Kingdom of Cambodia

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National Council for Sustainable Development
Ministry of Environment

Working Paper

Water Resources Adaptation Guide

2019

Water Resources Adaptation Guide

March 2019

Prepared by	National Council for Sustainable Development and Ministry of Environment
Funded by	Climate Investment Funds through Asian Development Bank
Technically Assisted by	International Centre for Environmental Management – ICEM (Authors)

Suggested citation	National Council for Sustainable Development and Ministry of Environment 2019. Water Resources Adaptation Guide. Phnom Penh, Cambodia.
More information	www.spcrcambodia.org, www.camclimate.org.kh and www.icem.com.au Ministry of Environment Morodok Techo Building (Lot 503) Tonle Bassac, Chamkarmorn, Phnom Penh, CAMBODIA, Phone: (855) 89 218 370

Foreword

Cambodia is considered one of the countries in Asia most vulnerable to the impacts of climate change and extreme climate events. Current climate hazards and long-term climate change have been identified as significant environmental and developmental issues in Cambodia. Climate variability and frequency of extreme weather events are projected to increase, causing more severe floods, droughts, storms (with above all, strong winds).

The National Council for Sustainable Development (NCSD) and Ministry of Water Resources and Meteorology in cooperation with concerned stakeholders prepared the Water Resource Adaptation Guide. The major aim of this guide is to provide the basic understanding and practical examples of adaptation measures to practitioners, policy makers, engineers, academia, and local communities who should be able to utilize such adaptation measures for their program/project planning and implementation, including agriculture, fisheries, forestry, energy, transportation, land-use planning and tourism. The adaptation measures are to provide the relevant users with practical examples of necessary actions that would allow for effective planning and response to climate-related disasters and changes in Cambodia.

The guide consists of 32 measures and is subdivided into three parts:

- Part A: an introduction to the guide; overview of the role of green infrastructure in water resource management; introduction to MOWRAM and its roles and responsibilities in the water sector; and an adaptation measure matrix for water resource management.
- Part B: introduction; adaptation measures grouped into three categories of sustainable management of surface water, sustainable management of groundwater and sustainable management of watersheds.
- Part C: government; Farmer Water User Communities; NGOs (civil society); and the private sector.

The Adaptation Guide for Water Resources has been developed in support to mainstreaming climate resilience into the strategic policy agenda and other national development plans. The Adaptation Guide also contributes significantly to the implementation of national strategic instruments closely related to climate change and disaster risk reduction management. These include: Cambodia Millennium Development Goals with a major focus on Goal 13, which is to take urgent action to combat climate change and its impacts; The National Strategic Development Plan (NSDP) 2014-2018; Rectangular Strategy Phase III (2014-2018); Cambodia Climate Change Strategic Plan (CCCSP) (2014-2023); Sectoral Climate Change

Strategic Plan (SCCSP) for Water Resources (2013-2018); and Climate Change Action Plan for Water Resource and Meteorology (2014-2018).

On behalf of the Ministry of Environment, and National Council for Sustainable Development (NCSD), we would like to take this opportunity to express our sincere gratitude to line ministries, agencies, development partners, CSOs, NGOs, private sector, academia and all stakeholders for their support and cooperation in developing this vital Water Resource Adaptation Guide.

Ministry of Environment, and National Council for Sustainable Development strongly believe that all relevant agencies and our partners will continue to work together to adopt the Water Resources Adaptation Guide, and to contribute towards climate change mitigation, poverty reduction and sustainable socio-economic growth for the Kingdom of Cambodia.

Phnom Penh, ..22...March..........2019

Chair of National Council for Sustainable Development and Minister of Environment

Say Sam Al

Acknowledgement

This Water Resource Adaptation Guide was produced under the TA8179-CAM as part of the Strategic Program for Climate Resilience (SPCR) Phase II of the National Council for Sustainable Development/Ministry of Environment and Ministry of Water Resource and Meteorology in close collaboration with all relevant partners.

On behalf of the TA8179 team and officials, I would like to highly appreciate the noble support and guidance provided by **H.E Lim Kean Hor**, Minister of Water Resource and Meteorology; **H.E Say Sam Al**, Chair of National Council for Sustainable Development and Minister of Environment; all esteemed NCSD members.

Our highest gratitude goes to **H.E. Tin Ponlok**, Secretary General of NCSD; **H.E. Chuop Paris**, Deputy Secretary General; **H.E Vann Monyneath**, Deputy Secretary General; **Mr. Sum Thy**, Director of Department of Climate Change; and all concerned officials for their devotion and full support to the SPCR implementation process in close collaboration with all relevant stakeholders.

Special thanks go to MOWRAM Adaptation Working Group members (**H.E Ponh Sachak**, Secretary of State; **Mr. Oum Ryna**, Director of Department of Meteorology; and **Mr. Bak Bunna**, Deputy Director of Department of Water Resources Management and Conservation), and MOWRAM officials for his endless support and coordination during the Adaptation Guide preparation.

Our sincerest thanks also go to MOE's Program Management Unit, **Mr. Meas Sophal**, Acting Director General of General Directorate of Administration for Nature Conservation and Protection and Program Director; **Mr. Ou Chanthearith**, Deputy Director of Department of Science and Technology and Project Manager; **Mr. Sim Touch**, Chief of Climate Change Office and Project Assistant Manager; **Mr. Doeun Dara**, Deputy Chief of Bureau of Department of Climate Change and Chief Finance, and their staff for the valuable advice and insights. We also acknowledge and appreciate the support and collaboration provided from all SPCR staff and their associated consultants.

We are also grateful for the guidance and direction on this guide from **Dr. Srinivasan Ancha,** Principal Climate Change Specialist and Climate Change Focal Point for Southeast Asia, ADB, and **Ms. Valerie Pacardo**, SPCR Program Coordinator of the Southeast Asia Department of ADB, **Mr. Suos Pinreak**, National SPCR Coordination Specialist; **Mr. Chanthou Hem**, Senior Project Officer, ADB Cambodia Resident Mission; and relevant ADB technical specialists for providing technical comments to finalize the adaptation guide.

Finally, we would like to also extend our profound appreciation to the comments made by the concerned government agencies, academia, NGOs, civil society, development partners and private sector to finalize the Water Resource Adaptation Guide.

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
AWG	Adaptation Working Group
CAM	Climate Change Adaptation and Mitigation Methodology
CCAP	Climate Change Action Plan
CCCSP	Cambodia's Climate Change Strategic Plan
CIF	Climate Investment Funds
CMDG	Cambodia Millennium Development Goals
CNMC	Cambodia National Mekong Committee
FDP	Flood Protection Dyke
FWUC	Farmer Water User Community
GHG	Greenhouse Gas
GMS	Greater Mekong Sub-region
ICEM	International Centre for Environmental Management
MAFF	Ministry of Agriculture, Forestry and Fisheries
MEF	Ministry of Economy and Finance
MOE	Ministry of Environment
MOI	Ministry of Interior
MOP	Ministry of Planning
MOWRAM	Ministry of Water Resources and Meteorology
MPWT	Ministry of Public Works and Transport
NCDD	National Committee for Sub-national Democratic Development
NCDM	National Committee for Disaster Management
NCSD	National Council for Sustainable Development
NGO	Non-Government Organization
NSDP	National Strategic Development Plan
PDWRAM	Provincial Department of Water Resources and Meteorology
PFERNA	Post-Flood Early Recovery Needs Assessment
PIMD	Participatory Irrigation Management and Development

PPCR	Pilot Program for Climate Resilience
RGC	Royal Government of Cambodia
SAW	Strategic Plan on Agriculture and Water
SCCSP	Sectoral Climate Change Strategic Plan
SPCR	Strategic Program for Climate Resilience
TA	Technical Assistance
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change

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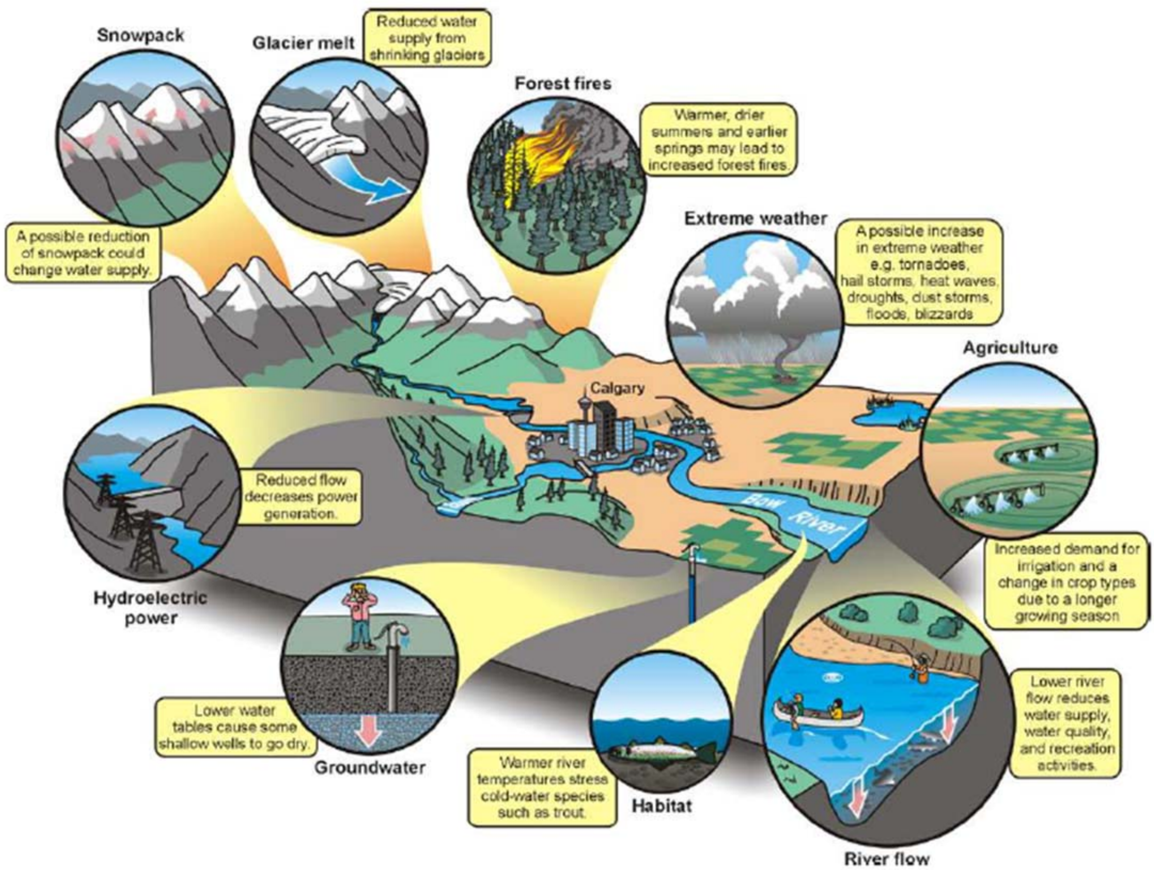
A Introduction to the guide

1. Introduction

The importance of freshwater to our life support system is widely recognized, as can be seen clearly in the international context (e.g. Agenda 21, World Water Forum, the Millennium Ecosystem Assessment and the World Water Development Report). Freshwater is indispensable to all forms of life and is needed, in large quantities, for almost all human activities. Climate, freshwater, biophysical and socio-economic systems are interconnected in complex ways, and a change in any one of these induces a change in another (Figure 1).

Figure 1: Impact of climate change on water



(Source: www.nrcan.gc.ca)

As the earth's temperature continues to rise, we can expect a significant impact on our freshwater supplies with potential devastating effects on these resources. As temperatures increase, evaporation increases, sometimes resulting in droughts. Cambodia is currently one of the countries in Southeast Asia most vulnerable to climate change, and has been affected by the negative impacts of climate change events, like flood and droughts, every year since the last decade.

Anthropogenic climate change adds major pressure to nations already confronted with the issue of sustainable freshwater use. For Cambodia, these challenges are: too much water in the wet season, too little in the dry season, and gradually increasing pollution, particularly in populated cities. Each of these problems may be exacerbated by climate change. Freshwater-related issues play a pivotal role among the key regional and sectoral vulnerabilities.

Therefore, the relationship between climate change and freshwater resources is of primary concern and interest. Climate change leads to the following trends or step changes to groundwater and surface water quality and quantity:

- Increase in average air temperature, leading to higher temperature of freshwater bodies, lakes, seas and oceans, and increased evapotranspiration. This leads to changes in chemical composition and ecological water quality and may lead to changes in fish stocks. Increased evapotranspiration can lead to water scarcity and vegetation changes, with possible concurrent increases of erosion, land degradation and sediment loads in rivers, lakes and coastal zones.
- Sea level rise with increased risk of floods and salt intrusion. It also obstructs drainage in river deltas and coastal provinces like Koh Kong, Preah Sihanouk, Kampot and Kep.
- Changes in global and regional precipitation averages, intensities and/or distribution. On a global scale, it is expected that the hydrological cycle will intensify and average rainfall will increase, but this differs for different parts of the planet; some areas will become wetter, and others dryer. Climate models differ regards which parts become wetter or dryer, so uncertainty should be assumed.
- Changes in frequency and intensity of weather events, such as timing of rainfall, storms and droughts. This is the least known and predictable aspect of climate change, as it takes place at regional and local scale, and is not well described by global models. It is expected that weather events will become more severe, with more frequent and intense rainstorms and longer and more intense droughts. Changing weather influences frequency, timing and intensity of peak flows and dry season minimal flow and water availability. It may also change the recharge of shallow groundwater and the groundwater level, with consequences for vegetation, agriculture and water availability in wells.

Besides air temperature, water is the primary medium through which climate change impacts will be felt by humans and the environment (this is stated in the IPCC Technical Paper on Water and Climate Change by Bates et al., 2008). Water is also critical in relation to climate change mitigation, as many mitigation actions rely on water availability for their long-term success and operation.

Climate change in Cambodia has resulted in two visible events: floods and droughts. Severe floods damage infrastructure, interrupt economic activities, and cause loss of human life, livestock and agricultural products. In the 2000 floods, about 370,000 ha of farmland were inundated and 6,081 houses were destroyed, affecting 3.44 million people living in 132 districts. Flood status has changed over the last few decades, with: 1) an increase in the number of unexpected floods in the Mekong River; 2) heavy rain in the Mekong tributaries; and 3) an increase in flood levels.

The most recent droughts occurred in 1992, 1993, 1998, 1999 and 2015. The drought of 1999 was the most severe. The impact of drought has been addressed with a number of programs aiming to improve irrigation, rehabilitate pumping stations and water pumps and improve water supply and sanitation. Farmer Water User Committees (FWUCs) were also established. MOWRAM's achieved objectives for 2001-2005 include 290 irrigation rehabilitation projects covering 532,673 ha of wet season rice and 154,368 ha of dry season rice fields at a cost of some US$607 million. Up to 2003, 315 irrigation projects had been implemented, covering 153,149 ha of paddy rice fields, of which 89,383 ha were wet season and 63,766 ha were dry season varieties (MOWRAM, 2008).

2. The role of green infrastructure in water resources management

Green infrastructure approach to water management protects, restores, or mimics the natural water cycle. It is effective, economical, and enhances community safety and quality of life (American Rivers 2017).

Green infrastructure combines natural environment and engineered systems to provide clean water and other benefits to people and wildlife, whilst conserving ecosystem values and functions. Green infrastructure entails planting trees and restoring wetlands instead of building water treatment plants. Water efficiency measures are prioritised over building new water supply dams, and floodplain restoration is undertaken instead of building taller levees (American Rivers 2017).

Green infrastructure solutions can be applied on different scales, from house or building to a whole landscape. On the small scale, they include rain gardens, permeable pavements, green roofs, infiltration planters, trees and tree boxes, green embankment and rainwater harvesting systems. At the largest scale, green infrastructure includes preservation and restoration of natural landscapes such as forests, floodplains and wetlands (American Rivers 2017).

Green infrastructure investments boost the economy, enhance community health and safety, and provide recreation, wildlife, and other benefits. These green solutions create good jobs in many sectors, including plumbing, landscaping, engineering, building and design. Green infrastructure also supports supply chains and the jobs connected with manufacturing of materials including roof membranes, rainwater harvesting systems, and permeable pavements. Many cities in Europe, North America and Asian developed countries are already embracing green infrastructure (American Rivers 2017).

3. Ministry of Water Resources and Meteorology

MOWRAM is responsible for the management of water resources, including river basin, sub-basins, watershed run-off, groundwater and aquifers, in collaboration with all concerned ministries (Article 10, Law on Water 2007). MOWRAM was established in 1999 by Kram (Royal Legislation) no. NS/RKM/0699/08, dated 23 June 1999. It is mandated to play a main coordination role for the RGC in project/program related water resources management and development.

At the national level, there are several main technical departments in MOWRAM, which play important roles in improving water management for development:

- Department of Water Resources Management and Conservation;
- Department of Meteorology;
- Department of Hydrology and River Work;
- Department of Irrigation and Drainage; and
- Department of Water Supplies and Sanitation.

Why is Green Infrastructure Important to Water Resource Management?

Nature works best: Rivers, streams, wetlands, floodplains, and forests provide a suite of critical services like clean water, shelter and flood protection, and should be viewed as essential and effective components of our water infrastructure. New York City, for example, has great quality tap water because the city invested in water protection by purchasing land around its Catskills reservoirs to ensure that polluted runoff from roads and lawns doesn't enter the water supply.

It is cost effective: Spending money wisely means investing in multi-purpose solutions that lower costs and provide more benefits. Using locally available resources like wetlands, trees, aquatic plants and other bio-textile materials are relatively cheap in comparison to conventional building materials and are suitable to local climate conditions.

It enhances community safety and enjoyment: Traditional infrastructure isn't designed to withstand increased floods and droughts associated with global warming, hence a modern approach to public health and safety protection and enhanced quality of life is necessary. Green solutions provide communities with the necessary security and flexibility. Green infrastructure can create green spaces and new parks for multipurpose activities like recreation and markets (American Rivers 2017).

MOWRAM's role is two-fold: coordination and implementation at the government ministry level, and managing line departments that represent MOWRAM at sub-national levels. Each province consists of one Provincial Department of MOWRAM (PDOWRAM).

3.1 POLICIES AND REGULATIONS

Since its creation, national managerial capacity has grown through technical assistance and experience, and additional financial and technical support has been mobilized. At institutional, i.e. policy, level Cambodia has adopted the following laws and regulations:

- Law on Water Resources Management (2007)
- Strategic Plan on Agriculture and Water (SAW) for 2006-2010 (2007) and 2009-2013 (2010)
- National Policy on Water Resources Management (2004)
- Participatory Irrigation Management and Development (PIMD)
- Prakas (proclamation) No. 306 for establishing community-based water management
- Circular No. 1 on the implementation of sustainable irrigation policy (2000)

- Sub-decrees on the procedure for establishing a FWUC (2015)
- River basin management (2015).

Other pending policies and regulations include (i) water licenses, and (ii) water quality.

A number of agencies and sub-agencies have roles related to the management of natural resources and the environment that are of importance to water resource management, and these perform or have the mandate to perform a coordinating role. These are:

- Ministry of Water Resources and Meteorology (MOWRAM)
- Ministry of Environment (MoE)
- Ministry of Agriculture, Forestry and Fisheries (MAFF)
- Ministry of Mine and Energy
- Ministry of Rural Development
- Tonle Sap Authority (reports its activities to the Council of Ministers, but falls under daily coordination of MOWRAM)
- Cambodia National Mekong Committee (CNMC)
- National Committee for Disaster Management (NCDM) (reporting to the Council of Ministers)
- National Committee for Subnational Democratic Development (NCDD) (reporting to Ministry of Interior and Council of Ministers).

MOWRAM coordinates and implements programs on climate risk management and the rehabilitation of small- and medium-scale irrigation schemes in the country, especially in the Tonle Sap Basin and Mekong. With support of the World Bank's Pilot Program for Climate Resilience (PPCR), MOWRAM implemented programs on the enhancement of flood and drought management in Tonle Spa Basin. These programs are implemented in collaboration with MAFF, MoE and the NCDM in selected provinces, and are intended to involve provincial, district and commune level stakeholders, including NGOs, water user associations and local community representatives.

3.2 MOWRAM's Climate Change Strategic Plan

According to MOWRAM's Climate Change Strategic Plan 2013-2017, the impacts of climate change on water in Cambodia include:

- **Water resources sector:** increased floods and droughts, changes in water supply and water quality, and increased competition for water. The irregular seasonal times of wet and dry months caused by climate change, especially during the last few decades, impacts on water resource management and development efforts. At the same time, there is an increased demand for water from emerging sectors, including industry, livestock, domestic use, and especially agriculture; coupled with seasons changing due to climate change, this creates many more social problems. Concurrent with global warming, Cambodia's overall temperature has increased, leading to water loss from evaporation. Groundwater requires recharging annually from rain water. Due to climate change impacting the amount of rain, the recharge rate is seriously reduced, leading to Cambodian farmers having insufficient groundwater for farming. It is worth noting that groundwater provides 3.1% of 4.5% current irrigation water, while the rest is provided by surface water (MOWRAM, 2008).

- **Reservoirs:** many reservoirs are gradually getting shallower due to sedimentation caused by deforestation of surrounding forested areas, which leads to reduced capacity for water storage.
- **Irrigation systems and hydraulic infrastructure:** irrigation systems and hydraulic infrastructure have not yet been modernized, or designed to consider climate change in almost any areas of the country. Floods and droughts impact on irrigation systems and hydraulic infrastructure. Significantly, floods have tremendous and negative impacts on irrigation systems located in low-lying areas.
- **Dams/weirs:** frequent floods destroy dams. Most of these are old (built in the 1960s and 1970s) and the impacts of climate change on them have not been considered.
- **Flood protection dykes (FPD):** during each flood, water overflows the FPDs and destroy the dykes. The potential impacts of climate change were not taken into account when the FPDs were designed. Moreover, FPDs are made from soil which is not strong structure to cope with the impact of severe floods.
- **Riverbanks and coastal areas:** the erosion of beaches/banks caused by floods and/or high speed waves brought on by climate change, impacts negatively on rural livelihoods, especially on farmers who are wholly dependent on limited land.

3.3 Hydrological Stations of Cambodia (Hydromap)

The hydro map below shows the hydrological stations within Cambodia. The stations were installed to collect real-time data on water levels of main rivers and streams, particularly along the Mekong River, the Tonle Sap River and the Tonle Sap Great Lake. In addition, real-time data on water levels assists with effective weather forecasting and preparation of appropriate emergency responses to disasters like floods. MOWRAM has a total of 131 stations around the country, but only 59 are operational. Of these, 47 stations are installed along the Mekong River and 12 on key tributaries in Cambodia.

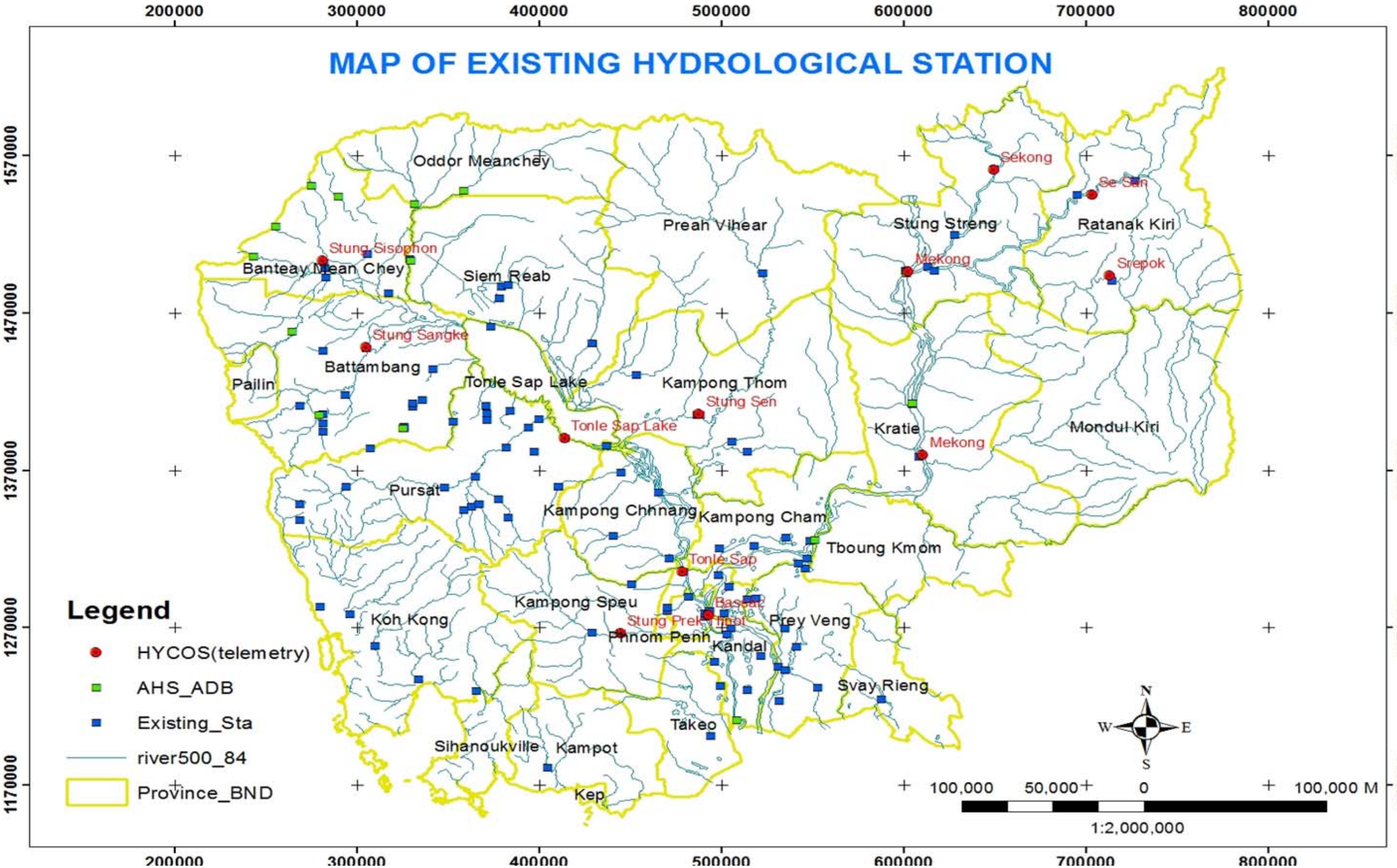


Figure 1. Hydrological stations in Cambodia

4. Water Resources Adaptation Guide

This **Water Resources Adaptation Guide**, prepared under the TA 8179 - CAM Mainstreaming Climate Resilience into Development Planning project, provides a systematic analysis of the most relevant information available on the local climate change adaptation approaches to manage water resources in a sustainable manner.

A set of 32 measures is selected for climate change adaptation in water resource management. They are divided into 3 sections:

- Sustainable management of surface water
- Sustainable management of groundwater
- Sustainable management of watersheds

The outline of the guide is as follows: part A gives an introduction to the guide; part B presents the 32 adaptation measures suitable for water resources management in Cambodia; and part C provides information on key players to promote green infrastructure in water resources management in Cambodia.

Each part is divided into subsections. Part A includes Section 1 – Introduction, Section 2 – The role of green infrastructure in water resources management, Section 3 – Ministry of Water Resources and Meteorology, Section 4 – Water Resources Adaptation Guide, and Section 5 – Adaptation measure matrix for water resources management. Part B includes Section 1 – Introduction, and Section 2 to Section 4 which presents the adaptation measures grouped into three categories as mentioned above. Part C includes Section 1 – Government, Section 2 – Farmer Water User Community, Section 3 – NGOs (civil society), and Section 4 – Private sector.

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

Information provided for each measure is presented as follows: (1) description – which describes the measure and its purpose/objectives; (2) the measure's contribution to climate resilience; (3) the strengths and benefits of the technology/approach; (4) limitations – limitations in use of the measure; and (5) supplementary sources of information – sources of more information on the measure. Further information is also provided on the application of the measure, specific to location and context.

5. Adaptation Measure Matrix for Water Resource Management

The matrix of adaptation measures for water resources shows the importance and multiple benefits of each measure to different river basins (ecozones) and water management needs in the sector. In addition, it details the usefulness of measures used individually, and applied in combination with others to policymakers and practitioners for ease of selecting the most appropriate measures for any circumstance. On the other hand, we need a combination of measures to cope with certain climate change induced impacts. The matrix is arranged into adaptation measures, river basin and water management needs. For water resource management and planning purposes, the surface water system in Cambodia is categorized according to the river basins as officially used by MOWRAM. The country is divided into four main basins:

1. Upper Mekong: covering Kampong Cham, Tboung Khmum, Kratie, Stung Treng, and the 3S rivers (Sesan, Sekong and Srepork) which can be classified into ecozones of plateau and mountainous region.
2. Tonle Sap River and Tonle Sap Great Lake: provinces surrounding the Great Lake. It is similar to the Tonle Sap region.
3. Lower Mekong River and delta: including the lower Mekong and the Tonle Bassac bordering Vietnam. It is similar to the delta.
4. Coastal zone: covering the four coastal provinces with watershed line. It is identical to the coastal region and, according to ecozone classification, is partly in mountainous region and plateau.

Below is the matrix of adaptation measures for water resource which provides the structure for describing the adaptation technologies listed in this guide.

Adaptation measure	Basin				Water management need																		
	Coast	Delta	Tonle Sap	Plateau & Mountain	Aquifers	Bore wells/ Dug wells	Bridges	Bridge abutments	Buildings	Canals	Coastline	Culverts & drains	Drainage	Dykes	Embankments	Farms	Floodgates	Houses	Markets	Reservoirs	Roads & footpaths	Stormwater outfall	Wastewater treatment plants
Biological geotextile	X			X			X	X		X	X	X	X	X	X		X					X	
Brush mattress	X			X			X			X		X		X	X		X					X	
Bioretention pond	X	X	X	X	X			X					X								X	X	X
Bioswale	X	X	X	X	X			X					X								X	X	X
Constructed wetland	X	X	X	X									X						X		X	X	X
Downspout planter	X	X	X	X					X									X	X				
Drainage corridor	X	X	X	X						X			X									X	
Field trenches	X	X	X	X						X		X	X	X		X						X	
Greywater recycling	X	X	X	X					X							X		X	X				X
Injection well	X	X	X	X	X	X										X				X			
Live crib wall	X			X			X			X			X	X	X						X		X
Live fascine	X			X			X			X			X	X	X						X		X
Live staking	X			X			X			X			X	X	X						X		X
Log terracing	X			X			X			X			X	X	X						X		X
Mangrove forest planting	X										X			X									
Palisade	X			X			X			X			X	X	X						X		X
Permeable paving	X		X	X	X				X				X						X	X	X		
Planting pit	X	X	X	X	X											X							
Plastic liner for ponds and reservoirs	X	X	X	X					X							X		X	X	X			
Rainwater harvesting (Land)	X	X	X	X					X							X		X	X	X			
Rainwater harvesting (Rooftop)	X	X	X	X	X	X			X							X		X	X	X			
Rain garden	X	X	X	X	X				X									X	X			X	
Recharge pit	X	X	X	X	X	X										X				X			
Soak pit	X	X	X	X	X	X										X				X			
Solar water pump	X	X	X	X												X		X	X				
Storm water tree pits	X		X	X	X				X				X						X		X		
Urban river terracing		X	X							X													X
Vegetated check dam	X	X	X	X	X	X						X	X	X		X							
Vegetated gabion	X			X				X		X		X		X	X		X					X	
Vegetated geotextile	X			X			X			X	X	X		X	X		X		X		X	X	
Vegetated revetment	X			X						X		X		X	X		X					X	
Vegetated riprap	X			X						X		X		X	X		X					X	
Vetiver grass coverage	X			X			X			X		X	X				X					X	

B ADAPTATION MEASURES

6. Introduction

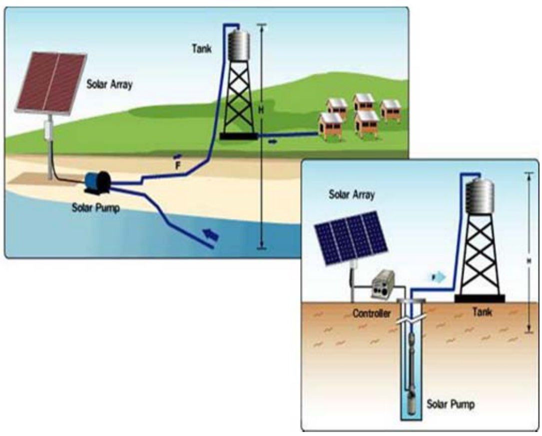
The adaptation measures in this guide can be promoted and built into sector policies and design standards, delivering the key objectives of the MOWRAM mandate. They are multi-use and can be applied in numerous water resources management contexts, and many times their applications overlap across sectors.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

7. Sustainable Management of Surface Water

A key aspect of increasing the climate resilience of water resources is sustainable management of surface water. Surface water plays an important role in supplying water for agricultural, industrial, commercial and domestic uses. The green infrastructure measures presented in this section can be applied to manage the risks of surface water pollution, riverbank erosion, and water shortage. Many can also be applied to manage groundwater and watersheds as presented in sections 3 and 4. As with green infrastructure on the whole, when possible, sustainable management of surface water measures are often most effective when used in combination to maximise benefits.

7.1 SOLAR-POWERED WATER PUMP

Application	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 available from collected sunlight. Solar water pumps are a low-cost and dependable method for providing water in situations where water resources are spread over long distances, power lines 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.



Strengths

- The operation of solar powered pumps is more economical mainly due to lower operation and maintenance costs.
- Solar pumps are useful where grid electricity is unavailable and alternative sources (in particular wind) do not provide sufficient energy.
- It has less environmental impact than pumps powered by internal combustion engines.
- May be especially useful in small-scale or community-based irrigation.

Limitations

- Potentially high capital costs (mainly for solar panels).
- Water storage is required for cloudy periods, lower output in cloudy weather.
- Must have good sun exposure between 9AM and 3PM.
- Repairs often require skilled technicians.

Sources

http://www.homepower.com/articles/solar-electricity/design-installation/solar-powered-water-pumping

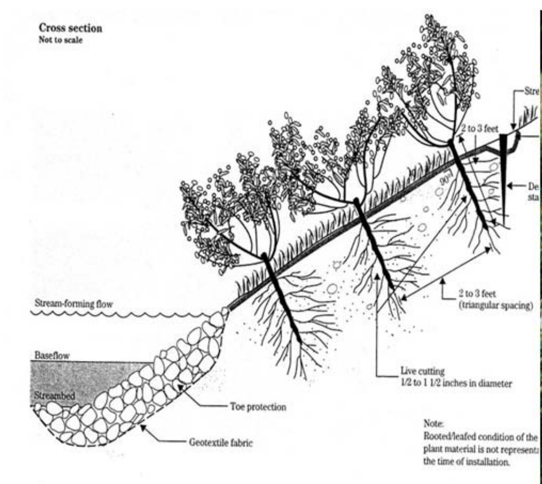
http://infohub.practicalaction.org/oknowledge/bitstream/11283/314192/1/535e1143-5804-4c58-b561-18590a000075.pdf

http://www.indiamart.com/eco-world-solar/solar-water-pump-system-agriculture-pump.html

http://www.solarsponsoring.com.au/benefits-of-solar-energy/solar-water-pumps/

7.2 LIVE STAKING

Application	Bridges, canals, drainage, dykes, embankments, roads, footpaths, wastewater treatment plants
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 above-ground brush. It also is 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 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 locally available 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.



Strengths

- 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.
- Create favourable conditions for natural colonization of vegetation from the surrounding plant community.
- Stabilize intervening areas between other soil bioengineering techniques.

Limitations

- 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.

Sources

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https://www.nswa.ab.ca/sites/default/files/Lives%20staking%20%26%20joint%20planting.pdf

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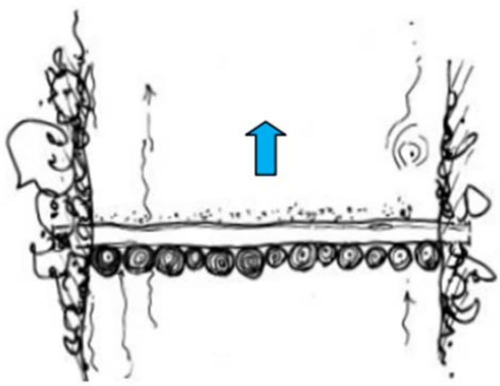
7.3 PALISADE

Application	Bridges, canals, drainage, dykes, embankments, roads, footpaths, wastewater treatment plants
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 slopes in gullies and tributaries, encourage deposition of sediments especially in fine soils, and form a strong barrier to reinforce the slope especially once cuttings have taken 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 locally available materials, they require less energy to produce, are far more sustainable, and can be applied quickly.



Strengths

- A large amount of material and labour is required.
- Traps material moving down the slope.
- Low-cost where materials are available on site.
- Quickly and easily built.
- Provides immediate protection.
- Usually grows well.
- Stabilises and reinforces slope.

Limitations

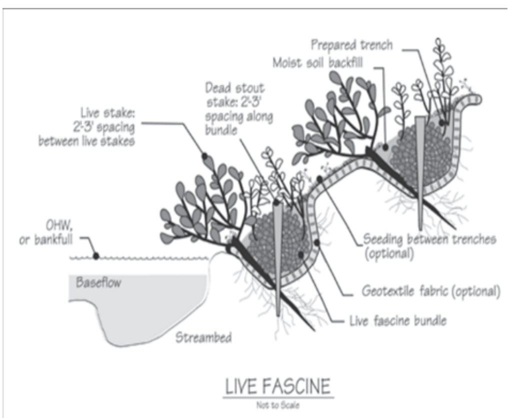
- Palisades are only effective up to 6m wide and 24m long.
- Availability of material for palisades might be restricted (long, straight poles).
- Only for restricted water and debris flow.

Sources

https://www.nswa.ab.ca/sites/default/files/Lives%20staking%20%26%20joint%20planting.pdf
http://www.cesvi.org/aaa-root/o/Erosion%20control_Tajikistan2013.pdf
http://lib.icimod.org/record/27708/files/Chapter%204%20Bioengineering.pdf

7.4 LIVE FASCINE

Application	Bridges, canals, drainage, dykes, embankments, roads, footpaths, wastewater treatment plants
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 crib walls. They can also be used to "soften" existing rock rip-rap, 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 stream banks to extreme climatic events.



Strengths

- Simple and requires little time to build and can be installed with little site disturbance.
- Can provide a living filter to intercept and absorb excess nutrients and pollutants before they reach the water.
- Provides immediate protection once installed.
- Requires no heavy machinery, which makes it a good option at remote, or inaccessible sites.
- Improves fisheries habitat, provides substrate for aquatic organisms, and improves water quality and aesthetics.
- Most effective when combined with live staking and riprap.

Limitations

- Should not be used in situations where they would experience rapid undercutting or on sites experiencing mass movement.
- The streambank should have a slope no steeper than 1:2.
- The bank needs to be composed of a material that can easily be trenched and that can hold moisture to support growing vegetation.
- Fairly labour intensive process.
- Should not be planted below base flow levels to prevent dying from submersion.
- Construction should occur during dormancy.

Sources

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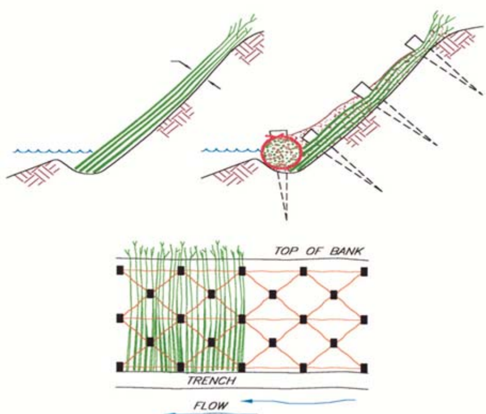
http://riparianhabitatrestoration.ca/575/livefascines.htm
http://www.ontariostreams.on.ca/PDF/OSRM/Tech9.pdf
https://www.wilderness.net/toolboxes/documents/restoration/pdf06232815dpi72pt09.pdf
http://www.bender-rekultivierungen.de/en/services/bioengineering/

7.5 BRUSH MATTRESS

Application	Bridges, canals, culverts and drains, dykes, embankments, floodgates, stormwater outflow
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 which will eventually root along the entire length of the structure and provide long-term vegetation stabilization. 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 locally available materials, it can be repaired quicker than traditional civil engineering structures.



Strengths

- Useful on steep, fast-flowing streambanks.
- Can restore riparian vegetation and habitat.
- Enhance conditions for colonization of native plants.
- Serves as habitat for birds, animals, insects and other organisms that in turn are fed upon by fish and other higher organisms.
- Provides shade to the stream - lowering water temperatures, offering protection from predators, and generally improving fish habitat.
- Very cost-effectiveness, using locally available materials and low-cost labour in comparison to more elaborate civil engineering works.

Limitations

- As brush mattresses use dormant cuttings, they must be installed during the non-growing season.
- Should be initiated in conjunction with a revegetation strategy as it is more difficult to establish supplementary vegetation once the mats become established.
- Not recommended for streambanks steeper than 2.5:1 nor should they be used on streambanks where mass wasting (movement) occurs.
- Must have a secure toe.
- Only effective on upper slopes, and large amount of live material required to cover bank.

Sources

http://projects.geosyntec.com/npsmanual/Fact%20Sheets/Brush%20Mattresses.pdf

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http://www.spa.usace.army.mil/Portals/16/docs/civilworks/regulatory/Stream%20Information%20and%20Management/ERDC%20Brush%20Mattresses.pdf

http://www.ernstseed.com/products/bioengineering/brush-mattresses-and-wattles-fascines/

7.6 LOG TERRACING

Application	Bridges, canals, drainage, dykes, embankments, roads, footpaths, wastewater treatment plants
Description	The log terracing technique uses alternating terraced logs staked in along steep slopes to stop surface erosion on eroding slopes, which is critical for successful revegetation efforts. Trees and shrubs are planted behind them. 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 to provide 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 locally available 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.

Strengths

- 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.
- Increases infiltration, adds roughness, reduces erosion, and helps retain small eroded soil on site.

Limitations

- Implementing log terracing is labour intensive and can pose possible safety hazards due to the use of logs on a slope.
- Heavy equipment required to place large logs.
- Their effect diminishes greatly on slopes steeper than 50 percent.

Sources

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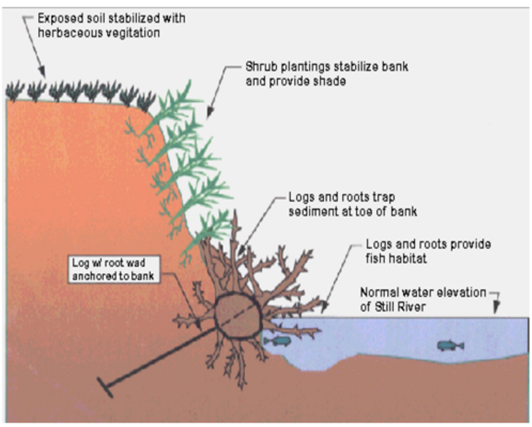
http://www.wsdot.wa.gov/publications/manuals/fulltext/M25-30/740.pdf

https://peaceofearthfarmalbany.wordpress.com/page/9/

http://www.northernmichiganstreams.org/sbeinfo.asp

7.7 VEGETATED REVETMENT

Application	Canals, culverts and drains, dykes, embankments, floodgates, stormwater outfall
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 water velocity, 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 stabilize the eroded or undercut bank until trees and shrubs become established to provide permanent protection. Tree revetments decrease erosion and slow the nearshore 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 streambanks 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.



Strengths

- Uses inexpensive and typically readily available materials.
- Can act as a natural sediment accumulator, enhancing certain habitats.
- Self-repairing.
- Protects both the toe of slope and bank from the erosive force of water.
- Lowers stream temperatures and decreases stream velocity.
- Provides habitat value both above and below the waterline for aquatic and other wildlife.

Limitations

- Incorporated vegetation 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.
- Should not be used near bridges or other structures where there is a potential for downstream damage if a revetment dislodges.
- If a revetment does not run the entire length of an eroding bank, the structure may be ineffective.

Sources

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http://projects.geosyntec.com/npsmanual/Fact%20Sheets/Tree%20Revetments.pdf

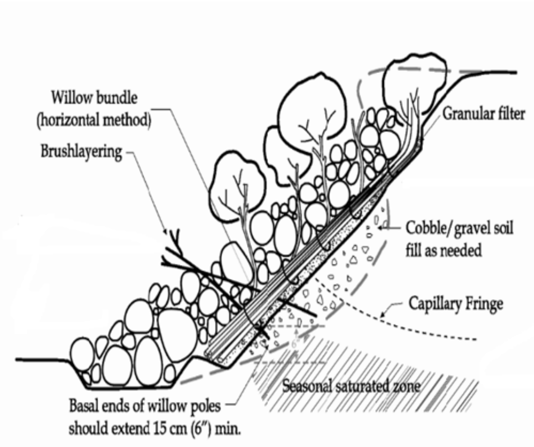
https://www.bookstore.ksre.ksu.edu/pubs/MF2750.pdf

http://www.salixrw.com/solution/river-rhiw-bank-protection/attachment/04-installing-a-live-brush-mattress-revetment-with-whole-tree-toe/

http://www.danbury.org/stillriver/tree1.htm

7.8 VEGETATED RIPRAP

Application	Canals, culverts and drains, dykes, embankments, floodgates, stormwater outfall
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 the development of root mass. In addition, it provides a more natural appearance to the installed rocks. Woody vegetation establishment will prevent soil loss (piping) from behind the structures and increase pull-out resistance. Five methods for construction 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 (an alternative source of food to agriculture), and supplying fodder for local livestock. 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.



Strengths

- Resists hydraulic forces, increases geotechnical stability, and prevents soil loss.
- Improves fish habitat by creating shade, cover and an input of small organic debris to the stream.
- Potential supply of fodder for animals.
- Provides shade and improves aesthetics.
- Roots, stems, and shoots help anchor rocks and resist 'plucking' and gouging by debris.

Limitations

- 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

http://www.terraerosion.com/VegetatedRiprap.htm

http://docs.trinitycounty.org/departments/Planning/PDF/Environ-IS/Monitoring%20Plan%20AppendixA.pdf

http://dnr.wi.gov/topic/Waterways/shoreline/erosioncontrol-vegetated.html

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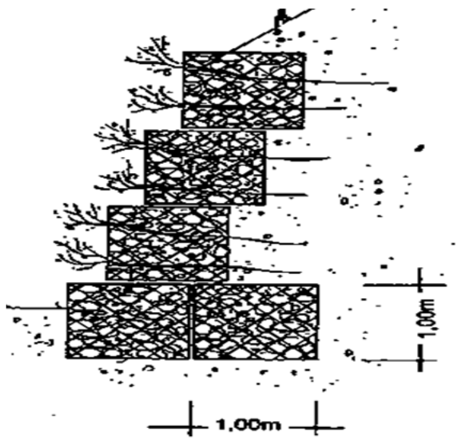
7.9 VEGETATED GABION

Application	Bridge abutments, canals, culverts and drains, dykes, embankments, floodgates, 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 rock. The vegetation layer of the structure is a geotextile with live cut branches placed in horizontal layers between the rock-filled gabion baskets which serves to hold soil and or rocky backfill in place until roots from live cuttings grow enough to serve that purpose. 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 erosion caused by floods or rainfall by stabilizing the base of steep slopes. Because they can be repaired using local labour and locally available 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.



Strengths

- Natural appearance and less visually intrusive than a structural treatment alone.
- Fast and simple construction. Can be installed without special skills or equipment.
- Allows for stabilization of steep slopes where live fascines and brush layers alone are inadequate.
- 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, used also for wet sites with fine soil material.
- Used for unstable slopes endangered by erosion, especially along streams or in debris areas.

Limitations

- Establishing vegetation after the construction of the gabion is difficult.

Sources

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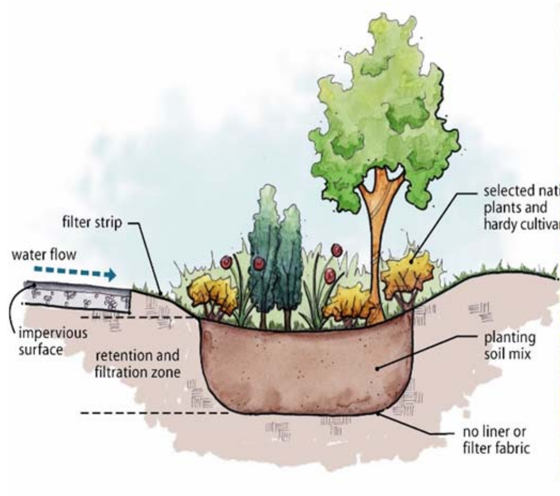
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.545.2505&rep=rep1&type=pdf
http://ponce.sdsu.edu/alamar_hydroecology_final_report_figure_03b.jpg
http://www.fao.org/3/a-y5576e/x0622e0s.htm

7.10 RAIN GARDEN

Application	Aquifers, buildings, houses, markets, stormwater outfall
Description	A rain garden is a small bioretention cell that cleans and reduces stormwater in volume once it enters the rain garden. Specially designed garden beds slow the velocity of stormwater runoff and give it more time to infiltrate. Runoff is collected and settle on the garden surface, then soak through the plants and soil layers before entering the groundwater system. Rubbish and sediment is trapped on the surface. Nutrients dissolved in the stormwater are used by the plants and toxins stick to the soil. Root systems enhance infiltration, maintain or even augment soil permeability, provide moisture redistribution, and sustain diverse microbial populations. Also, through the process of transpiration, rain garden plants return water vapour to the atmosphere. The soil and plant roots work together to naturally filter the water and remove pollutants. A rain garden improves water quality in nearby bodies of water and ensures that rainwater becomes available for plants as groundwater rather than being sent through stormwater drains straight out to sea.
Contribution to climate resilience	A rain garden cleans stormwater, thus improving water quality for nearby water bodies. This reduces demand for freshwater supplied by local water authorities. By slowing down water velocity, a rain garden also ensures that more water is absorbed into the ground (thus replenishing groundwater) rather than being drained out to sea. Improved management of water is one of the best ways to improve resilience to likely changes in climate



Strengths

- Improves water quality.
- Greywater can be used to enhance nearby wetlands.
- Reduces demand on municipally supplied fresh water.
- Less strain on water treatment plants.
- Provides water for groundwater recharge.
- Reduces cost and energy required to pump municipal water.
- Self-watering and easy to maintain.

Limitations

- Water should only pool for a maximum of a few hours to protect plant species and reduce mosquito concerns.

Sources

http://www.lowimpactdevelopment.org/raingarden_design/whatisaraingarden.htm

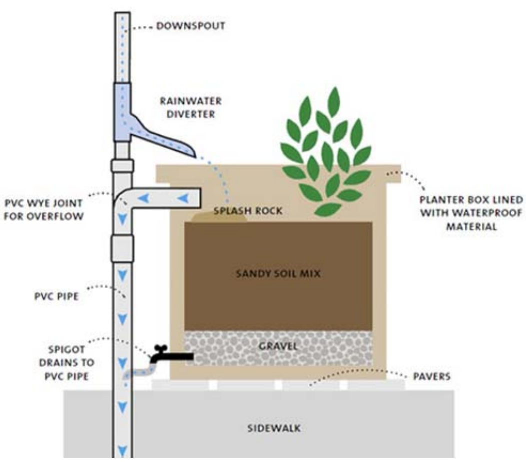
http://www.melbournewater.com.au/getinvolved/protecttheenvironment/raingardens/pages/what-is-a-raingarden.aspx

https://www.epa.gov/soakuptherain/rain-gardens

http://mother-natures-backyard.blogspot.com/2013/03/harvesting-rain-rain-gardens-and.html

7.11 DOWNSPOUT PLANTER

Application	Buildings, houses, markets
Description	A downspout planter is a decorative garden planter filled with gravel, soil and vegetation that utilizes rainfall from the roof as irrigation. It is placed along or at the end of a downspout to capture the water before it enters the sewer. Downspout planters range from very simple planters on the ground to one or more planters along the downspout. Rainfall is captured by the planter, slowing water down, and allowing for infiltration and the capture of pollutants. It can be constructed in many sizes and shapes, and with various materials, including concrete, brick, plastic, lumber or wood. A planter box will last longer if it is lined with plastic as the soil will tend to be moist and will rot much quicker than a normal planter. Plastic lumber is an option as it will last indefinitely. An overflow outlet is important as the planter will be close to the building and could cause moisture problems if the overflow is not directed away from the building.
Contribution to climate resilience	A downspout planter reduces the velocity and quantity of rainwater flow, thus reducing erosion and excessive drainage issues associated with storms and heavy rains. It also cleans the water which passes through it, reducing water pollution downstream. Improved management of water is one of the best ways to improve resilience to likely changes in climate.



Strengths

- Slows down the flow of water.
- Can act as a bio-filter, filtering sediment and pollutants as water infiltrates through the planter.
- Provides both stormwater retention and a reduction of stormwater flow during rain events.
- An attractive addition to a yard or patio.
- Particularly useful when space is limited.

Limitations

- An inline planter should be properly secured considering the weight of moist soil.
- If its location is inaccessible, low maintenance plants like grasses will work best.

Sources

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http://www.phillywatersheds.org/whats_in_it_for_you/residents/downspout-planters

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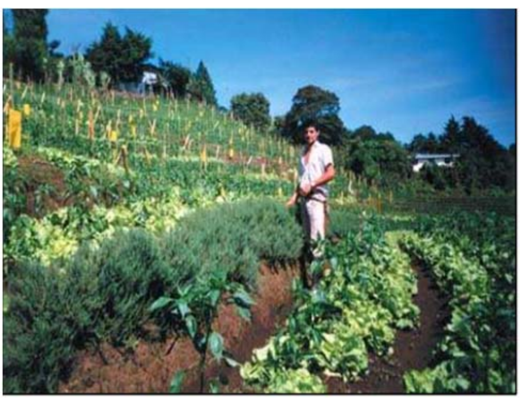
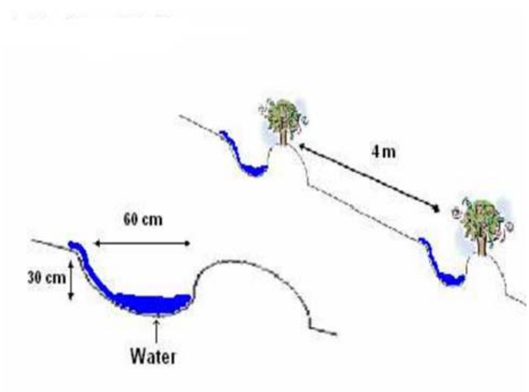
7.12 FIELD TRENCHES

Application	Canals, culverts and drains, drainage, dykes, farms, stormwater outfall
Description	Field trenches is extensive ploughing to the right angle of a field's slope. By breaking the slope of the ground, they increase precipitation harvesting and reduce the velocity of water runoff. Field trenches filter runoff water and hence reduce soil degradation 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 the continuous ones 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 locally available materials, they are highly adaptable to climatic events and help to increase the resilience of the agricultural systems they support.





Strengths

- Construction is simple, requiring basic tools 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.
- Comparably simple construction, requiring only basic construction material such as stakes, shovels, picks, crops, and possibly a tractor.
- Vegetation may stabilise the trench and therefore decreases the need for repairing.

Limitations

- Intense labour is needed 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 be reapplied to the field uphill the trench from time to time.

Sources

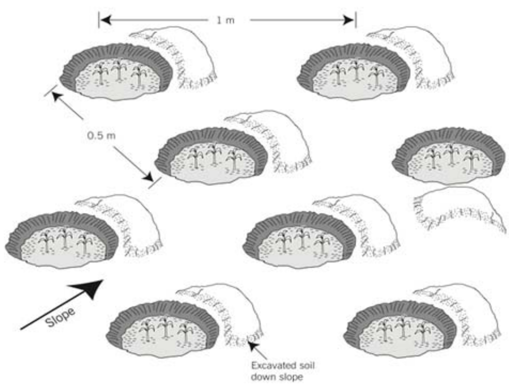
http://www.sswm.info/content/field-trenches

http://www.sswm.info/sites/default/files/reference_attachments/MALESU%202007%20Green%20Water%20Management%20Handbook.pdf

http://www.bebuffered.com/downloads/sussman_contour_trenches.pdf

7.13 PLANTING PIT

Application	Aquifers, farms
Description	Planting pits is 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 used for crops planted in close proximity. To further increase crop production, organic matter (such as compost or manure) can be placed in the pits as fertilizer. 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 suitable to semi-arid areas for annual and perennial crops (such as sorghum, maize, sweet potatoes and bananas).
Contribution to climate resilience	Planted pits prevent water run-off, thus reducing erosion from heavy rainfall. Collected water is used to irrigate nearby crops, reducing dependence on other water sources.



Strengths

- Simple implementation and maintenance.
- No equipment costs arise, because digging can be done with common and available tools.
- Weeding is not necessary, because vegetation growth is unlikely to occur on the degraded soil between the pits.
- Increased infiltration leads to soil regeneration.
- The design of planting pits is very flexible.
- The soil does not need to be deep or even.
- Due to the manure placed in the pits, termites can be attracted, transporting further nutrients from deeper soils to the top layers.

Limitations

- Labour intensive.
- During very wet seasons, water logging is possible. Organic debris placed in the pits may help to soak up excess water.
- Already shallow soil gets even thinner where the pits are dug. This may require planting on the top of the ridges.
- Digging the pits should be done during the dry season, so that they are ready when the rainy season starts.
- In the second year of implementation, new pits need to be dug in order to retain soil fertility.

Sources

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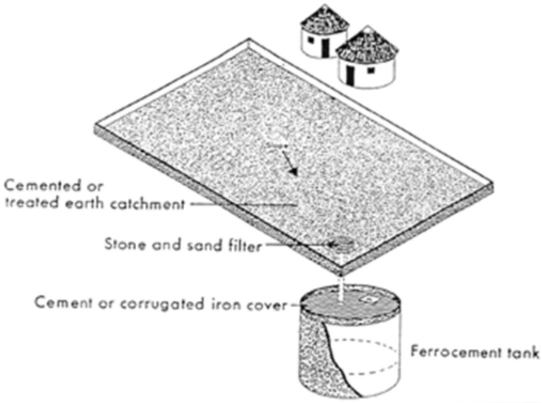
7.14 RAINWATER HARVESTING (LAND)

Application	Aquifers, bore well/ dug well, buildings, farms, houses, markets, reservoirs
Description	Rainwater harvesting with a land surface catchment is a technique that provides more opportunity for collecting rainwater and stormwater from a larger surface catchment area in comparison to a rooftop catchment technique. The land surface catchment technique varies from small scale to large scale reservoir rain harvesting systems depending on the geographic area and engineering design techniques. It can be designed with low cost earthen dams, dykes and canals to collect and storage the water. The dams are constructed at the lower part of the catchment or reservoir areas to retain the flows of small creeks and streams and surface water runoff in the storage reservoir system. The sluice gate of the canal is an important component of the system. It helps to retain the water, and discharge it if overflowing in order to manage flooding downstream and upstream in the catchment. The harvested water can be used as a water resource for agricultural purposes, livestock, and domestic use with proper treatment. It can also be used as drinking water, longer-term storage and to recharge bore wells or dug wells and groundwater.
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 store water during heavy rainfall in the wet season and reduce scarcity during the dry season - both events likely to become more severe with climate change. Rainwater harvesting ponds are particularly suited to households which cannot install rainwater tanks due to sloping land or geographical isolation.



Strengths

- Provides an important water resource for agricultural and domestic uses.
- Recharges groundwater.
- Recharges bore wells/dug wells.
- Maintains soil moisture of catchment area.
- Provides an independent water supply for regions with water restrictions or when there is drought.
- Manages flooding, particularly in downstream catchment area.

Limitations

- Rainwater harvesting systems require regular maintenance. They can become breeding grounds for rodents, mosquitoes, algae growth, insects and lizards if they are not properly maintained.
- If used for agricultural or domestic purposes, a possibility of high rates of water loss due to infiltration into the ground can be a problem.
- Not having good rainfall makes the system less cost-effective.

Sources

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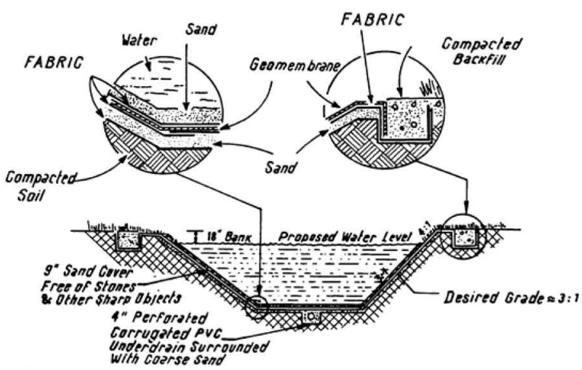
7.15 PLASTIC LINER FOR PONDS AND RESERVOIRS

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 punctures and tears. Custom engineered fabrication and sizes up to an acre are available to minimize in-field seaming.
Contribution to climate resilience	Plastic liners increase 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.



Strengths

- Improves water storage of ponds and reservoirs, and prevents pollution of groundwater.
- Protect 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.

Limitations

- 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, it is critical to get liner measurements correct.
- 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.

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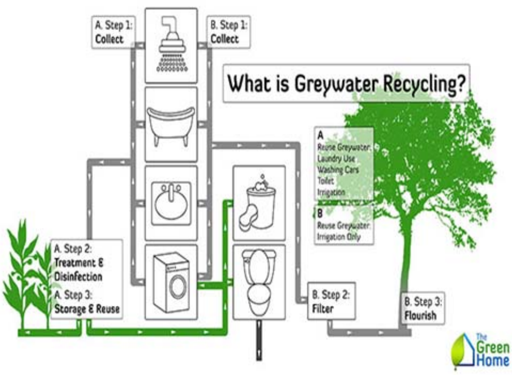
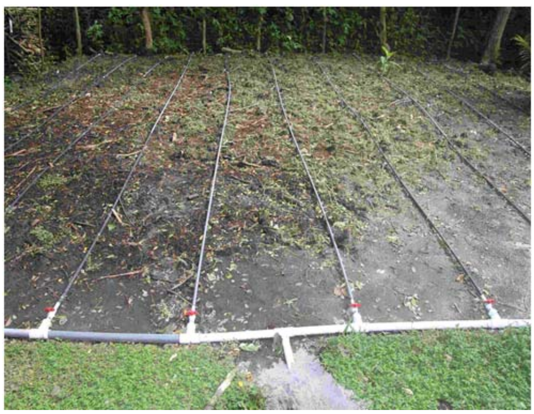
7.16 GREY WATER RECYCLING

Application	Buildings, farms, houses, markets, wastewater treatment plants
Description	Greywater recycling systems collect the water from sinks, showers, and baths. Using state-of-the-art filtration, the system cleans the water and plumbs it back into toilets, washing machines, and outdoor taps. The easiest way to use greywater is to pipe it directly outside and use it to water decorative plants or fruit trees, or to clean pavements, cars, and dust. Greywater recycling systems have been successfully adapted for 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 increases the availability of fresh water 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 fresh water. Improved water management is one of the best ways to improve climate resilience.





Strengths

- Keeps dirty water from polluting sensitive ecosystems.
- Greywater can be used to enhance nearby wetlands.
- Reduces demand on municipally supplied fresh water.
- Reduces strain on water treatment plants.
- Provides water for groundwater recharge.
- Reduces cost and energy required to pump municipal water.

Limitations

- Greywater recycling produces water for non-potable uses. Greywater can be used for irrigation, but it should not touch edible parts of the plant.
- Greywater cannot be stored for more than 24 hours.
- Contact with greywater should be minimized.
- Greywater should infiltrate into the ground, and must not be allowed to pool up or run off as it can provides mosquito breeding grounds.

Sources

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7.17 BIORETENTION POND

Application	Aquifers, bridge abutments, drainage, roads, footpaths, stormwater outfall, wastewater treatment plants
Description	A bioretention pond is a shallow planted depression designed to retain or detain stormwater before it is infiltrated or discharged downstream. The primary component is a filter bed, which has a mixture of sand, soil, and organic material as the filtering media with a surface mulch layer. During storms, surface runoff is directed into shallow, landscaped depressions as sheet flow or concentrated flow. It temporarily ponds 6-12 inches above the mulch layer and then rapidly filters through the bed. The depressions incorporate many of the pollutant removal mechanisms that operate in a forested ecosystem such as microbial soil processes, infiltration, evapotranspiration and plants. They create an environment for runoff reduction, filtration, biological uptake, and microbial activity, and provide high pollutant removal. Depending on the design, they can provide retention or detention of runoff water, and will trap and remove suspended solids and filter or absorb pollutants to soil and plant material. Bioretention ponds can be included in the designs for yards, commercial developments, parking lot islands, and roadways.
Contribution to climate resilience	A bioretention pond detains stormwater before it is infiltrated or discharged downstream, thus improving water quality (by removing pollutants) and reducing erosion and other damage associated with runoff. It thus reduces the negative impacts of heavier rainfall and storms, which are expected to increase (in the wet season) with climate change.

Strengths

- Pollutant removal for stormwater runoff.
- Provides stormwater peak flow and volume control as well as water quality control where stormwater infiltration is used.
- Reduces temperature impacts of runoff.
- Can be applied in almost any soils or topography.
- Provide aesthetic values.

Limitations

- Bioretention areas should only be used on small sites (i.e., five acres or less) as larger ponds tend to clog.
- Should be separated from the water table to ensure that the groundwater never intersects with the bottom of the bioretention area, which prevents possible groundwater contamination and practice failure.

Sources

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7.18 BIOSWALE

Application	Aquifers, bridge abutments, drainage, roads, footpaths, stormwater outfall, wastewater treatment plants
Description	Bioswales are stormwater runoff conveyance systems that collect, infiltrate and treat stormwater runoff before releasing it to the watershed or storm sewer. They are linear ditches filled with vegetation, compost and/or riprap. The water flow path, along with the wide and shallow ditch, is designed to maximize the time water spends in the swale, which aids the trapping of pollutants and silt. The vegetation reduces water velocity, allowing it to accumulate in a bioswale, and filters suspended sediments. Microbes in the soil digest organic nutrients. The water then moves to another filtration level made of sand or rocks. If bioswales are constructed on porous soils, the stormwater detained in the trenches can infiltrate into the ground below. This allows the rainwater to recharge the groundwater below rather being flushed into the sewer system. Bioswales may be designed to contain check dams that facilitate pond formation, further increasing infiltration and decreasing stormwater flow.
Contribution to climate resilience	Bioswales detain stormwater before it is infiltrated or discharged downstream, thus improving water quality (by removing pollutants) and reducing erosion and other damage associated with runoff. They thus reduce the negative impacts of heavier rainfall and storms, which are expected to increase (in the wet season) with climate change.

Strengths

- Traps and breaks down common pollutants.
- Improves water quality in surrounding waterbodies using soil, vegetation and microbes.
- Reduces stormwater runoff and increases infiltration and groundwater recharge.
- Increases green space and aesthetic appeal.
- Provides habitat for aquatic and other wildlife.
- Can be easily retrofitted during any landscape modification or parking lot/street resurfacing.
- Construction and maintenance costs are often lower than those of conventional systems.

Limitations

- A bioswale is primarily a conveyance system and must be designed to transport water of a specific storm severity without flooding.
- Regular inspection of bioswales should be conducted to identify signs of erosion, accumulation of debris around structures and signs of excessive sedimentation.
- Should not be installed in areas with high water tables where groundwater reaches the bottom of the swale.
- Impractical for areas with very flat grades or steep slopes.

Sources

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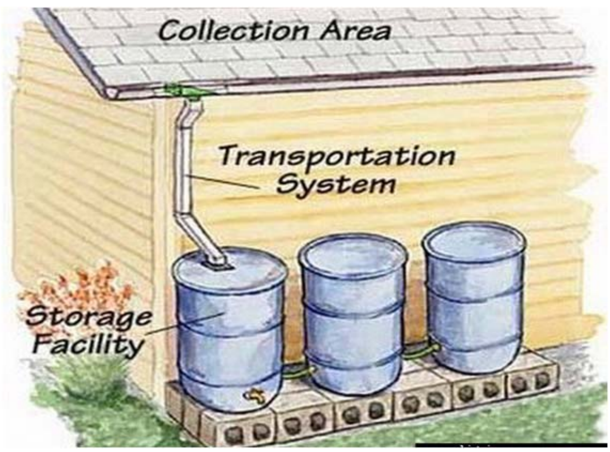
8. Sustainable Management of Groundwater

Groundwater is often withdrawn for agricultural, municipal, and industrial use by constructing and operating extraction wells. Groundwater is often cheaper, more convenient and less vulnerable to pollution than surface water. Therefore, it is commonly used for public water supplies. This often leads to overexploitation of groundwater, lowering the groundwater-table and resulting in reduced quantities of available groundwater. Polluted groundwater is less visible, but more difficult to treat than surface water pollution. Groundwater pollution poses serious threats to human health and ecosystems. Groundwater recharge and pollution control, therefore, is essential. As with the measures described in section 7, many of the measures in this section can also be used to manage surface water and watersheds. At the same time, measures such as greywater recycling, bioretention ponds and bioswale can help with groundwater management. To maximise benefits, measures are best used in combination whenever possible.

8.1 RAINWATER HARVESTING (ROOFTOP)

Application	Aquifers, bore wells/dug wells, buildings, farms, houses, markets, and reservoirs
Description	Rainwater harvesting from a rooftop is one of the techniques to collect rainwater from surfaces on which rain falls, filtering it and storing it for multiple uses. The harvested water can be used for gardens, livestock, irrigation, domestic use after proper treatment, and indoor heating for houses. It can also be used as drinking water, to recharge groundwater and bore and dug wells and can be stored relatively long-term. The main components of a simple roof water collection system are the roof catchment area, conveyance system or gutter and piping connected to a container (jar, pot or tank).
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.



Strengths

- Can be diverted to recharge groundwater.
- Simple technologies for locals to implement, and 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 roof catchments is usually of acceptable quality for domestic purposes.
- Reduces flow of pollutants to surface water.
- Serves as a backup water supply during emergencies and natural disasters and mitigates flooding of low-lying areas.
- Provides an independent water supply.

Limitations

- The rooftops should be constructed of chemically inert materials such as wood, tiles, tin, aluminium, or fiberglass, and cleaned regularly to avoid adverse effects on water quality.
- Unpredictable rainfall might pose a problem.
- Rainwater harvesting systems require regular maintenance. They can become a breeding ground for rodents, mosquitoes, algae, insects and lizards if not properly maintained.

Sources

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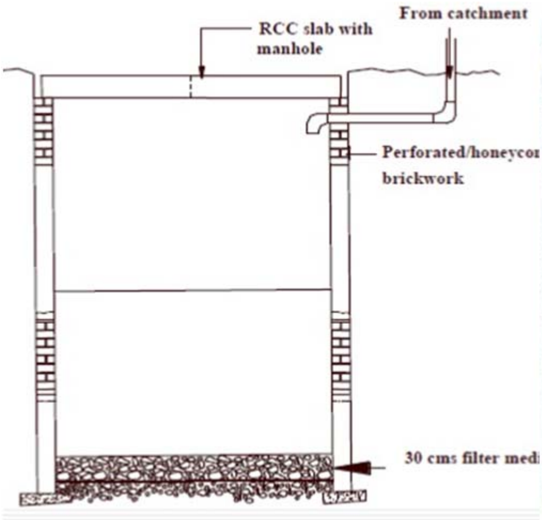
8.2 RECHARGE PIT

Application	Aquifers, bore well, dug well, farms, reservoirs
Description	Recharge pits are small pits of any shape (rectangular, square or circular) constructed with brick or stone masonry walls with weep holes at regular intervals. It is located at the lowest point of a catchment, and rainwater flowing overland is directed into it. A casing pipe with small holes is covered with nylon mesh, before filling the filter material. The top of pit can be covered with perforated covers. The bottom of pit should be filled with filter material. The capacity of the pit can be designed on the basis of catchment area, rainfall intensity and recharge rate of the soil. Usually, the dimensions of the pit are 1-2 m wide and 2-3 m deep depending on the depth of pervious strata. The water passes through the filter material and clear water enters the bore well and recharges underground aquifers. These pits are suitable to recharge bore wells and shallow aquifers, increase soil moisture and for use by small households.
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 (scenarios 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.



Strengths

- Allows rainwater to replenish groundwater.
- Can be built to recharge a bore well or to encourage water infiltration.
- Can be totally invisible when completed.
- Constructed with locally available materials.
- Low cost and easily maintained by local people.

Limitations

- The 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.
- Care must be taken to never let polluted water infiltrate groundwater.

Sources

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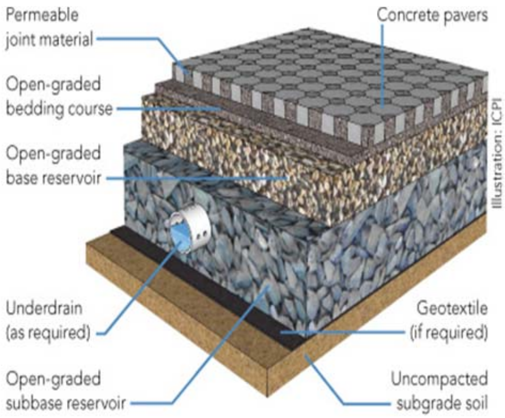
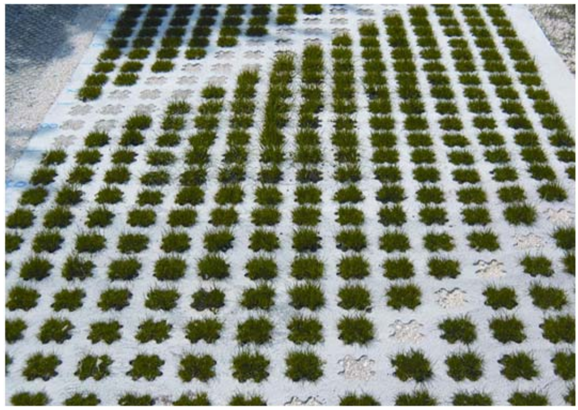
8.3 PERMEABLE PAVING

Application	Aquifers, buildings, drainage systems, markets, reservoirs, roads and footpaths
Description	Permeable paving is a range of sustainable materials and techniques that allow the movement of stormwater through the surface of paving into the soil below. It may be constructed from pervious concrete, porous asphalt, permeable interlocking pavers, and several other materials. They function similarly to sand filters, filtering the water by forcing it to pass through different aggregate sizes and filter fabric. The spaces among the aggregates store water and enable infiltration into the soil subgrade rather than generating surface runoff. In addition, permeable paving surfaces trap and break down suspended solids, preventing pollutants from entering water and soil underlying the roadway, or to be carried to surface waters. They allow for water seepage to recharge groundwater while reducing peak flows and flooding. Permeable pavers are carefully laid piece by piece after site preparation, which includes excavating the area and then installing a layer of gravel. A geotextile fabric is then laid over the surface, followed by a layer of sand. The paver units are then installed by hand or with special machinery. The holes or voids are filled with washed gravel, sand, pea gravel or soil.
Contribution to climate resilience	By reducing surface run-off, permeable pavers contribute to groundwater recharge and reduce flood flows. This increases the level of water in the aquifer for use in the dry season, increasing communities' resilience to droughts that are likely to get worse with climate change.





Strengths

- Increases road safety and durability by increasing skid resistance, preventing water splash and spray from passing vehicles, and reducing noise.
- Reduces flooding during storm events.
- Provides urban trees rooting space to grow.
- Recharges underlying aquifers.
- Helps prevent stream erosion problems.
- Improves water quality by capturing pollutants and reducing the pollutant load in local waterways.

Limitations

- Permeable paving is only suitable in light vehicle traffic areas such as parking lots, road shoulders, sidewalks, and driveways.
- Should not be applied when runoff sources are highly contaminated, due to groundwater contamination risks.

Sources

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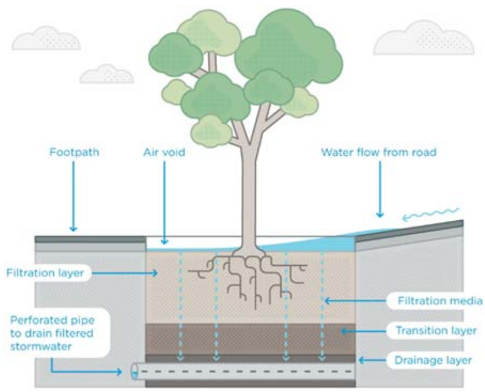
8.4 STORMWATER TREE PITS

Application	Aquifers, buildings, drainage, markets, roads and footpaths
Description	Stormwater tree pits are similar to traditional street tree pits except they are modified to have bigger growing space, are interconnected through an underground structure, collect and store stormwater in the empty spaces between the stones, and treat stormwater runoff using bioretention. Bioretention systems collect and filter stormwater through soils and plant roots, where pollutants are removed via filtration and absorption. The underground structure is a continuous soil trench underneath the pavement connecting individual tree pits to increase the benefits of the system. Treated stormwater is then slowly infiltrated into the ground or, if infiltration is not appropriate, discharged into a traditional stormwater drainage system.
Contribution to climate resilience	By reducing surface run-off, stormwater tree pits contribute to groundwater recharge and reduce flood flows. This approach ensures that there is more water in the aquifer for use in the dry season, increasing communities' resilience to drought that are likely to get worse with climate change.



Strengths

- Reduces stormwater runoff volume, flow rate and temperature.
- Increases groundwater infiltration and recharge.
- Removes sediments and pollutants from stormwater runoff, improving quality of local surface water.
- Improves aesthetic appeal of streets and neighbourhoods.
- Provides habitat for trees and wildlife.
- Requires limited space and is simple to install.

Limitations

- Stormwater tree pits generally capture and treat stormwater runoff from small, frequent storms but are not designed to capture all runoff from large storms or extended periods of rainfall.
- Not suitable to low locations.
- Soil mixes containing clay or silt are unsuitable as they do not allow good drainage.

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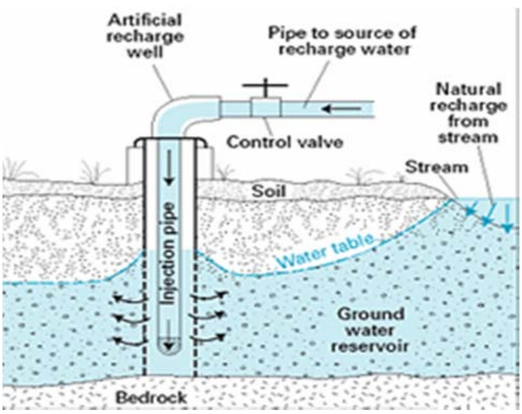
8.5 INJECTION WELL

Application	Aquifers, bore wells, dug wells, farms, reservoirs
Description	An injection (recharge) well is a device that places fluid deep underground into porous rock formations, such as sandstone or limestone, or into or below the shallow soil layer. Its flow is the reverse of a pumping well, but its construction should be the same. It is used to replenish groundwater resources when aquifers are located at greater depth and confined by materials of low permeability by directly discharging water into deep water-bearing zones. It can be cased with the material covering the aquifer. If this material is unconsolidated, a screen can be placed in the well in the zone of injection. It is particularly useful for aquifers with a long retention time; in areas where land is scarce; in areas where water and groundwater resources are heavily utilised; where acute problems with dropping watersheds, soil salinization or water scarcity are experiences; and for adding freshwater to coastal aquifers experiencing saltwater intrusion in coastal areas.
Contribution to climate resilience	Injection wells recharge groundwater reservoirs with surface water, thus making use of increased rainfall in the wet season and mitigating water shortages during the dry season. Making use of surface water also reduces runoff and erosion. This approach ensures that there is more water in the aquifer for use in the dry season, increasing communities' resilience to drought that are likely to get worse with climate change.



Strengths

- May provide a "drought-pool" water supply (from groundwater).
- Technology is easy to understand and operate.
- Collects water during wet season for use in dry season, when demand is highest.
- Surface water runoff is controlled due to aquifer recharge, resulting in less sedimentation problems.
- Recharge with less-saline surface water or treated effluents improve the quality of saline aquifers, facilitating the use of the water for agriculture and livestock.

Limitations

- Unless significant volumes can be injected into an aquifer, groundwater recharge may not be economically feasible.
- Discharge of nutrients and micro-pollutants may negatively affect the receiving soil and the aquifer.
- Potential groundwater contamination from injected surface water runoff, especially from agricultural fields and road surfaces.
- Recharge can degrade the aquifer unless quality control of the injected water is adequate.

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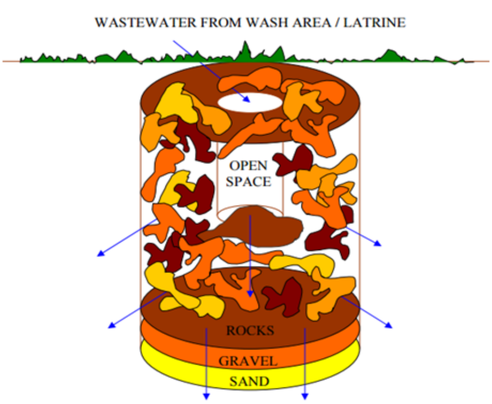
8.6 SOAK PIT

Application	Aquifers, bore wells, dug wells, farms, reservoirs
Description	A soak pit, also known as a soak-away or leach pit, is a covered, porous-walled chamber that allows water to slowly soak into the ground and thereby recharge groundwater. As wastewater percolates through the soil from the soak pit, small particles are filtered out by the soil matrix and organics are digested by microorganisms. 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 will 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.



Strengths

- Can be built and repaired with locally available materials.
- Simple technique to apply for all users.
- Small land area is required.
- Low capital and operating costs.
- Recharges groundwater bodies.
- Cost-efficient opportunity for partial treatment of waste- grey- or stormwater from a primary treatment.
- Odourless and not visible.

Limitations

- Sub-soil layers should be water permeable in order to avoid fast saturation.
- High volumes of daily discharged effluents should be avoided.
- Should be kept away from high-traffic areas.
- Should be located a safe distance from a drinking water source (more than 30 m).
- Should never be less than 2 m above the groundwater table.
- Not suitable for raw sewage. Primary treatment is required to prevent clogging.

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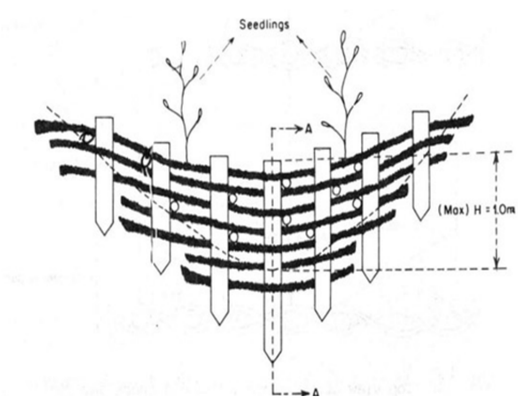
8.7 VEGETATED CHECK DAM

Application	Aquifers, bore wells, dug wells, culverts and drains, dykes, farms
Description	A check dam (also called gully plug) is a small, temporary or permanent dam built across a drainage ditch, swale, or channel to lower run-off speed. By reducing the original gradient of the gully channel, erosion and gully erosion are prevented and sediments and pollutants settle. Furthermore, it allows groundwater recharge and possibly retains soil moisture due to infiltration. It can be built from wooden 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 stones 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 to construct a gully plug.
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 constructed by labour and materials available locally, they require less energy to produce, are far more sustainable, and can often be applied in a quicker timeframe than traditional civil engineering works.



Strengths

- Vegetation patterns change runoff peaks and prevent soil loss.
- Water speed is slowed down, which reduces erosion and prevents unwanted gullies forming during a flood.
- No trench design required, existing gully drainage pattern are used.
- Can assist recharge of groundwater and shallow wells.
- Can reduce salinity in groundwater.
- Cost effective – dams can be constructed with locally available materials.

Limitations

- They have to be inspected and maintained regularly.
- 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.
- Infiltration rates can be slow due to silt build-up.
- If designed incorrectly, it may block fish passage.
- When only focussing on gully plug construction, the main cause of gully development is missed.
- Some expert knowledge is required to construct the correct check dam.

Sources

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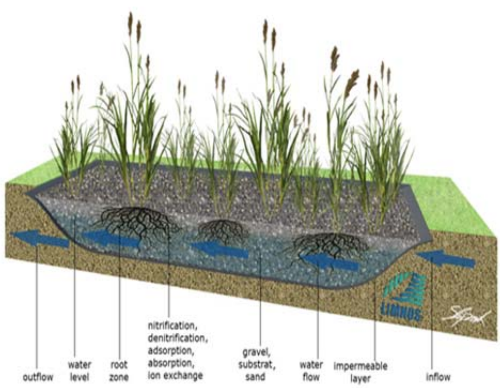
9. Sustainable Management of Watersheds

All activities that occur within a watershed will somehow affect that watershed's natural resources and water quality. Pollution from surface water runoff, groundwater depletion and soil erosion are some of the issues damaging the health of the watershed. The impacts of climate change are increasingly impairing the management of watersheds through slope erosion, more frequent and more intense floods, and soil loss. Enhancing the sustainable management of watersheds through the use of green infrastructure is critical. Many measures presented in previous sections are applicable to this section, and vice versa. The measures presented here are also best used in combination, when possible, to maximise the available opportunities and benefits.

9.1 CONSTRUCTED WETLAND

Application	Drainage systems, markets, roads and footpaths, stormwater outfall, wastewater treatment plants
Description	A constructed wetland is an artificial wetland consisting of shallow ponds or channels where aquatic plants have been planted. It is created to emulate the features of a natural wetland, acting as biofilter or removing sediments and pollutants such as heavy metals 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 people, livestock and wildlife as a source of water during drought.



Strengths

- Cost-effective water treatment.
- May also serve as a habitat for native and migratory wildlife.
- Improves water quality.
- Aesthetically pleasing.
- Offers flood protection, drought relief and opportunities for recreation.

Limitations

- Complex to design and requires on-going management.
- Should be located on the contour with drainage directed away from the system to avoid surface water inflow causing overloading problems. A barrier to sediment, such as rock landscaping or sod, is needed to minimize erosion and wetland cell problems.
- Knowledge of the operation of a natural wetland is required to control the operation and efficiency of a constructed wetland.
- Generally requires larger land areas than conventional wastewater treatment systems.

Sources

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9.2 MANGROVE FOREST PLANTING

Application	Coastlines, dykes
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 salt water immersion and wave action. The dense root systems of mangrove forests slow the flow of water over the soil surface and traps sediments flowing down rivers and off the land. This helps stabilise the coastline and prevents erosion due to waves and storms. By filtering out sediments, the forests also protect coral reefs and seagrass meadows from being smothered in sediment. Mangroves reduce the height and energy of wind and swell waves passing through them, reducing the danger of sediment erosion and damage to structures such as dikes and sea walls.
Contribution to climate resilience	Mangroves increase the resilience of coastal areas and communities by absorbing wave energy, protecting shorelines from erosion, and reducing damage caused by floods, exceptional tides, storms, typhoons and tsunamis. They also contribute to climate change mitigation by sequestering and storing carbon in biomass above and below ground, and in 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 coastal land by offering more resilient land management options instead of intensive agriculture.

Strengths

- Reduces damage from storms and tsunamis.
- Provides many timber and plant products. Mangrove wood is resistant to rot and insects and can be used for construction material and fuel, medicinal plants occur in mangrove ecosystems and leaves are fodder for animals.
- Protects shorelines from erosion.
- Serves as valuable nursery areas for a large variety of fish, crab, shrimp, and mollusc species.
- Supports threatened and endangered species.
- Can be a tourism attraction.
- Acts as carbon sink and sequestration.

Limitations

- Mangroves are under threat from many development pressures, including overharvesting, conversion for alternative uses (urban, agriculture, aquaculture) and infrastructure development.
- Mangroves can be impacted by measures taken quite far away from them.
- Once destroyed, restoring a mangrove forest with a full complement of biodiversity is a complex and long-term process.

Sources

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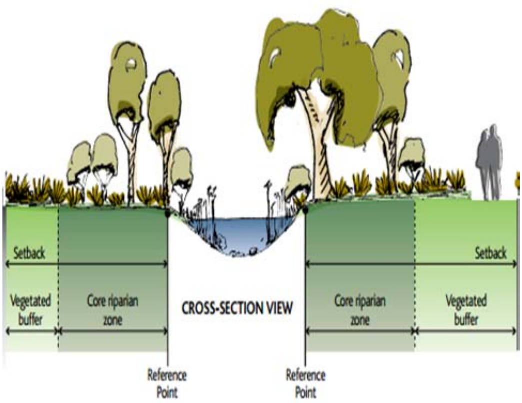
9.3 DRAINAGE CORRIDOR

Application	Canals, drainage, stormwater outfall
Description	A drainage corridor is a waterway and its surrounding area designed for multipurpose use within an urban context. Creating natural drainage corridors normally involves converting a ditch or storm drain into a natural creek flowing within a multipurpose corridor or, by rehabilitating and enhancing natural creeks and streams. They greatly reduce the number of drainpipes and other costly technologies required to manage stormwater runoff, and reduce flood management costs overall. Stormwater is collected in a traditional pit and pipe network within the road reserves. The pit and pipe network conveys flows to the drainage corridor, where wetland conditions treat runoff before discharging into the natural watercourse.
Contribution to climate resilience	Drainage corridors improve the management of stormwater runoff in urban areas, thus reducing the impacts of flooding. They improve water quality by treating the runoff before it is discharged into the natural watercourse. This approach helps to increase resilience to potentially damaging floods, which are expected to become more common as climate changes.



Strengths

- Improves drainage during storms.
- Reduces flooding.
- Natural drainage corridors help direct stormwater flows, thus reducing flooding in built and residential areas.
- Natural stormwater and pollution filtration.
- Increased habitat for plants and animals.
- Improves flow, which reduces stagnant water and associated odour and disease vectors.

Limitations

- Natural drainage corridors require sufficient land allocation.
- Must be recognised as a legitimate land use that needs to be appropriately considered during the planning of new urban developments and the redevelopment of existing urban areas.

Sources

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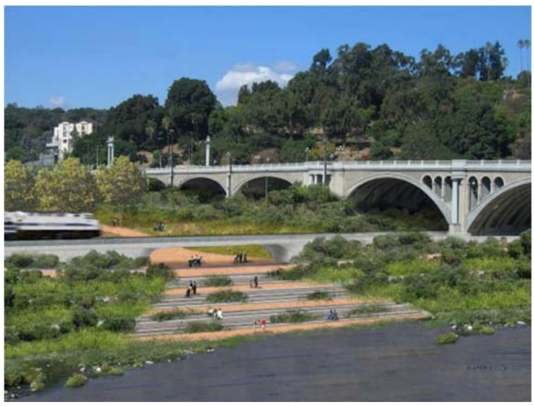
9.4 URBAN RIVER TERRACING

Application	Canals, wastewater treatment plants
Description	The main objectives of urban river terracing are flood protection, master landscaping, and the improvement of environmental conditions. The philosophy is to move from flood resistance to flood accommodation. In a stream area, the flood plain is widened and deepened, allowing it to fill during rain events and preventing storm water from flooding urban areas. Between heavy rain events, the floodplain is made available as a park and green space for local residents. Secondary channels are built parallel to the main stream to allow for more drainage during heavy rainfall. Dykes, streambed stabilisation, and other technologies used to guide the stream are built using natural materials to maximise water filtration and rehabilitation benefits.
Contribution to climate resilience	Urban river terracing prevents storm water from flooding urban areas. In addition, natural materials used to guide the stream provide water filtration and act as habitat for fish and other wildlife. This is part of increasing the preparedness of cities for the greater floods that are likely to be associated with future climate change.



Strengths

- Reduced flood risk in inhabited areas.
- Increased ecological functions such as water filtration.
- Creates fish, bird, and wildlife habitat.
- Creates recreational and tourism opportunities.

Limitations

- Urban river terracing can require large investments in order to dredge and stabilise the area.

Sources

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9.5 BIOLOGICAL GEOTEXTILE

Application	Bridges, bridge abutments, canals, coastline, culverts and drains, drainage systems, dykes, embankments, floodgates, stormwater outfall
Description	Biological geotextiles are potentially excellent biodegradable and environmentally friendly materials effective in soil erosion control. 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 to stabilize slopes and prevent erosion. Vegetation provides root strength and absorbs effective stress, by acting as a drain and providing permanent filter stability. It can be used to protect riverbanks, embankments and coastlines, and to consolidate soft soil.
Contribution to climate resilience	Biological geotextiles reduce erosion by protecting slopes, 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 developed with the use of 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.

Strengths

- Very cost-effective, using locally available materials and low-cost labour in comparison to more elaborate civil engineering works.
- Reduces erosion on slopes, road construction sites and riverbanks.
- Provides high initial tensile strength.
- Maintains tensile strength for a very long time.
- The high moisture retention rates of water hyacinth can promote the growth of vegetation.
- Easy to install as they are laid on the ground, not buried like synthetic geotextiles.

Limitations

- Whilst a simple method, it can be labour intensive.
- Knowledge of how to undertake it correctly (appropriate opening sizes, installation, channelling of surface water, accompanying vegetation) is critical.
- Applied incorrectly, it can result in further erosion and failure.

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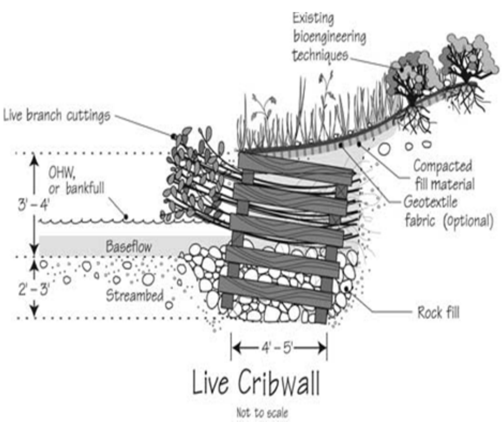
9.6 LIVE CRIB WALL

Application	Bridges, canals, drainage, dykes, embankments, roads, footpaths, wastewater treatment plants
Description	A live crib wall 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 earth fill behind them to create a wall. The 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 stream bank and protect it from erosion. The roots will eventually take over the structural purpose of the timbers. A live crib wall acts as a retaining wall and is effective for reducing erosion and streambank instability, especially on the outer bank of a stream-bend where the strongest currents are, and when reconstructing a streambank where extreme erosion has occurred. It can also be used to reduce the angle of a slope by building a low wall to protect the toe and grade the soil above it back at a gentler grade.
Contribution to climate resilience	Live crib walls prevent erosion, and can be used to 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 constructed with local labour and materials, they require less energy to produce, are far more sustainable, and can often be constructed in a quicker timeframe than traditional civil engineering works.



Strengths

- Requires minimal space.
- Provides stability above and below the water level.
- Stabilises the toe of the slope and protects it against undercutting.
- The submerged rocks and logs can provide excellent aquatic habitat.
- Immediate slope stabilisation and protection.
- Alternatives to structural treatment such as gabions or concrete blocks.

Limitations

- It is not intended to be used where the integrity of a road or structure is dependent on the crib wall since it is not designed to resist large lateral earth pressures.
- When used to protect streambanks, live crib walls should not be placed in areas that experience large, lateral earth stresses or mass wasting.
- A large amount of material and labour is required.
- Can be costly to construct.

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9.7 VEGETATED GEOTEXTILE

Application	Bridges, canals, coastlines, culverts and drains, dykes, embankments, floodgates, markets, roads and footpaths, 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 stabilized 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. In addition, having the branch cuttings present before the completion of the wall enables the vegetation to grow as rapidly as possible. Finally, 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 erosion caused by rainfall as it covers and protects the soil surface and provides soil reinforcement through the vegetation roots. The velocity of run-off is slowed down and infiltration is increased. 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 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.

Strengths

- Can be used on shores that drop off suddenly, where the bank has severely eroded or cannot be modified to create a gentle slope.
- Rapid vegetation growth from the live cuttings, which slows water flow.
- Can withstand relatively high current velocities and shear stresses.
- Traps sediment and rebuilds the streambank.
- Live woody vegetation provides habitat and aesthetic value.
- A wide variety of geotextile products are available to match specific needs.
- Effectiveness increases with time as vegetation becomes permanently established.

Limitations

- A large amount of soil and rock must be available to fill the geotextiles.
- Installation is complex and requires heavy machinery.
- The cost is relatively high.
- Can be labour intensive depending on the choice of geotextile material.
- When placing live cuttings in the geotextile, plants must be installed during their dormant season in order for them to properly take root.

Sources

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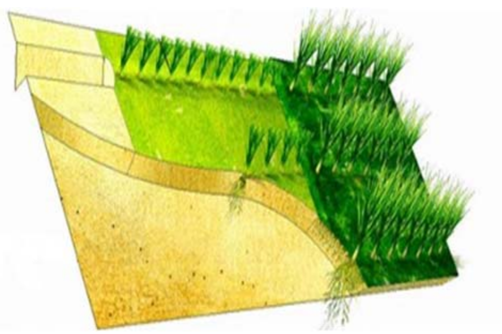
9.8 VETIVER GRASS COVERAGE

Application	Bridges, canals, culverts and drains, drainage, embankments, floodgates, stormwater outfall
Description	Vetiver grass (*Chrysopogon zizanioides*) is planted as a hedgerow along the contours of sloping land to form a dense vegetative barrier that slows run-off, helps the water soak into the soil rather than washing off the slope, and provides significant soil reinforcement through its roots. 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, vetiver grass can be an important tool to reduce erosion, improve groundwater recharge, remove pollutants from water, reduce the risk of flooding, and improve economic benefits to communities. Vetiver is native to India, is sterile, non-invasive and has to be propagated by clump subdivision. It is a low-cost, labour-intensive technology.
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 locally available materials, it requires less energy, is far more sustainable, and can often be applied in a quicker timeframe than traditional civil engineering works.



Strengths

- Will not turn into an invasive species or weed.
- Detoxifying capacity helps clean toxic areas.
- Drought- and frost-tolerant.
- Requires little maintenance once established.
- Can be introduced on farms with minimum changes to the existing farm layout.
- Does not compete with neighbouring crops for water and nutrients.
- Can grow in many soil types including sand, gravels and clay.
- Can handle lengthy submergence and is suitable for the edges of dams, ponds, rivers and bridge abutments.

Limitations

- Intolerant to shading, especially in its establishment phase; must be grown in full sun to succeed.
- Vetiver used alone can inhibit biodiversity and native vegetation.

Sources

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C KEY PLAYERS

10. Government: MOWRAM

10.1 MANDATE

MOWRAM was established in 1999. Its mandate is to manage, lead and supervise the implementation of the present law on water resources management. MOWRAM has coordination and implementation roles for the RGC in projects and programs related to water resources management and development.

MOWRAM, in collaboration with other concerned agencies, may designate any floodplain area as a Flood Retention Area for the purposes of flood protection. Within a Flood Control Area, MOWRAM, together with other agencies and local authorities, shall develop plan(s) on measures for flood prevention and mitigation to ensure the safety of human life, animals and property. MOWRAM may suspend temporary activities that damage flood protection works or obstruct the natural flow of water.

In relation to international rivers management, MOWRAM shall pay particular attention to the optimum and effective use of the Mekong River Basin in all fields, including navigation and transport, consistent with the governing principles of the CNMC. In addition, MOWRAM's key duties and responsibilities are:

- To identify policy and strategic development of water resources, business development, maintenance and preservation according to national and international policies and regulations in accordance with policy context of the RGC;
- To study and research potential water resources, including groundwater, surface water and precipitation, based on technical and scientific principles which fit the national framework;
- To develop short-, medium-, and long-term plans for business development and conservation of water resources to serve national economic development and improve the livelihoods of all people;
- To manage and control all business ventures related water resources directly and indirectly, and to minimize the impact of disasters;
- To develop regulation and legislation for the efficient management and monitoring of water resources;
- To collect and document meteorologic and hydraulic information for the benefit of national and international sectors;
- If necessary, provide support and technical advice to stakeholders such as private sector, NGOs, communities and people to appropriately correct or improve water resources business operations;

- To upgrade and introduce appropriate technologies, train MOWRAM officials and relevant practitioners in their use, and then disseminate to the public as widely as possible;
- To participate in the execution of all works related to the Mekong River Basin in accordance with MOWRAM's duties and responsibilities; and
- Strengthen and promote national and international cooperation on integrated water resources use and management, and meteorology.

10.2 LEGISLATION AND POLICIES

Certain laws and policies support sustainable use of water resources, equitable sharing of water and poverty alleviation, but these have yet to take climate change into detailed consideration. These include:

(i) National Policy on Water Resources Management (2004)
(ii) Law on Water Resources Management (2007)
(iii) SAW for 2006-2010 (2007) and 2009-2013 (2010)
(iv) PIMD
(v) Prakas (proclamation) No. 306 for establishing community-based water management - Circular No. 1 on the implementation of sustainable irrigation policy (2000)
(vi) Sub-decrees on the procedure for establishing a FWUC (2015)
(vii) River basin management (2015)

Other pending policies and regulations include (i) water license, and (ii) water quality.

MOWRAM has developed and implemented two national water resources management and meteorology strategies: the 2006-2010 and the 2009-2013 strategies. These strategies align with national policy and development goals such as the National Strategic Development Plan (NSDP) and the CMDG, and aim at sustainable water resources management and development for all sectors consuming water, such as agriculture, livestock, domestic use, industry and others. The strategies' main efforts are to rehabilitate and improve irrigation systems, build new canals, establish pumping stations, establish FWUCs, conduct research and development studies and develop human resource capacity in sustainable water resource management. Flood and drought management (pre-, during-, and post-disaster) are other main focuses of the strategy.

With NCDM efforts in disaster risk reduction management, MOWRAM has played an important role in coordination among key government and non-government actors for disaster prevention and rehabilitation.

10.3 MAINSTREAMING CLIMATE CHANGE

MOWRAM has committed itself to addressing climate change issues, in particular sustainable water development and good governance of water resources. It is a significant opportunity for MOWRAM to implement water-related laws and regulations to achieve the vision, mission and objectives of water resources management and sustainable development in Cambodia.

MOWRAM has recently developed the Climate Change Action Plan (CCAP) for Water Resource and Meteorology, 2014-2018 (2014). The CCAP plan entails 16 strategic actions in five areas: hydro-meteorology, irrigation, floods and droughts, sea level rise and saline intrusion, and climate change and gender. The 16 strategic actions are:

Hydro-meteorology

i. Strengthening climate change information and early warning systems
ii. National and provincial water resources departments' capacity building for climatic data collection, recording, etc.
iii. Improving institutional structures and networking with mass media for public weather and climate forecasting dissemination
iv. Installation of gauging stations to monitor rainfall, wind speed, storms and sea level rise (in four provinces)

Irrigation related works

i. Climate risk management and rehabilitation of small, medium and large irrigation infrastructure
ii. Promoting innovative irrigation technologies in areas affected by torrential rain (Mondulkiri, Pursat and Preah Sihanouk)
iii. Capacity building and awareness raising on climate change and Disaster Risk Reduction for FWUC
iv. Capacity development for irrigation engineers on climate risk management
v. Upscaling mobile pumping stations (20) and permanent stations (10) in response to mini-droughts

Flood and drought

i. Development and rehabilitation of flood protection dikes (Kampong Trabek, Bateay) for agricultural and urban development
ii. Improve capacity for flood and drought forecasting and modeling of technical offices at national and sub-national level
iii. Establishment of national hydrology (flood) forecasting center
iv. Promoting scientific and comprehensive methods for groundwater supply in response to droughts and climate risks

Sea level rise and saline intrusion

v. Promoting climate resilience of agriculture through building sea dikes in coastal areas
vi. Assessment of potential impact of sea level rise and salt water intrusion (in the Mekong Delta and coastal areas)

Climate change and gender

i. Promoting gender balance in water management and climate change and adaptation

11. Farmer Water User Community

The Farmer Water User Community (FWUC) was established by RGC's sub-decree in 2015 as key local organizations for the management and operation of water resources and water-based infrastructure (like secondary irrigation systems). They are to ensure the efficient and sustainable utilization and management of irrigation.

Farmers using water from the same irrigation system or part thereof have the right to establish a FWUC. MOWRAM and Provincial Departments of Water Resources and Meteorology (PDWRAM) are mandated to establish and support FWUCs but require technical, human, and financial resources to do so.

The statutes of a FWUC shall be registered with the PDWRAM. After registration, the FWUC shall be officially recognized and be in charge of the implementation of their status. The procedures for the establishment, functioning and dissolution of FWUC shall be determined by way of sub-decree.

12. NGOs (civil society) and Private Sector

The RGC promotes the collaboration among and participation of RGC institutions, private investors, stakeholders, beneficiaries at all levels, NGOs and international organizations in activities related to the management, investment, exploitation, protection and development of water resources.

Everyone has the right to use a water resource without a license or permit when the amount of water used, diverted or abstracted does not exceed the basic needs of drinking, washing and bathing, as well as other purposes such as the feeding of domestic animals and buffaloes, fishing and the irrigation of gardens and orchards, while avoiding impacts on other people. When the diversion, abstraction and use of water resources for agriculture (commercial scale) or industrial purposes are more than the basic human need, a license or permit issued by government (MOWRAM) is necessary.

The construction of bridges over water courses, lakes, canals and reservoirs, the construction of ports, and the building of other structures on the beds, banks and shores of water courses, lakes, canals and reservoirs, are subject to prior technical approval by MOWRAM.

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More information

info@icem.com.au

Published in 2019