials, they require less energy to produce, are far more sustainable, and can be applied quickly.

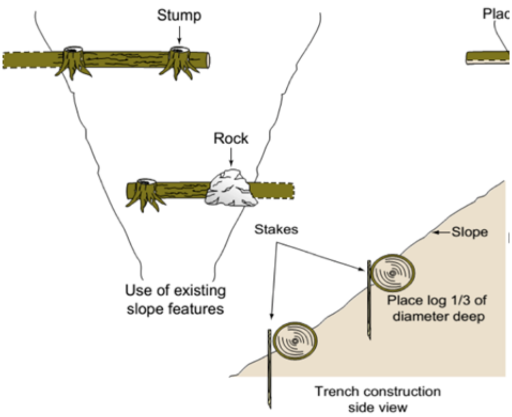

Illustration of palisades


Palisades stabilise gully floor and trap material

Strengths	Limitations
➢ A large amount of material and labour is required. ➢ Trap material moving down the slope. ➢ Low costs where materials are available at site. ➢ Quickly and easily built. ➢ Provide immediate protection. ➢ Usually grow well. ➢ Stabilise and reinforce slope.	➢ Palisades are only effective up to 6m wide and 24m long. ➢ Availability of material for palisades might be restricted (long, straight poles).

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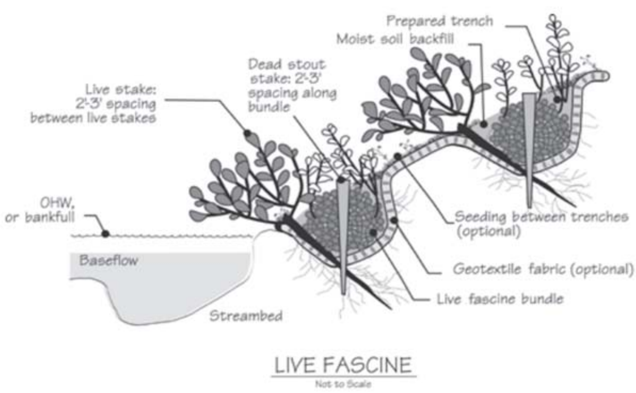
6.5 LIVE FASCINE

Application	Bridges, canals, drainage, dykes, road embankments, roads and footpaths
Description	Live fascines are long bundles of live woody vegetation buried in a streambank in shallow trenches placed parallel to the flow of the stream. The plant bundles sprout and develop a root mass that will hold the soil in place and protect the streambank from erosion. They act as a water retention system when placed horizontally or can serve as a drainage system if installed at a slight angle. Live fascines are also used to bench eroded slopes or gullies and to improve infiltration and other riparian zone functions. In conjunction with other methods, fascines can be used to protect the toe of brush mattresses, and the top leading edge of cribwalls. They can also be used to ‘soften’ existing rock riprap, gabion baskets, or concrete blocks, by placing them along the top edge of the stone, or if possible, along the edge of the water.
Contribution to climate resilience	Live fascines are most useful in controlling erosion in weak and unconsolidated materials, where deep gullies might form, and are often used to stabilize long slopes. By these means, they increase the resilience of streambanks to extreme climatic events.



Design of live fascine

Live fascine protects slope from erosion

Strengths	Limitations
➢ Simple and requires little time to build and can be installed with little site disturbance. ➢ Provide a living filter to absorb excess nutrients and pollutants before they reach the water. ➢ Provide immediate protection once installed. ➢ Require no heavy machinery, which makes it a good option at remote, or inaccessible sites. ➢ Improve fishery habitats, water quality and aesthetics, and provide substrate for aquatic organisms. ➢ Most effective when combined with live staking and riprap.	➢ Should not be used where sites with rapid undercutting or mass wasting. ➢ The streambank should have a slope no steeper than 1:2. ➢ Bank needs to be composed of a material that can easily be trenched and can hold moisture to support growing vegetation. ➢ Fairly labour intensive process. ➢ Should not be planted below base-flow levels or plants risk dying from being submerged too long.

Sources

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6.6 VEGETATED REVETMENT

Application	Canals, culverts and drains, dykes, floodgates, river embankments
Description	A vegetation revetment is an engineered slope with trees planted along banks, shorelines or cliffs to reduce slope erosion by absorbing energy and reducing velocity or water, capturing soil, and creating a natural habitat enhancing conditions for planting or colonization of native species. It is constructed of trees (without root wads) that are cabled together and anchored along the structures by earth anchors, which are buried in the bank. The sediment trapped in and behind revetments provides a moist, fertile seedbed for vegetation establishment. The primary purpose of a revetment is to stabilise the eroded or undercut bank until trees and shrubs become established to provide permanent protection. Tree revetments decrease erosion and slow the near shore current so that silt and sand can be deposited on the bank.
Contribution to climate resilience	Vegetated revetments prevent erosion by stabilizing the bank and slowing the near-shore current so that silt and sand can be deposited. This increases the resilience of stream banks to extreme climatic events. Because they are developed using local labour and locally available materials, they require less energy to produce, are far more sustainable, and can be applied in as quick a timeframe as traditional civil engineering works.

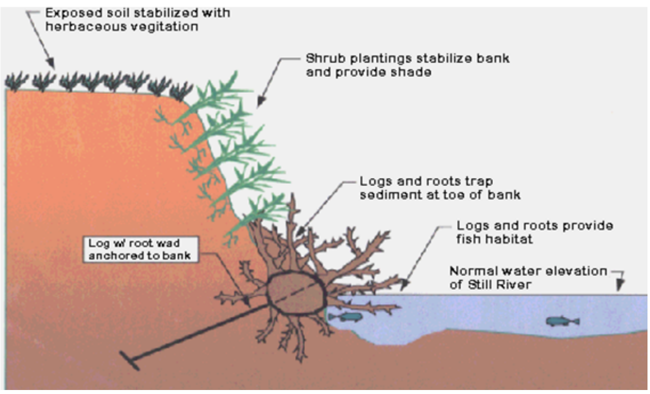

Illustration of vegetated revetment

Installing vegetated revetment

Strengths	Limitations
➢ Use inexpensive and typically readily available materials. ➢ Can act as a natural sediment accumulator, enhancing certain habitats. ➢ Self-repairing. ➢ Protect both the toe of slope and bank from the erosive force of water. ➢ Lower stream temperatures and decrease stream velocity. ➢ Provide habitat value both above and below the waterline for aquatic and other wildlife.	➢ Vegetation incorporated into the revetment must be planted at medium density to avoid excessive sediment deposition and projection into the stream. ➢ It is extremely important to anchor each tree at the base or toe of the eroding bank. ➢ Not suitable at sites with structures downstream that can potentially be damaged if a revetment dislodges. ➢ Structure may be ineffective if revetment does not run the entire length of an eroding bank.

Sources

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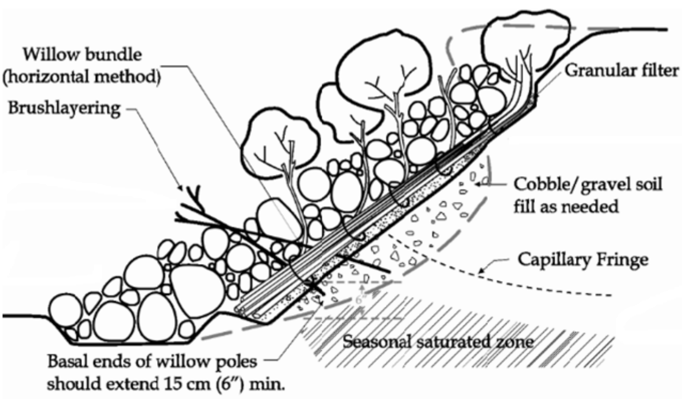
6.7 VEGETATED RIPRAP

Application	Canals, culverts and drains, dykes, floodgates, river embankments
Description	Vegetated riprap incorporates a combination of rock and native vegetation in the form of live cuttings. Long and living willow or cottonwood posts for example can be planted in conjunction with the placement of rock used to armour the banks of watercourses or redirect flows. Adding vegetation to riprap can protect the soil surface from erosive forces or improve stability of soil slopes that are subject to seepage or have poor soil structure through development of root mass, in addition to providing a more natural appearance to the installed rocks. Establishment of woody vegetation will prevent soil loss (piping) from behind the structures and increase pull out resistance. Five methods for constructing vegetated riprap that have proven effective are: vegetated riprap with willow bundles; vegetated riprap with bent poles; vegetated riprap with brush layering and pole planting; and vegetated riprap with soil cover, grass and ground cover and joint or live stake planted riprap.
Contribution to climate resilience	Vegetated riprap prevents bank erosion by protecting the surface and undermining of slopes. It also increases the resilience of local communities to drought by creating a habitat for fish (a source of food alternative to agriculture), and supplying fodder for local livestock. Because they are developed using local labour and materials, they require less energy to produce, are far more sustainable, and can be applied in as quick a timeframe as traditional civil engineering works.



Design of vegetated riprap

Vegetated riprap along a riverbank

Strengths	Limitations
➢ Resists hydraulic forces, increases geotechnical stability, and prevents soil loss. ➢ Improves fish habitat by creating shade, cover and an input of small organic debris. ➢ Potential supply of fodder for animals. ➢ Provides shade and improves aesthetic and recreation. ➢ Roots, stems, and shoots will help anchor the rocks and resist 'plucking' and gouging by debris.	➢ Installing plants that can survive at various submersions during the normal cycle of low, medium, and high stream flows is critical to the success of vegetative riprap. ➢ It is sometimes difficult to drive the willow stakes between the rock joints, through filter fabric and into the native soil.

Sources

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6.8 MANGROVE FOREST PLANTING

Application	Coastline, dykes, sea walls
Description	Mangroves are shrubs or small trees that grow in coastal saline or brackish water. The term is also used for tropical coastal vegetation consisting of such species. Mangroves are salt tolerant and can cope with saltwater immersion and wave action. The dense root systems of mangrove forests slow the flow of water over the soil surface and trap sediments flowing down rivers and off the land. This helps stabilise the coastline and prevents erosion from waves and storms. By filtering out sediments, the forests also protect coral reefs and sea grass meadows from being smothered in sediment. Mangroves reduce the height and energy of wind and waves passing through them, reducing their ability to erode sediments and to cause damage to structures such as dikes and sea walls.
Contribution to climate resilience	Mangroves increase the resilience of coastal areas and the communities inhabiting them by absorbing wave energy, protecting shorelines from erosion, and by reducing damage caused by floods, exceptional tides, storms, typhoons and tsunamis. They also contribute to climate change mitigation by sequestering and storing carbon in above- and below-ground biomass, as well as soils. Mangroves also act as nurseries for fish, crabs and shrimp, which improves resilience to drought by providing alternative sources of food. By contributing important food resources, they also reduce pressure on land close to the coast so that more resilient land management options are possible instead of intensive agriculture.

Planting mangroves in Kampot, Cambodia

Planting mangroves in Kampot, Cambodia

Strengths	Limitations
➢ Reduce damage from large storms and tsunamis. ➢ Provide many timber and plant products (mangrove wood is resistant to rot and insects and can be used for construction material and fuel, medicinal plants from mangrove ecosystems, mangrove leaves as animal fodder). ➢ Protect shorelines from erosion. ➢ Serve as valuable nursery areas for large variety of fish, crab, shrimp, and mollusc species. ➢ Support threatened and endangered species. ➢ Can be a tourism attraction. ➢ Carbon sink and sequestration.	➢ Mangroves are under threat from development pressures, including overharvesting, conversion for alternative uses and development of infrastructure. ➢ Mangroves can be impacted by measures taken quite far from them. ➢ Restoring a mangrove forest, once destroyed, with a full complement of biodiversity is a more complex and long-term process.

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7. RURAL ROADSIDE SLOPE PROTECTION

Rural roads play an important role in connecting rural people with key services and facilitating the provision and consumption of agricultural products. Due to climate change, many areas of Cambodia are expected to experience heavier rainfall, and more intense riverine and flash floods. This will lead to greater erosion of rural roads, resulting in reduced mobility for rural communities. This, in turn, will impair agricultural production, trade, and access to health services and schools.

Measures described below seek to reduce this erosion via various stabilization techniques, with emphasis on bioengineering. The key benefit of bioengineering is that it increases self-reliance of communities - because infrastructure is constructed using local labour and materials, local communities can repair the structures quicker and more easily than for traditional civil engineering works. Similar to Section 2, measures described in this section can also be applied to water infrastructure and are best used in combination to maximise benefits.

7.1 BRUSH MATTRESS

Application	Bridges, canals, Culverts and drains, dykes, floodgates, stormwater outfall
Description	A brush mattress is a protective mat of interlaced live branches placed on a slope or streambank and staked sufficiently to hold it in place using wire or twine, live stakes, and dead stout stakes. It is a simple and cost effective means of protecting the soil surface on slopes from erosive forces through the creation of a dense stand of woody vegetation that will eventually root along the entire length of the structure and provide long-term vegetable stabilisation. The brush mattress has the potential to immediately slow velocities along the bank and accumulate sediment flowing down the streambank, which can improve non-point pollution control. This technique is often used in conjunction with other methods that protect the toe of the slope from undercutting, such as wattles, tree or rock revetments.
Contribution to climate resilience	A brush mattress protects the soil surface of slopes from erosion via root stabilization, and by slowing down surface water velocity and increasing infiltration. By accumulating sediment, it can also reduce road maintenance and improve the quality of water in runoff entering streams. Because it is constructed using local labour and materials, it can be repaired quicker than traditional civil engineering structures.

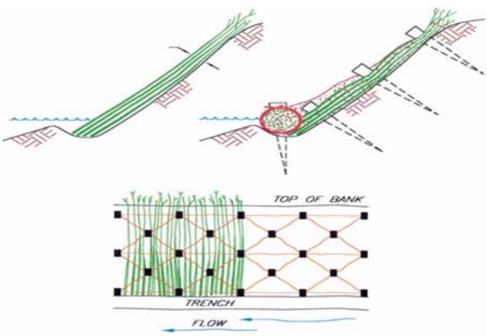

Illustration of brush mattress


Brush mattress protecting riverbank

Strengths	Limitations
➢ Useful on steep, fast-flowing streams. ➢ Can restore riparian vegetation and habitat. ➢ Enhances conditions for colonisation of native plants. ➢ Serves as habitat for birds, animals, insects and other organisms fed on by fish. ➢ Provides shade, lowering water temperatures, offering protection from predators, and improving fish habitats. ➢ Cost-effective, uses local materials and low-cost labour compared to civil engineering works.	➢ Must be installed during the non-growing season as it necessitates dormant cuttings. ➢ Should be initiated with a revegetation strategy. Brush mattresses make it more difficult to establish supplemental vegetative plantings once the mats established. ➢ Brush mattresses are not recommended for streambanks steeper than 2.5:1 nor should they be used on banks where mass wasting occurs. ➢ Must have a secure toe. ➢ Only effective on upper slopes; requires large amount of live material to cover the bank.

Sources

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7.2 LOG TERRACING

Application	Bridges, canals, drainage, dykes, road embankments, roads and footpaths
Description	Log terracing uses alternating terraced logs staked along steep slopes to stop surface erosion, which is critical for successful revegetation efforts. Trees and shrubs are planted behind the logs. Log terracing shortens the slope length and gradient between each structure, providing stable planting areas throughout most of the slope face. It is a way to intercept water running down a slope along the contour, and bedding logs or coir logs in shallow trenches. Contour logs reduce water velocity, break up concentrated flows, and induce hydraulic roughness to burned watersheds. Log terracing should be effective for a period of one to three years, providing short-term protection on slopes where permanent vegetation will be established that provides long-term erosion control. It is better to use coir logs made locally than to fell trees.
Contribution to climate resilience	By reducing the velocity of water running down the slope and breaking up concentrated flows, log terracing reduces erosion. Because it can be developed using local labour and materials, it can be applied in a quicker timeframe than traditional civil engineering works. If designed and constructed carefully, log terracing can be valuable in preparing for likely changes in climate.

Log terracing prevent sand from sliding down the bank

Log terracing

Strengths	Limitations
➢ Reduces length and steepness of the slope. ➢ Provides stable areas for establishment of other vegetation such as trees and shrubs. ➢ Provides immediate slope stabilisation and helps to store sediment. ➢ Increase filtration, adds roughness, reduces erosion, and helps retain small eroded soil on site.	➢ Implementing log terracing is labour intensive and can pose possible safety hazards due to the use of logs on steep slopes. ➢ Heavy equipment required to place the large logs. ➢ Their impact diminishes greatly on slopes steeper than 50 percent.

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7.3 MACADAM

Application	Erosion, roads and footpaths
Description	Macadam is a type of road construction appropriate for rural roads, especially in wet regions. Single-sized crushed stone layers of small angular stones are placed in shallow lifts and compacted thoroughly. A binding layer of stone dust, crushed stone from the original material may form; it may also, after rolling, be covered with a binder of fines and small crushed rock. Water-bound macadam includes using a mixture of stone dust and water to fill the gaps between surface rocks to provide a smoother surface, and a strong and free-draining pavement. A coat of bitumen can be used to seal macadam roads. This requires very good subsoil drainage to keep the roadbed firm, but results in a thinner road that is cheaper to build.
Contribution to climate resilience	Macadam provides good drainage from road surfaces, making roads more resilient to increased rainfall and flooding anticipated with climate change. Because macadam roads can be built using local labour and materials, they can be repaired in a quicker timeframe than traditional civil engineering works, making them more adaptable to climate events and increasing the resilience of the areas they serve.

Building a macadam road in Cambodia

Macadam road in Cambodia

Strengths	Limitations
➢ Uses local materials, keeping costs low. ➢ Local communities can provide labour for construction and maintenance. ➢ Suitable as an all-weather road. ➢ Provides good drainage on roads. ➢ Can withstand wet climate. ➢ Provides better slip resistance. ➢ Easy to repair when it is damaged.	➢ Local materials may not be available for all layers of macadam road construction. ➢ Labour intensive. ➢ Can be time-consuming as the stone layers have to be manually spread/placed.

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7.4 VEGETATED GABIONS

Application	Bridge abutments, canals, culverts and drains, dykes, floodgates, river and road embankments, stormwater outfall
Description	A gabion is a rectangular container fabricated from a triple twisted, hexagonal mesh of heavily galvanized steel wire. Gabions are normally supplied folded flat and bundled together for easy handling. They are then filled with small to medium size rocks. The vegetation layer of the structure is a geotextile with live cut branches placed in horizontal layers in between the rock-filled gabion baskets that serves to hold soil and or rocky backfill in place until roots from live cuttings grow. The gabions are laced together and installed at the base of a bank to form a structural toe or sidewall. Gabions are used to stop undercutting and/or scouring at the base of steep slopes.
Contribution to climate resilience	Gabions reduce flood- or rainfall-caused erosion by stabilizing the base of steep slopes. Because they can be repaired using local labour and materials, they can be restored in a quicker timeframe than traditional civil engineering works, making them more adaptable to climate events and increasing the resilience of the areas they serve.

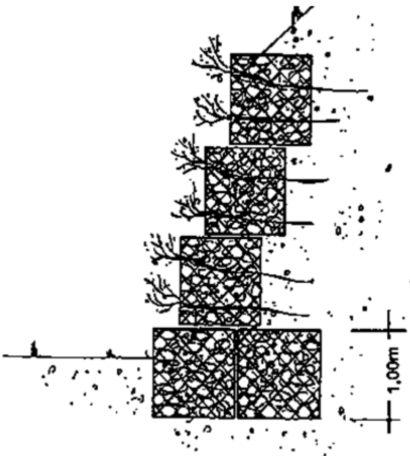

Illustration of vegetated gabions

Example of vegetated gabion channel

Strengths	Limitations
➢ A more natural appearance and is less visually intrusive than structural treatment alone. ➢ Fast and simple construction. Can be installed without special skills or equipment. ➢ Allows for stabilisation of steep slopes where live fascines and brush layers alone are inadequate. ➢ Can withstand higher shear stress. ➢ Gabions adjust to stresses and soil settlements. ➢ Simple field maintenance is feasible without the use of heavy equipment. ➢ Elastic structure with multi-purpose use – can be combined with other measures. ➢ No danger of water impoundment, also used for wet sites with fine soil material. ➢ Used for unstable slopes endangered by erosion, especially along streams or in debris areas.	➢ Vegetating after the construction of the gabion is difficult.

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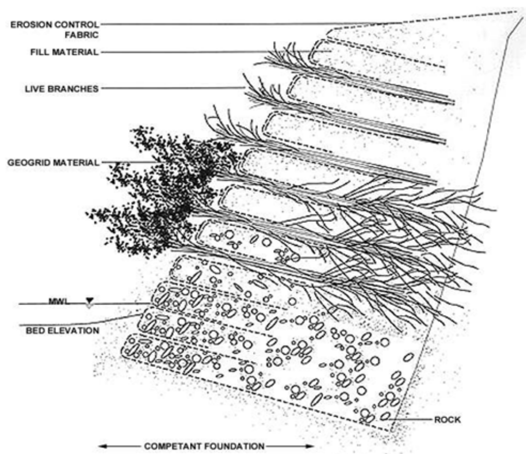
7.5 VEGETATED GEOTEXTILES

Application	Bridges, canals, culverts and drains, dykes, floodgates, river and road embankments, stormwater outfall
Description	A vegetated geotextile consists of alternating layers of live branch cuttings and compacted soil with erosion control fabric (natural or synthetic geotextile) wrapped around each soil layer. The geotextile is secured by tucking it into the slope, keeping the soil in place. Live cuttings are placed between the geogrids, and a root structure is established to bind the soil within and behind the geogrids. The toe of the bank is stabilised by layers of rock on top of the soil layers. The live branch cuttings serve several practical purposes: they act as a buffer to reduce wave energy and shear stress at the face of the wall; having the branch cuttings present before the completion of the wall enables the vegetation to grow as rapidly as possible; and once established the branches serve to bind the geogrids together and provide a root structure behind the wall, attaching it more securely to the shore.
Contribution to climate resilience	Vegetated geotextiles reduce rainfall-caused erosion due to their surface coverage and sub-surface root structure, and by slowing down runoff water velocity and increasing infiltration. This increases the resilience of roadside slopes to extreme climatic events. Their effectiveness increases with time as the vegetation becomes fully established. Because they are developed using local labour and materials, they require less energy to produce, are far more sustainable, and can often be applied in a quicker timeframe than traditional civil engineering works.



Vegetated geotextile stablising Dixie Creek, Illinois, US

Design of vegetated geotextile

Strengths	Limitations
➢ Can be used on shores with sudden drops and where gentle slopes cannot be created. ➢ Can be used on severely eroded bank. ➢ The live cuttings enable rapid vegetation, which slows water during high water stages. ➢ Can withstand relatively high current velocities and shear stresses. ➢ Traps sediment and quickly rebuilds streambank. ➢ Provides habitat and aesthetic value. ➢ A wide variety of geotextile products are available to match specific needs. ➢ Effectiveness increases with time as vegetation establishes.	➢ A large amount of soil and rock must be available to fill the geotextiles. ➢ Installation is complex and requires heavy machinery. ➢ Has a relatively high cost. ➢ Can be labour intensive depending on the choice of geotextile material ➢ Plants must be installed during their dormant season in order for them to properly take root.

Sources

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7.6 VETIVER GRASS

Application	Bridges, bridge abutments, canals, culverts and drains, drainage, floodgates, stormwater outfall
Description	Vetiver grass (*Chrysopogon zizanioides*) is planted as a hedgerow along the contours of sloping land to form a very dense vegetative barrier that slows down run-off, helps the water soak into the soil rather than washing off the slope, and provides significant soil reinforcement through its roots. Combined with a deep and strong root system, a wide range of pH tolerance, a high tolerance to most heavy metals, an ability to remove nitrates, phosphates and farm chemicals from soil and water, the vetiver plant can be an important tool to reduce erosion, reduce and conserve rainfall runoff, improve groundwater recharge, remove pollutants from water, reduce the risk of flooding, and provide economic benefits to communities.
Contribution to climate resilience	The planting of vetiver grass reduces erosion by protecting the soil from the impact of intense rainfall, slowing down run-off, facilitating water absorption and strengthening the soil with its roots. By these means it increases the resilience of roadside slopes to extreme climatic events. Because it is planted using local labour and materials, it requires less energy, is far more sustainable, and can often be applied in a quicker timeframe than traditional civil engineering works.

Vetiver grass lines on hillside

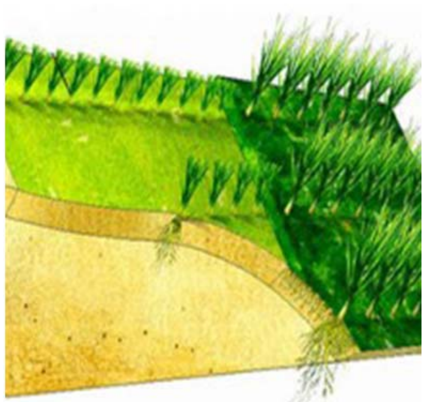

Illustration of Vetiver grass lines

Strengths	Limitations
➢ Will not develop into an invasive species or weed. ➢ It is a low cost, labour intensive technology. ➢ Detoxifying capacity helps clean toxic areas. ➢ Drought and frost tolerant. ➢ Requires little maintenance once the hedge is established. ➢ Can be introduced on farms with minimum changes to the existing farm layout. ➢ Do not compete with neighbouring crops for water and nutrients. ➢ Can grow in many soil types including sand, gravels, and clay. ➢ Vetiver can stand lengthy submergence in water.	➢ Vetiver is intolerant to shading, especially in its establishment phase. ➢ Vetiver used alone can inhibit biodiversity, native vegetation.

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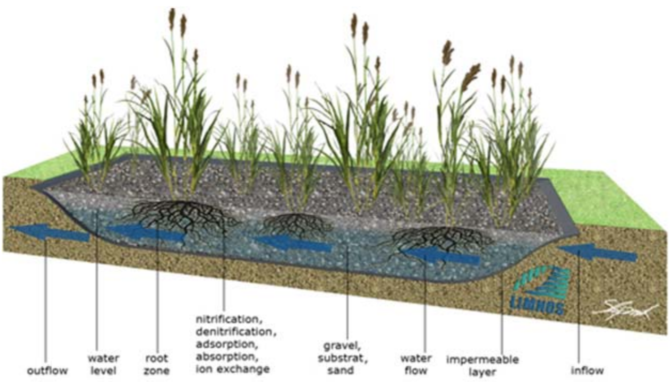
8. SUSTAINABLE WATER USE AND MANAGEMENT

Managing water runoff, storage and use with green infrastructure results in water and flood management, pollution management and rural infrastructure protection, and many other complementary services. Most importantly, agriculture is heavily dependent on water. Enhancing water availability through adaptation measures for sustainable water use and management ensures water supply to increase agricultural productivity and secure food security in rural areas, contributing to rural development. The measures presented here can also be used in combination with the other measures presented in this guide to maximise the opportunities and benefits available.

8.1 CONSTRUCTED WETLANDS

Application	drainage, markets, roads and footpaths, stormwater outfall
Description	A constructed wetland is an artificial wetland consisting of shallow ponds or channels that have been planted with aquatic plants. It is created to emulate the features of a natural wetland, such as acting as a bio-filter or removing sediments and pollutants from the water. It uses natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality. As water flows through a wetland, it slows down and many of the suspended solids become trapped by vegetation and settle out. Other pollutants are transformed to less soluble forms, taken up by plants or become inactive. Vegetation in a wetland provides a substrate (roots, stems, and leaves) upon which microorganisms can grow and remove pollutants from the water. They are generally built on seriously degraded wetlands or new areas where there are problems with drainage and water quality. Wetlands are frequently constructed by excavating, backfilling, grading, diking and installing water control structures to establish desired hydraulic flow patterns. Wetland vegetation is then planted or allowed to establish naturally.
Contribution to climate resilience	Constructed wetlands reduce the impacts of floods by retaining large volumes of water and then discharging it slowly. They also provide wastewater treatment services, and can be used by humans, farm livestock and wildlife as a source of water during drought.



Design of a constructed wetland

Newly planted constructed wetland

Strengths	Limitations
➢ Cost-effective water treatment. ➢ May also serve as a habitat for native and migratory wildlife. ➢ Improves water quality. ➢ Aesthetically pleasing, flood protection, drought relief and opportunities for recreation.	➢ Appear simple but are complex to design and require on-going management. ➢ The system should be located on the contour with drainage directed away from the system. Surface water inflow can cause overloading problems. A barrier to sediment, such as rock landscaping or sod, is needed to minimise erosion and wetland cell problems. ➢ Knowledge of the natural processes used in their operation and efficiency is required. ➢ Larger land areas are required than conventional wastewater treatment systems.

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8.2 RAINWATER HARVESTING (ROOFTOP)

Application	Buildings, farms, houses, markets
Description	Rainwater harvesting is the process of collecting rainwater from surfaces on which rain falls, filtering it and storing it for multiple uses. Various technologies can be used to collect and store rainwater from rooftops, the land surface, or rock catchments, ranging from simple techniques, such as jars, nets and pots, to more complex techniques such as underground check dams. The harvested water can be used for gardens, livestock, irrigation, domestic use with proper treatment, and indoor heating for houses, etc. It can also be used as drinking water, longer-term storage and for other purposes such as groundwater recharge. Commonly used systems have three principal components: the catchment area, the collection device, and the conveyance system.
Contribution to climate resilience	Rainwater harvesting improves water availability for agriculture, livestock, household use (washing, cooking) and personal consumption (with proper treatment). It consequently reduces pressure on other water sources such as groundwater. Construction materials for most rainwater harvesting technologies are locally available, and installation and repair can be undertaken by households, improving their ability to cope with and recover from emergencies.

Example of a rainwater harvesting system

Illustration of a rainwater harvesting system

Strengths	Limitations
➢ Basic technology that locals can easily be trained in, construction materials are readily available. ➢ Provision of water at the point of consumption is convenient, and family members have full control of their own systems, which greatly reduces operation and maintenance problems. ➢ Very low to negligible running costs. ➢ Water collected from a roof is usually of acceptable quality for domestic purposes. ➢ Accessible replacement for groundwater. ➢ Reduces pollutants and flow into surrounding surface waters. ➢ Serves as a backup water supply during emergencies and mitigates flooding of low-lying areas. ➢ Provides an independent water supply for regions during times of shortage.	➢ Rooftops should be constructed of chemically inert materials and kept clean to avoid adverse effects on water quality. ➢ Unpredictable rainfall might pose a problem. ➢ Regular maintenance required. They can become a breeding ground for many animals (rodents, mosquitoes, insects, algae, etc.) if not properly maintained.

Sources

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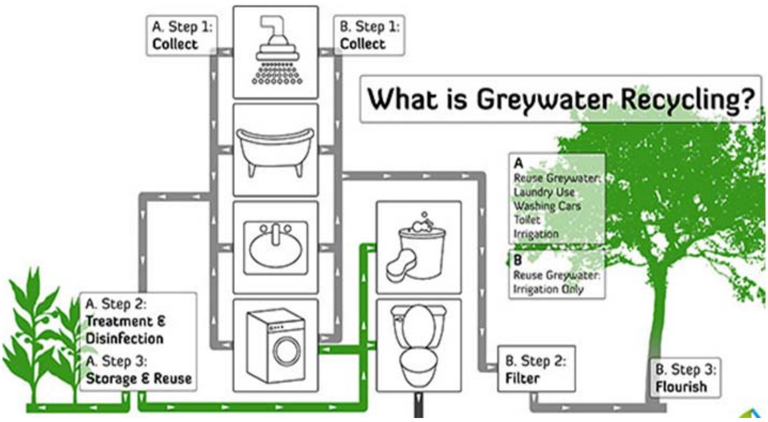
http://lms.sjp.ac.lk/fas/wordpress/?p=329

8.3 GREYWATER RECYCLING

Application	Buildings, farms, houses, markets
Description	Greywater recycling systems collect used water from sinks, showers, and baths. Using state-of-the-art filtration, the system cleans the water and returns it to toilets, washing machines, and outside taps. The easiest way to use greywater is to pipe it directly outside and use it to water plants and trees, or to clean pavements, cars, etc. Greywater recycling systems have been successfully adapted to suit large commercial buildings such as hotels and even industrial plants, but at the moment it is too expensive to install in a family home. Unlike a rainwater harvesting system, which relies on rainfall, greywater is replenished daily.
Contribution to climate resilience	Greywater harvesting increasing the availability of freshwater for consumption and agriculture by reducing the demand for it for other uses (toilets, washing machines, pavement cleaning, etc.). It is also more reliable than rainwater harvesting, but does require a steady supply of freshwater. Improved water management is one of the best ways to improve climate resilience.



Design of a greywater recycling system

Greywater recycling

Strengths	Limitations
➢ Keeps dirty water from polluting sensitive ecosystems. ➢ Grey water can be used to enhance nearby wetlands. ➢ Reduces demand on municipally supplied freshwater. ➢ Reduces strain on water treatment plants. ➢ Provides water for groundwater recharge. ➢ Reduces cost and energy required to pump municipal water.	➢ Produces non-potable water that can be used for irrigation, but it should not touch edible parts. ➢ Greywater cannot be stored for more than 24 hours. ➢ Contact with grey water should be minimised. ➢ Grey water should not be allowed to pool or runoff, becoming breeding grounds for mosquitos.

Sources

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8.4 SOLAR-POWERED WATER PUMPS

Application	Buildings, farms, houses, markets
Description	A solar-powered pump is essentially an electrical pump system in which electricity is generated by photovoltaic panels or the radiated thermal energy collected from sunlight. Solar water pumps are a low cost and dependable method for providing water in situations where water resources are spread over long distances, powerlines are lacking or non-existent, or fuel and maintenance costs are considerable. They can deliver drinking water as well as water for livestock or irrigation purposes. A typical solar powered pump system consists of a solar panel array that powers an electric motor, which in turn powers a bore or surface pump. The water is often pumped from the ground or stream into a storage tank that provides a gravity feed, so energy storage is not needed for these systems.
Contribution to climate resilience	With climate change, expected higher temperatures and reduced rainfall in the dry season will inevitably result in certain water sources (such as community and household ponds) drying out. Solar-powered water pumps mitigate this by allowing households to pump water from far-away sources such as rivers, reservoirs and groundwater.

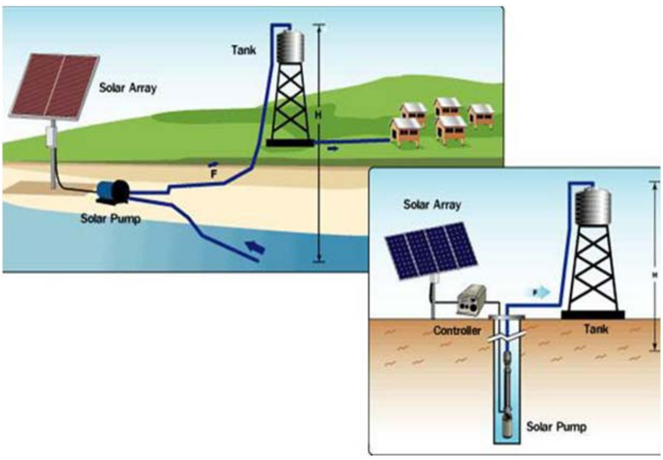

Illustration of solar-power water pumps

Example of solar water pump system

Strengths	Limitations
➢ Operation is more economical, mainly due to the lower operation and maintenance costs. ➢ Have less environmental impact than pumps powered by an internal combustion engine. ➢ Solar pumps are useful where grid electricity is unavailable and alternative sources (in particular wind) do not provide sufficient energy. ➢ May be especially useful in small-scale or community-based irrigation.	➢ Potentially high capital costs (mainly for solar panels). ➢ Water storage is required for cloudy periods, because output is lower in cloudy weather. ➢ Repairs often require skilled technicians. ➢ Must have good sun exposure between 9 am and 3 pm.

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8.5 PLANTED PITS

Application	Farms
Description	Planting pits are a form of micro-catchment for precipitation harvesting to prevent water runoff and thereby preserve soil and soil moisture, increase infiltration and reduce erosion. The water collected is provided for various crops planted within or close to them. To further increase crop production, organic matter (such as compost or manure) can be placed in the pits as fertiliser. Basically, holes are dug 50-100 cm apart from each other with a depth of 5-15 cm in order to prevent water runoff. Planting pits are most suitable on soil with low permeability, such as silt and clay. When heavy rainfall occurs, the organic matter can additionally help to soak up excess water, preventing unwanted water accumulation. They are applicable to semi-arid areas for annual and perennial crops (such as sorghum, maize, sweet potato, and bananas).
Contribution to climate resilience	Planted pits prevent water run-off, thus reducing erosion associated with heavy rainfall. Collected water is used to irrigate nearby crops, reducing consumption from other water sources.

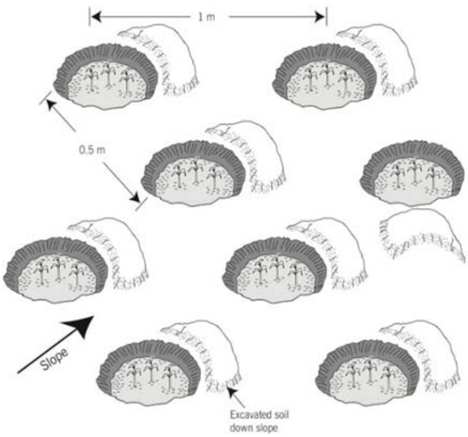

Illustration of planted pits

Example of planted pits

Strengths	Limitations
➢ Simple implementation and maintenance. ➢ No equipment costs, because digging can be done with commonly available tools. ➢ No weeding required, as vegetation is unlikely to grow in the degraded soil between the pits. ➢ Increased infiltration can lead to regeneration of the soil. ➢ The design of planting pits is very flexible. ➢ The soil does not need to be deep or even. ➢ The manure placed in the pits can attract termites, transporting further nutrients from deeper soils to the top layers.	➢ Labour intensive. ➢ Water logging is possible during wet seasons; organic debris in pits may help to absorb water. ➢ Shallow soil becomes thinner where pits are dug, and may require planting on ridge tops. ➢ Pits should be dug in the dry season to be ready when the rainy season begins. ➢ New pits need to be dug in the second year of implementation to retain the soil's fertility.

Sources

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8.6 VEGETATED CHECK DAM

Application	Culverts and drains, dykes, drainage, farms
Description	A check dam (also called gully plug) is a small, temporary or permanent dam built across a drainage ditch, swale, or channel. It lowers the speed of run-off by reducing the original gradient of the gully channel and thereby prevents erosion and promotes the settlement of sediments and pollutants. Furthermore, it allows groundwater recharge and possibly retains soil moisture due to infiltration. It can be built from wood logs, stone, pea gravel-filled sandbags or bricks and cement. Tree seedlings, as well as shrub and grass cuttings planted in gullies, can grow without being washed away by flowing water. Thus, a permanent vegetative cover can be established in a short time. Temporary structural measures such as woven-wire, brushwood, logs, loose stone and boulder check dams are used to facilitate the growth of this permanent vegetative cover. Depending on the topography, amount of precipitation, material and financial resources available, there are several methods of construction.
Contribution to climate resilience	By reducing water speed during floods, vegetated check dams reduce erosion. They also improve water availability by contributing to groundwater recharge. Because they are developed using local labour and materials, they require less energy to produce, are far more sustainable, and can often be applied in a quicker timeframe than traditional civil engineering works.

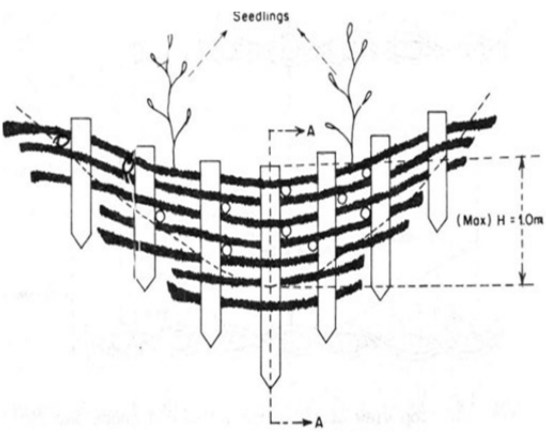

Illustration of vegetated check dam

Check dam stopping gully erosion in East Africa

Strengths	Limitations
➢ Vegetation patterns change runoff peaks and prevent soil loss. ➢ Water speed is slowed, reducing erosion and unwanted gully formation during floods. ➢ No trench design required, just uses existing gully drainage pattern. ➢ Can assist recharge of groundwater and shallow wells. ➢ Can reduce salinity in groundwater. ➢ Cost effective – these dams can use locally available materials.	➢ Check dams must be inspected regularly and any damages repaired. ➢ The sides of the check dam must be higher than the centre so that water is always directed over the centre of the dam to avoid the dam being outflanked by the flow. ➢ Levels of infiltration can be slow due to silt build-up. ➢ Incorrect design may block fish passage. ➢ When only focussing on gully plug construction, the main cause of gully development is missed. ➢ Expert knowledge is required.

Sources

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8.7 FIELD TRENCHES

Application	Canals, culverts and drains, drainage, dykes, farms
Description	Field trenches can be seen as extensive ploughing to the right angle of a field's slope. By breaking the slope of the ground, it increases precipitation harvesting and reduces the velocity of water runoff. They filter runoff from rainfall and hence reduce soil degradation and erosion and enhance infiltration of surface run-off and soil moisture. A great advantage of field trenches, in comparison to other types of water harvesting measures, is their applicability to both even land and steep slopes, and to all soil and rainfall conditions. For optimal performance, trenches are constructed along contour lines. Therefore, the lines need to be marked before starting shovelling. When digging the trench, the excavated soil is placed downslope along the edge of the trench. Crops are then planted on the elevated land between the trenches. While continuous trenches are best suited for moisture conservation in regions with low rainfall, interrupted trenches are best suited to high rainfall areas.
Contribution to climate resilience	By breaking the slope of the ground, field trenches reduce the velocity of water run-off caused by heavy rainfall and flash floods, thus reducing erosion. They also harvest water which helps sustain crops planted between the trenches. Because they are constructed using local labour and materials, they are highly adaptable to climatic events and help to increase the resilience of the agricultural systems they support.

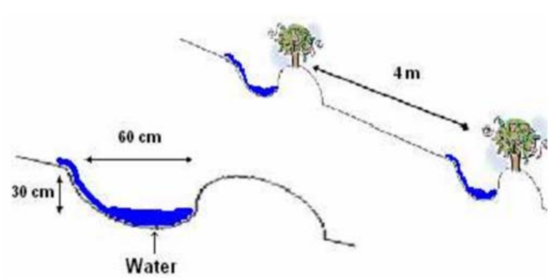

Illustration of field trenches

Example of field trenches

Strengths	Limitations
➢ Construction is simple, requiring only basic tools, materials and skills. ➢ Applicable to all soil and rainfall conditions. ➢ Prevents soil degradation and erosion. ➢ Enhances surface water infiltration and soil moisture. ➢ Helps to reduce flood hazards. ➢ Vegetation may stabilise the trench and therefore decreases the need for repairing.	➢ Intense labour is required for maintenance. ➢ Less land is available for cultivation. ➢ May create temporary waterlogging in dense soil. ➢ On-going maintenance is inevitable and can be time consuming. ➢ Sediment should be removed from the bunds and reapplied to the field uphill periodically.

Sources

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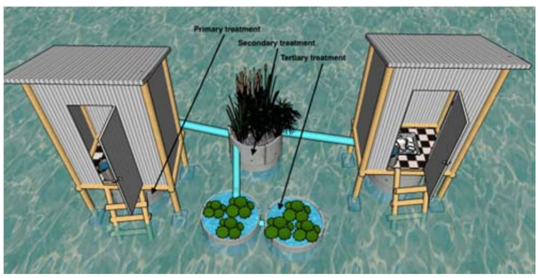
8.8 IMPROVED SANITATION FOR FLOATING AND FLOOD-PRONE VILLAGES

Application	Sanitation, wastewater treatment in challenging situations, e.g. floating villages, flood prone areas and isolated institutions
Description	Poor sanitation and contaminated industrial wastewater affect human health, decrease the availability and access to safe water, and degrade vital habitats. Wetlands Work! Ltd is a Cambodian social enterprise that designs and builds innovative treatment systems and promotes awareness of wetland values. It also works on behaviour change to ensure adoption and longevity of its products. Using WW!'s HandyPod treatment system, wastewater from a floating or a flooded household can be contained and treated to a high greywater standard. An aquatic handy pod is inserted under a floating house's toilet, capturing raw sewage and treating it within the pod using microbial and the other life forms residing around wetland plants and their root systems (such as insects). The pod was successfully tested in a floating village on the Tonle Sap Lake, Cambodia for over three years, leading to a product that isolates and treats wastewater efficiently with no aesthetic problems in terms of smell or 'visuals', no mosquitoes, no chemicals, and little maintenance required. This three-stage treatment design for flood-resilient sanitation is the first appropriate system for poor, marginalized populations living in flooded conditions. The system significantly improves upon current practices in excreta disposal and management (open or pit defecation) in seasonally high groundwater-table areas. The design takes only 6 m^2 of space; it relies on gravity flow and an appropriate retention period for anaerobic and aerobic microbial activity, and no energy, electrical, or chemical systems are required.
Contribution to climate resilience	With climate change, many areas of Cambodia are expected to experience greater flooding. The aquatic handy pod improves household sanitation in flooded conditions, reducing incidence of related diseases.

WW! Handy Pod in Akol Floating Village



WW! design for sanitation in flood prone and high water table areas

Veal Sbov, Cambodia is prone to adverse impacts due to flooding

Polishing pond for single family treatment in Sihanoukville, Cambodia

Strengths

- Wastewater treatment in challenging situations such as floating villages and flood-prone areas
- Breakdown of organic material and removal of coliforms and pathogens
- Safe discharge of wastewaters into surrounding waters
- Simple to operate and with no power requirements
- Uses natural wetland plants

Limitations

- Requires a small amount of land for each household
- Requires some maintenance and training to keep operating
- Requires occasional solids removal

Sources

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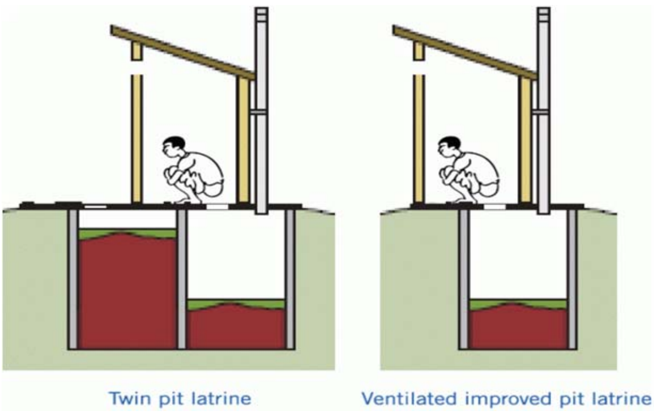
8.9 HYGENIC PIT LATRINE

Application	Buildings, farms, houses, markets
Description	Hygienic pit latrines are improved versions of simple pit latrines. Situated away from water resources and dwellings, it includes the sealing of the passage between the squat hole and the pit to effectively block the pathways for flies and other insect vectors. A slab with a hole to cover the pit prevents people from falling into the pit, increases convenience and reduce odour. When the pit is full, it needs to be either emptied or covered and abandoned, and a new latrine built. By constructing twin pits (double pit latrine), it is possible to dig out a full pit without any objectionable smell, while the other pit is in use. The pits can therefore be reused (no need to construct a new one each year) and there is less risk of groundwater pollution in densely populated areas. Ventilated improved pit latrines are latrines that incorporate a vent pipe, designed to draw flies and smells away from the pit and cabin. Flies are trapped by a screen located at the top of the vent pipe and eventually die.
Contribution to climate resilience	Hygienic pit latrines do not require flushing, and thus increase the availability of fresh water for consumption and agriculture. They are constructed using only local labour and materials, so they can be built quickly at a minimal cost. They help to increase the resilience of communities using them in the event of climate-induced disasters or other emergencies.



Design of hygenic pit latrine

Example of a hygenic pit latrine

Benefits	Limitations
➢ Can be built and repaired with locally available materials. ➢ Requires little land. ➢ Can decrease the spread of disease by reducing the amount of human faeces in the environment from open defecation and breaking the cycle disease transmission. ➢ Conserve water since they need little to no water for flushing. ➢ Waste can be reused as fertiliser.	➢ Flies and odours are normally noticeable. ➢ Costs to empty may be significant compared to capital costs. ➢ Pits are susceptible to failure/overflowing during floods. ➢ Stagnant water in pits may promote insect breeding. ➢ Due to soil infiltration, there always remains the danger of groundwater contamination, especially in densely populated areas. ➢ Pit emptying is often done in a very unsafe manner.

Sources

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8.10 SOLAR TUBEWELL

Application	Buildings, farms, houses, markets
Description	A solar tubewell is run by solar power to provide water. A tubewell is a type of water well in which a long, 100-200 mm wide stainless steel tube or pipe is inserted into an underground aquifer. The lower end is fitted with a strainer, and a pump lifts water for irrigation. Solar power is used to operate the pump instead of diesel. Casing to support the external surfaces of the borehole against collapse may be needed, either temporarily or permanently, and is often made of polyvinyl chloride (PVC) pipe, which is both cheap and inert. Solar tubewells can lift water from about 30 m below ground level. They are designed to last at least 10 years and can be easily maintained. A small reservoir of water is made at the outlet of the tube well.
Contribution to climate resilience	With climate change, expected higher temperatures and reduced rainfall in the dry season will inevitably result in certain surface water sources (such as community and household ponds) drying out. Solar tubewells mitigate this impact by allowing households to access groundwater at very low operational cost, which can be used for agriculture and household consumption. These installations help to improve resilience to droughts.

Solar tubewell in Kehror (Layah), Pakistan

Solar tubewell in Bhakar, Pakistan

Benefits	Limitations
➢ Provide access to relatively safe water for drinking, washing and cooking where groundwater is easily available. ➢ Reduce the use of diesel and fossil fuels and saves spending on electricity. ➢ More reliable during periods of drought when surface water dries up. ➢ Able to irrigate much larger areas.	➢ Increased use of viable wells increases wear and tear and water demand. ➢ Damage to the well or borehole increases the risk of contamination entering the water source. ➢ Collaboration with other users of the aquifer such as irrigation farmers and private well owners are necessary to manage the resource effectively.

Sources

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8.11 RECHARGE PIT

Application	Farms, houses
Description	Recharge pits are suitable for recharging bore wells, increasing soil moisture, recharging shallow aquifers, and providing water for small houses. They are small pits of any shape, constructed with brick or stone masonry walls with openings (weep-holes) at regular intervals. They are located in a catchment at its lowest point and rainwater flowing overland is directed into it. The water passes through filter material and enters the bore well and underground aquifers. Small holes made with casing pipe and covered with nylon mesh, are filled with filtering materials. The top of the pit can be covered with perforated covers. The pit bottom should also be filled with filter media. Pits are usually 1-2 m wide and 2-3 m deep, depending on the catchment area size, rainfall intensity, and soil recharge rates.
Contribution to climate resilience	Recharge pits allow rainwater to replenish groundwater, thus making use of heavier rainfall in the wet season and increasing the availability of water during the dry season (likely to become more severe with climate change). Because it is constructed using local labour and locally available materials, it can be repaired quickly, making it very resilient to both routine wear-and-tear and natural disasters.

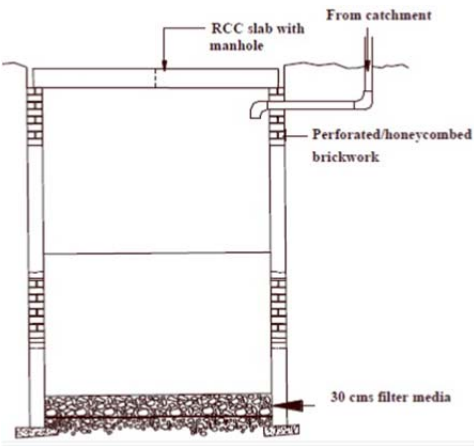

Illustration of recharge pit

Recharge pit with plenty of water

Benefits	Limitations
➢ Allows rainwater to replenish groundwater. ➢ Can be built to recharge a bore well or help water infiltration in an area. ➢ Can be totally invisible when finished. ➢ Uses locally natural materials. ➢ Low cost and easily maintainable locals.	➢ Site should have a sufficiently clean and large catchment, free from biological and chemical pollutants. ➢ Location should be such that it permits fast infiltration and percolation. ➢ Never allow polluted water to recharge the ground.

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8.12 SOAK PIT

Application	Farms
Description	A soak pit (soak away or leach pit) is used to recharge groundwater and acts as a partial treatment of wastewater, greywater, or stormwater. It is a covered, porous-walled chamber that allows water to slowly soak into the ground. As wastewater percolates through the soil from the soak pit, the soil matrix filters out small particles and microorganisms digest organics. The wastewater effluent is absorbed by soil particles and moves both horizontally and vertically through the soil pores. It can be left empty and lined with a porous material to provide support and prevent collapse, or left unlined and filled with coarse rocks and gravel. The rocks and gravel will prevent the walls from collapsing, but still provide adequate space for the wastewater. In both cases, a layer of sand and fine gravel should be spread across the bottom to help disperse the flow. To allow for future access, a removable (preferably concrete) lid should be used to seal the pit until it needs to be maintained.
Contribution to climate resilience	Soak pits facilitate recharging of groundwater by partially treating wastewater, greywater and stormwater and allowing it to slowly soak into the ground. This increases the availability of water during the dry season, which is likely to become more severe with climate change. Because they are constructed using local labour and locally available materials, they can be repaired quickly, making them very resilient to both routine wear-and-tear and natural disasters.

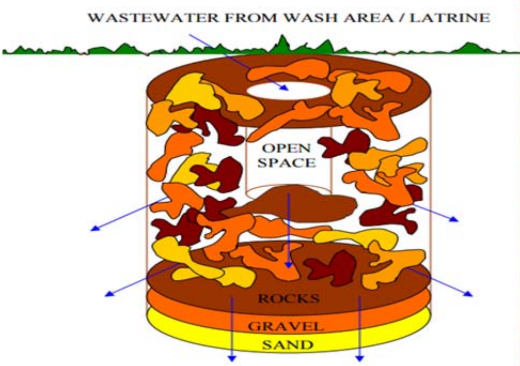

Illustration of soak pit

Soak pit with installed PVC pipes

Benefits	Limitations
➢ A cost-efficient option for a partial treatment of wastewater, greywater, or stormwater. ➢ Recharges groundwater bodies. ➢ Can be built and repaired with locally available materials. ➢ Technique simple to apply for all users. ➢ Small land area is required. ➢ Low capital and operating costs.	➢ Sub-soil layers should be water permeable in order to avoid fast saturation. ➢ High daily volumes of discharged effluents should be avoided. ➢ Should be kept away from high-traffic areas. ➢ Should be located at a safe distance from a drinking water source (more than 30 m). ➢ Should never be less than 2 m above the groundwater table. ➢ Not used for raw sewage. Primary treatment is required to prevent clogging.

Sources

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8.13 RAINWATER HARVESTING PONDS

Application	Buildings, farms, houses, markets
Description	Rainwater harvesting ponds is a system of rainwater harvesting tanks designed to provide water for areas not suitable for tank construction such as villages located on sloping lands or scattered households. Typically, a large water-harvesting pond (main tank) is constructed a specified distance from the targeted areas where the land is suitable for construction. Timber platforms with hand pumps are installed to lift water from the tank to store in plastic/PVC tanks and then transferred to sub-tanks and homes using gravity. Sub-tanks, connected to the main tank through pipes, are built near the village, and a separate pond can be constructed near the main tank, at a lower elevation that, for instance, buffalo can use for bathing and washing. Tanks should be fenced to prevent intrusion of cattle or humans. The system can provide a reliable and cost-efficient source of water for horticultural crop production and supplementary water for household uses such as washing and laundry. The network of hand pumps reduces the use of diesel and save electricity.
Contribution to climate resilience	Rainwater harvesting ponds improve drought resilience by increasing the availability of water for agriculture, livestock, and household uses such as washing and laundry. They make use of heavier rainfall in the wet season and reduce scarcity during the dry season, both situations likely to become more severe with climate change. They are particularly suited to households which cannot install rainwater tanks due to sloping land or geographical isolation.

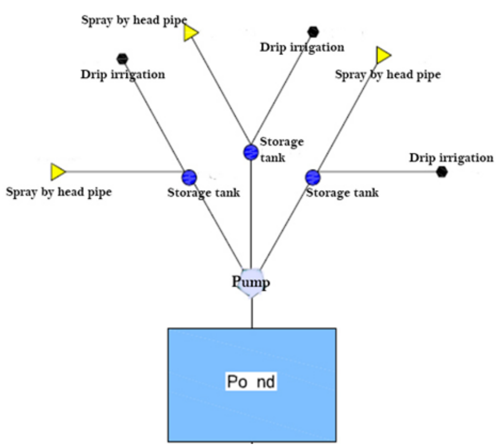


Illustration of a rainwater harvesting pond network

Rainwater harvesting pond in Sigiriya, Sri Lanka

Benefits	Limitations
➢ Provides water for home irrigation, cattle, and supplementary water for household use. ➢ Provides additional climate resilience to the villages most vulnerable to drought. ➢ Suitable in areas that are located on sloping lands or where households are scattered. ➢ Can be built and repaired with local materials and are easily operated by local people. ➢ Allows families to grow their own vegetables and fruits.	➢ Rainwater harvesting ponds require regular maintenance. ➢ Can become a breeding ground for many unwanted organisms if they are not properly maintained, for example, rodents, mosquitoes, algae growth, insects and lizards. ➢ A lack of good rainfall makes the system less cost-effective.

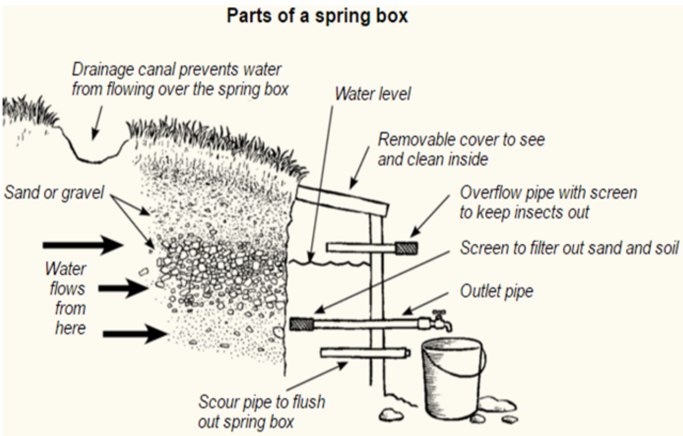
Sources

CAM 40253: Greater Mekong Subregion Biodiversity Conservation Corridors Project: Feasibility Study – Rainwater Harvesting Ponds with Climate-Resilient, High-Value Crop Productivity for Srae I Village Draft Final Report, February 2014.

http://www.appropedia.org/index.php?title=Original:Rainwater_harvesting&mobileaction=toggle_view_mobile#

8.14 PROTECTED SPRINGS

Application	Buildings, farms, houses, markets
Description	Protected springs are a way to provide a safe water supply for drinking and other domestic uses. Spring water is filtered through rocks and soil and moves quickly; therefore it is considered safe unless it is contaminated at the surface. To protect springs against contamination, a spring catchment box and other protective measures can be constructed. The spring box is a covered container made of masonry, brick, or concrete. A spring box also makes it easier to collect water at the spring or direct water into pipes to community taps or storage tanks. The box needs a lid that can be opened to enable cleaning. This should be mounted to prevent animals or leaves from entering, and should be kept locked. Fencing the area around the spring will keep animals out and digging drainage ditches can help carry away surface runoff and waste. Native trees can be planted to prevent erosion.
Contribution to climate resilience	Protected springs provide an additional source of safe drinking water, reducing the demand from other sources. Because they are constructed using local labour and materials, they can be repaired quickly, making them very resilient to both routine wear-and-tear and natural disasters.



Design of protected springs

Namungogna protected springs, Uganda

Benefits	Limitations
➢ Water naturally rising to the surface limits the need for pumping, reducing the use of diesel/fuel. ➢ Low maintenance and running costs. ➢ Can be high yield source of good quality water – no need for treatment. ➢ Provide a safe water supply for drinking and other domestic uses. ➢ Can be constructed and maintained using local material and labour.	➢ Yield can diminish or dry up during extreme drought periods. ➢ Regular maintenance needed around the springhead to prevent pollution. ➢ Spring boxes need to be checked to ensure the spring continues to provide safe water. ➢ Requires careful conservation of the catchment of the spring.

Sources

http://en.hesperian.org/hhg/A_Community_Guide_to_Environmental_Health:Protect_your_Spring

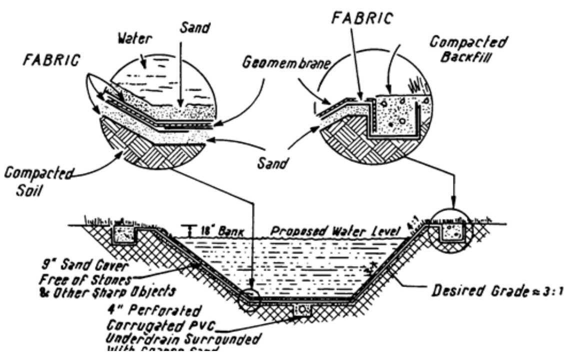
http://www.who.int/water_sanitation_health/hygiene/emergencies/fs2_4.pdf

www.wateraid.org/~/media/Publications/Protection-of-spring-sources.pdf

http://barlowsinuganda.blogspot.com/2010/04/spring-is-in-air-but-in-uganda-we-are.html

8.15 PLASTIC LINER FOR PONDS AND RESERVOIRS

Application	Pond, reservoir
Description	In many parts of Cambodia, rainwater is not stored due to inadequate collection and storage facilities. This contributes to water shortage for drinking and other uses. Using synthetic liners in rainwater harvesting ponds improves the effectiveness of rainwater collection and storage, improving availability of water for agriculture, aquaculture and livestock. Synthetic liners (or 'geomembranes') are low-permeability man-made membranes or barriers used to control fluid migration in an earthen storage structure. They can be made of PVC or high density polyethylene. Alloyed polyethylene liners are manufactured to exact standards and provide superior performance in almost any environment due to improved resistance to puncture and tear. Custom engineered fabrication and sizes up to an acre are available and minimize in-field seaming.
Contribution to climate resilience	Plastic lining increases the effectiveness of rainwater harvesting ponds, thus improving drought resilience by increasing the availability of water for agriculture, livestock, and household uses such as washing and laundry. This also reduces pressure on other water sources such as groundwater and reduces costs associated with pumping.



Design of plastic liner for ponds and reservoirs

Example of plastic liner

Benefits	Limitations
➢ Improves water storage of ponds and reservoirs, and prevents pollution of groundwater. ➢ Protects the slopes and banks from erosion due to wind and wave action. ➢ Eliminates fouling due to soft soil substrates. ➢ Lightweight and easy to handle, enabling quick and easy transportation and installation. ➢ Durable and robust for easy cleaning without significant surface maintenance requirements. ➢ Non-toxic, with low friction and high impact strength.	➢ Soil samples should be collected from sites under consideration to help determine the type of pond sealer or liner that is needed. ➢ For optimal performance, correct liner measurements are critical. ➢ Careful preparation of the area to be lined is very important. Take extra care to remove rocks, debris, tree roots or anything else that might cause a puncture during the installation. ➢ The pond should be filled immediately after liner installation to stabilize the liner and cover the soil layer. ➢ The water level of the pond should be kept at a sufficient level to minimize erosion of earth material covering the liner.

Sources

Pond Sealing Methods. Warren's - TerraBond Field Manual and Specification Guide.

http://www.essenpoly.com/geomembrane_liner.html

Technical Reference Document for Liquid Manure Storage Structures SYNTHETIC LINERS

9. CAPACITY BUILDING AND STAKEHOLDER ORGANISATION

Key concepts around climate change adaptation are not universally agreed on. Any adaptation technology must be tailored for local contexts – especially social and cultural norms. Decision making processes should be participatory, facilitated and consensus oriented. Therefore, policymakers should work with national and subnational stakeholders to make informed decisions about appropriate technology options for rural areas, and to implement the various adaptation technologies at the grass roots in communities and on farms.

9.1 COMMUNITY-BASED AGRICULTRAL EXTENSION

Application	Farmer groups, farming community, small-scale farmers
Description	Agricultural extension is the application of scientific research and the latest knowledge to agricultural practices through farmer education. The community-based rural agricultural extension model provides specialised and intensive technical training to one or two people in a community who then promote a variety of appropriate technologies and provide technical services to the rest of the community, with occasional support and review from a supporting organisation. It provides assistance to many communities that would otherwise not receive technical support services. Farmer-to-farmer systems of extensions are based on the key principles of motivating farmers to experiment with new technologies on a small scale; using rapid, recognisable success in these to motivate others to innovate; using technologies that rely on inexpensive, locally available resources; beginning with a limited number of technologies to retain focus; and, train and support villagers in teaching other farmers.
Contribution to climate resilience	Community-based agricultural extension increases climate resilience of farmers by disseminating climate-smart agriculture and water conservation techniques, as well as training to identify climate variability and choosing an appropriate response. By using local farmers as trainers, it reaches communities that otherwise might not have received technical support services due to geographic isolation or lack of capacity of government staff.

Agricultural extension meeting

Women participating in workshop, Cambodia

Benefits	Limitations
➢ Relatively low cost. ➢ High success rate in identification and adoption of technologies that increase productivity. ➢ Community capacity to identify and select appropriate strategies to respond to the impacts of climate variability is improved. ➢ Enables local communities to develop affordable new products for markets.	➢ May face barriers where rural farmers do not have the means or willingness to pay for technical services. ➢ The model depends on adequate, local technical expertise, either from civil society, NGOs, government or private entities, and the capacity of a local institution to adequately integrate this information into local know-how.

Sources

http://www.climatetechwiki.org/content/community-based-agricultural-extension-agents

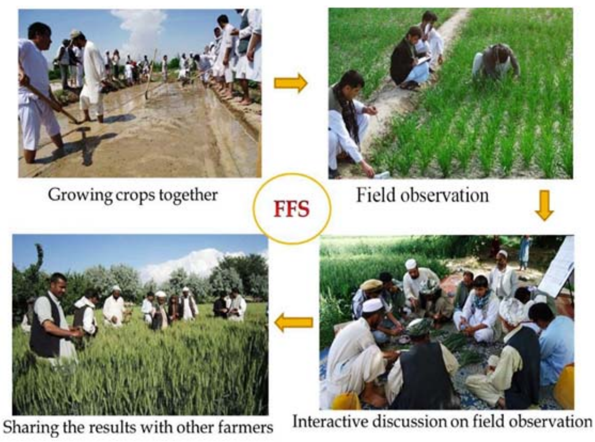
http://psychology.wikia.com/wiki/Agricultural_extension_workers

http://brinjal.org.uk/themes/themes.html

https://biocharinnovation.wordpress.com/category/meetings-workshops/

9.2 FARMER FIELD SCHOOL

Application	Farmer groups, farming community
Description	A farmer field school is a group-based process. A learning environment that includes learning networks is created, providing farmers the opportunity to learn about a wide range of sustainable land management issues and ways to address them through observation, discussion and participation in practical field exercises. Issues can range from management of soil fertility and water resources, risks associated with toxic pesticides to development of marketing skills, diversification of farming systems, and improved irrigation.
Contribution to climate resilience	Farmer field schools increases climate resilience of farmers through group-based learning on climate-smart agriculture and water conservation techniques. Training on identifying climate variability and choosing an appropriate response is provided. By reducing the reliance on external trainers, it reaches communities that otherwise might not have received technical support services due to geographic isolation or lack of capacity of government staff.



Farmer Field School method

Farmer Field School session held at farm

Benefits	Limitations
➢ An effective mechanism for group training. ➢ Empowers individual and groups of farmers to effectively participate in agricultural development. ➢ Increases the likelihood of farmers eventually 'owning' and adopting improved practices. ➢ Establishes the habit and ability to constantly adapt to changing climate.	➢ Requires more time commitment from both farmers and extensionists. ➢ May initially generate more failure than success. ➢ Requires substantial changes to the capacity of agricultural extension services, both in terms of the policies of agricultural development and the abilities of those who execute it. ➢ Resistance at all levels can be a significant impediment.

Sources

http://www.fao.org/nr/land/sustainable-land-management/farmer-field-school/en/

http://www.fao.org/agriculture/ippm/programme/ffs-approach/en/

http://www.climatetechwiki.org/content/farmer-field-schools

http://www.fao.org/docrep/006/ad487e/ad487e02.htm

https://portal.mtt.fi/portal/page/portal/efarp/Extension

http://ipm-af.org/ffs-2/

9.3 WATER USER ASSOCIATION

Application	Farmer groups, farming community
Description	A Water User Associations (WUA) is a group of water users, such as irrigators, who pool their technical, financial, material, and human resources for the operation and maintenance of a water system, to their mutual benefit. They operate at a restricted localised level and are fundamentally a participatory, bottom-up approach with a non-profit structure. Membership is typically based on contracts and/or agreements between the members and the association. These associations play a key role in integrated approaches to water management that seek to establish a decentralised, multi-sectoral and multi-disciplinary governance structure.
Contribution to climate resilience	WUAs improve the availability of water for irrigation by maintaining and repairing tertiary canals (funded by membership fees) and establishing rules for water sharing in the community. By promoting community-based water management, they facilitate more equitable outcomes in the face of reduced water availability.

Water User Association monthly meeting

Water User Association meeting in Cambodia

Benefits	Limitations
➢ Can play a critical role in changing from centralised control of natural resources to local management. ➢ Particularly important for climate change adaptation efforts in which local monitoring of water resources, improvements in infrastructure (such as canals and irrigation) and public participation in decision-making leads to more reliable and equitable distribution of supplies. ➢ Increases agricultural productivity and income opportunities by supporting livelihood diversification and improving water management infrastructure.	➢ Can be difficult if the area of operation does not match a hydraulic boundary. ➢ Could heighten conflict between users where its membership is based on an existing community boundary rather than a representative selection of all water users within a particular system.

Sources

https://www.scribd.com/document/262531075/NEP-PDA-Demonstrating-Enhanced-Productivity-of-Irrigated-Agriculture-System-through-Multifunctional-Water-Users-Associations-Midterm-Report

http://www.iwmi.cgiar.org/regional-content/central_asia/pdf/wua_eng.pdf

http://www.thewaterchannel.tv/thewaterblog/147-on-water

http://www.nationalwatermission.gov.in/?q=node/69

http://www.sustainablecambodia.org/cambodia/

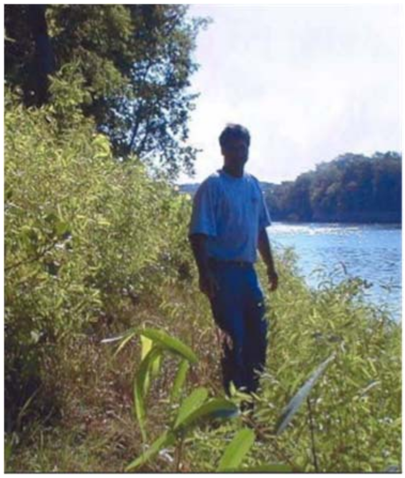
http://pdao-cambodia.org/gallery.php

C CASE STUDIES

10. STREAMBANK AND COASTLINE

10.1 RESTORATION OF RIVERBANKS, NASHVILLE (USA)

Category	Erosion control, riverbank protection, streambank protection
Problem	A one-mile long section of the Cumberland riverbank along the greenway trails in Shelby Park (Nashville, Tennessee) suffered extreme scour and bank failure. The slopes had become steep and badly eroded, causing trees to become loose and falling into the river. An entire mile of shoreline had been eroded to nearly a vertical gradient. Due to the location, mechanised equipment could not be brought to the site.
Solution	C125BN, a temporary erosion control blanket composed of fully biodegradable components, including a 100% coconut fibre matrix sewn with biodegradable thread on 1.5 inch centres between two jute nets, was used in conjunction with live staking, live fascines, brush mattress and seeding.

Results

- Live plantings and grass became very well established vegetation within three months.
- Provided immediate coverage for the soil and preventing further soil loss from the bank.
- The installation resisted physical damage and no plant materials were lost.
- Enhanced the area's overall aesthetic and natural appeal.
- Provided superior erosion control for this portion of the Cumberland River and good moisture retention at the soil surface for quick seed germination.

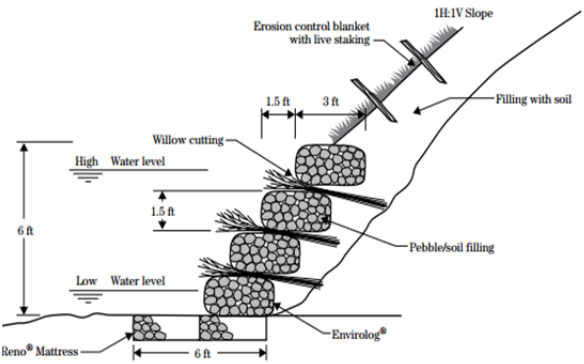
Sources

http://www.tensarnagreen.com/FileDownload.ashx?id=%7B902D78A6-44B9-4989-9FE5-F3E993284C45%7D

http://www.salixrw.com/product/eronet-c125-photodegradable-blanket/

10.2 STREAMBANK STABILISATION, NEW HAMPSHIRE (USA)

Category	Erosion control, riverbank protection, streambank protection
Problem	Waves caused by passing boats caused bank destabilisation on the Merrimack River in New Hampshire, USA. The waves caused exposed soil at the toe of slopes to detach, causing undercutting and mass wasting. Properties along this reach of the river were lost due to flooding, ice scouring, and mass wasting of large trees. Stabilisation interventions (mainly concrete walls) resulted in flow being redirected to downstream neighbours, causing further instability along this reach of the riverbank.
Solution	A vegetated gabion technique was selected to stabilise the riverbank. Green Gabion®, a trapezoidal-type of gabion, and Envirolog®, a cylindrical type of gabion, were selected. Each was lined with 900 grams per square metre of coconut mat in the facing. The gabion structure voids (30 to 40%) were filled with topsoil. To retain the topsoil in these units for vegetation, the wire mesh basket was lined with a thick layer of coconut mat. Between each row, willows and dogwood shrubs were placed at intervals of 30 cms.



Results

- Soil loss was minimised and soil moisture preserved. After only one growing season, the vegetation was generally well established where it was planted.
- The vegetated gabions combined with thick coconut blankets resisted erosion for three to five years before seeing any degradation of the coconut blanket.
- Few repairs or follow ups have been necessary.
- The landowner now has a stable riverbank.

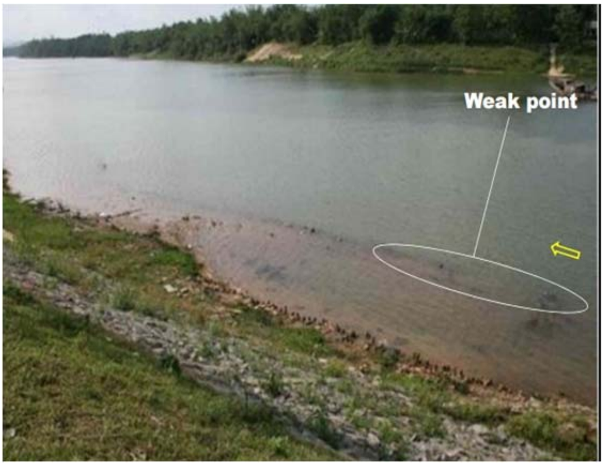
Sources

http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17794.wba

http://www.interempresas.net/Mineria/Articulos/151544-Tecnicas-y-experiencias-en-bioingenieria-empleando-productos-derivados-del-acero.html

10.3 RIVERBANK PROTECTION, KIM NGOC VILLAGE (VIETNAM)

Category	Check dam, erosion control, water use and management
Problem	In Kim Ngoc Village, Vietnam, the Ta Trach River rose up to two metres alongside a community road each year. The river flow eroded 300 m of the riverbank during the 2007 floods and the erosion progressed a further 15 m over the next three years. People reported that further erosion in 2009 caused by typhoon Ketsane threatened 120 houses and the community road.
Solution	Vegetated gabions made of bamboo combined with a live cribwall (bamboo) were used to effectively protect the foot of the riverbank. Riprap and grass were used on the upper riverbank to prevent soil loss. All material was sourced locally, and the bamboo gabion was completed by local workers.



Results

- Riverbank erosion was prevented, and the flow conditions changed from erosion to sedimentation.
- Increased sedimentation and erosion prevention has prevented floods from further eroding the riverbank.
- The riverbank has gained 0.3 m of sediment in the four years since construction.
- Natural vegetation became well established and villagers have also planted vegetables on the newly secured land.
- Flooding has decreased in velocity as the protected foot of the riverbank ensures a shallower water depth.

Sources

http://www.tensarnagreen.com/FileDownload.ashx?id=%7B902D78A6-44B9-4989-9FE5-F3E993284C45%7D

http://www.salixrw.com/product/eronet-c125-photodegradable-blanket/

10.4 RIVERBANK PROTECTION, BAC KAN AND SON LA PROVINCES (VIETNAM)

Category	Erosion control, riverbank protection, streambank protection
Problem	As part of the ADB-funded project ‘Promoting Climate Resilient Rural Infrastructure in Northern Vietnam’, one riverbank site in Thanh Mai Commune, Bac Kan Province and one in Thom Mon and Chieng Ly communes, Son La Province were selected to demonstrate low cost, easily implementable measures to reduce the vulnerability of rural infrastructure to extreme climate events. At the site in Bac Kan, active erosion and riverbed scouring during flood events are threatening community infrastructure (an access track). Heavy rains at any time of year can result in sudden floods of 300m^3/s or more and cause riverbank erosion. The site in Son La is also susceptible to riverbank erosion during floods, damaging adjacent farmland and houses.
Solution	Various bioengineering techniques were used to protect the riverbanks. Techniques include: vegetated riprap for toe protection, vegetated gabion, brush layers, live poles, live fences, fascines and vetiver grass lines for bank protection. Locally sourced woody plants such as willow-leaved water croton, Indian willow and weeping fig were used.

Results

- High vegetation coverage with little to no exposed soil.
- Riverbanks are protected with little or no erosion or slope failure.
- Some sections experienced slope or toe erosion.
- Cheap, readily available local materials were used, thus minimising the cost.
- Additional job opportunities were created for local people.

Sources

http://icem.com.au/portfolio-items/vietnam-resilience/

10.5 STONE REVETMENT AT TATAI BRIDGE (CAMBODIA)

Category	Erosion control
Problem	The abutment of Tatai Bridge in Koh Kong Province (Cambodia) and the bank of the adjacent canal built to drain stormwater are affected by erosion caused by stormwater runoff.
Solution	A stone revetment technique was used to protect the bridge abutment and the bank of the canal from erosion. Construction was carried out by local labour and with locally sourced materials. The revetment was built without mortar to bind the rocks together, and the use of comparatively costly methods using cement and steel was avoided. A stone revetment is a measure that can be readily maintained and managed by local government without any major additional investment. Because the underlying substrate is soil, it will allow for natural regeneration of vegetation. Bioengineering methods that use vegetation as part of construction (vegetated revetment), rather than relying on slower processes of natural regeneration would have further provided the opportunity for planting multi-use plants.

Results

- Acts as a gravity wall to reduce exposure of the slope of the bridge abutment to hydraulic impacts.
- Retains soil and helps with drainage of the canal.
- A cheaper method than those that make use of cement or steel, rather making use of locally sourced materials and labour.
- Ongoing maintenance by local community is possible.
- Natural vegetation is slowly regenerating.
- Labour intensive.

Sources

http://icem.com.au/portfolio-items/mainstreaming-climate-resilience-into-development-planning/

11. ROADSIDE SLOPE STABILISATION

11.1 STABILISATION OF HO CHI MINH HIGHWAY (VIETNAM)

Category	Erosion control, road slope stabilisation
Problem	Costly conventional roadside slope stabilisation measures used along 2000 km of the Ho Chi Minh highway in Vietnam have failed to control erosion and landslides.
Solution	In 2003 the Ministry of Transport (Vietnam) authorised the use of vetiver grass to stabilise the slopes along hundreds of kilometers of the Ho Chi Minh highway, including all new sections and on the eroded slopes of the completed sections (as well as other national and provincial roads in Quang Ninh, Da Nang, and Khanh Hoa provinces).

Results

- Provided effective erosion control on very steep and hostile slopes, trapping sediment and runoff water.
- Protected slopes against very high rainfall (2000 mm per year), including extreme events under typhoon conditions.
- Provided a microclimate that allowed native plant species to naturally establish and replace the vetiver to the extent that in 2014 there was little evidence of vetiver at some sections. Where native species did not establish, vetiver has continued to grow and protect the slopes.
- Resulted in a reduced investment cost (an estimated 90% saving in comparison to hard engineering solutions), and minimal annual maintenance costs.
- Occasional eroded batters and small slips have occurred, partly due to uncontrolled animal grazing and poor internal drainage. Vetiver still does a very good job in slowing down the failures and reducing the failed mass.
- It maintains the rural aesthetic and eco-friendliness of the road.

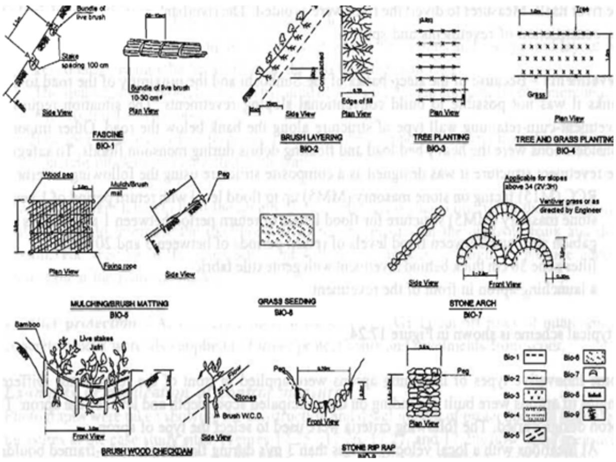
Sources

http://vetivernetinternational.blogspot.com/2014/05/stabilization-of-2000-km-highway-in.html

http://www.vetiver.org/VNN_HCMH.pdf

11.2 LANDSLIDE CONTROL AND STABILISATION (NEPAL)

Category	Erosion control, road slope stabilisation
Problem	The Arniko Highway runs along one of the most fragile river valleys in Nepal. The alignment mostly follows the banks of Bhotekoshi, Sunkoshi, and Chak Khola watercourses. It has been severely affected by a number of natural disasters, including glacial lake floods in 1964 and 1981, and a flood in 1987. The results were frequent landslides and bank erosion.
Solution	A combination of measures was applied to prevent and control landslides and stabilise the road slopes, including water management and drainage, structural support measures, and surface stabilisation measures. Bioengineering was used to stabilise the surface. Brush mattress, live fascines, live staking and palisade, planting grass and trees, and grass seeding were among selected techniques.



Results

- Re-established vegetation on slopes protected them from splash and sheet erosion.
- The selected techniques provided highly successful protection against active and moderately active landslides.
- Rainfall erosion has been reduced, due to the techniques offering rainfall interception and resulting in reduced evapotranspiration.
- Road planners, consultants and contractors in Nepal recognised bioengineering measures as essential components of all stabilisation systems and applied them to all landslides.

Sources

http://lib.icimod.org/record/21570/files/c_attachment_96_792.pdf

http://www.iteconepal.com/

11.3 BIOENGINEERING TO PROTECT ROADSIDE SLOPES (VIETNAM)

Category	Erosion control, road slope stabilisation
Problem	As part of the ADB project ‘Promoting Climate Resilient Rural Infrastructure in Northern Vietnam’, roadside slopes at Nhau Pass, Thai Nguyen Province and in Phong Lap Commune, Son La Province were selected to demonstrate low-cost, easily implementable measures to reduce the vulnerability of rural infrastructure to extreme climate events. At the site in Thai Nguyen, both cut slopes and fill slopes experienced erosion and required stabilisation and protection. In the rainy season, heavy rainfall coupled with steep catchments caused flash floods and landslides, which affect the local people in the communes. The cut slope in Son La is also susceptible to surface erosion and landslides due to intense rainfall causing flash floods.
Solution	A combination of bioengineering techniques was used to stabilise the slopes. Techniques included: brush layers, palisades, vetiver grass lines, jute net with seeding, live fences, fascines, vegetated gabion, local short grass, and truncheon cuttings. Local plants such as golden dewdrop, broad-leafed carpet grass, tiger grass, and lesser spear grass were used.

Results

- High vegetation coverage with little to no exposed soil.
- Cheap, readily local materials were used, thus minimising the cost.
- Additional job opportunities for local people were created.
- Roadside slopes in Thai Nguyen and Son La demonstration sites so far did not experience any slope erosion after one rainy season.

Sources

http://icem.com.au/portfolio-items/vietnam-resilience/

11.4 CLIMATE RESILIENT ROAD CONSTRUCTION (CAMBODIA)

Category	Climate resilient road, road slope stabilisation
Problem	Provincial road no. 1489A in Mondul Seima district, Koh Kong was built on a seawater floodplain with soft-soil pit foundation, while the city road in Krong Sen Monorom, Mondulkiri was built on a mountain slope. Heavy rain and flooding caused frequent slope erosion to these roads. High tides overflow onto the road, allowing seawater to soak into the sub-base and slowly damage the road. Storms, storm surges, and wet condition are also threats to this infrastructure.
Solution	Macadam base technique was used to increase the resilience of the two roads. The macadam base method was chosen because it can withstand wet climates, provides good slip resistance, and is easy to repair when damaged. In addition, a Double Bituminous Surface Treatment (DBST) was applied to slow down the oxidation process, prevent water from entering the base material and reduce washout problems and dust.

Results

- A high quality and durable base type was created.
- The pavement is still in good condition after several monsoon seasons.
- The stone skeleton is less susceptible to water in the layers.
- Additional job opportunities for local people were created.
- The process was labour-intensive and time-consuming.

Sources

http://icem.com.au/portfolio-items/mainstreaming-climate-resilience-into-development-planning/

12. WATER USE AND MANAGEMENT

12.1 SOLAR WATER PUMP IN DADAAB REFUGEE CAMP (KENYA)

Category	Solar water pump, water use and management
Problem	Dadaab is one of the world's largest refugee camps, located 70km from Kenya close to the border with Somalia. In 2011 and 2012, the camps experienced a mass influx of refugees mainly from Somalia due to civil war and drought. The United Nations High Commissioner for Refugees (UNHCR) has constantly raised concerns on the rising cost of running and maintaining the boreholes that provide the only source of water in the camps, due to the rising cost of fuel and the availability of replacement parts, machinery and personnel to maintain diesel generators.
Solution	One of the diesel generator powered pumps was replaced with a LORENTZ solar powered pump. The water is pumped from a depth of 130 m below ground into storage tanks raised 20 m above ground level.

Results

- The water is distributed around the common watering points by gravity, making it available 24 hours a day without the need for generator or battery power.
- Resulted in significant operating cost savings of around US$10 000, compared to a generator-powered system of a similar capacity (the annual operation costs were therefore reduced by over 70%, and by 60% if the capital cost of the system is included).
- Removes both risk and complexity in water supply.
- The solar powered water pump provides a sustainable water supply for thousands of beneficiaries in Dadaab Refugee Camp.

Sources

https://www.lorentz.de/pdf/lorentz_casestudy_dadaab_kenya_en-en.pdf

https://www.nrc.no/news/2015/january/innovation-in-dadaab/

https://ec.europa.eu/echo/blog/more-water-solar-power-dadaab-kenya_fr

12.2 ROOFTOP RAINWATER HARVESTING IN KARNATAKA (INDIA)

Category	Rainwater harvesting, water use and management
Problem	In Karnataka (India), people in rural areas lack access to clean water and sanitation, and are highly dependent on groundwater for meeting drinking and domestic needs. Falling water table levels present a problem, as does the decline in water quality due to the presence of fluorides, nitrates, iron and salt in the deep groundwater. With electricity restricted to a few hours of the day, people have to queue for water when the power comes on and store water for use later.
Solution	The government of Karnataka has initiated a programme to cover one village in each Taluk (an administrative division comprising several villages) of the state with at least 20 rooftop rainwater harvesting structures. A 2000 to 2500 litre tank is constructed of locally available materials such as bricks or stones, or even concrete blocks. Called 'Thotti', it is plastered from the inside and outside and has a (pre) stone-slab cover on top to completely close it and prevent any mosquito or insects from going in. Rainwater from the sheet roofs is then collected using PVC gutters. The rainwater is filtered through indigenously designed sand filters and collected in the tank.


Results

- The tank is multi-purpose: a water storage tank, which also harvests rainwater.
- The collected water lasts for five to 15 days.
- Provides psychological satisfaction to know that water is available when needed.
- Provides water to the doorstep of the house; saving people the trip to collect water from bore wells.
- People don’t have to queue every day and are free from concern regards the availability of water from community taps.
- Sustainable provision of domestic water in rural Karnataka.

Sources

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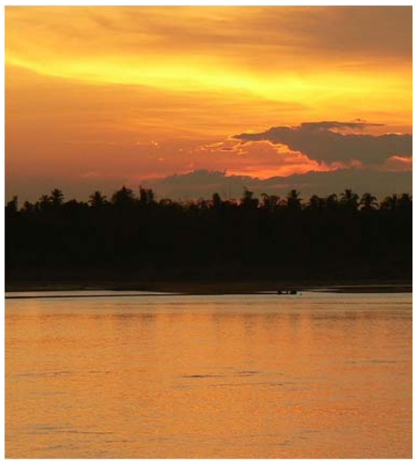
13. CAPACITY BUILDING

13.1 FARMER WATER USE COMMUNITY IN PREY VENG (CAMBODIA)

Category	Capacity building, stakeholder organisation, Water User Association
Problem	Boeung Sne is a large freshwater lake in Prey Veng province, Cambodia. There are 34 villages in six communes over two districts (four communes in Peam Ro, and two communes in Baphnom) that share use of Boeung Sne Lake. The lake keeps water year round, but in the wet season the lake expands, and shrinks in the dry season. The complexity of water management to support the many communities requires the establishment of an organisation to manage water efficiently.
Solution	In 2011, MOWRAM established the Farmer Water Use Community (FWUC) of Boeung Sne, with about 5,527 households becoming members. The FUWC Committee manages water regulation as established and approved by MOWRAM. Farmers from each village selected the committee, which consists of a chairman, members and cashiers. At present, it comprises seven members: three of who are women, and two from Provincial Departments of Water Resources and Meteorology (PDoWRAM).



Results

- Farmers use water from the lake, rather than rainfall, resulting in two or three crops a year.
- The FWUC has contributed to increased collective action and the participation of local communities in water management to improve their farming.
- Farmers pay a water use fee, but not every farmer has paid, affecting the transparency and accountability.
- The FWUC has contributed to flood protection and reduced flood risk.
- FWUC has created a platform to engage communities and stakeholders to manage water.
- The management of water is very much reliant on MoWRAM and PDoWRAM, and the community does not yet have ownership of the resource.
- Increased water demand could result in competition among farmers and cause conflicts over water, risking failure of farmers to cooperate.

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